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Emergency Management and Homeland Security Division
Michigan Department of State Police

# Michigan Hazard Analysis (Natural Hazards)

Attachment to the Michigan Hazard Mitigation Plan

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# PREFACE

The Michigan Hazard Analysis (MHA) serves as both a standalone white paper and as an attachment to the Michigan Hazard Mitigation Plan (MHMP). The publication can be used as a starting point for local governmental planners and the general public in identifying common emergency management related risks that may be present in their communities.

Emergencies can result from hazards as varied as tornadoes, power outages, pandemics, floods, terrorism, chemical spills, and forest fires. It can be useful to group certain hazards together into broad categories, sometimes referred to as a hazard taxonomy. While some general principles exist, such groupings can be organized in various ways. This publication broadly places hazards into three main categories: **natural hazards**, **technological hazards**, and **human-related hazards**.

This 2024 edition of the MHA includes chapters related to the state's natural hazards. Content for technological hazards and human-related hazards can be found in the 2020 edition of the MHA. See Appendix D for additional information.

While hazards do not always lead to catastrophic disasters, managing their threats represents a continual challenge. To meet it, emergency managers must first obtain a thorough understanding of the hazards they confront to better understand the nature, magnitude, and destructive potential of the risks affecting their communities. By examining the locations where hazard related incidents have already occurred, and by analyzing emerging trends, it is possible to estimate the relative frequency of these events.

Hazards do not exist in isolation, and the materials in this publication are added to those in the MHMP, which also examines Michigan's population distribution, socio-economic trends, and climate considerations. This creates a powerful planning tool for setting hazard mitigation goals, resource allocation, and overall emergency preparedness. The MHA also helps to inform the Michigan Emergency Management Plan, which outlines federal, state, and local responsibilities during emergency response.

## DOCUMENT ORGANIZATION

Individual sections in this publication may be presented in slightly different ways due to the unique nature of each hazard's risk. Introductory portions group similar topics and contain information related to hazard interconnectedness and cascade. Each individual chapter contains similar headers and elements, generally formatted as follows, and sometimes appearing in section introductions or overviews.

***Hazard Description***
A broad introduction to the hazard and its covered scope.

***Hazard Analysis***
A discussion on the topic and relevant statistics designed to give the reader a greater understanding of the nature and frequency of the hazard. Significant analysis may also be present in other parts of the chapter.

***Specific Impacts***
A summary of considerations regarding hazard risks and their impacts upon (1) the public, property, facilities, and infrastructure, (2) the economic condition of the state, (3) responders, continuity of operations, and continued delivery of services, and (4) the environment.

***Select Hazard Examples*** [Note: actual header titles will vary.]
Summaries of actual incidents, by date and location. The Storm Events Database (Appendix B) is a common source of information. Provided damage totals should be considered as estimates, potentially preliminary in nature, and aren't adjusted for inflation. Abbreviations may be used for billion (B), million (M), and thousand (K) when providing damage totals. Out of state incidents may be included to better illustrate the full scope of a hazard's potential.

***Select Agencies, Programs, or Laws*** [Note: actual header titles will vary.]
Brief descriptions of agencies and organizations doing hazard related work. This includes initiatives or regulations that are designed to mitigate or oversee a hazard. Emphasis is placed on state and federal levels and is intended only for general educational purposes. Information is not comprehensive and should not be construed as legal guidance.

***Supplemental Material***
May include detailed technical data, maps, or other information that would interrupt the organizational flow of a chapter.

## USE IN LOCAL PLANNING

Compiling Michigan's most common emergency management related hazards, the MHA serves as a state overview while also providing a multitude of regional historical examples. Its listings are not meant to be exhaustive, however, nor does it contain hyper-localized data. Not including a specific hazard example for one location should not be taken to mean that such a hazard has never presented itself there in the past (or may not present itself in the future).

Emergency managers referencing this publication when writing local plans should also use the many resources at their disposal. County health departments, local road agencies, and whole community stakeholders are important sources for identifying nearby risks and emerging trends. The more specific an analysis is to its own community the better. For example, proximity to the Great Lakes alters the nature of many state hazards. One locality concerned about extreme temperatures may prioritize cold weather while others may see extreme heat as the greater threat.

Localities should however still consider how neighboring areas may affect them. Wind and water in particular ignore county lines. Far away national events (e.g., hurricanes, earthquakes) may nevertheless be felt closer to home, even if primarily impacting the economy, resource availability, or the housing of mass evacuees. A major disaster in Canada could still have significant effects on Michigan's water, air quality, and energy supply.

Hazards also often share common dependencies or are otherwise connected, creating domino effects. For example, a computer hacker in Europe could launch an attack against a Michigan utility on Thanksgiving Day. Resulting blackouts could then affect several hospitals and gas stations in the midst of a pandemic, holiday travel, and extreme cold. Seemingly isolated incidents can quickly become full-blown disasters without continual analysis, planning, and mitigation efforts. The introductory sections within the MHA include discussions related to the potential for such hazard cascades.

## LEGAL AUTHORITY AND REGULATIONS

The MHMP is developed under the authority of 1976 PA 390, the Michigan Emergency Management Act, as amended. This Act and its subsequent administrative rules provide the Michigan State Police, Emergency Management and Homeland Security Division (MSP/EMHSD) with broad authority to carry out the emergency management activities of mitigation, preparedness, response, and recovery within the state, including for the publication of this document. The MHA is also developed based upon federal law and policy guidance provided by the Federal Emergency Management Agency (FEMA), as well as in accordance with the standards of the Emergency Management Accreditation Program (EMAP).

This edition of the MHA went into effect in April 2024 and is valid for a five-year period ending in April 2029. It will receive interim updates when required or necessary (see Appendix D). Additional information on how the MHA was developed is included in the 2024 MHMP. A list of MSP/EMHSD publications is also available.

## WEATHER INTRODUCTION

Many natural hazards are directly associated with short term extreme weather events or prolonged abnormal weather patterns. To better understand their frequency and severity it is also important to consider Michigan's overall general weather patterns. This introduction is meant to complement the following overviews and chapters:

1. Thunderstorm Hazards Overview:
    a. Lightning
    b. Hail
    c. Tornadoes
2. High Winds
3. Winter Hazards Overview:
    a. Snow (blizzards, squalls, lake effect)
    b. Freezing Rain and Sleet (ice storms, freezing fog)
    c. Extreme Cold

**Michigan Weather**

While latitude is the major climatic control in annual seasonal cycles, proximity to the Great Lakes plays an important and somewhat unique role. Michigan's roughly 97,000 square miles includes just over 41% of its state territorial area as covered by water (roughly 40,000 square miles).

The term "lake effect" is generically used to describe the influence of the Great Lakes on the region. Among the most large-scale direct impacts is an increase in cloudiness in downwind areas, especially during late fall and winter months when the passage of relatively cooler and drier air across open lake water leads to the formation of clouds. These clouds may produce precipitation, especially in areas close to the lakes themselves (within 30-60 miles). In addition, wind flow across the lakes acts to keep air temperatures in downwind lakeshore areas generally cooler in the warm season and milder in the cool season. These combined factors generally result in an overall reduction of daily and annual temperature cycles for most parts of Michigan than would ordinarily be experienced at more typical mid-continental locations (e.g., Minnesota).

Average mean temperatures (Fahrenheit) during the year generally range from the upper teens during January, the coldest month, to the upper sixties during July, the warmest. Temperatures on a given day or for a given time period may not always increase when going from north to south across the state, as is typical elsewhere in the Midwest. They also may follow the contours of the lakeshores, with coolest summertime temperatures along the lakeshore areas and the warmest temperatures in interior sections. The reverse tends to be true in the winter.

Spatially averaged across the state, Michigan averages just under 33 inches of precipitation per year. Total annual precipitation varies from less than 28 inches in east central and northeastern sections of the Lower Peninsula to just above 38 inches in the extreme western Upper and southwestern Lower Peninsulas. The former area is the driest climatologically in the continental United States (US) east of the Mississippi River. The spatial pattern of most precipitation-related extremes across Michigan differs somewhat from that of temperature, with heaviest and highest frequencies of heavy precipitation events across southern and western sections of the state generally decreasing towards the north and east. See the Thunderstorm Hazards Overview following this introduction for additional information.

In terms of seasonality, February is climatologically the driest month, while June, August, or September tends to be wettest. About 60% of the annual total is recorded during the May-October growing season. Summer precipitation falls primarily in the form of showers or thunderstorms, while a more steady type of precipitation of lighter intensity (much of it frozen in the form of snowfall) dominates the winter months. Months without any precipitation are rare across the state.

Prevailing surface winds in Michigan are westerly. During the summer months winds are predominantly from the southwest and shift to the west to northwest during the cold season. On warm spring and summer days when prevailing winds are generally light, a localized wind pattern frequently develops along lake shore areas and extends inland for several miles or more. This is referred to as the "lake breeze" and typically develops during late morning or early afternoon hours when relatively warmer and less dense air over the heated land areas begins to rise and allows cooler air over the (relatively cooler) lakes to move inland. Air temperature differences of 10-15°F or more between lakeshore areas and inland areas are common. At night this pattern may be reversed, creating what is known as a "land breeze" (although typically not as pronounced). These types of wind circulations are also sometimes observed on a much smaller scale along the shores of the larger inland lakes.

Detailed climate records for individual locations in Michigan begin in the mid-19th century. However, statistics on many hazards (e.g., tornadoes) are only available for the past several decades. In addition, many of the climatic variables associated with the hazards have changed over time (e.g., increasing annual precipitation during the past 50 years). Analysis of hazard risk ideally involves current or recent observed data and consistent periods of record for the variables analyzed. The current period of record utilized by the international climate science community for climate “normal” is defined as a 30-year length which changes the first year of every decade (currently 1991-2020).

Some all-time records for temperature and precipitation extremes across the state are given in the following table to serve as a general observed range of conditions.

| **Michigan All-Time Climate Records Table (through 2022)** | | | |
|---|---|---|---|
| Event | Record | Location(s) | Date |
| Maximum Temperature | 112°F | Mio, Stanwood | July 13, 1936 |
| Minimum Temperature | -51°F | Vanderbilt | February 9, 1934 |
| 24-Hour Precipitation | 12.92” | Fountain | July 20, 2019 |
| 24-Hour Snowfall | 32” | Herman | December 2, 1985 |
| Snow Depth | 117” | Eagle Harbor | January 31, 1948 |

(source: NOAA NCEI and the Office of the Michigan State Climatologist)

The extreme maximum temperature recorded in the state is 112°F, which occurred at both Mio and Stanwood on July 13, 1936 (during the height of the ”Dust Bowl” era and driest decade in Michigan’s history). It is important to note that the environmental surroundings of observing sites can play a role in the occurrence of the extremes. For example, Mio is located in the north central Lower Peninsula, where the wind fetch of hot air from southerly sources not passing over any (moderating) lake water surfaces is relatively great. It is also in a region of very sandy soils, which tend to dry and heat more quickly than other soil types. The all-time extreme minimum temperature of -54°F occurred at Vanderbilt, not far from Mio, but in a relatively low-lying area that tends to trap cold air draining from the surrounding landscape.

**Crop Considerations**

Because of the Great Lakes’ slow response to temperature changes and dominating westerly winds, the arrival of both summer and winter seasons has typically been somewhat delayed. In the spring, the cooler water temperatures slow the development of vegetation. In the fall, the warmer lake waters temper the first outbreaks of cold air, allowing additional time for crops to mature or reach a stage which is free from damage by frost. This modification in temperature extremes by the lakes enables Michigan to commercially produce a variety of crops more ideally suited to the climate of the states much further south. The shortest average growing season, of less than 120 days between the last freeze of the spring and the first freeze of the fall, occurs in the interior sections of western Upper and northern Lower Michigan. This increases to 140-150 days or greater as one moves toward the lakeshores or southward to the southern Lower Peninsula. Michigan's maximum average growing season of 175 days is found in the southwest and southeastern corners of the state.

**Overlap Between Weather Hazards and Other Sections of the Hazard Analysis (Hazard Cascade)**

Precipitation extremes, whether too much or too little, can cause or exacerbate flooding, drought, and erosion. Rainwater may overwhelm or destroy water systems, and its runoff may contaminate land (especially in high pesticide or industrial areas). Dams may be overtopped. Lightning may start wildfires. Tornadoes and high winds may damage or destroy key buildings and infrastructure (e.g., hospitals, bridges). Many weather hazards may lead to power outages. Snow depth, icy conditions, and limited visibility can lead to transportation incidents (to include transport of hazardous materials) on land. Propane delivery may be blocked or delayed. Air and water travel is also impacted. Water infrastructure may be impacted by freezing wells or burst watermains and pipes. Accumulated snow and ice may melt quickly, especially sleet, leading to increased flooding in the near term or at the end of the season with accumulated snowpack. Extreme cold creates frozen ground and ice jams that exacerbate flooding potential. Water mains may break, and wells may freeze, limiting potable water. Colder weather may see increased cases of flu and similar diseases.

# THUNDERSTORM HAZARDS OVERVIEW

## *Hazard Description*

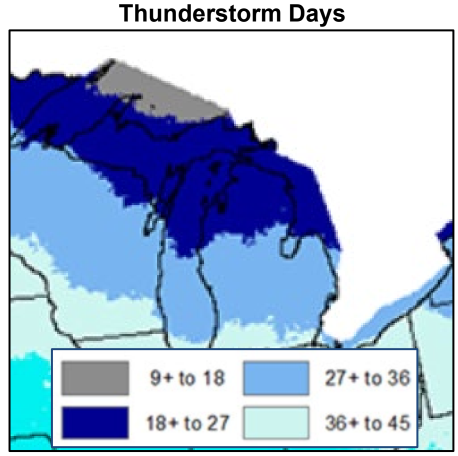
Thunderstorms and their weaker form, showers, are examples of convective circulation in the atmosphere. The American Meteorological Society defines thunderstorms as a local storm, invariably produced by a cumulonimbus cloud and always accompanied by lightning and thunder, usually with strong gusts of wind, heavy rain, and sometimes hail. They may form as single clouds, clusters of storms, or lines of storms but are typically short-lived (often lasting no more than 2 hours) with variable rates of movement (nearly stationary to more than 50 mph). The National Weather Service (NWS) categorizes a thunderstorm as "severe" if it has wind speeds of at least 58 mph, produces a tornado, or generates hail of 1 inch in diameter or greater. The NWS definition for a severe thunderstorm does not address the presence of lightning or heavy rain. Flash flooding is nevertheless another potential hazard associated with thunderstorms.

## *Hazard Analysis*

Thunderstorms are relatively simple to understand but difficult to broadly analyze because of the range of variable hazards they are associated with. As such, separate chapters will provide additional focused studies on hail, lightning, tornadoes, high winds, and flooding. Historical information on these hazards can be obtained through the National Centers for Environmental Information (NCEI) Storm Events Database.

The remainder of this overview serves as a more generalized analysis of thunderstorms, which when not severe are typically thought of as simple rain events. Thunderstorm frequency in Michigan is generally highest in the southwest Lower Peninsula and decreases as one moves northeast. The Upper Peninsula receives less thunderstorm days overall, although parts of Gogebic County are an exception.

**Thunderstorm Days**




The accompanying NWS map highlights this general pattern. "Thunderstorm days" is a statistical average of days in which thunderstorms are observed in an area being studied. The map shows mean annual thunderstorm days from 1993-2018, defined as the mean annual frequency of days with one or more lightning flashes within a 5.75-mile radius of a given location (Thomas Koehler, 2019). A Michigan specific legend (in days) is provided below the map.

Putting Michigan data into perspective, Florida averages well over 80 thunderstorm days per year, with a small part of the state averaging over 108 days. Some portions of other states near the warm, moist air of the Gulf of Mexico also see higher numbers of days. It is estimated that there are as many as 40,000 thunderstorm occurences each day worldwide, although it is important to keep in mind that not all of these are rated as "severe".

Thunderstorms can happen at any time but are most frequent during the warm spring and summer months of May through September. They sometimes move very slowly or impact large areas and can thus dump tremendous amounts of precipitation onto a location. This risk is particularly high with clusters of thunderstorms called mesoscale convective systems which may be hundreds of times larger than individual storms and persist for several hours or more. While there are several hazards associated with thunderstorms, they are an important source of needed precipitation and are part of the natural hydrologic cycle.

**Heavy Daily Rainfall Climatology in Michigan**

Daily duration (24-hour) rainfall precipitation events can be analyzed based on the historical frequency with which they have occurred. The following table estimates the maximum 24-hour rainfall events (in inches of precipitation) for various recurrence intervals based on methodology by Kunkel et al (2020) and data from 1950-2021. As shown on the next page, the recurrence interval is the average amount of time that elapses between when similar precipitation events may happen again. For example, the 10-year recurrence interval total of 2.9 inches in the table for Alcona County describes the *maximum* 24-hour rainfall event total expected to occur in Alcona only once every 10 years (on average). The most extreme events listed in the table are those with a 100-year recurrence interval, expected (on average) to occur once per century. Highlighted counties in the table represent the 16 counties with one-year recurrence intervals above 2.2 inches of rain, mostly in southwest Michigan and/or along the southern lakeshore of Lake Michigan. Some of these counties also carry 6 inches or higher 24-hour rain estimates for the 100-year recurrence interval. While Michigan rainfall amounts exceeding these values is possible, they would be both historically rare and exceptionally extreme events.

**Precipitation Estimates (inches) for 24-Hour Rainfall Event**

| | Average Recurrence Interval: | | | | | | |
|---|---|---|---|---|---|---|---|
| **County** | **1 Year** | **2 Year** | **5 Year** | **10 Year** | **25 Year** | **50 Year** | **100 Year** |
| Alcona | 1.85 | 2.10 | 2.52 | 2.90 | 3.43 | 3.87 | 4.32 |
| Alger | 1.93 | 2.20 | 2.66 | 3.06 | 3.63 | 4.09 | 4.56 |
| Allegan | 2.27 | 2.58 | 3.18 | 3.77 | 4.70 | 5.52 | 6.42 |
| Alpena | 1.82 | 2.05 | 2.46 | 2.82 | 3.34 | 3.77 | 4.22 |
| Antrim | 1.92 | 2.21 | 2.73 | 3.20 | 3.89 | 4.47 | 5.09 |
| Arenac | 1.93 | 2.20 | 2.70 | 3.17 | 3.90 | 4.53 | 5.21 |
| Barry | 2.23 | 2.52 | 3.08 | 3.60 | 4.40 | 5.09 | 5.83 |
| Baraga | 2.10 | 2.43 | 3.00 | 3.49 | 4.20 | 4.77 | 5.36 |
| Bay | 2.02 | 2.28 | 2.81 | 3.34 | 4.19 | 4.96 | 5.82 |
| Benzie | 2.08 | 2.35 | 2.87 | 3.38 | 4.21 | 4.95 | 5.77 |
| Berrien | 2.32 | 2.61 | 3.16 | 3.70 | 4.56 | 5.32 | 6.16 |
| Branch | 2.33 | 2.64 | 3.20 | 3.70 | 4.45 | 5.08 | 5.75 |
| Calhoun | 2.26 | 2.55 | 3.07 | 3.56 | 4.30 | 4.94 | 5.63 |
| Cass | 2.41 | 2.71 | 3.29 | 3.85 | 4.74 | 5.52 | 6.38 |
| Charlevoix | 1.93 | 2.20 | 2.70 | 3.14 | 3.81 | 4.37 | 4.96 |
| Cheboygan | 1.86 | 2.13 | 2.60 | 3.02 | 3.65 | 4.16 | 4.71 |
| Chippewa | 1.86 | 2.10 | 2.55 | 2.99 | 3.67 | 4.27 | 4.92 |
| Clare | 2.02 | 2.28 | 2.79 | 3.29 | 4.08 | 4.77 | 5.54 |
| Clinton | 2.17 | 2.46 | 3.01 | 3.52 | 4.30 | 4.97 | 5.70 |
| Crawford | 2.00 | 2.28 | 2.78 | 3.23 | 3.89 | 4.44 | 5.02 |
| Delta | 1.98 | 2.27 | 2.77 | 3.19 | 3.80 | 4.29 | 4.80 |
| Dickinson | 2.07 | 2.36 | 2.87 | 3.31 | 3.97 | 4.51 | 5.07 |
| Eaton | 2.17 | 2.43 | 2.92 | 3.38 | 4.09 | 4.71 | 5.38 |
| Emmet | 1.83 | 2.08 | 2.54 | 2.95 | 3.57 | 4.09 | 4.65 |
| Genesee | 2.08 | 2.31 | 2.79 | 3.27 | 4.07 | 4.78 | 5.58 |
| Gladwin | 2.00 | 2.29 | 2.82 | 3.32 | 4.10 | 4.78 | 5.51 |
| Gogebic | 2.22 | 2.56 | 3.20 | 3.82 | 4.81 | 5.68 | 6.65 |
| Gr. Traverse | 2.08 | 2.33 | 2.83 | 3.30 | 4.04 | 4.68 | 5.39 |
| Gratiot | 2.10 | 2.41 | 2.99 | 3.55 | 4.43 | 5.20 | 6.04 |
| Hillsdale | 2.26 | 2.56 | 3.09 | 3.57 | 4.28 | 4.88 | 5.52 |
| Houghton | 1.98 | 2.28 | 2.81 | 3.27 | 3.95 | 4.50 | 5.08 |
| Huron | 1.95 | 2.21 | 2.70 | 3.17 | 3.91 | 4.56 | 5.27 |
| Ingham | 2.14 | 2.40 | 2.89 | 3.35 | 4.08 | 4.70 | 5.38 |
| Ionia | 2.21 | 2.53 | 3.13 | 3.67 | 4.50 | 5.21 | 5.97 |
| Iosco | 1.91 | 2.19 | 2.67 | 3.09 | 3.71 | 4.21 | 4.74 |
| Iron | 2.08 | 2.39 | 2.94 | 3.43 | 4.15 | 4.76 | 5.39 |
| Isabella | 2.08 | 2.36 | 2.92 | 3.47 | 4.37 | 5.17 | 6.07 |
| Jackson | 2.17 | 2.43 | 2.90 | 3.35 | 4.05 | 4.66 | 5.32 |
| Kalamazoo | 2.30 | 2.59 | 3.14 | 3.66 | 4.48 | 5.19 | 5.97 |
| Kalkaska | 2.00 | 2.28 | 2.79 | 3.26 | 3.95 | 4.53 | 5.15 |
| Kent | 2.21 | 2.56 | 3.20 | 3.80 | 4.72 | 5.50 | 6.35 |
| Keweenaw | 1.85 | 2.13 | 2.62 | 3.04 | 3.65 | 4.14 | 4.66 |
| Lake | 2.15 | 2.42 | 2.97 | 3.54 | 4.49 | 5.35 | 6.32 |

| | Average Recurrence Interval: | | | | | | |
|---|---|---|---|---|---|---|---|
| **County** | **1 Year** | **2 Year** | **5 Year** | **10 Year** | **25 Year** | **50 Year** | **100 Year** |
| Lapeer | 2.04 | 2.28 | 2.76 | 3.24 | 4.03 | 4.74 | 5.53 |
| Leelanau | 2.02 | 2.28 | 2.77 | 3.24 | 3.98 | 4.62 | 5.33 |
| Lenawee | 2.19 | 2.48 | 3.00 | 3.46 | 4.15 | 4.72 | 5.33 |
| Livingston | 2.10 | 2.37 | 2.87 | 3.33 | 4.06 | 4.68 | 5.37 |
| Luce | 1.89 | 2.14 | 2.61 | 3.04 | 3.71 | 4.27 | 4.88 |
| Mackinac | 1.94 | 2.18 | 2.61 | 3.03 | 3.67 | 4.23 | 4.85 |
| Macomb | 2.04 | 2.31 | 2.81 | 3.26 | 3.94 | 4.52 | 5.13 |
| Manistee | 2.13 | 2.40 | 2.95 | 3.51 | 4.44 | 5.28 | 6.23 |
| Marquette | 2.05 | 2.36 | 2.88 | 3.33 | 3.96 | 4.47 | 4.99 |
| Mason | 2.19 | 2.47 | 3.06 | 3.68 | 4.70 | 5.62 | 6.67 |
| Mecosta | 2.11 | 2.39 | 2.95 | 3.52 | 4.46 | 5.30 | 6.24 |
| Menominee | 2.05 | 2.32 | 2.80 | 3.23 | 3.88 | 4.42 | 5.00 |
| Midland | 2.06 | 2.32 | 2.85 | 3.38 | 4.25 | 5.02 | 5.89 |
| Missaukee | 2.02 | 2.27 | 2.77 | 3.24 | 3.99 | 4.63 | 5.35 |
| Monroe | 2.07 | 2.35 | 2.85 | 3.30 | 3.98 | 4.54 | 5.15 |
| Montcalm | 2.08 | 2.40 | 2.99 | 3.56 | 4.47 | 5.26 | 6.13 |
| Montmorency | 1.88 | 2.15 | 2.61 | 3.01 | 3.59 | 4.07 | 4.56 |
| Muskegon | 2.26 | 2.59 | 3.25 | 3.91 | 4.99 | 5.96 | 7.05 |
| Newaygo | 2.17 | 2.44 | 3.01 | 3.60 | 4.58 | 5.47 | 6.48 |
| Oakland | 2.13 | 2.41 | 2.92 | 3.40 | 4.14 | 4.77 | 5.45 |
| Oceana | 2.26 | 2.59 | 3.25 | 3.91 | 5.01 | 6.01 | 7.12 |
| Ogemaw | 1.94 | 2.22 | 2.72 | 3.16 | 3.82 | 4.37 | 4.96 |
| Ontonagon | 2.08 | 2.39 | 2.96 | 3.49 | 4.30 | 5.00 | 5.75 |
| Osceola | 2.15 | 2.42 | 2.97 | 3.37 | 4.21 | 4.96 | 5.81 |
| Oscoda | 1.86 | 2.10 | 2.52 | 2.90 | 3.47 | 3.94 | 4.45 |
| Otsego | 1.98 | 2.27 | 2.78 | 3.23 | 3.90 | 4.46 | 5.04 |
| Ottawa | 2.25 | 2.60 | 3.27 | 3.92 | 4.95 | 5.86 | 6.85 |
| Presque Isle | 1.85 | 2.11 | 2.56 | 2.95 | 3.53 | 4.00 | 4.49 |
| Roscommon | 1.94 | 2.21 | 2.71 | 3.18 | 3.88 | 4.49 | 5.14 |
| Saginaw | 2.08 | 2.36 | 2.92 | 3.47 | 4.36 | 5.16 | 6.05 |
| Sanilac | 2.02 | 2.25 | 2.71 | 3.17 | 3.92 | 4.59 | 5.34 |
| Schoolcraft | 1.93 | 2.21 | 2.69 | 3.11 | 3.72 | 4.22 | 4.75 |
| Shiawassee | 2.11 | 2.38 | 2.89 | 3.40 | 4.20 | 4.90 | 5.67 |
| St. Clair | 2.03 | 2.30 | 2.79 | 3.25 | 3.96 | 4.56 | 5.21 |
| St. Joseph | 2.36 | 2.66 | 3.23 | 3.76 | 4.57 | 5.28 | 6.04 |
| Tuscola | 2.04 | 2.28 | 2.77 | 3.27 | 4.11 | 4.86 | 5.71 |
| Van Buren | 2.35 | 2.65 | 3.22 | 3.78 | 4.67 | 5.45 | 6.32 |
| Washtenaw | 2.08 | 2.36 | 2.87 | 3.32 | 4.00 | 4.57 | 5.17 |
| Wayne | 2.08 | 2.36 | 2.87 | 3.32 | 4.00 | 4.57 | 5.17 |
| Wexford | 2.12 | 2.38 | 2.89 | 3.40 | 4.21 | 4.93 | 5.73 |

(source and highlights: see accompanying narrative)

### *Select Agencies, Programs, or Laws*

Thunderstorms produce a variety of hazards, many of which share common outcomes. For example, both high winds and tornadoes may be especially damaging to manufactured housing. Flooding may result from intense rain or hail. Some common thunderstorm-related information resources are grouped in this overview to minimize duplication across chapters. Those related to flooding will be part of chapters more closely associated with water inundation.

National Weather Service
Thunderstorm hazards have some degree of predictability and are closely monitored by the NWS, which issues Watches and Warnings. A "Severe Thunderstorm Watch" means that thunderstorms with damaging winds and/or large hail are possible in a given area. A "Severe Thunderstorm Warning" signifies that severe thunderstorms (with damaging winds and hail) are imminent or already in the area. Although tornadoes may be part of a severe thunderstorm, their watches and warnings are done separately.

The NWS Storm Prediction Center is a useful tool. Five forecast offices also serve Michigan in Gaylord, Grand Rapids, Marquette, White Lake/Pontiac, and Syracuse (Indiana). These stations provide Doppler Radar images that track the movement of thunderstorms and other severe weather threats. The Syracuse office covers portions of southwest Michigan (www.weather.gov/iwx), the Grand Rapids office covers the remainder of southwest Michigan (www.weather.gov/grr), the White Lake/Pontiac office covers Southeast Michigan (www.weather.gov/dtx), the Gaylord office covers the northern Lower Peninsula and eastern Upper Michigan (www.weather.gov/apx), and the Marquette office is responsible for the central and western Upper Peninsula (www.weather.gov/mqt).

The NWS transmits information directly to radio and television stations, which in turn pass the warning on to the public. The NWS also provides warning information at www.weather.gov, via National Oceanic and Atmospheric Administration (NOAA) Weather Radio, and as part of their weather information network for emergency managers.

Other Public Warning Systems
Numerous communities in Michigan have outdoor warning siren systems in place to warn the public about impending tornadoes and other hazards (many of these systems were originally purchased to warn residents of a nuclear attack). The Integrated Public Alert Warning System (IPAWS) alerts the public through the Emergency Alert System (EAS) and by Wireless Emergency Alerts (WEA). Many private alerting systems exist beyond IPAWS, EAS, and WEA.

American Red Cross & Sheltering
The American Red Cross may open shelters for a variety of reasons, including thunderstorms and convective weather hazards. Their website includes resources to help people find one of their shelters in case of emergency. The United Way's Michigan 2-1-1 is another resource to help find shelter and other community resources.

Manufactured Home Anchoring
Manufactured homes are especially vulnerable to wind damage and flash floods when not anchored down. Local communities may work with the Manufactured Housing Commission in the regulation of manufactured housing via ordinances. State anchoring system standards are outlined in related state codes. The National Flood Insurance Program (NFIP) has anchoring requirements related to manufactured homes in floodplains that also help to mitigate wind-related hazards.

Michigan Public Service Commission (MPSC)
Wind-related damage to electric equipment and power lines is a concern for utilities. Consumers Energy, DTE Energy, and other companies have ongoing programs to decrease the risk associated with severe storms. Some of these efforts focus on trimming trees to prevent the encroachment of overhead lines, protecting equipment from lightning strikes, and placing select distribution lines underground. The MPSC oversees these utility programs to help minimize thunderstorm-related power outages.

Urban Forestry/Tree Maintenance Programs
Urban forestry programs can be effective in minimizing thunderstorm damage caused by falling trees, but in many areas, a public works agency or road commission performs the bulk of trimming work. Proper tree selection, placement, and care are also important. Utilities also have tree trimming programs that local communities can collaborate with.

Michigan State Police
There are several steps people can take for themselves, their homes, and their cars before, during, and after severe thunderstorms. The MSP MIREADY program website provides tips and other useful information.

# LIGHTNING

*The discharge of electricity from within a thunderstorm.*

## *Hazard Description*

Lightning results from the buildup of static electrical fields, typically associated with the rapid movement of air in and around a storm. This electrical field is similar to a battery, with a positive charge concentrated at one end and a negative charge at the other. Electrical discharge (lightning) occurs when the difference between these points is great enough to overcome air resistance and allow for transfer. Lightning may stay within a cloud or jump from cloud to ground, ground to cloud, or cloud to cloud/air. Most lightning stays within the clouds, with roughly 20% involving contact with the ground. Lightning can generate current levels of 30,000 to 40,000 amperes, with air temperatures often higher than 50,000ºF and leading to sonic booms (thunder). Snowstorm lightning is possible but occurs less frequently due to less atmospheric instability and moisture in the air during the winter. Lightning is also associated with more unusual events (e.g., pyrocumulonimbus clouds, volcanic eruptions) involving strong, localized movement in the atmosphere.

## *Hazard Analysis*

Approximately 100,000 thunderstorms (a storm with at least one lightning discharge) occur each year in the US. Often associated with rain, lightning can occur with storms not producing precipitation at the ground level or otherwise “away from storms”. A single thunderstorm can produce hundreds or even thousands of individual discharges of lightning. While the vast majority present little concern they can still damage equipment, ignite buildings, start wildfires, or disrupt air and boat travel. Multiple people may be killed by the same lightning strike, and outdoor gatherings (e.g., sporting events, concerts, campgrounds) should receive special attention.

The odds of a person being struck by lightning in a given year are less than one in a million. Despite this, lightning may still kill more people than some other deadly hazards (e.g., tornadoes, hurricanes) depending on the year and regions studied. Those not killed may suffer debilitating injuries. Sixty-five percent of fatal strikes occur during the high frequency thunderstorm months of June (20%), July (29%), and August (16%), according to a study by Jensensius (2020) with the National Lightning Safety Institute (NLSI) using data from 2006-2019. Roughly two-thirds of victims had been participating in outdoor leisure activities. Water-related activities topped the list, with fishing ranked highest. Boating, beach activities, soccer, golf, and running were also highly ranked. The majority of victims were males aged ten to 60. An earlier NLSI study found most deadly/injurious strikes were reported between 2 p.m. – 6 p.m.

According to NWS records, Michigan saw 101 lightning deaths and 716 injuries from 1959-2021, ranking it near the top in the nation for this long time period. Looking specifically at 1959-1995, Michigan recorded 812 lightning-related casualties (i.e., deaths and injuries), ranking it 2nd in injuries and 12th in deaths for the nation. However, Michigan recorded only three fatalities from 2012-2021, which ranked it 22nd in lightning-related deaths, well below the highest ranked states of Florida (52 deaths) and Texas (22 deaths). This more recent rank change may be attributed to shifting population statistics compared to other states, a state decline in certain outdoor activities, or the success of educational campaigns increasing awareness for lightning-related dangers.

**Lightning-Related Deaths in Michigan: 1959- 2021**

| | **LIGHTNING DEATHS: 101** | |
|---|---|---|
| **Number of Deaths** | **Location** | **Percent of Total** |
| 29 | Open fields, ball fields | 29% |
| 26 | Under trees (not golf) | 26% |
| 11 | Boats/water-related | 11% |
| 10 | Golf course | 10% |
| 4 | Near tractors/heavy equipment | 4% |
| 2 | At telephone | 2% |
| 19 | Other location/unknown | 19% |

(source: NOAA NCEI storm data)

**Michigan Lightning* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Lightning Events | Total Property Damage | Deaths | Injuries |
|---|---|---|---|---|
| Washtenaw | 21 | $1,820,000 | 2 | 4 |
| Wayne | 21 | $857,000 | 3 | 18 |
| Livingston | 13 | $1,844,000 | | 5 |
| Oakland | 40 | $2,323,000 | 1 | 5 |
| Macomb | 25 | $2,927,000 | | 7 |
| **5 County Metro Area** | **24.0 avg.** | **$9,771,000** | **6** | **39** |
| Berrien | 3 | $840,000 | | 1 |
| Cass | | | | |
| St. Joseph | 6 | $30,000 | 1 | 2 |
| Branch | | | | |
| Hillsdale | 1 | | 1 | |
| Lenawee | 18 | $880,000 | 1 | |
| Monroe | 10 | $180,000 | | 2 |
| Van Buren | 2 | $200,000 | | 2 |
| Kalamazoo | 3 | $20,000 | | 10 |
| Calhoun | 1 | $11,000 | | |
| Jackson | | | | |
| Allegan | 1 | $5,000 | | |
| Barry | 1 | | | 1 |
| Eaton | | | | |
| Ingham | | | | |
| Ottawa | 3 | $60,000 | | 1 |
| Kent | 3 | $1,000,000 | | |
| Ionia | 1 | | | 1 |
| Clinton | | | | |
| Shiawassee | 6 | $225,000 | | 1 |
| Genesee | 15 | $222,500 | 1 | 11 |
| Lapeer | 10 | $1,327,000 | | 4 |
| St. Clair | 6 | $28,000 | | 1 |
| Muskegon | 1 | $40,000 | | |
| Montcalm | 1 | | | 4 |
| Gratiot | | | | |
| Saginaw | 7 | $202,500 | | |
| Tuscola | 1 | $100,000 | | |
| Sanilac | 5 | $145,000 | | |
| Mecosta | 2 | $50,000 | | 4 |
| Isabella | 1 | $10,000 | | |
| Midland | 6 | $70,000 | | |
| Bay | 5 | $63,000 | | |
| Huron | 5 | $570,000 | | |
| **34 County Southern Lower Peninsula** | **3.6 avg.** | **$6,319,000** | **4** | **45** |

(continued on next page)

| COUNTY/AREA | Reported Lightning Events | Total Property Damage | Deaths | Injuries |
|---|---|---|---|---|
| Oceana | | | | |
| Newaygo | 1 | $100,000 | | |
| Mason | | | | |
| Lake | | | | |
| Osceola | | | | |
| Clare | 1 | $5,000 | | |
| Gladwin | 1 | | 1 | 6 |
| Arenac | 1 | $500 | | |
| Manistee | 2 | | 1 | |
| Wexford | 1 | | | |
| Missaukee | 3 | $1,000 | | 2 |
| Roscommon | 2 | $55,000 | | |
| Ogemaw | 2 | | | 6 |
| Iosco | 3 | $15,000 | | 6 |
| Benzie | 1 | | | |
| Grand Traverse | 6 | $170,000 | 1 | 1 |
| Kalkaska | 2 | | | 1 |
| Crawford | 1 | | | 1 |
| Oscoda | 2 | | 2 | 1 |
| Alcona | | | | |
| Leelanau | 2 | $40,000 | | |
| Antrim | 2 | $80,000 | | |
| Otsego | 4 | $503,000 | | |
| Montmorency | | | | |
| Alpena | 1 | | | 1 |
| Charlevoix | 1 | | | |
| Emmet | 1 | $4,000 | | |
| Cheboygan | 3 | $75,000 | | 3 |
| Presque Isle | 3 | $4,000 | 1 | |
| **29 County Northern Lower Peninsula** | **1.6 avg.** | **$1,052,500** | **6** | **28** |
| Gogebic | 2 | | 1 | 1 |
| Iron | 2 | $50,500 | | |
| Ontonagon | | | | |
| Houghton | 2 | $25,000 | | |
| Keweenaw | | | | |
| Baraga | 1 | $2,000 | | |
| Marquette | 8 | $78,500 | | |
| Dickinson | 3 | $171,000 | | |
| Menominee | 1 | $500,000 | | 1 |
| Delta | 2 | $130,000 | | |
| Schoolcraft | | | | |
| Alger | 3 | $20,000 | 1 | 3 |
| Luce | 1 | $70,000 | | |
| Mackinac | 1 | $150,000 | | |
| Chippewa | 1 | $2,800 | | |
| **15 County Upper Peninsula** | **1.8 avg.** | **$1,199,800** | **2** | **5** |
| **MICHIGAN TOTAL**** | **318** | **$18,343,000** | **18** | **117** |
| **Michigan Annual Avg.** | **11.6** | **$671,186** | **0.7** | **4.3** |

*Uses the NCEI Storm Data category for "Lightning". **One event may take place in multiple counties. State totals may be less than the sum of all counties.

Although Michigan's counties experience roughly 20 to 35 thunderstorm days per year (see separate Thunderstorms Overview), many of those storms do not contain cloud-to-ground lightning, resulting in a far smaller number of known events on the preceding table. Michigan's average deaths from lightning are just under one per year. The Southeastern part of Michigan has a noticeably greater rate of damaging lightning events than other areas, with those counties averaging almost one damaging event per year (compared to the rest of the state at about one-tenth of this rate). The data thus reveals some correlation between urbanized land uses and reported lightning events. This may be partly due to urban areas having more people and vulnerable property to damage, but there is also a greater incidence of lightning damage specifically within the southeastern counties as a result of increased thunderstorms in that area.

Lightning may also damage electrical infrastructure, causing localized power outages and damage to computers, phone lines, and other electronics. Statistics for lightning-related property losses vary widely according to the source. For generalized purposes, examples include data from the Insurance Information Institute, which has previously estimated lightning damage at roughly 5% of all paid insurance claims. Nationwide electric utility companies have estimated over $1 billion per year in damaged equipment and lost revenue. The Federal Aviation Administration reported approximately $2 billion per year in airline industry and passenger-related costs.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
In addition to the casualties and damages noted in this chapter, lightning has a discouraging effect on outdoor activities (e.g., jogging, golfing, swimming). Boaters on the water may be put at risk. Exposed stadiums, such as for sporting events or concerts, may be evacuated. Struck buildings may see damaged appliances, including medical equipment. Electrical and communications infrastructure such as radio towers can be affected by lightning strikes, sometimes causing power outages, impacting cell phone coverage, or disrupting the internet. Airports, with tall control towers and fueling operations, are also at risk.

Impact on the Economic Condition of the State
Lightning has historically affected only specific locations. It is possible for strikes upon an important production facility or infrastructure component to cause notable impacts in a particular economic sector or geographic area of the state, even though such impacts may seem unlikely.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responders tend to be working outdoors in conditions from which most residents are taking shelter. Safety considerations, including for electrical line workers, may slow repair times or endanger search and rescue missions. Delivery of specialized services may be affected if a facility is damaged. Statewide operations are not typically affected.

Impact on the Environment
Trees can be blown apart or otherwise damaged when struck by lightning. Strikes may ignite wildfires (dry lightning occurs with no precipitation at ground level and is a cause of natural wildfires). Wildlife may be killed or injured when struck by lightning. Lightning has been determined to have an effect on atmospheric chemistry, such as with ozone.

### *Select Lightning Incidents*

Numerous lightning incidents in Michigan have resulted in multiple injuries. The list is for educational purposes and is not meant to be comprehensive. To conserve space, dollar references for thousand (K), million (M), and billion (B) have been abbreviated.

July 8, 2021 – Livingston County
Four men were injured by a lightning strike as they worked outside in a field near Gregory. One of the workers was transported to a hospital, while the other three declined medical treatment.

July 5, 2021 – Delta County
Lightning strikes resulted in two structure fires and a tree fire in Escanaba. It took over three and a half hours for firefighters to extinguish the first fire which started in the attic. A man and his dog were rescued from one of the apartments at this residence. Firefighter fatigue was reported to be a major difficulty at this fire due to the heat and humidity, and one firefighter sustained a minor injury while fighting the blaze. Total property damage from all three fires was estimated at $100K.

July 25, 2017 – Menominee County
The Seventh Day Adventist Church near Wilson was struck by lightning, and the subsequent fire resulted in about $500K in damage, destroying the building.

May 16, 2017 – Lapeer County
Lightning struck a house at 4 a.m., blowing out windows and causing extensive damage to the home's interior. A back deck and siding were also affected ($40K in damages).

August 3, 2015 – Wayne County
A large home in Canton Township was struck by lightning, catching it on fire ($300K in damages).

July 18, 2015 – Jackson County
During the "Faster Horses Festival" at the Michigan International Speedway, severe weather caused a concert to be evacuated around 8 p.m., with tens of thousands of persons in attendance. The main stage was dismantled after visible lightning appeared in the sky, delaying the concert for three hours.

August 30 and September 7, 2013 – Ingham County
Michigan State University's Spartan Stadium was completely evacuated twice in the same season due to lightning.

July 18, 2013 – Luce County
Lightning started a house fire resulting in $70K in damages and the death of an elderly man.

June 18, 2012 – Ellsworth (Antrim County)
Lightning set a home on fire, completely destroying it ($80K in damages).

April 26, 2011 – Portage (Kalamazoo County)
Nine people were injured and sent to the hospital (one severe) after lightning struck at a soccer field in Westfield Park. One man went into cardiac arrest but was treated at a hospital and released.

September 21, 2010 – Kent County
Various fire departments reported that about a dozen house fires were ignited, in an area from Ada south to Caledonia, by lightning strikes produced by severe storms during the late afternoon. Total damages were estimated at $500K.

July 15, 2010 – Vestaburg (Montcalm County)
Lightning struck four young persons between 9 and 18 years of age at a baseball diamond. All survived after being taken away by emergency medical flights.

July 22, 2009 – Big Rapids (Mecosta County) and Gaylord (Otsego County)
A non-severe thunderstorm saw lightning strike pine trees at Ferris State University as construction workers stood nearby, injuring four of them. That same day, a lightning strike north of Gaylord ignited an apartment complex, destroying it ($500K in damages) and leaving 52 persons homeless.

July 17, 2006 – Southeastern Michigan (Saginaw and Wayne Counties)
Lightning damaged a church bell tower in Saginaw ($106K in damages). Separately, one injury and one death occurred in Wayne County when a couple sought refuge from rain by going under a tree that was then struck during the storm.

July 16, 2005 – Macomb Township (Macomb County)
One house was completely destroyed by fire as a result of a lightning strike. Five additional house fires started due to other lightning strikes from the same storm event. Total damages were $1M.

July 4, 2003 – Oscoda (Iosco County)
Lightning destroyed a large business sign whose fragments damaged nearby vehicles. One car had four occupants injured by shattering glass. Overall damages were estimated at $10K.

September 19, 2002 – Ann Arbor (Washtenaw County)
One roofer was killed, and two others were badly injured when they were hit by lightning.

June 12, 2001 – Benton Harbor (Berrien County)
Lightning struck an apartment complex in Benton Township, resulting in 35 residents being evacuated. The total property damage from the fire was $800K.

December 11, 2000 – Ann Arbor (Washtenaw County)
Northwest of Ann Arbor, $1.1M in property damage resulted when lightning caused a large home to be destroyed in the middle of a winter storm emergency.

July 27-28, 2000 – Southeast Michigan (Macomb, Lapeer, and Sanilac Counties)
Lightning caused three fires: a manufacturing building in Dryden ($650K in damages), a barn near Sandusky ($15K in damages), and an auto mall near Romeo ($1M in damages).

May 18, 2000 – Detroit Metropolitan Airport (Wayne County)
Lightning struck the steel superstructure of a new terminal under construction at Detroit Metropolitan Airport, injuring nine workers (two requiring hospitalization).

May 11, 2000 – Northville (Wayne County)
Lightning struck at a soccer field as a group was headed for shelter, knocking several persons down and requiring a 12-year-old boy to be hospitalized. Lightning later struck a tree in Dearborn Heights, and a man working nearby was struck by a limb from the tree, causing injuries that hospitalized him.

August 10, 1998 – Brighton (Livingston County)
A lightning-caused fire destroyed a store near Brighton ($1.5M in damages).

July 21, 1998 – Southern Lower Peninsula (Muskegon, Kent, Ottawa, Macomb, and Wayne Counties)
Thunderstorms in Muskegon, Kent, and Ottawa Counties caused over $500K of damage from lightning strikes and resultant fires (e.g., an attic fire in Muskegon Township, a storage building fire in Egelston Township). A lightning-caused fire at a Grand Rapids apartment complex was the most expensive, destroying six units on the top floor and damaging at least ten more when the roof caved in. Roughly 15,000 homes lost electricity throughout the Grand Rapids metro area. The southeastern part of the state was even more heavily impacted, resulting in state and federal disaster declarations in Wayne and Macomb Counties, where the storms produced over 4,300 cloud-to-ground lightning strikes (some of which caused fires that destroyed a house and an apartment building, leaving 16 persons homeless and causing $275K in damages in Sterling Heights).

June 16, 1998 – Southern Lower Peninsula (Wayne, Washtenaw, and Kent Counties)
A severe thunderstorm produced a great amount of lightning. A man was struck and killed when walking to his car in Detroit, and a woman and boy were injured by a lightning strike at a Little League game in Taylor. A transmitting antenna for a radio station in the Hudson Mills area was struck and had to be replaced ($100K in damages). A Livonia residence was struck ($2K in damages). Lightning in Alto started a fire that destroyed a new building at a church.

September 19, 1997 – Midland, Van Buren, Barry, and Kalamazoo Counties
Lightning damaged two houses in Waterford Township and an apartment building in Westland. The South Haven Community Hospital received a direct strike to its radio tower, disabling communications ($200K in damages). Lightning started a house fire in Climax Township ($20K in damages). Lightning at a farm in Coleman killed four horses. A Hastings boy received minor injuries when lightning struck near him.

July 18, 1996 – Gladwin (Gladwin County)
A bolt of lightning from a distant thunderstorm killed a pitcher during a softball game. Several in the infield were knocked to the ground and taken to a hospital. Three additional people were also injured.

June 21, 1995 – Ishpeming (Marquette County)
Lightning caused a fire that destroyed a 100-year-old church, with damages estimated at over $1M.

July 7, 1994 – Potterville (Eaton County)
Lightning struck a swimming lake at Fox Memorial Park, injuring 22 people (one critically). This strike seemingly came from “out of the blue” as there was not a storm actually overhead when it occurred (the lightning traveled a considerable horizontal distance from the parent storm).

June 20, 1979 – Camp Grayling (Crawford County)
Lightning struck a mess tent, injuring 45 members of the National Guard (three hospitalizations).

August 23, 1975 – Leslie (Ingham County)
A campground was struck by lightning, injuring 90 people (one seriously).

### *Select Agencies or Programs*

National Weather Service
The NWS provides information related to lightning victims that includes data on lightning fatalities since the 1940s as well as analysis for more recent years. A lightning safety page includes downloadable tip sheets and brochures. Please see the section and chapters related to thunderstorms, tornadoes, and high winds for additional information related to the NWS and other applicable programs and services dealing with convective weather.

National Lightning Safety Council (NLSC)
The NLSC is a non-governmental organization dedicated to lightning safety and education. Their website contains safety-related resources along with national fatality tables and state rankings since 2013. The NLSC ranks Michigan at 15th among states for death rates per million people.

Lightning Detection Networks and Systems
Cloud-to-ground and intra-cloud lightning flashes are detected and mapped in real-time by two different networks in the US: the National Lightning Detection Network (NLDN), a system owned and operated by Vaisala Inc., and the Earth Networks Total Lightning Network. The NWS provides a 24-hour cumulative lightning strike archive for some locations, with data provided by the NLDN. Local detection systems can also be installed at golf courses, parks, pools, sports venues, and other outdoor locations. The MSP/EMHSD does not officially endorse any one network or company, nor vouch for the accuracy of its systems. One free website, Blitzortung.org, is provided here as a representative example.

# HAIL

*Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds.*

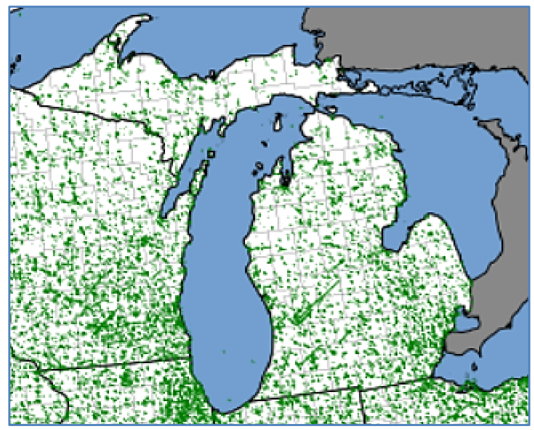
## *Hazard Description*

Hail is produced by certain thunderstorms when strong updrafts carry water droplets above the atmospheric freezing level and lead to the formation of ice. Some particles subsequently cycle up and down, growing larger with additional moisture/ice layers until their weight causes them to fall to earth. While most thunderstorms don't produce any meaningful levels of hail, it should be kept in mind that such storms may also be producing strong winds or tornadoes.

## *Hazard Analysis*

Hail is most likely for severe thunderstorms that also produce large amounts of precipitation. As a thunderstorm passes over, hail usually falls near the center of the storm, along with the heaviest rain. A thunderstorm's strong winds can occur at high altitudes and may blow hailstones in unexpected directions. Areas, where hail accumulates on the ground, may be referred to as hail streaks, sometimes viewable by satellite after a storm. Michigan hail streaks typically cover areas up to roughly one mile wide and less than five miles long. Those longer than 100 miles have been observed. The likelihood of hailstorms in specific Michigan counties is largely determined as a function of how many thunderstorms they have. Which counties that may be more prone to experience especially severe hail is difficult to analyze, with random chance playing a role. Maps such as those on the right that highlight reported hail may be biased to reflect instances from populated areas or those containing crops.

**Severe Hail Reports (1955-2021)**



(source: NWS Storm Prediction Center)

Most hail is frequently small and relatively non-threatening to people. Larger hailstones may batter structures and cause injury. The size of hail is typically proportional to the intensity of the storm cell that generates it. Hailstones in Michigan typically range in size from a pea (¼ inch diameter) to a golf ball (1¾ inch diameter), but hailstones larger than baseballs (2¾ inch diameter) are possible. The following table shows a range of sizes and historical occurrences.

**Hail Size Comparison (Michigan, 1996-2021)**

| Relative Hail Size | Diameter | # of MI events | Description/Impacts: |
|---|---|---|---|
| Pea | ¼" (6mm) | Too many to include | Minimal structural impacts, but crop damages can be severe |
| Marble or mothball | ½" (13mm) | | |
| Penny or dime | ¾" (19mm) | Too many to include | Old threshold for severe hail, raised to 1" in 2009 |
| Nickel | 0.9" (22mm) | | |
| Quarter | 1" (25mm) | 1349 (combined) | $70.12M property damage, $3.55M in crop damage |
| Half-dollar | 1¼" (32mm) | | |
| Walnut/ping-pong ball | 1½" (38mm) | 543 (combined) | $229.07M property damage, $3.83M crop damage, 3 injuries |
| Golf ball | 1¾" (44mm) | | |
| Hen's egg | 2" (51mm) | 79 | $29M in property damage, $855K in crop damages, 1 injury |
| Tennis ball | 2½" (64mm) | 14 | |
| Baseball | 2¾" (70mm) | 18 | |
| Teacup | 3" (76mm) | 14 | Damages: $12M property, $2.8M crop |
| Grapefruit | 4" (102mm) | 4 | $1.8M in property damage |
| Softball | 4½" (114mm) | 1 | $32.6M in property damage |
| | Total of Included: | 2,022 | $375M property, $11M crop |

(sources: Adapted from NCEI Storm Events Database (2021))

Events producing the largest-sized hail are not always the most destructive, and events with (relatively) smaller-sized hail may sometimes still result in greater damage. Even pea sized hail has the potential to damage some crops.

**Michigan Hail* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Hail Events | Total Property Damage | Total Crop Damage | Injuries |
|---|---|---|---|---|
| Washtenaw | 203 | $10,000 | | |
| Wayne | 164 | $7,000 | | |
| Livingston | 63 | | | |
| Oakland | 184 | $25,011,000 | | |
| Macomb | 148 | $2,000 | | |
| **5 County Metro Area** | **152 avg.** | **$25,030,000** | **$0** | **0** |
| Berrien | 69 | $10,000 | $1,300,000 | |
| Cass | 34 | $12,000 | | |
| St. Joseph | 53 | $7,000 | | |
| Branch | 55 | $1,000,000 | | |
| Hillsdale | 42 | $2,000,000 | | |
| Lenawee | 106 | $2,150,000 | | 1 |
| Monroe | 86 | | | |
| Van Buren | 36 | $50,420,000 | $305,000 | |
| Kalamazoo | 61 | $130,205,000 | $370,000 | |
| Calhoun | 40 | $525,000 | $385,000 | |
| Jackson | 39 | $385,000 | $225,000 | |
| Allegan | 59 | $2,712,000 | $402,000 | |
| Barry | 44 | $1,860,000 | $205,000 | |
| Eaton | 46 | $510,000 | $325,000 | |
| Ingham | 45 | $512,000 | $235,000 | |
| Ottawa | 61 | $497,000 | $302,000 | |
| Kent | 82 | $15,112,000 | $395,000 | |
| Ionia | 19 | $4,680,000 | $100,000 | |
| Clinton | 30 | $220,000 | $125,000 | |
| Shiawassee | 41 | $2,800,000 | $2,000,000 | |
| Genesee | 168 | | | |
| Lapeer | 68 | | | |
| St. Clair | 79 | $125,000 | | |
| Muskegon | 46 | $965,000 | $260,000 | |
| Montcalm | 36 | $1,180,000 | $165,000 | 1 |
| Gratiot | 32 | $405,000 | $130,000 | |
| Saginaw | 103 | $300 | | |
| Tuscola | 71 | | | |
| Sanilac | 55 | $155,000 | $10,000 | |
| Mecosta | 28 | $575,000 | $170,000 | |
| Isabella | 39 | $205,000 | $215,000 | |
| Midland | 98 | $10,127,000 | | |
| Bay | 92 | $20,050,000 | | 2 |
| Huron | 61 | $5,500 | | |
| **34 County Southern Lower Peninsula** | **60 avg.** | **$249,409,800** | **$7,624,000** | **4** |

(continued on next page)

| COUNTY/AREA | Reported Hail Events | Total Property Damage | Total Crop Damage | Injuries |
|---|---|---|---|---|
| Oceana | 32 | $260,000 | $175,000 | |
| Newaygo | 38 | $325,000 | $235,000 | |
| Mason | 18 | $195,000 | $40,000 | |
| Lake | 16 | $135,000 | $65,000 | |
| Osceola | 16 | $130,000 | $70,000 | |
| Clare | 32 | $715,000 | $110,000 | |
| Gladwin | 34 | | | |
| Arenac | 38 | $10,000 | | |
| Manistee | 33 | | $35,000 | |
| Wexford | 29 | | | |
| Missaukee | 28 | | | |
| Roscommon | 40 | | | |
| Ogemaw | 40 | $32,600,000 | | |
| Iosco | 52 | | | |
| Benzie | 15 | | | |
| Grand Traverse | 32 | | | |
| Kalkaska | 13 | | | |
| Crawford | 26 | | | |
| Oscoda | 38 | | | |
| Alcona | 46 | | $500 | |
| Leelanau | 35 | $85,000 | $3,055,000 | |
| Antrim | 34 | $95,000 | $1,030,000 | |
| Otsego | 43 | $5,000 | | |
| Montmorency | 33 | | $50,000 | |
| Alpena | 32 | | $100,000 | |
| Charlevoix | 31 | $45,000 | | |
| Emmet | 16 | $100,000 | | |
| Cheboygan | 17 | | | |
| Presque Isle | 31 | $3,500,000 | $300,000 | 1 |
| **29 County Northern Lower Peninsula** | **31 avg.** | **$37,995,000** | **$5,265,500** | **1** |
| Gogebic | 54 | $750,000 | | |
| Iron | 51 | $4,102,000 | | |
| Ontonagon | 51 | | | |
| Houghton | 64 | $10,000 | | |
| Keweenaw | 5 | | | |
| Baraga | 46 | $10,020,000 | | |
| Marquette | 175 | $64,653,000 | | |
| Dickinson | 75 | $225,000 | | |
| Menominee | 76 | $600,000 | | |
| Delta | 78 | $19,000 | | |
| Schoolcraft | 37 | $100,000 | | |
| Alger | 58 | $5,000 | | |
| Luce | 19 | $1,004,000 | | |
| Mackinac | 16 | | | |
| Chippewa | 29 | | | |
| **15 County Upper Peninsula** | **56 avg.** | **$81,488,000** | **$0** | **0** |
| **MICHIGAN TOTAL**** | **4,508** | **$394,128,300** | **$12,889,500** | **5** |
| **Michigan Annual Avg.** | **165** | **$14,421,495** | **$471,638** | **0.2** |

*Uses the NCEI Storm Data category for “Hail”. **One event may take place in multiple counties. State totals may be less than the sum of all counties.

On average, Michigan counties will experience two or more hail events per year of various intensities. The vast majority of reported property damage stems from just a few events, with usually at least one severe hailstorm in the state each year causing significant damage. Hailstorm damage should be looked at similarly as to how tornado damage is experienced, in that they rarely greatly damage any one specific location but the damage those events do cause can be extremely high. All general areas of the state have historically endured extensive damage from hail events at one time or another. Severe thunderstorm forecasts from the NWS typically provide sufficient warning for residents to take appropriate action to reduce potential hail damage where possible. Statistics from the past few decades indicate that approximately 50% of the severe thunderstorms that produce hail have occurred during the months of June and July, and nearly 80% have occurred during the prime crop growing season of May through August.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
Most people have experienced small and harmless hail, but injuries may occur when people underestimate the severity of a storm. Motorcyclists traveling at high speeds may be especially vulnerable, as are people on exposed watercraft such as canoes. Hail damaging airplanes while in flight is rare but possible. Most hail in general causes little property damage but can vary significantly based on size and other factors. Most damage involves outer layers of structures such as windows, skylights, siding, roofs, air-conditioning units, and outdoor lighting. Greenhouses or temporary structures may be especially vulnerable. In very unusual storms bigger infrastructure may be damaged, such as at electrical substations. An accumulation of ice on the ground can potentially clog or reduce the effectiveness of drainage grates and paths.

Impact on the Economic Condition of the State
Although a severe hail event can do a great deal of damage to property and crops, this tends to occur within only a small area of the state for a short time. True economic hardship tends to be limited, such as with canceled or impacted outdoor events or agricultural areas that suffer extensive crop damage (e.g., potatoes, beans, tomatoes, corn, soybeans, apples, peaches, grapes, plums, cherries, and raspberries). Livestock may also be injured. Businesses with many unsheltered vehicles and planes (e.g., auto dealerships, and airports) may suffer significant damage all at one time.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responders may not be able to take shelter depending on their duties. Vehicles with destroyed windshields may be vulnerable to other hazards (e.g., heavy rain, and winds). Aircraft may be damaged. Hail in general should have little if any significant impact on the continuity of operations, especially in the long term.

Impact on the Environment
Hail may damage the natural environment, affecting vegetation and harming wildlife. Younger or smaller forms of vegetation may not survive a severe hailstorm. Damages can lead to an increased risk of bacterial infections that can kill healthy trees, and wildlife can be injured in ways that impede their survival chances. The impact of hail can cause soil erosion that may exacerbate flooding over time.

### *Select Hailstorms in Michigan since 1997*

The following list is for general educational purposes and is not meant to be comprehensive. Hail occurs as part of thunderstorms, typically those associated with high precipitation and potentially other hazards (e.g., damaging winds). To conserve space, dollar references for thousand (K), million (M), and billion (B) have been abbreviated.

July 20, 2023 – Southeast Michigan
Severe weather included twelve thunderstorm warnings. One supercell produced fast-falling hail up to 2.75 inches over Davison (Genesee County), damaging homes and businesses. An automobile dealership reported that every car on their lot was damaged in some way, with smashed windshields or dented hoods. The hail also crashed through the majority of the building's skylights. In other areas, Ypsilanti (Washtenaw County) saw 2-inch hail, and slightly smaller hail in Ann Arbor still resulted in an outdoor art fair temporarily shutting down for a couple of hours as attendees sought shelter. The included photo shows hail from Davison.

June 19, 2021 – Hillsdale and Lenawee Counties
A thunderstorm developed in southern Lower Michigan, becoming severe with wind damage reported in Cass County. Hail up to 4 inches in diameter was observed in Hillsdale County while locations near Hudson saw up to 3 inches in diameter.

August 29, 2019 – Newaygo, Muskegon, Kent, and Montcalm Counties
Storms resulted in isolated wind damages. There were several reports of large hail ranging from 1.75-2.5 inches in diameter. Estimated event property damages included $20K for Newaygo County, $25K for Muskegon County, and $10K for Kent County. Both Newaygo and Kent also saw $25K in crop damages.

June 1, 2019 – Jackson and Calhoun Counties
Thunderstorms caused numerous reports of large hail as well as some wind damage. Observed hail ranged from 1.75-2.75 inches in diameter. Estimated property damage was $100K in Calhoun County and $5K in Jackson County.

June 30, 2018 – Luce, Marquette, and Alger Counties
A severe thunderstorm over portions of west and central Upper Michigan included Muskallonge Lake State Park, where rangers reported hail ranging in size up to 4 inches. All 159 campsites at the park sustained hail damage to campers, cars, and other property. The roofs of several park buildings, including its headquarters, was assessed for replacement. Property Damage in Luce County was estimated at $1M.

July 8, 2016 – Alcona, Alpena, Antrim, Arenac, Charlevoix, Grand Traverse, Leelanau, and Roscommon Counties
Thunderstorms produced isolated damaging winds and large hail. Some locations experienced hail as large as 3 inches in diameter, damaging vehicles, house windows, and skylights. Trees fell and some streets were briefly closed in Grand Traverse County. Many areas suffered extensive damage to orchards and vineyards. Approximately 60% of the cherry crop in the northwest Lower Peninsula was damaged. Total crop damages were estimated at $4.15M, of which $3M occurred in Leelanau County and $1M in Antrim County. Property damage amounted to about $261K ($66K due to strong winds) and was especially noted in the following municipalities: McGinn, Kerston, Alpena, Central Lake, Standish, East Jordan, Bates, Empire, and Houghton Lake.

August 2, 2015 – Ogemaw County
A series of severe thunderstorms crossed over the Lower Peninsula, producing widespread straight-line winds and the largest-sized hail ever recorded in Northern Michigan at up to 4.5 inches in diameter. The results added up to roughly $32.6M in property damage in Ogemaw County according to a NOAA database. About 350 structures were damaged by hail, along with a large number of vehicles, some of which were considered destroyed.

July 27, 2014 – Bay, Midland, and Oakland Counties
A set of thunderstorms swept across the Lower Peninsula, initially pelting Bay and Midland with hail up to 3 inches in diameter. Oakland felt impacts a few hours later, with hail of up to 2.5 inches in diameter. Wind damages also occurred, with total damages estimated at $100M. Damages specifically from hail amounted to about $20M in Bay County, $10M in Midland County, and $25M in Oakland County. Smaller, less damaging hail also fell in various other counties.

April 26, 2011 – Southern Lower Peninsula
Several thunderstorm supercells produced large hail reported up to 2 inches in diameter. A tornado near Burnips (Allegan County) and an injurious lightning strike in Portage (Kalamazoo County) also occurred during this weather event. Significant hail damage was seen in Ionia ($4M), Montcalm ($1M), Kalamazoo ($4M), and Kent ($2M) Counties.

April 5, 2010 – Southwestern Michigan
Severe thunderstorms produced large hail and winds greater than 80 mph. The siding of many homes was destroyed near Schoolcraft by hail about 1.75 inches in diameter. The most significant damage occurred in the southern portions of Kalamazoo County, with damages estimated at $125M (from wind and hail). Van Buren County was also struck with damages estimated at $50M.

July 26, 2007 – Southern Lower Peninsula (especially Shiawassee and Lenawee Counties)
Hail sometimes as large as golf balls hammered areas in a 3-mile radius around Durand for 50 minutes. A local newspaper reported $1.8M in hail damages to homes alone. Hundreds of homes and vehicles were significantly damaged, with the latter averaging $4K per vehicle ($1M in total vehicle damages). Many crops in the area were also destroyed. One farmer estimated $400K in losses to soybeans alone. Total crop damages were estimated at $2M in Shiawassee County. A newspaper reported $75K in damages to vehicles at the Lenawee County Fair.

June 20, 2007 – Marquette County
A significant storm pummeled downtown Marquette and Harvey. While most of the hail was less than golf ball size, there were a few reports of hail 3 inches in diameter. Hail accumulated to several inches deep in downtown Marquette, and storm drains clogged from shredded leaves later caused melting hail to flood some streets. Hundreds of houses sustained significant damage to roofs and sidings. Thousands of cars were damaged. Damage estimates from the storm for Marquette and surrounding areas were reported at over $64M.

July 28, 2006 – Western Upper Peninsula (Gogebic, Baraga, Houghton, Ontonagon, and Delta Counties)
A widespread outbreak of severe weather resulted in hail of up to 4 inches in diameter and caused significant damage to roofs, siding, and automobiles. Revised damage estimates from this hail are currently listed in the NCEI storm events database as totaling $750K in Wakefield, $50K in Covington, $10K in Kenton, $4K in Ewen, and $3K in Garden.

July 13, 2004 - Presque Isle County
A devastating hailstorm caused extensive damage in the small town of Posen. Hail up to 2.75 inches in diameter was driven by winds gusting at times to 60 mph. Holes were punched in roofs and siding, cars were dented, and windows were broken. A local church patched 300 holes in its roof. Damage to a school was estimated at nearly $200K, and a local greenhouse lost over a thousand two-foot by two-foot windowpanes. One individual suffered a badly bruised back. Substantial damage was done to crops (largely potatoes, along with some beans, tomatoes, and corn) in nearby fields.

July 14, 2000 - St. Clair County
Hailstones as large as baseballs (2.75 inches in diameter) fell in Algonac, causing $125K in damage to cars and homes. The hailstones damaged roofs, ripped gutters off of homes, dented air conditioning units, and broke windows. The force of impact when the hailstones landed in the canals in Algonac caused the water to splash 5 feet into the air.

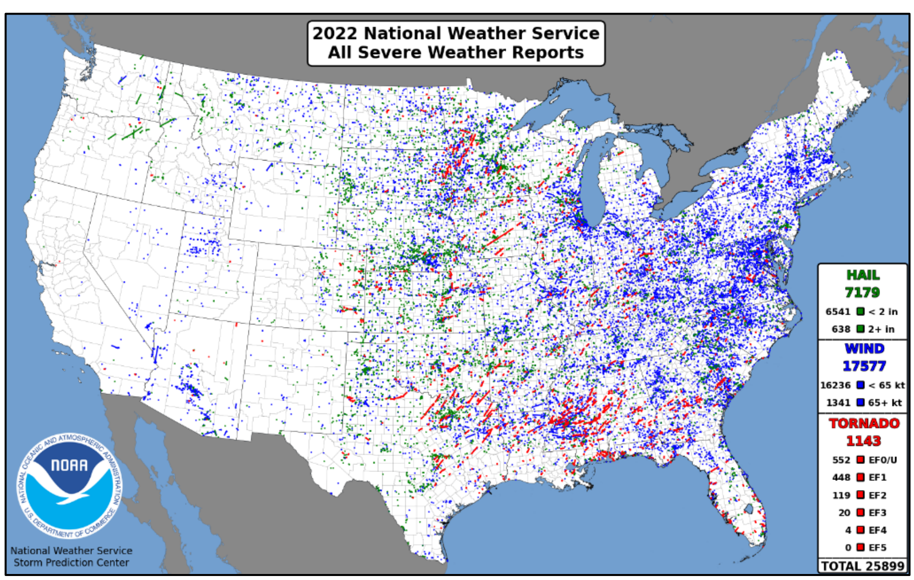
June 9, 2000 - Iron and Dickinson Counties
A line of thunderstorms produced 1.75-inch hail that damaged approximately 575 homes and 700 vehicles in a two-mile wide swath across the northern two-thirds of the city of Iron River. The hail caused approximately $2.3M in roof and siding damage. Ping-pong ball sized hail in the Randville-Grand Bluff area caused an additional $225K in damage to 20 homes and 20 vehicles. Total hail damage in Iron County was estimated at $4.1M.

Sept. 26, 1998 - Lower Peninsula (Northern Counties)
A line of severe thunderstorms produced hail up to 2 inches in diameter in Manistee County, destroying 30,000-35,000 bushels of apples at area farms. The same storm system produced tennis ball-sized hail north of Gladwin, damaging several homes and vehicles. Hail 3.5 inches in diameter damaged crops and injured some livestock in Arenac County.

July 2, 1997 - Lower Peninsula
Damaging hail was reported in numerous locations, just one of the impacts of a storm system that would eventually spawn deadly tornadoes in southeast Michigan and lead to a Presidential Disaster Declaration. Berrien County saw 1-2.25-inch diameter hail that caused agricultural losses of nearly $1M, destroying 280 acres of fruits and 100 acres of vegetables in a two-mile wide swath from Stevensville southeast to the county line.

### *Select Agencies or Programs*

National Weather Service
The NWS Storm Prediction Center includes an annual national map showing locations of reported hail and other hazards associated with thunderstorms. Please see the section and chapters related to thunderstorms, tornadoes, and high winds for additional information related to the NWS and applicable programs and services related to convective weather. Map source: NWS, Storm Prediction Center (2022).



## TORNADOES

*An intense rotating column of wind that extends from the base of a severe thunderstorm to the ground.*

### *Hazard Description*

Tornadoes are violently rotating columns of air that can have winds exceeding 200 mph and widths over one mile long. From a technical standpoint, tornadoes must be in contact with the ground and a convective cloud at the same time (pendant from a cumuliform cloud or underneath a cumuliform cloud, often visible as a funnel cloud). Multiple tornadoes can form simultaneously, either in the rotating column circulation itself (referred to as multiple vortex tornadoes) or nearby from other locations within the parent thunderstorm (referred to as satellite tornadoes). Waterspouts, some of which are considered tornadic, may occur over water. Another similar hazard, a "gustnado", is a small whirlwind which forms as an eddy in thunderstorm outflows. Despite possible wind speeds up to 100 mph they are technically not tornadoes because they do not connect with a parent cloud-base rotation.

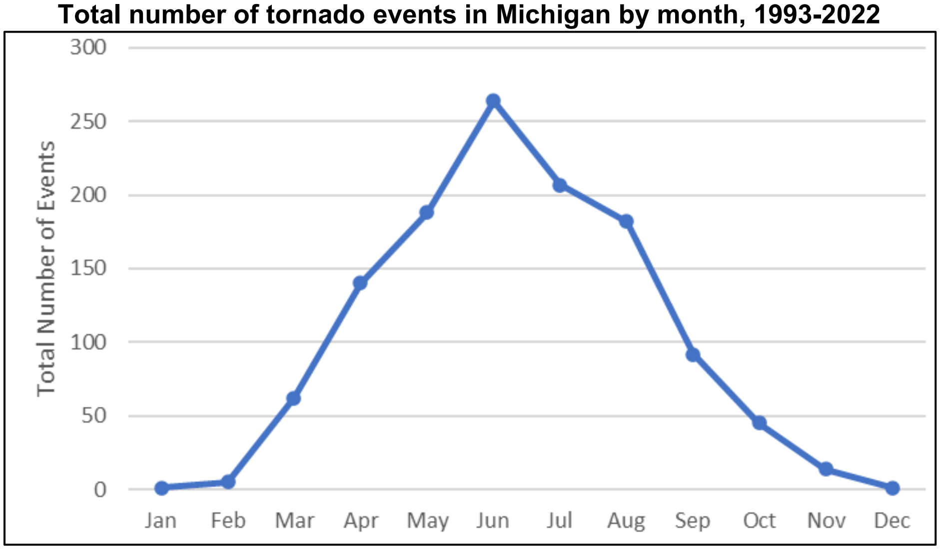
A tornado's winds may be invisible until the air pressure in a tornado's circulation drops low enough to cause condensation of water vapor in the rotating column, or its circulation picks up a sufficient amount of dirt and debris to allow for it to be more readily recognized. Although tornadoes most typically form and move from the trailing edges of their parent thunderstorms, it is possible for them to be present in other locations (e.g., along a thunderstorm leading edge gust front) and/or obscured by rain or hail and less recognizable as a result. Some of the largest tornadoes (usually multiple vortex-type storms) can appear as if an entire thunderstorm cloud has sunk down to touch the ground and may not present with an easily discernable funnel. Regardless, tornadic winds often reach well beyond existing visible funnels.

### *Hazard Analysis*

Michigan lies at the northeastern edge of the nation's primary tornado belt, which extends from the southern Great Plains and interior Gulf region northward into the Midwest. Tornadoes follow the paths of their parent thunderstorms, with most Michigan tornadoes moving from southwest to northeast (a significant fraction also move from northwest to southeast).

While Michigan tornadoes may occur in any month of the year, they are most frequent in the late spring and summer months (when air temperatures and humidity are relatively high and atmospheric instability is greatest). Between 1993 and 2022, 82% of the 1,201 total reported tornadoes in the state occurred between the months of April through September, with a peak of 22% during the month of June.

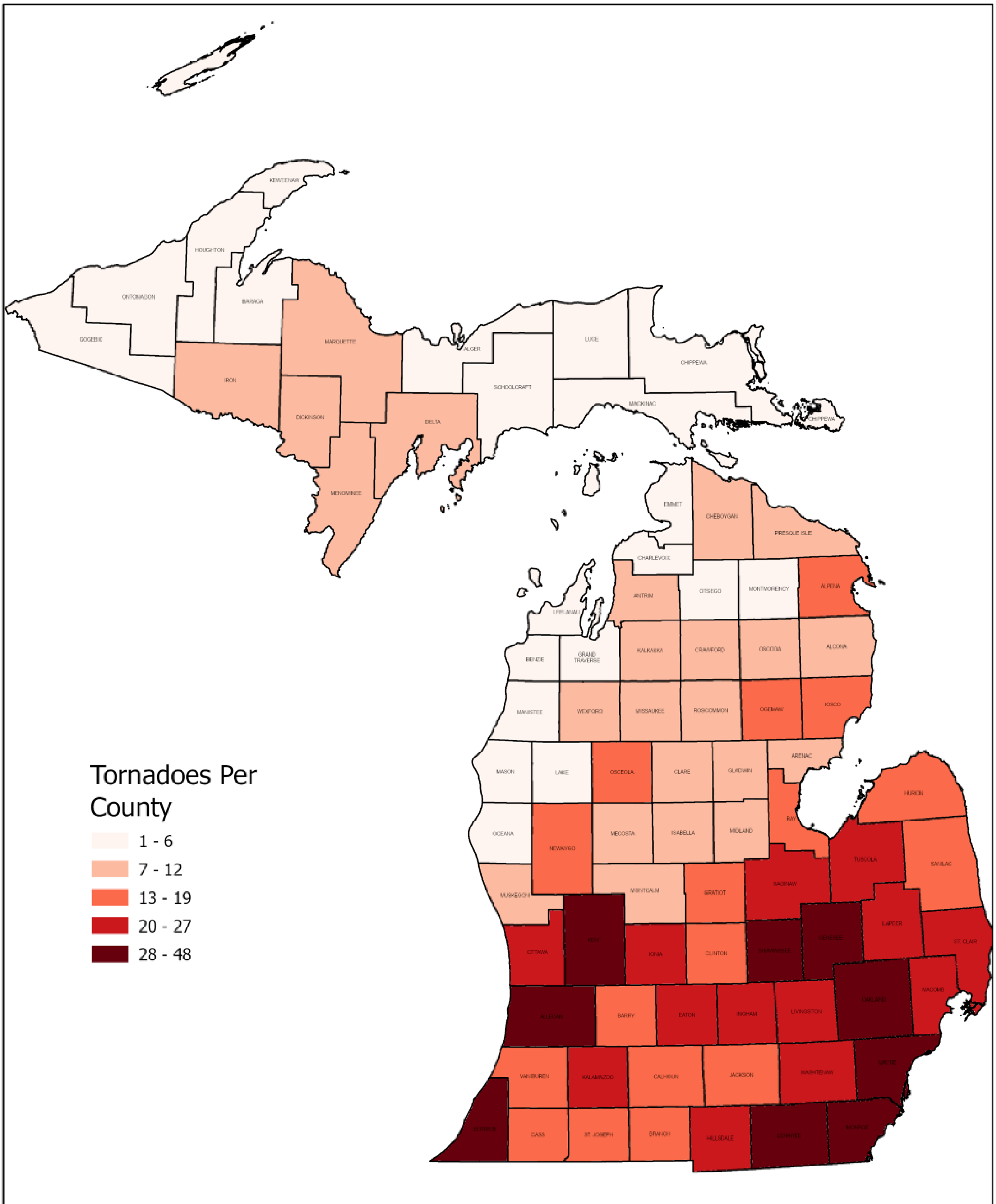
**Total number of tornado events in Michigan by month, 1993-2022**




(source: NOAA NCEI)

While they are possible at any hour of the day, there is a strong diurnal frequency pattern, with 79% of all tornadoes occurring between the hours of 1 p.m. and 8 p.m. when daily atmospheric instability tends to be highest. Historical distribution by county for the period of 1951-2022 is shown on the following map. Although clear distribution patterns emerge, it should be noted that the map has not been adjusted based on the differing square mile sizes of counties.

# MICHIGAN TORNADOES BY COUNTY: 1951-2022




Michigan State Police
Emergency Management and
Homeland Security Division

0 15 30 60 Miles

N

An examination of the map indicates that tornadoes occur more frequently in the southern half of the Lower Peninsula than any other area of the state (which is geographically closer to the south-central US national area of maximum frequency). This area could be referred to as Michigan's "tornado alley." Most of the counties south of Kent and Genesee have had two to three times the number of tornadoes touching down within their boundaries than had been observed in other parts of Michigan. When adjusting for the size of each county, the highest-risk counties on a per-land area basis are Genesee, Monroe, Ingham, and Berrien. North of Flint and Grand Rapids, Saginaw County has also had a relatively high occurrence of tornadoes. The Upper Peninsula and some northern portions of the Lower Peninsula have a relatively lower risk of tornadoes.

Most tornadoes are brief with lifetimes on the order of a few minutes. However, some thunderstorms possess special atmospheric conditions in which the rotational circulation aloft may be maintained for up to several hours. These so-called supercell thunderstorms lead to the vast majority of large, violent, and long-lived tornadoes. The typical length of a tornado path across the US is approximately 16 miles, but tornado tracks much longer than that (up to 200 miles) have been reported. Tornado path widths are generally less than one-quarter mile wide.

It is important to note that the size of a tornado is not necessarily an indication of its intensity. Large tornadoes can be weak, small tornadoes can be extremely strong, and vice versa. It can be difficult to judge the intensity and power of tornadoes while they are occurring. They are classified after they have passed, typically based on measured damage. Tornado intensity is currently measured on the Enhanced Fujita (EF) Scale, which examines the damage caused by a tornado on homes, commercial buildings, and other man-made structures.

**The Enhanced Fujita Scale of Tornado Intensity**

| EF Scale | Intensity Descriptor | Wind Speed (mph) | Type/Intensity of Damage |
|---|---|---|---|
| EF0 | Gale tornado | 65-85 | Light damage. Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards. |
| EF1 | Weak tornado | 86-110 | Moderate damage. The lower limit is the beginning of hurricane wind speed. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed. |
| EF2 | Strong tornado | 111-135 | Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated. |
| EF3 | Severe tornado | 136-165 | Severe damage. Roof and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown. |
| EF4 | Devastating tornado | 166-200 | Devastating damage. Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated. |
| EF5 | Incredible tornado | Over 200 | Incredible damage. Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile-sized missiles fly through the air in excess of 100 meters; trees debarked; steel reinforced concrete structures badly damaged; incredible phenomena will occur. |

(source: NCEI)

Despite the scale's terminology, it should be noted that meteorologists (and others) often classify tornadoes as follows: Weak Tornado (EF0, EF1), Strong Tornado (EF2, EF3), and Violent Tornado (EF4, EF5). Michigan's tornado records since 1950 show approximately 67% of all Michigan tornadoes classified as weak, with 29% strong and 4% violent.

About 95% of tornado-related deaths occur in the months of April, May, and June (June represents 54% of all deaths).

**Tornado-Related Deaths in Michigan, by Month: 1950-2022**

| JAN | FEB | MAR | APR | MAY | JUN | JULY | AUG | SEPT | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 3 | 77 | 25 | 132 | 3 | 1 | 1 | 0 | 1 | 0 | 246 |

(source: NCEI)

Michigan has ranked relatively higher in some past national tornado statistical categories, including "tornado deaths per 10,000 square miles" and "killer tornadoes as a percent of all tornadoes". This is influenced by high death tolls from older tornadoes such as from the 1953 Beecher Event and the 1965 Palm Sunday tornadoes.

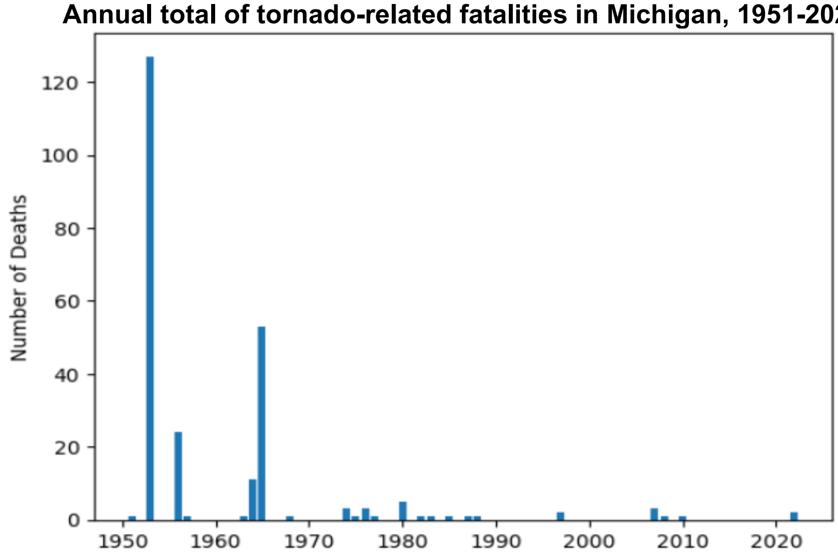
**Killer Tornadoes: Select Top Ten Lists**

| Rank | Single Killer Tornadoes (Date, State, # Deaths, F-Scale) | Tornado Deaths Per 10,000 Sq. Miles | Killer Tornadoes as % of all Tornadoes |
|---|---|---|---|
| 1 | March 18, 1925, MO-IL-IN, 695 deaths, F5 | Massachusetts | Tennessee |
| 2 | May 6, 1840, LA-MS, 317 deaths, severity unknown | Mississippi | Kentucky |
| 3 | May 27, 1896, MO-IL, 255 deaths, F4 | Indiana | Arkansas |
| 4 | April 5, 1936, MS, 216 deaths, F5 | Alabama | Ohio |
| 5 | April 6, 1936, GA, 203 deaths, F4 | Ohio | Alabama |
| 6 | April 9, 1947, TX-OK-KS, 181 deaths, F5 | **Michigan** | Mississippi |
| 7 | May 22, 2011, MO, 158 deaths, F5 | Arkansas | North Carolina |
| 8 | April 24, 1908, LA-MS, 143 deaths, F4 | Illinois | **Michigan** |
| 9 | June 12, 1899, WI, 117 deaths, F5 | Oklahoma | New York |
| 10 | **June 8, 1953, MI, 116 deaths, F5** | Kentucky | Massachusetts |

(sources: NOAA and The Tornado Project)

It should be noted that many competing sources of information exist, sometimes using unclear data sets or being updated on irregular intervals. Caution should be used before drawing broad conclusions. The trend over time in Michigan has generally been toward fewer tornado deaths, especially since the 1950s when 153 deaths occurred.

**Annual total of tornado-related fatalities in Michigan, 1951-2022**




(source: NOAA NCEI)

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

Large sections of land can be flattened by tornadoes with neighborhoods reduced to piles of debris. Damage may be sporadic in an area, with completely destroyed structures next to those left relatively unscathed. Communities may see many residents without homes, areas with no electricity or natural gas, burst pipes, and long clean-up and recovery times. People may have to permanently relocate. While smaller structures, mobile homes, and automobiles are particularly vulnerable, hospitals, fire stations, schools, and virtually any building run the risk of being substantially damaged or destroyed. Roadways, airports, and other transportation modalities may be affected. Waterspouts may impact lake and shoreline areas. Fatalities or injuries are likely to occur depending on the strength and location of the tornado, how long it stays on the ground and other factors.

Impact on the Economic Condition of the State
Although tornadoes can be locally devastating and can easily overwhelm local resources, most tornadoes do not have a broader impact on the economy of the entire state. Vital manufacturing facilities could however be impacted. There is the possibility that a tornado might destroy a critical supply-chain component within a major industry. A major airport being destroyed could carry significant consequences. Crop damage can occur and domesticated livestock may be killed. Region wide impacts are possible, and tornadoes can be part of broader damaging storm damage.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responders often work outdoors in conditions from which most residents are taking shelter. There is a potential for responders or their facilities/equipment to be directly hit. Resources may be spread thin and multiple jurisdiction response may be needed. Search and rescue efforts may be significant. Impeded traffic, power failures, debris, and road closures often make response activities and the use of equipment more difficult.

Impact on the Environment
Tornadoes can cause direct environmental damage, especially to trees. Fires may be triggered by tornadoes in some circumstances. A tornado may strike areas that contains hazardous or toxic materials, farm chemicals, medical waste, or radioactive materials. Debris from damaged and destroyed structures and vehicles may contaminate the land and water. This material may be spread around the immediate area of a touch down or be carried aloft further away. Animals (including domesticated livestock) may be killed, which may result in decomposition risks to the environment.

### *Select Michigan Tornado Events (1950s to present)*

The events listed below are for educational purposes and are not meant to be comprehensive. It should be noted that recent events may rate tornadoes using the Enhanced Fujita (EF) Scale, whereas some older incidents may reference an older Fujita (F) Scale. Events occurring before 1950, including two F5 events from 1896 and 1905, are not included. To conserve space, dollar references for thousand (K), million (M), and billion (B) have been abbreviated.

August 24, 2023 – Southern Lower Peninsula (multiple locations)
Thunderstorms brought high winds and heavy rains, also spawning seven tornadoes across several locations. Impacts included downed trees and power lines, some damage to buildings, and overwhelmed water systems leading to closed roads and some urban flooding (see the Flooding Chapter). Tornadoes ranged in intensity from EF0 to EF2, touching down in Kent, Ingham, Livingston, Monroe, and Wayne Counties. The EF2 tornado (peak winds of 125 mph) cut across Williamston and Webberville, traveling along portions of I-96 where several cars and semi-trucks were blown off the road or flipped over (one person killed) and closing I-96 and M-52. Two EF1 tornadoes hit Monroe County, where at least 13 mobile homes suffered major damage and the Estral Beach Wastewater Treatment Plant temporarily lost power. Kent County also had a mobile home park with 12 trailers seeing major damage or destruction. The South Lyon Department of Public Works building was severely damaged ($1.4M repair estimate), with workers needing to first clear their own facility before being able to assist others. Nearly 500,000 customers lost power at some point across the state, with roughly half that amount stretching into at least the weekend before full restoration. Beyond the jurisdictions already mentioned, Eaton, Ionia, and Macomb (partial) Counties were also included in a Governor's Declaration. Preliminary overall damage estimates were over $40M. The City of Lansing was particularly hard hit, with $10.4M in damages and the death of one woman after a fallen tree hit her home.

July 13, 2023 – St. Joseph and Branch Counties
An EF1 tornado hit Colon, with an estimated peak wind speed of 90 mph (50-yard path width and 3-mile track). A storage facility had its garage doors blown in and a significant amount of roof decking damage. The tornado blew over and topped a number of trees before dissipating in Branch County. Building, tree, and minor crop damage was $50K.

May 20, 2022 – Antrim and Otsego Counties
An EF3 tornado hit Gaylord and some surrounding areas. The tornado formed in Antrim and continued into Otsego, moving east northeast for almost 16 miles before dissipating. Multiple units were completely destroyed in the Nottingham Forest manufactured home community (two fatalities). Three businesses suffered collapses of exterior walls. Damage observed at homes on the northeast side of Gaylord suggested estimated wind speeds of up to 150 mph. The majority of property damage occurred in Otsego County ($50M), which experienced 44 injuries and a tornado path width of 200 yards. This was the first significant (EF2 or greater) tornado in the county warning area since late 2007, and the first time in recent recorded history (since 1950) that Gaylord was directly hit by a tornado.

July 24, 2021 – Huron, Genesee, Macomb, and Oakland Counties
Storms spawned three confirmed tornadoes in White Lake, Armada, and Clayton Township, with an additional tornado later produced over Port Austin. Straight-line wind damage was also observed, especially in Oakland County. Tornadoes were rated as EF0 and EF1 in intensity, with peak winds of 100 mph. Several healthy trees were uprooted and snapped, roofs were damaged, and a garage door was completely blown off. A minor injury occurred when trees fell onto a house. Between the tornadoes and wind damage, Oakland County saw an estimated $10M in damage ($4.5M for Macomb). Genesee County losses were $1M from multiple storm-related impacts. Many areas saw at least 1-2 inches of rain. Some flooding occurred. At least 140,000 DTE customers lost power at the height of the storms.

June 26, 2021 – Huron County
Storms were bringing heavy rain to the area when an EF0 tornado touched down 4 miles southwest of Port Austin. The tornado then tracked northeast and escalated, producing EF2 damage to six houses (three roofs completely detached, one house with major roof damage, two garages and one barn completely destroyed, and substantial tree damage). The estimated peak winds were 120 mph. The tornado continued to move, eventually tracking across the Eagle Bay public access point and into Lake Huron. Total property damage was $1.9M, along with six injuries.

March 14, 2019 – Shiawassee and Genesee Counties
Storms produced four tornado touchdowns, three rated as EF0 and one near Vernon rated EF2. Some debris (insulation/lighter metal) from the M-71 area in Vernon was carried 7 miles. The Shiawassee Emergency Manager reported 135 structures, 94 homes, 4 businesses, 16 barns, and 22 RVs damaged or destroyed. Total property damage in Shiawassee County amounted to $9.8M (Genesee County saw $175K).

September 25, 2018 – Monroe and Wayne Counties
A moist air mass paired with ample wind shear generated three tornadoes, with one reaching EF1 strength (garage doors were blown in and many trees uprooted). Later EF0 damage to siding and tree limbs was noted before the tornado dissipated. Both counties each saw $650K in property damages.

August 20, 2016 – Southern Lower Peninsula (Allegan, Ottawa, Kent, and Ionia Counties)
More than $5M in property damage was caused by tornadoes, all rated as EF0 or EF1. The entire city of Bangor lost electric power for the afternoon. No injuries or deaths were reported.

June 22-23, 2015 – Southern Lower Peninsula
Seven persons were injured when tornado winds tore across Ionia and Saginaw Counties. The classification of these impacts ranged from an EF0 tornado to an EF2. A total of more than $4.6M in property damage was caused across the counties of Ionia, Saginaw, Tuscola, Sanilac, St. Clair, and Washtenaw Counties.

July 6, 2014 – Kent and Ionia Counties
Late night tornadoes injured six persons south of Grand Rapids and caused more than $4.5M in property damage. Winds reached 110 mph for an EF1 tornado, on the ground for 10 minutes and damaging numerous trees, structures, and power lines. Three weaker EF0 tornadoes followed.

March 15, 2012 – Southeast Michigan (Washtenaw, Lapeer, and Monroe Counties)
Three tornadoes resulted in roughly $12M in property damage. An EF3 tornado touched down near Dexter with maximum wind speeds of 135-140 mph, damaging at least 200 homes (20 severely) and destroying two more. An EF2 tornado struck near Lapeer, leaving a damage path roughly 4.6 miles long with a maximum width of 400 yards. A house was shifted off its foundation and a garage was destroyed. An EF0 tornado was also confirmed near Yargerville.

April 26, 2011 – Allegan County
An EF0 tornado collapsed a 100-foot section of a pole barn, tore a section of roof off a warehouse, knocked over several trailers, and blew the windows out of several cars. Some houses received minor roof and garage door damage. The tornado lifted after partially destroying a 75-year-old barn. Property damage totaled approximately $1M.

June 27, 2010 – St. Clair County
An EF1 tornado with winds up to 95 mph struck a campground in Clyde Township. One person was killed and four were injured. About 10 campers were damaged or destroyed, some blown into the water of a nearby pond. Total damages at the campground were estimated at $700K, with overall area damages pegged at $1.25M.

June 5-6, 2010 – Southern Lower Peninsula (Berrien, Cass, Calhoun, and St. Joseph Counties; later Monroe County)
Two tornadoes (EF1 and EF2) hit four counties for $2.6M in damages. Two similarly classified tornadoes then struck Monroe County after midnight, the stronger one tracking 13 miles (including through hard-hit Dundee) and measuring up to 800 yards wide. One tornado was noteworthy because it caused some damage at the Fermi nuclear power facility, and it also impacted a site where flood mitigation was underway at Estral Beach (significantly setting back the project). The Monroe tornadoes caused $60M in damages, including 311 buildings damaged and five homes destroyed.

October 18-19, 2007 – Lower Peninsula
Multiple tornadoes were highlighted by an EF2 (120-130 mph wind speeds) which began near Mason and moved through Williamston (where 100 nearby structures were damaged and two people died in a modular home). The tornado moved into Shiawassee County (one person was injured). Genesee, Tuscola, and Huron Counties also saw tornado impacts. Total property damages were $15M. This tornado “outbreak” also rocked the Northern Lower Peninsula, with Alcona, Alpena, Cheboygan, Kalkaska (one death), and Oscoda impacted.

August 24, 2007 – Southern Lower Peninsula
An EF3 tornado with wind speeds estimated at 140 mph produced some of its most severe damage near Potterville. Its path was 200-300 yards wide and 6.5 miles long. Fifteen homes were either destroyed or severely damaged and two barns were destroyed. Six persons were injured and property damages totaled roughly $25M. Tornado impacts were reported for the counties of Eaton, Genesee, Ingham, Lapeer, Livingston, Oakland, Shiawassee, and Washtenaw.

August 21, 2003 – Ingham County
A tornado rated as an F2 on the original Fujita scale had a path length of 4.5 miles long and up to ½-mile wide. A collapsed house trapped two persons inside, injuring both. Another house was destroyed, a barn leveled, and a pickup truck blown off the road. Tornado-related property damage was $500K with crop damage estimated at an additional $200K.

July 20, 2003 – Battle Creek (Calhoun County)
An F1 intensity tornado stayed on the ground for three miles, causing a garage to be torn from a house and an older farmhouse to be rotated off its foundation. Three outbuildings and a barn were destroyed, part of $1M in property damages along with $200K in crop damage. Hundreds of trees were also uprooted or broken off.

September 30, 2002 – Dickinson County
An F1 intensity tornado developed in Florence County, Wisconsin, and crossed the Menominee River just south of the Iron Mountain-Kingsford airport. Overall, the storms produced three tornadoes and extensive downburst wind damage. Numerous trees and power lines were knocked down, blocking highway US-2, and disrupting electric power and telephone service. Gas lines were ruptured and several commercial buildings sustained substantial roof damage in Kingsford. Property damage due to all of the storms was estimated at around $7M.

September 9, 2001 – Eaton and Ingham Counties
An F1 intensity tornado carved an 8-mile long by 900-yard-wide swath through Delta Township. The tornado damaged several structures and destroyed the cooling towers at a Lansing Board of Water and Light power plant, causing $4M in damage and forcing the plant to shut down. Damages totaled $15M, mostly in Eaton County.

May 21, 2001 – Southern and Central Michigan
Severe thunderstorms spawned 21 tornadoes in 16 counties, causing $5.5M in property damage and $400K in crop damage (Kalamazoo, Kent, Livingston, and Oakland were hardest hit). Approximately $3M of the damage was from an F2 intensity tornado striking Hartland and Tyrone Townships, which tore through a golf course, destroying 12 vehicles and damaging 58 others, destroying a portion of the clubhouse and 35 golf carts, and injuring one person. Several cars and semi-trailers were flipped when the tornado crossed US-23. Additional damages were reported in the counties of Allegan, Barry, Clinton, Clare, Eaton, Genesee, Gratiot, Ionia, Isabella, Lapeer, Ottawa, and Shiawassee.

July 3, 1999 – Northeastern Lower Peninsula
A tornado touched down near Lewiston and traveled through Oscoda and Alcona Counties, causing damage to homes and businesses and injuring two persons. The destruction was devastating for the small Village of Comins. Nine homes were destroyed, 46 homes sustained damage, and eight businesses were damaged or destroyed. The Clinton Township Hall and Fire Department buildings were also destroyed, and the Post Office sustained damage. Local roads were blocked by debris and downed power lines, leaving residents without power for several days. A Governor’s Disaster Declaration was granted to Oscoda County. Damage estimates approached $2M.

October 6, 1998 – Central-West Michigan
A series of strong thunderstorms traveled through several counties. The City of Big Rapids (Mecosta County) was hardest hit by the storms, with a tornado damaging several buildings at Ferris State University and around the campus. The storm also brought rain, flooded streets, downed power lines, and a dozen injuries. Clare County saw a storm destroy one home, damage ten others, and injure three persons. Limited damages occurred in Isabella County.

July 2, 1997 – Lower Peninsula (Presidential Major Declaration, Five Counties)
Storms spawned 16 tornadoes, 13 of which occurred in Genesee, Lapeer, Livingston, Macomb, Oakland, Saginaw, and Wayne Counties. The tornadoes damaged or destroyed over 2,900 homes and nearly 200 businesses, causing $25M in public and $30M in private damages. A total of 16 deaths were attributed to the storms (two by tornadoes). Another 120 persons were injured (98 by tornadoes). Power was knocked out to 350,000 electrical customers. The Wayne County tornado was F2 in intensity, while in Genesee County there were two F3 tornadoes and two F1 tornadoes. Additional tornado impacts occurred in Arenac, Crawford, and Oscoda Counties.

July 13, 1992 – Cass County (Governor’s Disaster Declaration)
An F2 intensity tornado with a trail six miles long damaged or destroyed 40 homes, several agribusinesses, and a migrant labor camp. Twenty-five persons were injured, and another 100 were left homeless by the tornado. Property damage is currently estimated to have been $250,000, but earlier reports had also referred to nearly $2.7M in agricultural impacts.

April 16, 1992 – Plymouth (Wayne County)
An F2 intensity tornado touched down in a mobile home park, destroying 6 homes and damaging 14 others. Four residents of the mobile home park were injured. Total property damage was estimated at $2.5M.

March 27, 1991 – Lower Peninsula
Severe weather events covered a wide area and produced numerous tornadoes. Ogemaw, Iosco, and Alcona Counties were particularly hard-hit and suffered a total of more than $15M in property damage from F3 tornadoes that traveled dozens of miles. An F3 tornado in Calhoun County injured 18 persons, and an F3 tornado in Hillsdale County caused $25M in property damage. Other impacted counties included Ingham, Mecosta, Newaygo, Osceola, and St. Clair.

October 4, 1990 – Genesee County (Governor’s Disaster Declaration)
An F2 tornado left a trail 200 yards wide and 4.5 miles long. Over 30 homes and 20 businesses were severely damaged ($2.5M). Debris blocked numerous roads. One person was injured when their semi-truck overturned on I-69.

June 21, 1987 – Oakland County and July 4, 1986 – Menominee County
An F2 tornado in Novi caused 1 death, 6 injuries, and $250K in property damage. A 1986 tornado injured 12 and caused an estimated $2.5M in property damage during the Independence Day Holiday.

May 13, 1980 – Southwest Michigan (Presidential Declaration #621)
A tornado in Van Buren County damaged over 500 structures and injured 15 persons. A Kalamazoo tornado damaged over 1,200 homes and caused five fatalities and 79 injuries.

April 2, 1977 – Southern Lower Peninsula
Ten persons were injured in Kalamazoo and one person was killed and 44 injured in Eaton County by an F4 intensity tornado. The counties of Clinton, Ingham, Livingston, and Shiawassee experienced other tornadoes (F1 or F2).

March 20, 1976 – Southeastern Michigan
A pair of tornadoes of F4 and F3 severity killed two people and injured 58 (mostly in Oakland County), generating $26M in property damage. Impacts were reported for the counties of Calhoun, Eaton, Ingham, Ionia, Macomb, and Oakland.

April 3, 1974 – Southern Michigan (Part of the National “1974 Super Outbreak”)
The first mass national tornado event with more than 100 tornadoes in less than 24 hours saw eight tornadoes touch down in Michigan across Monroe, Hillsdale, Jackson, and Lenawee Counties. Damages totaled nearly $3M, with mobile homes especially affected. Two persons were killed and 44 injured.

July 4, 1969 – Southeastern Michigan
Numerous (65 persons) tornado injuries took place across Jackson, Washtenaw, and Wayne Counties. Total damage estimates exceeded $5M (predominantly in Washtenaw and Wayne), with some also reported in Hillsdale County.

April 21, 1967 – Southwestern and South-Central Lower Peninsula
Several tornadoes across the counties of Allegan, Barry, Berrien, Clinton (F4 intensity), Eaton, Ionia, and Kent caused more than $28M in property damages. A total of 51 people were injured.

April 11, 1965 - Southern and Central Michigan
Part of the "Palm Sunday Tornadoes", this notable midwestern tornado outbreak had a particularly devastating impact on Michigan, with a total of 25 tornadoes touching down in 15 counties (see table below). Several were rated as a strong F3 or F4. A particularly tragic impact occurred at Manitou Beach, where storms stuck a church filled with people. Overall state impacts included 53 fatalities, 800 injuries, and $310M in property damages (not adjusted for inflation). Nearby Indiana had 137 deaths, and Ohio had 60. A lengthy recovery process saw the National Guard being used to secure areas in order to prevent looting.

**April 11, 1965 (Palm Sunday) Tornado Outbreak: Michigan Impacts**

| County | Number of Tornadoes | Deaths | Injuries | Tornado Intensity |
|---|---|---|---|---|
| Allegan | 1 | 1 | 9 | F1 |
| Barry | 2 | 0 | 5 | F1 and F3 |
| Bay | 1 | 0 | 2 | F2 |
| Branch | 2 | 18 | 400 | F3 and F4 |
| Clinton | 1 | 1 | 8 | F4 |
| Gratiot | 4 | 0 | 1 | all F2 |
| Hillsdale | 2 | 6 | 94 | F3 and F4 |
| Kalamazoo | 1 | 0 | 17 | F3 |
| Kent | 2 | 5 | 142 | both F4 |
| Lenawee | 2 | 9 | 83 | F3 and F4 |
| Monroe | 3 | 13 | 39 | F3 and F4 |
| Montcalm | 1 | 0 | 0 | F2 |
| Ottawa | 1 | 0 | 0 | F4 |
| Shiawassee | 1 | 0 | 0 | F4 |
| Tuscola | 1 | 0 | 0 | F2 |
| **STATEWIDE:** | **25** | **53** | **800** | |

(source: The Tornado Project / NCEI Storm Events Online Database)

May 8, 1964 – Lower Peninsula
The counties of Grand Traverse, Macomb, Monroe, Oakland, and Presque Isle all suffered from damaging tornadoes on this day. Although numerous tornadoes occurred throughout the Lower Peninsula, the worst impact was in Macomb County, where 11 persons were killed, 224 were injured, and an estimated $2.5M in property damage was caused. Two additional injuries occurred in nearby Monroe and Oakland Counties.

May 12, 1956 – Genesee, Wayne, and other Lower Peninsula Counties
Three persons were killed and 116 were injured as a result of an F4 tornado in Flint. On the same day, an F4 tornado also touched down in Wayne County, injuring 22 persons. Other tornado impacts took place in the counties of Clinton, Gratiot, Livingston, Montcalm, Oakland, Saginaw, and Shiawassee on this same day.

April 3, 1956 – Hudsonville to Walker (Ottawa, Kent, and other Western Michigan Counties)
An F5 tornado struck Hudsonville and then traveled through Ottawa and Kent Counties, killing at least 14 and injuring 200. Over 700 homes were destroyed. Numerous other tornadoes classified as F4 took their toll on other counties such as Manistee (two killed, 24 injured), Grand Traverse, Benzie, and Allegan. Other impacts were reported in the counties of Barry, Montcalm, and Van Buren, all of which had F3 tornadoes the same day.

June 8, 1953 – Genesee County (and Southeastern Michigan)
The Beecher Tornado was one of the worst single-killer tornadoes to have occurred in the US. Death tolls have varied, with 113 from a 4-mile stretch in Flint alone. Total injuries have been pegged at 844 and damages estimated at $19M ($125M in 2003 dollars). Several tornadoes touched down in other locations in Michigan that day, resulting in an additional nine deaths. Counties with tornadoes included Alcona (F3), Genesee (F5, F5), Iosco (F2), Lapeer (F5, F4), Livingston (F3), Monroe (F4), Oakland (F3), St. Clair (F4), and Washtenaw (F3).

### *Select Agencies and Programs*

Please see the Thunderstorm Hazards Overview section for a listing of agencies and other information related to convective weather and high winds.

### *Supplemental Materials*

**Michigan Tornado* Data (Arranged by Geography, 1/1/1996 –4/30/2023)**
(see Appendix A for information related to geographic groupings)

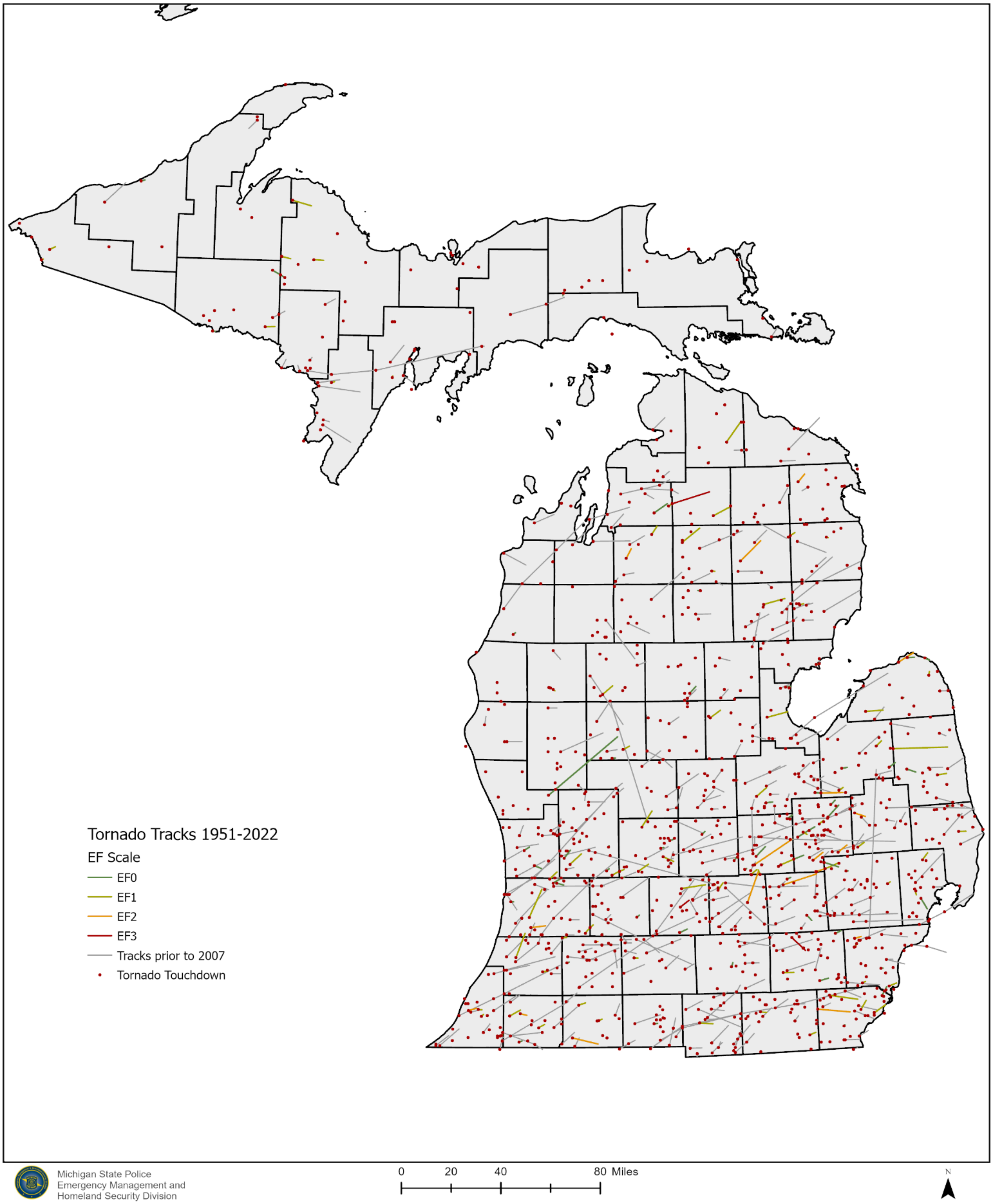
| COUNTY/AREA | Reported Tornado Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 6 | $12,895,000 | | | |
| Wayne | 7 | $91,950,000 | | | 90 |
| Livingston | 8 | $10,220,000 | | | 3 |
| Oakland | 10 | $15,852,000 | | 1 | |
| Macomb | 6 | $35,305,000 | | | 6 |
| **5 County Metro Area** | **7.4 avg.** | **$166,222,000** | **$0** | **1** | **99** |
| Berrien | 9 | $2,110,000 | | | |
| Cass | 10 | $6,000,000 | | | |
| St. Joseph | 7 | $822,200 | | 1 | |
| Branch | 2 | $50,000 | | | |
| Hillsdale | 5 | $351,000 | | | |
| Lenawee | 5 | $830,000 | | | |
| Monroe | 13 | $60,878,000 | | | 11 |
| Van Buren | 8 | $110,000 | $10,000 | | |
| Kalamazoo | 9 | $690,500 | $142,000 | | |
| Calhoun | 5 | $3,200,000 | $275,000 | | |
| Jackson | 4 | $800,000 | $50,000 | | |
| Allegan | 12 | $5,477,000 | | | |
| Barry | 5 | $470,000 | | | |
| Eaton | 11 | $50,357,000 | $225,000 | 1 | 6 |
| Ingham | 9 | $20,850,000 | $200,000 | 2 | 2 |
| Ottawa | 6 | $850,000 | $10,000 | | |
| Kent | 16 | $5,970,000 | $30,000 | | 6 |
| Ionia | 9 | $4,745,000 | $55,000 | | 5 |
| Clinton | 5 | $700,000 | $150,000 | | |
| Shiawassee | 13 | $10,515,000 | | | 1 |
| Genesee | 22 | $19,720,000 | | 1 | 2 |
| Lapeer | 9 | $1,880,000 | | | |
| St. Clair | 10 | $970,000 | | 1 | 4 |
| Muskegon | 5 | $50,000 | | | |
| Montcalm | 4 | $152,000 | $25,000 | | |
| Gratiot | 5 | $675,000 | $29,000 | | 1 |
| Saginaw | 15 | $6,608,000 | $5,500 | | 2 |
| Tuscola | 13 | $1,611,000 | | | 1 |
| Sanilac | 10 | $985,000 | | | |
| Mecosta | 4 | $1,450,000 | | | 12 |
| Isabella | 9 | $715,000 | $10,000 | | 1 |
| Midland | 3 | $225,000 | | | |
| Bay | 6 | $180,000 | | | |
| Huron | 12 | $2,480,000 | | | 7 |
| **34 County Southern Lower Peninsula** | **8.5 avg.** | **$213,476,700** | **$1,216,500** | **5** | **62** |

(continued on next page)

| COUNTY/AREA | Reported Tornado Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | | | | | |
| Newaygo | 4 | $62,000 | $10,000 | | |
| Mason | 1 | | | | |
| Lake | 3 | $350,000 | $50,000 | | |
| Osceola | 5 | $512,000 | $100,000 | | 1 |
| Clare | 4 | $310,000 | $10,000 | | |
| Gladwin | 2 | $90,000 | | | |
| Arenac | 6 | $130,000 | $1,000 | | 1 |
| Manistee | 1 | $15,000 | | | |
| Wexford | 2 | $268,000 | | | |
| Missaukee | 1 | | | | |
| Roscommon | 2 | $5,000 | | | |
| Ogemaw | 6 | $225,030 | | | |
| Iosco | 2 | $215,000 | | | |
| Benzie | | | | | |
| Grand Traverse | | | | | |
| Kalkaska | 4 | $1,260,000 | | 1 | 1 |
| Crawford | 5 | $145,000 | | | |
| Oscoda | 4 | $2,890,000 | | | 2 |
| Alcona | 3 | $315,000 | | | |
| Leelanau | 1 | $20,000 | | | |
| Antrim | 5 | $314,000 | | | |
| Otsego | 3 | $50,226,000 | | 2 | 44 |
| Montmorency | 3 | $210,000 | | | |
| Alpena | 5 | $491,000 | | | |
| Charlevoix | 1 | | | | |
| Emmet | 2 | | | | |
| Cheboygan | 3 | $50,000 | | | |
| Presque Isle | 2 | | | | |
| **29 County Northern Lower Peninsula** | **2.8 avg.** | **$58,103,030** | **$171,000** | **3** | **49** |
| Gogebic | 3 | $175,000 | | | |
| Iron | 4 | $187,000 | | | |
| Ontonagon | 1 | $20,000 | | | |
| Houghton | 1 | | | | |
| Keweenaw | 1 | | | | |
| Baraga | | | | | |
| Marquette | 9 | $72,000 | $5,000 | | |
| Dickinson | 8 | $7,013,000 | $120,000 | | |
| Menominee | 4 | $35,000 | | | |
| Delta | 12 | $188,000 | | | |
| Schoolcraft | 1 | | | | |
| Alger | 2 | | | | |
| Luce | 2 | $5,000 | | | |
| Mackinac | 1 | | | | |
| Chippewa | 2 | $200,000 | | | |
| **15 County Upper Peninsula** | **3.4 avg.** | **$7,895,000** | **$125,000** | **0** | **0** |
| **MICHIGAN TOTAL**** | **458** | **$445,697,030** | **$1,512,500** | **9** | **210** |
| **Michigan Annual Avg.** | **16.8** | **$16,308,439** | **$55,325** | **0.3** | **7.7** |

***** Combines NCEI Storm Data categories for “Tornado” “Dust Devil” “Funnel Cloud” and “Waterspout”.
**One event may take place in multiple counties.  State totals may be less than the sum of all counties.

MICHIGAN TORNADO TRACK MAP
TORNADO LOCATIONS AND TRACKS: 1951-2022




(source: MSP/EMHSD Map produced with ESRI ArcGIS viewer)

# HIGH WINDS (NON-TORNADIC)

*Non-tornadic winds with sustained velocities generally over 40 mph (or meeting other criteria).*

## *Hazard Description*

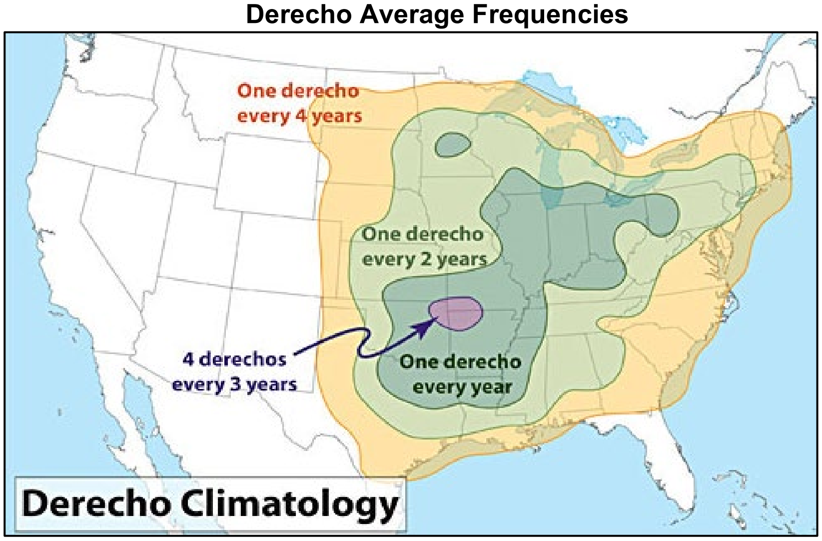
This chapter focuses on potentially impactful non-tornadic winds, also known as “straight line winds”, defined in part as those exceeding 40 mph for at least one hour. Terms such as “damaging winds” (exceeding 50-60 mph) may also be used, while other datasets focus exclusively on winds of at least 58mph (regardless of duration). For simplicity, this chapter generically refers to impactful non-tornadic winds as “high winds” and analyzes them based on whether they are related to thunderstorm activity or are part of larger synoptic scale wind producing systems. With exception, high wind areas from singular thunderstorms are generally smaller in size compared to synoptic systems that may be as large as one or more states. Multiple types of wind events may impact areas at one time, especially over large regions.

## *Hazard Analysis*

Wind behaves differently throughout the country based on topography, land cover, and other factors. Michigan statistics looking at high winds of at least 58 mph (1991-2021) show that thunderstorm-associated high winds occurred more frequently than those associated with synoptic weather events (roughly 88% vs. 12%). Events from both categories may occur during any month, but thunderstorm-related events are most common during the warm season when thunderstorms are more frequent (88.5% occurring between May and September (peaking in July) and on a daily basis between 1 p.m. – 8 p.m.). High winds associated with synoptic events are most common during the spring, fall, and winter. Compared to thunderstorm-related events, synoptic wind event frequencies are more uniformly distributed throughout the day, with somewhat higher frequencies during the late morning and afternoon hours. Between the two categories, it is not rare to still see high winds during the cold season capable of producing high speeds up to 60-70 mph.

The NWS historical observations (see table on the next page) indicate that non-tornadic high wind events occur more frequently in the southern half of the Lower Peninsula than in any other area of the state. On average, high wind events can be expected roughly three times per year in the Upper Peninsula, two times per year in the northern Lower Peninsula, and 4-12 times per year in the southern Lower Peninsula. While not all variants of high winds need to be discussed, microbursts and derechos will be mentioned here. A microburst, a type of downburst, is a localized but powerful wind gust that typically occurs with air rapidly descending from a single thunderstorm. Microbursts may cause serious non-tornadic (straight line) wind damages that are comparable to brief/weak tornadoes. Typical damage from microburst winds involves widespread downed trees and power lines, as well as minor structural damage.

**Derecho Average Frequencies**




(source: Storm Prediction Center, illustration credit Dennis Cain)

While many thunderstorm-related high wind events may be relatively isolated, clusters of individual thunderstorms may combine (typically in a single line) to form larger and longer-lived storm systems known as derechos. Wind speeds can exceed 100 mph and often result in damage that is more widespread than most Michigan tornadoes. The damage paths for some derechos may ultimately exceed 250 miles in length.

Like all thunderstorm-related high wind events, derechos can happen at any time but are most common in Michigan during the warmer half of the year.

**Michigan High Winds* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported High Winds Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 383 | $49,890,000 | | 1 | 4 |
| Wayne | 431 | $105,851,000 | | 8 | 35 |
| Livingston | 285 | $35,478,000 | | | 1 |
| Oakland | 576 | $75,601,000 | | 3 | 10 |
| Macomb | 358 | $68,662,000 | | | 2 |
| **5 County Metro Area** | **407 avg.** | **$335,482,000** | **$0** | **12** | **52** |
| Berrien | 236 | $893,500 | $120,000 | 2 | 9 |
| Cass | 164 | $1,264,000 | | 1 | 6 |
| St. Joseph | 210 | $750,550 | | 2 | |
| Branch | 188 | $455,000 | | | |
| Hillsdale | 185 | $613,000 | | | 2 |
| Lenawee | 262 | $25,882,000 | | | 5 |
| Monroe | 263 | $26,360,000 | | | 8 |
| Van Buren | 121 | $18,854,000 | $40,000 | 1 | |
| Kalamazoo | 138 | $28,744,000 | $145,000 | | 1 |
| Calhoun | 160 | $46,910,000 | $235,000 | 1 | 10 |
| Jackson | 143 | $14,858,000 | $30,000 | | |
| Allegan | 163 | $17,972,000 | $95,000 | | 3 |
| Barry | 106 | $15,006,000 | $55,000 | | |
| Eaton | 97 | $17,982,000 | $180,000 | | |
| Ingham | 119 | $18,335,000 | $55,000 | | |
| Ottawa | 132 | $58,846,000 | $10,060,000 | 5 | 21 |
| Kent | 161 | $87,072,000 | $20,085,000 | 4 | 60 |
| Ionia | 99 | $14,994,000 | $45,000 | | 2 |
| Clinton | 105 | $15,255,000 | $70,000 | 2 | |
| Shiawassee | 160 | $14,102,000 | | | |
| Genesee | 366 | $40,714,000 | | | 3 |
| Lapeer | 228 | $16,806,000 | | 1 | 1 |
| St. Clair | 256 | $35,893,000 | | | |
| Muskegon | 109 | $45,850,250 | $5,030,000 | 1 | 5 |
| Montcalm | 88 | $28,502,000 | $70,000 | | 23 |
| Gratiot | 63 | $14,757,000 | $15,000 | | |
| Saginaw | 267 | $35,159,000 | | | 5 |
| Tuscola | 201 | $13,023,950 | | | |
| Sanilac | 139 | $12,465,500 | $4,000 | | 1 |
| Mecosta | 49 | $11,549,000 | $10,000 | | |
| Isabella | 77 | $12,011,000 | $35,000 | | |
| Midland | 141 | $12,778,000 | | | |
| Bay | 150 | $15,211,000 | | 1 | |
| Huron | 186 | $12,462,000 | | 1 | |
| **34 County Southern Lower Peninsula** | **163 avg.** | **$732,329,750** | **$36,379,000** | **22** | **165** |

(continued on next page)

| COUNTY/AREA | Reported High Winds Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | 50 | $15,845,000 | $50,000 | | 37 |
| Newaygo | 74 | $12,797,000 | $50,000 | 2 | |
| Mason | 71 | $8,038,000 | $35,000 | | 5 |
| Lake | 43 | $7,633,000 | | | |
| Osceola | 44 | $5,932,500 | $35,000 | | 1 |
| Clare | 53 | $5,943,510 | $15,000 | 2 | 1 |
| Gladwin | 52 | $501,000 | | | |
| Arenac | 40 | $430,500 | | | 4 |
| Manistee | 55 | $645,500 | | | |
| Wexford | 53 | $404,500 | | | |
| Missaukee | 28 | $532,000 | | | |
| Roscommon | 73 | $515,500 | | | 1 |
| Ogemaw | 70 | $625,500 | | 1 | 2 |
| Iosco | 52 | $263,000 | | | 1 |
| Benzie | 33 | $236,000 | | | |
| Grand Traverse | 64 | $13,468,000 | $1,000 | | |
| Kalkaska | 42 | $665,000 | | | |
| Crawford | 40 | $1,570,000 | | | |
| Oscoda | 35 | $223,000 | | | 1 |
| Alcona | 48 | $141,500 | | | 1 |
| Leelanau | 56 | $24,245,000 | $8,000 | | |
| Antrim | 68 | $960,500 | | | 1 |
| Otsego | 60 | $2,041,000 | | | 1 |
| Montmorency | 45 | $287,000 | $5,000 | | 1 |
| Alpena | 54 | $292,000 | | | |
| Charlevoix | 44 | $323,000 | | | |
| Emmet | 52 | $623,000 | | | 1 |
| Cheboygan | 44 | $491,500 | | | |
| Presque Isle | 33 | $216,000 | | | 1 |
| **29 County Northern Lower Peninsula** | **51 avg.** | **$105,889,010** | **$199,000** | **5** | **59** |
| Gogebic | 120 | $1,450,000 | $1,000,000 | 1 | 1 |
| Iron | 79 | $406,000 | $2,000,000 | | |
| Ontonagon | 77 | $206,000 | $1,060,000 | | |
| Houghton | 154 | $548,000 | $1,000,000 | | |
| Keweenaw | 58 | $403,000 | | | |
| Baraga | 80 | $619,500 | | | |
| Marquette | 235 | $3,835,250 | | 2 | |
| Dickinson | 105 | $1,066,000 | | | |
| Menominee | 115 | $732,000 | | | |
| Delta | 107 | $1,308,000 | $4,250,000 | | 3 |
| Schoolcraft | 50 | $734,000 | $2,613,000 | | |
| Alger | 71 | $473,500 | $1,001,000 | | 1 |
| Luce | 47 | $200,000 | $1,000 | | |
| Mackinac | 29 | $150,000 | | | |
| Chippewa | 47 | $454,500 | | | 1 |
| **15 County Upper Peninsula** | **92 avg.** | **$12,585,750** | **$12,925,000** | **3** | **6** |
| **MICHIGAN TOTAL**** | **10,415** | **$1,163,454,097** | **$49,393,000** | **42** | **282** |
| **Michigan Annual Avg.** | **381** | **$43,407,193** | **$1,811,358** | **1.5** | **10.3** |

*Combines NCEI Storm Data categories for “High Wind,” “Strong Wind,” and “Thunderstorm Wind”.
**One event may take place in multiple counties. State totals may be less than the sum of all counties.

High winds have had significant effects on Michigan, resulting in 42 deaths, 282 injuries, and over $1.2 billion in property and crop damages since 1996. These are a result of high winds from most non-tornadic sources and does *not* include damage from tornadoes (see separate chapter).

A map highlighting damaging non-tornadic paths is included in the supplemental materials section of this chapter but should be approached with caution for analysis. It should be noted that the map does not show the majority of high wind events, many of which may be better represented by dots (indicative of local damage) rather than path lines.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
High winds impede transportation, causing slowed traffic, flight delays, and rough waters. Property damages can be comparable to weak tornadoes but often with a more widespread area of effect. Trees/limbs frequently break, blocking roads and toppling phone and power lines. Large scale and often lengthy power outages can be anticipated, sometimes during hot or cold weather. Loss of life from falling trees and flying debris is possible, but typically less than seen with tornadoes. Facilities, homes, and garages may have roofs removed or destroyed. Mobile homes are susceptible.

Impact on the Economic Condition of the State
Most storms will have only a moderate impact on the state, depending on location. The largest of storms may impact an entire region, hindering operations until debris can be cleared or power can be restored. Some businesses may be shuttered for safety reasons until fully repaired. Major shipping locations or airports that are damaged may impact the supply of goods. Building components may be in short supply if large areas are affected. High winds hitting the timber industry or agricultural areas may be disproportionally affected.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responders are exposed to high winds, which may occur suddenly or persist for several hours. Winds may tip vehicles or debris may block roads. Air and boat travel may be compromised, with search and rescue efforts hampered. Downed power lines may injure or kill workers. Mass care and sheltering may be needed due to damaged homes or those without power or heat. Large storms may affect large regions at a time, which must then compete for scarce resources.

Impact on the Environment
Full-grown trees may be uprooted and knocked down, with potentially large tracts of vegetative land destroyed. Debris from trees, structures, and other sources may foul land or waterways. Damaged structures may be made up of or contain toxic building materials, chemicals, or other environmental hazards. Lakeshore beach erosion may occur. Winds can stir up sediments in waterways and thus disrupt the local ecosystem. Wildlife species can be harmed.

### *Select High Wind Events in Michigan*

High-wind events occur frequently enough that any listing of historical events can be lengthy. For the sake of brevity not all impacts are included. The below examples attempt to focus on more inland events where possible, while some storms with significant Great Lakes shoreline wind/wave impacts (e.g., erosion, sunk ships, drownings) may be placed elsewhere. Thunderstorm-related events may be accompanied by both non-tornadic winds and tornadoes.

June 13, 2022 – Van Buren and Kalamazoo Counties
A severe thunderstorm with wind gusts up to 75 mph and hail brought down hundreds of tree limbs and numerous power lines. Debris was still being cleaned up two weeks later. Damages included one house that was likely a total loss and impacts near the Van Buren County Youth Fair. Total property damages between the two counties were $5M.

November 15, 2020 – Southeastern and East Central Lower Peninsula
A synoptic scale weather system led to widespread 40-60 mph winds, with isolated reports of 65 mph winds enhanced by thunderstorms. Over 200,000 customers lost power. Several counties saw between $200K-$1M in damages: Shiawassee, Macomb, Lenawee, Washtenaw, Wayne, Monroe, Livingston, Oakland, Genesee, Midland, Bay, Huron, Saginaw, Tuscola, Sanilac, Lapeer, and St. Clair. Total damages were $6.5M

June 26, 2020 – Southwestern Lower Peninsula
Two thunderstorms impacted Van Buren County, leading to $1M in damages and impacting other locations to much lesser degrees. The first storm produced wind gusts of 85-100 mph that blew down swaths of trees near Blue Star Highway and 65-85 mph wind gusts in downtown Covert. A second storm produced several swaths of 70-90 mph winds at additional locations. Some uprooted trees fell on houses, and downbursts damaged several garages.

September 11, 2019 - West Central Lower Peninsula (Kent, Ionia, Ottawa, Newaygo, and Eaton Counties)
Severe thunderstorms produced wind damage along a 50-mile path cutting through parts of Grand Rapids, including where most of the roof was ripped off of Belknap apartments from an isolated microburst (whose winds may have hit 100 mph). Hundreds of trees were impacted in other areas. Kent County saw $1.5M in damages out of $1.7M total.

February 24-25, 2019 – Central and Southern Lower Peninsula
A synoptic scale weather system brought blizzard conditions to many western counties, as well as 55-65 mph gusts across a broad region. The long duration (13-16 hours) of high winds was unprecedented for the area, causing widespread downed tree limbs and sporadic structural damage. Roughly one million people lost power. Damages of $60M occurred across the following counties (each with between $500K-$3M): Oceana, Gratiot, Ionia, Muskegon, Allegan, Eaton, Ingham, Kalamazoo, Calhoun, Montcalm, Clinton, Barry, Van Buren, Jackson, Ottawa, Midland, Macomb, Saginaw, Tuscola, Sanilac, Shiawassee, Genesee, Midland, Macomb, Huron, Saginaw, Lapeer, St. Clair, Livingston, Washtenaw, Lenawee, Monroe, Oakland, Wayne, and Bay. Kent County saw an additional $5M in damages.

May 4, 2018 – East Central and Southeastern Lower Peninsula
A synoptic scale weather system brought gusts ranging between 30-60 mph, along with scattered thunderstorms leading to winds near 70 mph. Downed large trees, branches, telephone lines, and power lines were reported, with around 230,000 customers without power during the peak. Falling trees killed one person in a car (Independence Township) and injured a postal worker (South Lyon). Winds blew over a semi on US-23, blocking all southbound lanes. Total damages amounted to over $36M across the following counties: Lapeer ($1M), Genesee ($3.5M), Midland ($1M), Saginaw ($2M), Shiawassee ($850K), Sanilac ($850K), Huron ($850K), Tuscola ($850K), Bay ($1.25M), Wayne ($3.5M), Macomb ($4M), St. Clair ($3M), Monroe ($3M), Lenawee ($1.5M), Washtenaw ($4M), Oakland ($5M), Livingston ($2M).

July 7, 2017 – West Central and Southern Lower Peninsula
Severe thunderstorms brought high winds and isolated hail. Numerous trees and power lines fell in a 100-mile-long and 30-mile-wide swath from Grand Haven to the northwest of Jackson. A wind gust of 91 mph was recorded on the north Grand Haven breakwater. A man was killed in his house by a large tree (Grand Haven). Wind gusts reached 60-80 mph across much of Ottawa County into Kent County. A gust to 88 mph was recorded in Allendale. Several trees and power lines fell near Muskegon where a wind gust of 61 mph was reported. Total damages amounted to about $500K across the following counties: Muskegon ($10K), Ottawa ($250K), Kent ($100K), Barry ($100K), and Eaton ($50K).

March 8, 2017 – Southern Lower Peninsula
A synoptic scale weather system brought winds up to 60-70 mph, damaging homes and buildings. The following counties each saw between $5M-$25M in damages: Allegan, Barry, Bay, Calhoun, Clare, Clinton, Eaton, Genesee, Gratiot, Huron, Ingham, Ionia, Isabella, Jackson, Kalamazoo, Kent, Lake, Lapeer, Lenawee, Livingston, Macomb, Mason, Mecosta, Midland, Monroe, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, Van Buren, Washtenaw, and Wayne. Oakland had $35M in damages, with Baraga and Iron at roughly 50K. Total damages were roughly $525M. Two people died in Clare County. One million residents lost power.

February 19, 2016 – Southeast Michigan
Damaging winds of 50-60 mph impacted trees and power lines. A peak of 117,000 customers lost electric power. A total of $30.5M in property damage was reported, involving the following counties: Livingston ($2M), Macomb ($7M), Oakland ($10M), Shiawassee ($500K), Washtenaw ($4M), and Wayne ($7M).

August 2, 2015 – Northern Lower Peninsula
Several waves of thunderstorms caused widespread wind damage. Ogemaw County also experienced large hail. Roughly 80 mph winds crossed portions of Leelanau County, where two homes were destroyed and over 700 damaged in some way. Thousands of trees were downed from the Sleeping Bear Dunes to Grand Traverse Bay. Area roads were closed for days, in some cases weeks, with Glen Arbor inaccessible for two days. A total of more than $38M in property damage was reported, the bulk of which was seen in Leelanau ($24M) and Grand Traverse ($13M) counties.

January 19th, 2013 – Southeast Michigan
An intense arctic front brought winds gusting 60 mph at times. Trees and power lines were blown down, leading to power outages for more than 120,000 DTE customers. Total property damages were $14M, with $2M in Wayne County, $1.5M each in Oakland and Macomb, $1M each in Tuscola, Huron, Genesee, and St. Clair, $750K each in Lapeer, Livingston, Monroe, Sanilac, Shiawassee, and Washtenaw, and $500K in Lenawee.

July 11, 2011 – Western Michigan (Kent, Ottawa, and Kalamazoo Counties)
Two waves of large thunderstorm systems created high winds, the first coming onshore north of Muskegon. The second, more destructive grouping landed further south, resulting in numerous reports of downed trees and power lines. One person died in Cutlerville from a fallen tree. Wind gusts up to 80 mph were reported and the storm resulted in more than $8M in damages—mostly in Kent County ($5M) but also in Ottawa ($2M) and Kalamazoo County ($1M). Allegan, Barry, Berrien, Calhoun, and Livingston Counties also had smaller amounts of wind-related property damage.

May 29, 2011 – Southern Lower Peninsula (Calhoun County)
Severe thunderstorms resulted in straight-line winds up to 100 mph and a state of emergency was declared in Calhoun County. Nearly 40,000 people lost power as a result of winds and lightning, with over 600 properties damaged, including 76 homes and 4 businesses destroyed in the Battle Creek area. Total damage estimates were over $30M, approximately $25M of which was in Calhoun County (which saw two injuries). Wind damage was also reported in Eaton, Genesee, Ingham, Kalamazoo, Lapeer, Lenawee, Livingston, Oakland, Shiawassee, and Wayne Counties.

July 18, 2010 – Lower Peninsula
A series of microbursts across southwestern Kent County produced wind gusts of 60-80 mph. Several trees and power lines fell in the Wyoming and Cutlerville areas, with eight sheds destroyed. Straight-line wind damages were reported in the counties of Berrien, Kent, Lenawee, and Roscommon. A separate tornado also damaged a home and destroyed several trees just northeast of Wayland (Allegan County).

August 9, 2009 – Lower Peninsula
Severe thunderstorms with 60-80 mph winds impacted utility infrastructure and hundreds of trees. Fruitport (Muskegon County) took the brunt of the storm, with wind gusts of 70-80 mph lasting ten minutes. Numerous homes were heavily damaged by falling trees. Significant damage to apple orchards occurred west of Sparta. A man was killed in Grand Haven. Wind damages were reported in the counties of Kent, Lapeer, Livingston, Macomb, Muskegon, and St. Clair. The storm complex also produced an EF0 tornado with a path 35 miles long and up to nine miles wide.

June 6 to 8, 2008 – Lower Peninsula
Numerous thunderstorms produced winds up to 75 mph. Some of the strongest were reported in the Saginaw area where dozens of trees were blown down, falling onto houses, blocking roads, hitting cars, and knocking down power lines (12,000 residents lost electricity). An entire roof was blown off a commercial building. Storm systems continued to cause wind damage during the next two days. A derecho swept across many counties in the southern Lower Peninsula, involving winds as high as 85 mph at Marine City. Damages were estimated at $17M (both property and crop), and the storm systems eventually saw seven deaths and three injuries. More than 10,000 people were without power for at least a week. The following counties reported wind-related casualties, property damage, and/or crop damage: Arenac, Bay, Branch, Cass, Clinton, Dickinson, Genesee, Gladwin, Gogebic, Huron, Kent, Lapeer, Lenawee, Livingston, Macomb, Marquette, Midland, Missaukee, Monroe, Montcalm, Oakland, Ogemaw, Ottawa, Saginaw, Sanilac, St. Clair, St. Joseph, Tuscola, Van Buren, Washtenaw, and Wayne. Some tornadoes and hail also occurred.

May 15, 2007 – Southern Lower Michigan
Severe thunderstorm winds affected many counties and measured as high as 95 mph (Three Rivers Airport). Significant damages were caused at locations as diverse as Centreville, Schoolcraft, North Aurelius, and Howell. A power plant's coal stacker near Essexville was destroyed when it was toppled over by strong winds, with damages estimated at $1.5M. Wind damages were reported in the counties of Bay, Berrien, Calhoun, Cass, Genesee, Ingham, Jackson, Kalamazoo, Lapeer, Lenawee, Livingston, Macomb, Oakland, Shiawassee, St. Clair, St. Joseph, and Wayne.

November 6, 2005 – Southeast Michigan
A synoptic scale wind system brought high winds along an associated cold front, knocking down trees and leading to approximately 200,000 power outages. Winds were sustained out of the southwest at 30-40 mph, with gusts as high as 60 mph. Street signs and traffic lights were damaged. Many streets and roads had to be temporarily closed until trees could be cleared. Property damage was estimated at $4.2M in Wayne County.

November 12, 2003 – Southeast Lower Michigan
Wind gusts up to 74 mph knocked down trees and power lines, cutting power to 370,000 customers. A power line fell across I-94, forcing the closure of the highway and causing a major traffic jam near the airport. Many school districts canceled classes. Wind caused property damage was noted within the following counties: Antrim, Bay, Charlevoix, Emmet, Genesee, Grand Traverse, Huron, Lapeer, Lenawee, Livingston, Macomb, Manistee, Midland, Monroe, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, Washtenaw, Wayne, and Wexford.

August 1, 2003 – Southern Lower Michigan (Calhoun, Jackson, Kalamazoo, Oceana, Shiawassee, and Van Buren Counties)
Severe thunderstorms and winds up to 77 mph killed two persons (a man was killed by a tree limb and a woman was struck by lightning). A young boy survived a separate lightning strike. The high winds caused about 127,000 electrical customers to lose power, most of which was restored in two days.

July 4-6, 2003 – Southern Lower Michigan
A line of thunderstorms brought 60 mph winds, knocking down trees and leaving 200,000 customers without electricity. Temperatures were high and many people lost perishable food. Some Brighton Twp. residents with electric wells were without water for several days. Nine fatal car accidents occurred over the holiday weekend due to the severe weather. Wind damages were noted for the counties of Allegan, Barry, Bay, Calhoun, Clare, Clinton, Eaton, Ingham, Ionia, Iosco, Jackson, Kalamazoo, Kent, Muskegon, Newaygo, Ottawa, St. Clair, Van Buren, and Washtenaw.

May 11, 2003 – Southeast Michigan
A cold front moved through the Great Lakes region, bringing 55-60 mph winds across much of Wayne and Washtenaw counties (other areas saw gusts of 45-50 mph). The winds caused several trees to blow down and several thousand homes and businesses across the area to lose power. The strong winds ripped into part of a Ypsilanti company's roof, smashing it into a distribution pipe and causing 100 gallons of hydraulic acid to leak.

October 24, 2001 – Southern Lower Michigan
Severe thunderstorm warnings were issued for 13 counties. Numerous funnel clouds were also sighted but only two touched down. The vast majority of damage was from straight-line winds, which in Lansing were estimated to peak at 120 mph. Region-wide, the storms killed two persons and injured at least 20, caused extensive flooding of roads and streets, downed thousands of trees (195,000 electrical customers without power), closed schools and businesses, and damaged hundreds of cars, homes, businesses, and public buildings. The counties of Berrien, Cass, Ingham, and Kalamazoo were most impacted. A Governor's Disaster Declaration was issued for Kalamazoo County.

May 9, 2000 – Southeast Michigan
A storm front produced a combination of straight-line winds and tornadoes (accompanied by large hail in many locations). Wind gusts of 70 mph caused considerable damage. In Lenawee County, several barns were destroyed, a mobile home flipped over, grain bins were destroyed, and three airport hangars were impacted. A railroad depot was destroyed in Monroe County. In Washtenaw County, hundreds of trees were downed and a church and a grocery store were damaged. An airport hangar collapsed in Wayne County, damaging the plane inside. At least six persons were injured.

July 24-25 and 31, 1999 – Southern Lower Michigan
A series of thunderstorms were fueled by high temperatures and humidity, producing 60-70 mph winds and heavy rain. A total of 430,000 electrical customers were left without power after the two weekend storms, many for more than 24 hours, while temperatures exceeded 90ºF and spoiled perishable food. Utility crews were hampered as new storms made repairs difficult and caused fresh outages. Damage to homes, businesses, vehicles, and boats was reported in southeast Michigan and the Saginaw Bay area. Detroit saw flooded freeway underpasses with up to two feet of water.

July 4-5, 1999 – International (The Boundary Waters-Canadian Derecho)
This derecho traveled over 1,300 miles through Minnesota, Wisconsin, Michigan, Ontario, Quebec, and Maine, lasting over 22 hours. There was a tremendous amount of associated lightning (6,000 strikes per hour). The event caused $100M in damage, killed two people, and injured 70. Over 700,000 homes and businesses lost power.

May 17, 1999 – Central and Southern Lower Michigan
A strong storm system brought winds, rain, and hail. Wind gusts of 60-70 mph downed power lines, leaving 150,000 customers without power. Peak wind gusts of 115 mph were recorded in Calhoun, Ingham, and Kent Counties. City agency (including municipal power) response and recovery costs were $1.5M in Lansing. Utility poles built to withstand 100 mph winds snapped along I-496, creating traffic jams and closing parts of the freeway for 26 hours. In Wyoming, a wind gust caused a home under construction to collapse, killing one person and injuring another.

September 26-27, 1998 – Northern Lower Michigan
A thunderstorm front roughly 12 miles wide and 15 miles long ran from East Jordan to Alpena. For Gaylord (Otsego County) the storm lasted only a few minutes but still produced tremendous damage from 80-100 mph winds accompanied by rain and hail. Thousands of trees were snapped off at waist level, homes and businesses were torn apart, power lines were downed, and several public facilities were substantially damaged (the courthouse lost half its roof). Approximately 818 homes were damaged throughout the county, including 47 that were destroyed and 92 that incurred

major damage. The storm injured 11 persons (none seriously). About 12,000 electrical customers lost power in the region. A Governor's Disaster Declaration was granted. Crawford and Charlevoix Counties also saw damage.

May 31, 1998 – Southern Lower Peninsula
A derecho produced 60-90 mph winds, with some gusts reaching 120-130 mph in portions of Ottawa and Kent Counties, 100 mph within Montcalm County, and 90 mph within Kent and Ottawa Counties. Over 861,000 homes and businesses lost electricity, with areas of Kent, Montcalm, and Gratiot Counties taking up to ten days for full restoration. Statewide, approximately 250 homes and 34 businesses were destroyed and 12,250 homes and 829 businesses were damaged. A Presidential Disaster Declaration was declared. Damages were reported in Barry, Bay, Calhoun, Clare, Clinton, Genesee, Gratiot, Huron, Ingham, Ionia, Isabella, Kent, Lake, Lapeer, Macomb, Mason, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oakland, Oceana, Oscoda, Ottawa, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, and Wayne Counties. Total damage estimates were $166M. There were four storm-related fatalities and 145 injuries (mostly minor).

October 5, 1997 – Delta and Schoolcraft Counties
Severe thunderstorms created numerous microbursts, where winds estimated in excess of 100 mph cut a 12-mile-wide swath in the two counties that damaged 600 buildings and numerous vehicles. Total property, tree, and agricultural losses were estimated at $3M. Roughly 9,000 acres of federal forest were impacted, along with the state reporting 500 acres of tree loss and corporate forests reporting 200 acres. The areas were lightly populated with no known injuries.

July 2, 1997 – South-Central and Southeast Michigan
A series of intense thunderstorms spawned severe straight-line winds, several tornadoes, and heavy rainfall. The straight-line winds reached 70-100 mph in some areas, causing significant structural damage and massive amounts of debris. The combination of winds knocked out power to 350,000 electrical customers and caused a total of seven deaths and 106 injuries. A Presidential Major Disaster Declaration was granted for the five-county area most severely impacted by the storm event. Significant straight-line wind damage occurred in the counties of Berrien, Calhoun, Cass, Clinton, Eaton, Gratiot, Ingham, Macomb, Midland, Saginaw, Washtenaw, and Wayne.

July 13-15, 1995 – Statewide (Damages in Thirty Counties)
Storms producing variable winds up to 100 mph with golf-ball-sized hail and severe lightning damaged hundreds of structures. Widespread power outages occurred, including 400,000 electrical customers in southeast Michigan. Over 100,000 trees were toppled by winds in Roscommon County. A girl was killed when her pontoon boat flipped over, a stranded driver died of a heart attack, and a person was killed when a barn collapsed.

July 7, 1991 – Southern Lower Michigan
A line of severe thunderstorms with wind speeds of 60-70 mph saw isolated gusts exceeding 80 mph. Several million dollars in damage occurred, and over one million electrical customers (more than 10% of the State's population at the time) were left without power, some for several days. A mobile home in Lapeer County was tipped over and windows were blown out of several homes. Property damages were tallied for the counties of Ingham, Kent, and Oakland.

March 27, 1991 – Central and Southern Lower Michigan
Thunderstorms generated a mix of tornadic and straight-line winds that damaged homes, businesses, and farms. Power was lost for 450,000 electrical customers (many for up to a week). Branch County saw several houses and mobile homes destroyed, with two vehicles blown off of I-69. Three deaths and 21 injuries were attributable to non-tornadic winds. A man trapped inside a mobile home removed from its foundation died of a heart attack (St. Clair County).

April 30, 1984 – Lower Michigan
A windstorm struck the entire Lower Peninsula, resulting in one death and several injuries. Wind gusts measured up to 91 mph in some areas. Damage was widely scattered with 6,500 buildings, 300 mobile homes, and 5,000 vehicles damaged. Over 500,000 electrical customers lost power. In addition, 10-16-foot waves on Lake Michigan caused severe shore erosion, which collapsed some cottages and drove many boats aground.

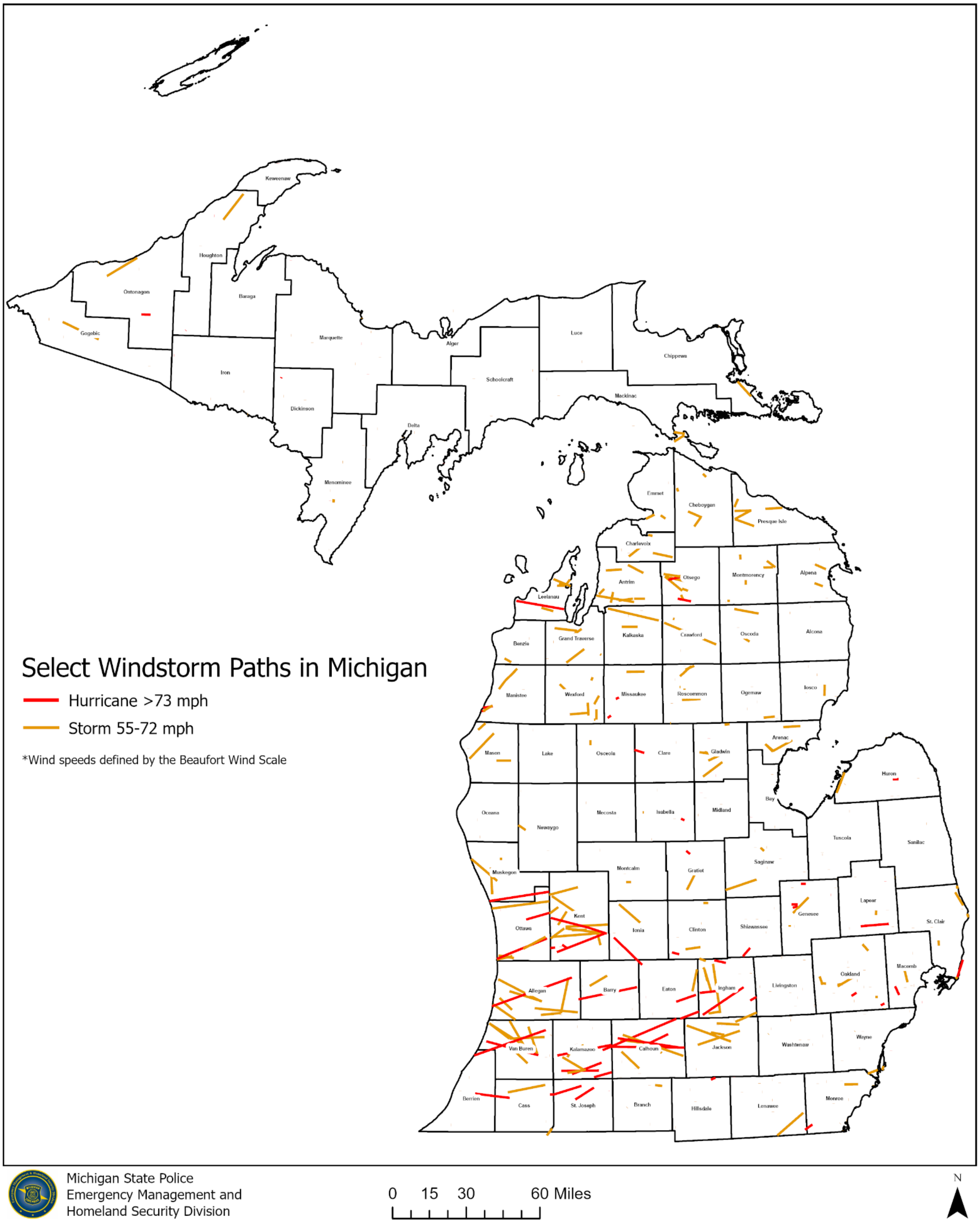
July 15-20, 1980 – Southern Lower Michigan
A Presidential Major Disaster Declaration was granted for ten counties. Over 300,000 electrical customers were left without power, some for several days. During the recovery process, almost $6.8M in public and private assistance was made available to affected local jurisdictions and to residents in the affected areas.

### *Select Agencies and Programs*

Please see the Thunderstorm Hazards Overview section for a listing of agencies and other information related to the damaging effects of high winds.

### *Supplemental Materials*

**Select Windstorm Paths (Non-Tornadic), 1955-2020**




Caution should be used when interpreting this map as not all windstorm paths are shown. See also the maps available at the NWS [Storm Prediction Center](#).

# WINTER HAZARDS OVERVIEW

Given Michigan's location in the mid-latitudes and the occurrence of subfreezing air temperatures at least eight months of the calendar year, precipitation in frozen form (e.g., snow, sleet, freezing rain) is a frequent statewide hazard. The cold weather hazards presented here focus on snowstorms, blizzards, ice storms, sleet storms, and storms with combinations of some or all of these precipitation types. While colloquially referred to as "winter" storms, they also occur in the fall and/or spring seasons. In Michigan, they are typically associated with regional synoptic-scale low-pressure systems originating from the southern Great Plains or the lower Gulf Regions that move into areas with near- or subfreezing surface air temperatures. They are most common during January, February, and December in Michigan, climatologically the three coldest months of the year. A chapter on extreme cold, with or without precipitation, is also included.

County-level historical data for significant snowstorms, blizzards, ice storms, and sleet is included in their relevant chapters and can be found in the Storm Events Database. Although snowfall amounts are highest in the Upper Peninsula and near many edges of the Lake Michigan shoreline (due to lake effect snow), it is important to note that every county in Michigan can experience severe winter weather. The risk of ice storms is a bit greater in the southern parts of the state, where temperatures cycle close to the freezing mark for a greater number of days each year.

## *Select Agencies or Programs*

Watches, Warnings, and Advisories of the National Weather Service
The NWS issues winter storm watches and warnings of various types to notify the public of imminent or potentially severe winter weather conditions. A *watch* indicates that severe winter weather conditions (freezing rain, sleet, or heavy snow) are possible for a given area, while a *warning* indicates that severe winter weather conditions are imminent.

- Winter Storm Watches and Winter Storm Warnings are only issued for severe winter storms that may occur only a couple of times per year. Some may not occur at all in a given winter. These storms would present a significant disruption to daily life, cause life-threatening conditions, and typically take several days to recover from.

- Blizzard Watches, Blizzard Warnings, Ice Storm Watches, and Ice Storm Warnings are issued for extremely rare winter storms that occur only once every several years and typically result in the cessation of all normal activities for extended periods of time (days or even weeks). People typically shelter in place and may experience lengthy power outages.

The NWS also issues *advisories* for less severe but still potentially impactful winter conditions like light accumulating snow, light freezing rain, blowing snow, wind chill, etc. Winter Weather Advisories are much more common than watches and warnings, and for many Michigan residents amount to potentially dangerous but still "typical" Michigan weather.

The NWS Storm Prediction Center is a useful tool. Five forecast offices also serve Michigan in Gaylord, Grand Rapids, Marquette, White Lake/Pontiac, and Syracuse (Indiana). These stations provide Doppler Radar images that track the movement of thunderstorms and other severe weather threats. The Syracuse office covers portions of southwest Michigan (www.weather.gov/iwx), the Grand Rapids office covers the remainder of southwest Michigan (www.weather.gov/grr), the White Lake/Pontiac office covers Southeast Michigan (www.weather.gov/dtx), the Gaylord office covers the northern Lower Peninsula and eastern Upper Michigan (www.weather.gov/apx), and the Marquette office is responsible for the central and western Upper Peninsula (www.weather.gov/mqt).

The NWS transmits information directly to radio and television stations, which in turn pass the warning on to the public. The NWS also provides warning information at www.weather.gov, via NOAA Weather Radio, and as part of their weather information network for emergency managers.

Other Public Warning Systems
Numerous communities in Michigan have outdoor warning siren systems in place to warn the public about impending tornadoes and other hazards (many of these systems were originally purchased to warn residents of a nuclear attack). The IPAWS alerts the public through the EAS and WEA. Many private alerting systems exist beyond IPAWS, EAS, and WEA.

American Red Cross & Sheltering
The American Red Cross may open shelters for a variety of reasons, including winter storms. Their website includes resources to help people find one of their shelters in case of emergency. The United Way's Michigan 2-1-1 is another resource to help find open warming centers or other resources in communities.

Michigan State Police
There are several steps people can take for themselves, their homes, and their cars before, during, and after severe winter weather. The MSP MIREADY program website provides tips and other useful information.

Center for Food Security and Public Health
While most winter weather occurs outside growing seasons, early winter storms may be especially damaging for certain crops. Fruit trees may be damaged at any time, and livestock can also suffer losses under cold winter conditions. This Iowa State University program works with Michigan and other states to provide information specific to rural communities.

Michigan Public Service Commission
Winter storm damage to electric equipment and power lines is a concern for utilities, especially during the winter from ice storms. The MPSC regulates privately owned utilities that supply electricity, natural gas, and propane to help ensure adequate supplies and reliability.

Urban Forestry/Tree Maintenance Programs
Urban forestry programs can be effective in minimizing winter storm damage caused by falling trees, but in many areas, a public works agency or road commission performs the bulk of trimming work. Proper tree selection, placement, and care are also important. Utilities also have tree trimming programs that local communities can collaborate with.

## SNOWSTORMS AND BLIZZARDS

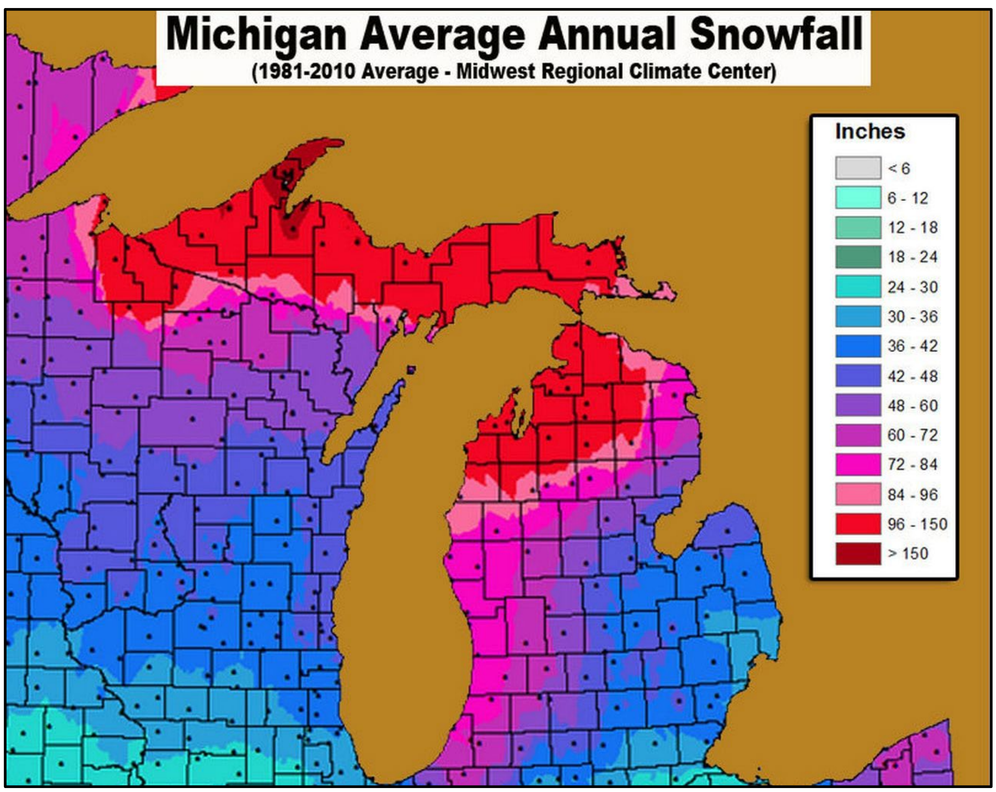
*Storms associated with the accumulation of snow. Accompanying high winds can greatly worsen secondary impacts such as drifting snow and lowered visibility.*

### *Hazard Description*

Most light snowfall is relatively harmless and can even be beneficial. Severe snowstorms however can impact communities over a period of days or weeks, especially with heavy accumulations or snowfall that is difficult to clear. Blizzards are the most dangerous of snowstorms, characterized by low temperatures and strong winds containing large amounts of falling or blowing snow. The majority of significant snowfall events in Michigan are associated with regional synoptic-scale low pressure systems which are in turn linked with migrating cyclonic waves. Many of these originate in the southern Great Plains or the lower Gulf Region and lead to the large-scale transport of water vapor into the region from sub-tropical oceans. The vast majority of frozen precipitation associated with these systems falls from horizontally oriented stratiform clouds with relatively constant rates. They may impact large areas of hundreds or thousands of square miles. Sufficient atmospheric instability may however lead to the formation of vertically oriented convective clouds (stratocumulus) with showers and thunderstorms (referred to as “thundersnow”) embedded within the stratiform clouds. These may produce heavy snowfall rates (some of Michigan’s worst snowstorms have included thundersnow).

### *Hazard Analysis*

Michigan experiences some of the heaviest seasonal snowfall totals and length of snow cover durations in the Continental US east of the Rocky Mountains. Major differences in snowfall frequency and totals exist within the state. The highest average annual snowfall amounts to over 220 inches occur near parts of the Upper Peninsula. Amounts exceeding 150 inches of annual snowfall are centered in northwestern Lower Michigan. Seasonal snowfall totals decrease rapidly from northwest to southeast across the state, with totals of less than 40 inches found to the southeast.




(source: Midwestern Regional Climate Center; dots represent weather stations)

An important factor for Michigan snowfall events is proximity to the Great Lakes (particularly those waters to the west). The relatively colder air that passes over them in the fall and winter brings moisture that, when cold enough, takes the form of snow showers or squalls generally better known as “lake effect” snow. In contrast to the snowfall of low-pressure systems, lake effect snow is typically associated with shallow convective clouds (stratocumulus) and is much more localized in geographical coverage. The bands of these snow-bearing clouds may typically be only a few miles wide and extend less than 100 miles inland but can carry intense snowfall rates (sometimes exceeding 3 inches an hour). "Lake enhanced" snowfall (which includes both synoptic and lake effect processes) may also be present.

While Michigan is not a particularly mountainous state, its topography also plays a role in snowfall climatology. Winds forcing moisture-laden air over topographical obstacles cools more rapidly and leads to increased precipitation rates. This explains why the heaviest seasonal snowfall totals in the state tend to be found on relatively higher elevation sites in the upper and northern Lower Peninsulas (i.e., along the spine of the Keweenaw Peninsula).

**Michigan Snowstorm* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Snowstorm Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 61 | $6,225,000 | | | |
| Wayne | 56 | $5,960,000 | | | |
| Livingston | 64 | $2,129,000 | | | 3 |
| Oakland | 65 | $6,400,000 | | | 3 |
| Macomb | 60 | $5,170,000 | | | |
| **5 County Metro Area** | **61 avg.** | **$25,884,000** | **$0** | **0** | **6** |
| Berrien | 134 | $20,000 | | | |
| Cass | 122 | | | | |
| St. Joseph | 83 | | | | |
| Branch | 73 | | | | |
| Hillsdale | 69 | | | | |
| Lenawee | 55 | $505,000 | | | |
| Monroe | 44 | $45,000 | | | |
| Van Buren | 135 | $50,000 | | | |
| Kalamazoo | 91 | $50,000 | | | |
| Calhoun | 66 | $2,350,000 | | | |
| Jackson | 61 | $1,325,000 | | | |
| Allegan | 154 | $125,000 | | | |
| Barry | 76 | $150,000 | | | |
| Eaton | 57 | $1,150,000 | | | |
| Ingham | 57 | $1,150,000 | | | |
| Ottawa | 145 | $350,000 | | | |
| Kent | 105 | $150,000 | | | |
| Ionia | 60 | $125,000 | | | |
| Clinton | 49 | $1,125,000 | | | |
| Shiawassee | 53 | $1,010,000 | | | |
| Genesee | 65 | $2,650,000 | | | 1 |
| Lapeer | 63 | $1,010,000 | | | |
| St. Clair | 73 | $1,045,000 | | | |
| Muskegon | 122 | $100,000 | | | |
| Montcalm | 68 | $180,000 | | | |
| Gratiot | 54 | $175,000 | | | |
| Saginaw | 60 | $2,025,000 | | | |
| Tuscola | 60 | $1,000,000 | | | |
| Sanilac | 82 | $1,005,000 | | | |
| Mecosta | 66 | $240,000 | | | |
| Isabella | 57 | $490,000 | | | |
| Midland | 57 | $1,000,000 | | | |
| Bay | 56 | $2,025,000 | | | |
| Huron | 68 | $2,500,000 | | | |
| **34 County Southern Lower Peninsula** | **78 avg.** | **$25,125,000** | **$0** | **0** | **1** |

(continued on next page)

| COUNTY/AREA | Reported Snowstorm Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | 118 | $100,000 | | | |
| Newaygo | 85 | $125,000 | | | |
| Mason | 117 | $150,000 | | | |
| Lake | 86 | $525,000 | | | |
| Osceola | 65 | $660,000 | | | |
| Clare | 58 | $500,000 | | | |
| Gladwin | 44 | | | | |
| Arenac | 47 | $4,000 | | | |
| Manistee | 97 | $350,000 | | | |
| Wexford | 72 | $283,000 | | | |
| Missaukee | 79 | $185,000 | | | |
| Roscommon | 66 | $104,000 | | | |
| Ogemaw | 56 | $55,000 | | | |
| Iosco | 54 | $14,000 | | | |
| Benzie | 103 | $600,000 | $2,000,000 | | |
| Grand Traverse | 127 | $618,000 | $5,000,000 | | |
| Kalkaska | 135 | $290,000 | | | |
| Crawford | 89 | $255,000 | | | |
| Oscoda | 60 | $100,000 | | | |
| Alcona | 50 | $3,000 | | | |
| Leelanau | 135 | $653,000 | $13,000,000 | | |
| Antrim | 162 | $270,000 | | | |
| Otsego | 134 | $342,000 | | | |
| Montmorency | 68 | $165,000 | | | |
| Alpena | 75 | $110,000 | | | |
| Charlevoix | 144 | $295,000 | | | |
| Emmet | 122 | $204,000 | | | |
| Cheboygan | 98 | $206,000 | | | |
| Presque Isle | 75 | $261,000 | | | |
| **29 County Northern Lower Peninsula** | **90 avg.** | **$7,427,000** | **$20,000,000** | **0** | **0** |
| Gogebic | 318 | $102,000 | | | 1 |
| Iron | 144 | $636,000 | | | |
| Ontonagon | 362 | $43,000 | | 1 | 2 |
| Houghton | 516 | $210,000 | | | |
| Keweenaw | 250 | $5,000 | | | |
| Baraga | 287 | $113,000 | | | |
| Marquette | 374 | $1,626,000 | | 1 | |
| Dickinson | 146 | $204,500 | | | |
| Menominee | 150 | $187,000 | | | |
| Delta | 208 | $76,000 | | | |
| Schoolcraft | 319 | $265,000 | | | |
| Alger | 405 | $80,000 | | | |
| Luce | 232 | $88,500 | | | |
| Mackinac | 105 | $50,000 | | | |
| Chippewa | 152 | $185,000 | | | |
| **15 County Upper Peninsula** | **265 avg.** | **$3,871,000** | **$0** | **2** | **3** |
| **MICH. TOTAL**** | **9,549** | **$62,306,500** | **$20,000,000** | **2** | **10** |
| **Michigan Annual Avg.** | **349** | **$2,279,849** | **$731,817** | **0.1** | **0.4** |

* Combines NCEI Storm Data categories for "Blizzard", "Heavy Snow", "Lake-Effect Snow", "Winter Storm", and "Winter Weather". **One event may take place in multiple counties. Combined totals may be lower for the State.

The map and table highlight that northern and western parts of the state see more snow and significant snow events. Considering county-based statistics, the frequency of events ranges from roughly two events/year for counties in the southeastern corner of the state to four to five events/year in western sections of the Lower Peninsula to 10-19 events/year in Upper Michigan. With the exception of a few counties in Upper Michigan, the spatial patterns for fatalities, injuries, and property damage are still strongly associated with higher county populations, such as in southeast Michigan (despite that area having the lowest frequencies of state snow events).

Although precipitation has gradually been increasing in Michigan, the proportion that falls in the form of snow rather than rain is difficult to quantify. Recent Great Lakes studies suggest that the overall fraction of precipitation falling in frozen form is decreasing in some areas, mainly the result of warmer cold season temperatures over time. In terms of long-term trends, seasonal snowfall totals in some southern and eastern sections of the state have remained level or are decreasing, while totals in some northern and western sections of the state are increasing. These overall trends are connected to a decrease in the amount of snowfall associated with synoptic weather (low pressure) systems in southern sections of the state and to an increase in lake effect snowfall in the northern and western sections (concurrent with increases in open water over the lakes and warmer lake temperatures during the winter). One additional important trend is an increase in annual variability of annual snowfall in some areas. Increasing variability suggests more years with very heavy snowfall totals and years with abnormally low totals, complicating planning efforts.

Snow type can vary in its consistency based on water content, temperature, humidity, and other factors. So called "wet snow" refers to relatively warm snow with a high moisture content which can be very heavy and difficult to shovel. It may form a hard crust when followed by cold temperatures. Areas may suffer flood risks when snow cover rapidly melts or is hit by significant rainfall. The National Operational Hydrologic Remote Sensing Center is a helpful source of information regarding snow cover depths and water content. So called "powder snow" typically refers to lighter, less dense, relatively uncompacted snow. It may be dry depending on humidity and more easily picked up by wind. Blizzard conditions may occur without any additional falling precipitation due to blowing.

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

Land, air, and water transportation can all be substantially impacted depending on the amount of snow, winds, and other factors. Visibility may be reduced to only a few feet and many roads may become impassable. People may become stranded on roadways or in homes. Winter holiday travel is often affected. The work required to move accumulated snow, or its drifting, may overwhelm individual residents or public workers. An increase in heart attacks may occur from shoveling/strenuous activity. Roofs can be vulnerable to the weight of accumulated snow, which sometimes also migrates under shingles and creates leaks within homes. Snow may cause tree branches to bend or break across utility lines, interrupting service. Hypothermia may occur, and warming centers/sheltering may be required.

Impact on the Economic Condition of the State

Economic impacts usually involve transportation delays or occasional power failures, which may occur around the Christmas Holiday shopping season. Road budgets may need to be increased based on storm duration and road maintenance costs (e.g., overtime, salt). Supply chains may be disrupted, becoming especially harmful for manufacturers using just in time inventory systems. Seasonal agricultural losses may occur. It is important to note, a lack of snowfall can also be economically damaging, especially to the tourism industry in northern Michigan.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services

Responders exposed to snowstorms may face injury or spend less time in the field. Slippery road conditions may delay response. Search and rescue missions for stranded people may be required. Snow removal is a high priority, especially for utility and ambulance access. Urban areas may be susceptible to snow removal problems due to limited space for snow clearance/storage (those relying on street side parking in residential areas are particularly vulnerable). Rural areas may have roads inaccessible for longer periods of time as high-volume traffic areas receive snowplow priority. Fire hydrants may become buried. Services that rely on electric power may have to switch over to generators (if available).

Impact on the Environment

Damage from snow is typically limited and largely dependent on snow depth and accompanying winds. Trees may topple or break in severe storms. Other effects include potential flooding from snow melt. Transportation incidents due to slippery conditions that involve hazardous materials may contaminate the environment. Some ice treatments put onto roads can be polluting.

## *Select Snowstorms in Michigan*

Because of their prevalence, many snowstorms will not be listed here, especially those before 1995. Some events included snow with other types of mixed precipitation, and to reduce redundancy may be placed in other winter-related chapters. For example, the important “Polar Vortex” of 2019 is included in the Extreme Cold chapter because of the mass threat it presented to residential heating.

October 16-18, 2022 – Marquette County
Two-day accumulations of wet snowfall included between 13-18 inches near National Mine, 14 inches at Clarksburg, and 13 inches in Negaunee Township. Schools throughout the county closed for one day. The heavy wet snow contributed to power outages (15,000 customers). Storm-force north winds whipped up waves as high as 20 feet near the Lake Superior shoreline. The threat of beach erosion caused Marquette officials to close Lakeshore Boulevard.

December 12, 2020 – Clare and Osceola Counties
A winter storm brought 6-8 inches of snow. There were thousands of power outages as a result of gusty winds and the weight of the heavy wet snow. Property damages were roughly $150K between the two counties.

February 23-25, 2019 – Central and Western Upper Michigan
A bomb cyclone produced heavy snow across much of Upper Michigan for several days, with periods of blizzard conditions of roughly 12 hours. Northwest winds gusting up to 50-60 mph caused considerable drifting and closed roads, including Highway M-28. Some higher terrain locations across the county reported nearly two feet of storm total snowfall. The accumulated snow from this event and earlier storms caused roof collapses for numerous businesses and a few farm buildings, including the roof of the Negaunee Bus Depot. Schools throughout Marquette County, including Northern Michigan University, were closed on the 25th due to lingering effects from the storm. Menominee County had a total of $150K in property damages, Dickinson County $20K, and Marquette County $1M in property damages.

March 3, 2017 – Schoolcraft County
Lake-effect snow produced poor visibility on Highway US-2 near Gulliver that contributed to a semi-truck accident with another vehicle. Three injuries and one death were reported. Property damages were $100K.

February 24-25, 2016 – Western and Central Southern Lower Peninsula
A winter storm produced heavy wet snow overnight. Total accumulations across many Lower Peninsula Counties ranged from 6-14 inches, causing scattered power outages as snow weighed down branches over utility lines. Barry, Calhoun, Eaton, Ingham, Jackson, Kalamazoo, and Van Buren Counties each saw an estimated $25K in damages.

January 30-31, 2013 – Upper Peninsula
Heavy snow arrived, with a weather spotter in Bessemer measuring 7.5 inches of snow within 24 hours. Poor visibility contributed to traffic accidents, including an injury involving a car and a snowmobile collision in Gogebic County.

March 2-3, 2012 – Northern Lower Peninsula
Wet snowfall totals were 6-14 inches. Lake Ann (Benzie County) hit 20 inches, with 95% of its residents losing power, property damages of $600K, and crop damages of $2M. Grand Traverse and Leelanau Counties each saw $625K in property damage ($5M and $13M for crops, including cherry trees). Most of the region lost power during or after the storm, sometimes for a week. Other per county property damages: Manistee ($350K), Wexford, Kalkaska, Antrim, Charlevoix, and Presque Isle ($250K); Otsego, Crawford, Emmet, and Cheboygan ($200K); Missaukee and Montmorency ($150K), and Roscommon, Oscoda, Alpena, Lake, Ogemaw, Chippewa, and Mackinac ($50K-$100K).

February 1-2, 2011 – Southern Lower Peninsula
A blizzard included 10-15 inches of snow and wind gusts over 40 mph, producing whiteout conditions and snowdrifts of 3-5 feet. Thunder accompanied the snow in some areas, with snowfall rates exceeding two inches per hour. Many businesses, schools (including major universities), and some government offices were closed the next day.

February 9-10, 2010 – Ottawa County
A storm producing 6-10 inches of snow closed I-94 for several hours and caused a multiple vehicle pileup on I-196. Many schools shut down on what was Michigan's “count day” (where student attendance helps determine local funding).

February 10, 2008 – Southwest Michigan
A blizzard involved extreme cold, frequent wind gusts up to 40 mph, and whiteout conditions. A fifty-car pileup on I-196 saw 20 people with minor injuries. Accumulations were the greatest in Allegan and Van Buren Counties. Snow drifts 3-5 feet deep were common in rural areas. Ottawa County property damage estimates were $250K.

February 6-7, 2008 – Saginaw County
Snowfall of 8-12 inches occurred along and north of the I-69 corridor in eastern Michigan, with up to 18 inches in Saginaw County. Road crews could not keep up with snow falling at 2-4 inches per hour. At least 50 cars were stranded.

February 3-4, 2007 – Southwest Lower Peninsula
Strong winds combined with both new snow and that already on the ground, resulted in numerous road closures, power outages, and car accidents. The Gerald R. Ford International Airport (Kent County) reported visibility at or under a quarter mile for much of a day. The highest snowfall total for the event was 17 inches in Grandville (Ottawa County).

November 24-25, 2005 – Northern Lower Peninsula
Lake effect snow caused accidents during Thanksgiving travel. Winds were 25-35 mph but up to 50 mph by the coastline. Visibility was near zero at times. Snowfall totals of 12-18 inches occurred in Otsego, Kalkaska, and Antrim Counties.

January 27, 2004 – Central Lower Peninsula
Up to 14 inches of snow accumulated in Montcalm County, with many areas in the region seeing 6-10 inches. Visibility was near zero when a pile-up involving 50 cars and trucks occurred on I-96 near Portland, shutting down both sides of the highway for three hours. Police responded to more than 200 accidents over the course of the day.

February 7 and 12, 2003 – Southwestern Lower Peninsula
Blizzard conditions caused a 72-car accident on I-94 in Benton Township (Berrien County). The accident began when a car slid under the back of a semi-tractor trailer during whiteout conditions. Between 6-12 inches of additional snow fell across many nearby areas five days later. Walker experienced 14 inches of snow.

December 23-29, 2001 – Southwestern and Northern Lower Peninsula
Lake effect snow began for several days, with 12-18 inches of snow being common. Up to 15 inches fell in Grandville (Kent County) in less than 24 hours as roughly 24-26 inches of total snow accumulated in a band from Ottawa County to Allegan County. Additional snowfall of 8-22 inches helped to set new records. Grandville (Kent County) saw over 70 inches of snow for the week. The cities of Petoskey and Charlevoix broke their 3-day snowfall total records with respective amounts of 60 and 39 inches.

January 5, 2001 – Livingston and Oakland Counties
Three persons were injured in Brighton when snow caused an awning-style roof to collapse along the edge of a warehouse ($75,000K). A man in Waterford Township fell to his death while trying to shovel snow from his roof.

December 11-31, 2000 – Central and Southern Lower Peninsula (Presidential EM-3160, 39 Michigan Counties)
A winter storm produced record snowfalls and canceled hundreds of airline flights. An 18-car pile-up saw responders sometimes using snowmobiles near Caro (Tuscola County), with 41 total accidents reported. Up to 200 cars were stranded on I-75 south of Flint. A Richmond home (Macomb County) burned down because firefighting vehicles were unable to reach it. Schools across much of the area were closed for several days. Many businesses were forced to close at the height of the Christmas shopping season. Ice dams and water seepage damaged thousands of structures well into January 2001. Several house fires resulted from melted water seeping into electric meters. Damage in Genesee County was estimated at $1.1M (a manufacturer's roof collapsed and injured one person). Another series of winter storms hit the following week, increasing depths in many counties to two feet or more. Public works crews operated at maximum capacity for two weeks in some areas, often around the clock and with almost no place to put it. Many communities used the majority of their annual snow-removal budget and salt supply to combat these storms.

January 12-14, 1999 – Southeastern Lower Peninsula
Large amounts of snowfall collapsed the roof of a shopping center and other businesses in the Detroit metropolitan area. Ice dams caused many leaking roofs, including at a University of Michigan library where rare documents were affected. Direct property damages totaled $1.8M, mostly within Wayne, Oakland, Washtenaw, and Macomb Counties.

January 2-4, 1999 – Southern Lower Peninsula, other locations (Presidential Declaration, 31 Michigan Counties)
An early morning storm produced record snowfalls, with high winds creating blizzard conditions. Ensuing days brought an additional foot of snow to many areas, collapsing numerous commercial building roofs. Ice dams on residential roofs were a widespread problem, damaging tens of thousands of structures. Hard-hit Detroit saw access to police, fire, and mail services hampered, as well as a 180,000-student school system closed for several days. Numerous planes landed at Detroit Metropolitan Airport only to sit on the runway apron for hours due to snowed-in gates and personnel shortages. National media attention was drawn to chaotic scenes as thousands of stranded travelers had few places to stay.

October 26-27, 1997 – Southern Lower Michigan
With significant foliage still on trees, branches broke under 2-8 inches of wet snow. The early season storm saw 195,000 lose power in the Grand Rapids area (330,000 customers statewide). Property damage estimates were $1.2M.

March 13-15, 1997 – Upper Peninsula (Keweenaw, Baraga, and Alger Counties)
A snowstorm lasted almost three days, dumping 16-20 inches of new snow in many communities. Nearly 33 inches fell on Marquette, producing a snow depth of 63 inches at Marquette County Airport. Phoenix saw 29 inches, Herman 25 inches, and Shingleton 21 inches.

January 10-12, 1997 – Western Lower Peninsula (Allegan, Ottawa, Kent, and Grand Traverse Counties)
Heavy snow in Allegan County measured 28 inches on Friday and 40 inches the next day. Some neighboring counties reported 12 inches or more. Grand Traverse County received 12-18 inches. Schools were used as emergency shelters for stranded motorists in some affected areas. Secondary roads across the area were blocked overnight, and interstates were also closed for a few hours late Friday into Saturday. January 10-12 saw traffic accidents occur at a rate of 50-100 per county each day.

December 9-12, 1995 – Sault Ste. Marie (Chippewa County)
A storm hovered near Sault Ste. Marie for nearly 24 hours, dumping 28 inches of snow. Totals reached 61.7 inches before the system passed. Piled and drifting snow made many city streets impassible and buried fire hydrants. Schools and most businesses closed. A Governor's Emergency Declaration was granted for Chippewa County on December 13, with the National Guard and state agency work crews helping to remove snow. Other areas receiving heavy snowfall, in inches, included Munising (53), Ontonagon (43), Silver City (34), and Houghton (34).

January 26-27, 1978 – Great Lakes Region (Presidential Emergency Declaration, all Michigan Counties)
The "Great Blizzard of 1978" measured 2,000 miles by 800 miles and produced 50-70 mph winds that piled snow into huge drifts. Up to 34 inches of snow fell in some areas. Estimates include 50,000 miles of blocked roadways and 104,000 abandoned vehicles. Over 390,000 homes were without power and 15,000 people needed shelter. Nearly 40 buildings suffered partial or total roof collapse. Two days after the storm, over 90% of the state's road system was still blocked with snow, 8,000 people were still in shelters, 70,000 vehicles were stranded, and 52,000 homes were without power. There were roughly 70 deaths across the region (Ohio accounting for 51). The entire Ohio Turnpike was closed, bringing some food shortages even as farmers needed to dump milk that had no way to be transported.

January 26, 1977 – Southern Michigan
A major snowstorm saw strong winds with extensive drifting. Many residents were isolated in rural residences or public shelters. The storm resulted in a Presidential Emergency Declaration for 15 counties: Allegan, Barry, Berrien, Cass, Chippewa, Hillsdale, Kalamazoo, Kent, Monroe, Muskegon, Newaygo, Oceana, Ottawa, St. Joseph, and Van Buren.

January 26-28, 1967 – Lower Peninsula
A snowstorm dumped 24 inches of snow and contributed to 17 deaths across the region. Hundreds of motorists were stranded in their cars and had to be rescued by the police and National Guard. Several public shelters were opened. The heavy snowfall caused the collapse of roofs on numerous buildings and shut down public transportation services.

November 7-12, 1913 – Eastern Michigan and Lake Huron; other locations
The blizzard was one of the worst ever in the Great Lakes, earning its "white hurricane" nickname from extreme wind coupled with swirling snow. Wind gusts of 70 mph were reported in Detroit, with heavy snow pummeling many other shoreline communities. Speeds up to 62 mph hit Port Huron and created 4–5-foot drifts that immobilized the city. Sailors on Lake Huron reported continuous, battering waves at least 35 feet high amid winds as strong as 90 mph. Low visibility and accumulating shipboard ice hampered navigation, leading to a dozen major shipwrecks, eight of which were large lake freighters that went down with all aboard. At least 235 fatalities occurred when totaled with other watercraft.

### *Select Programs or Agencies*

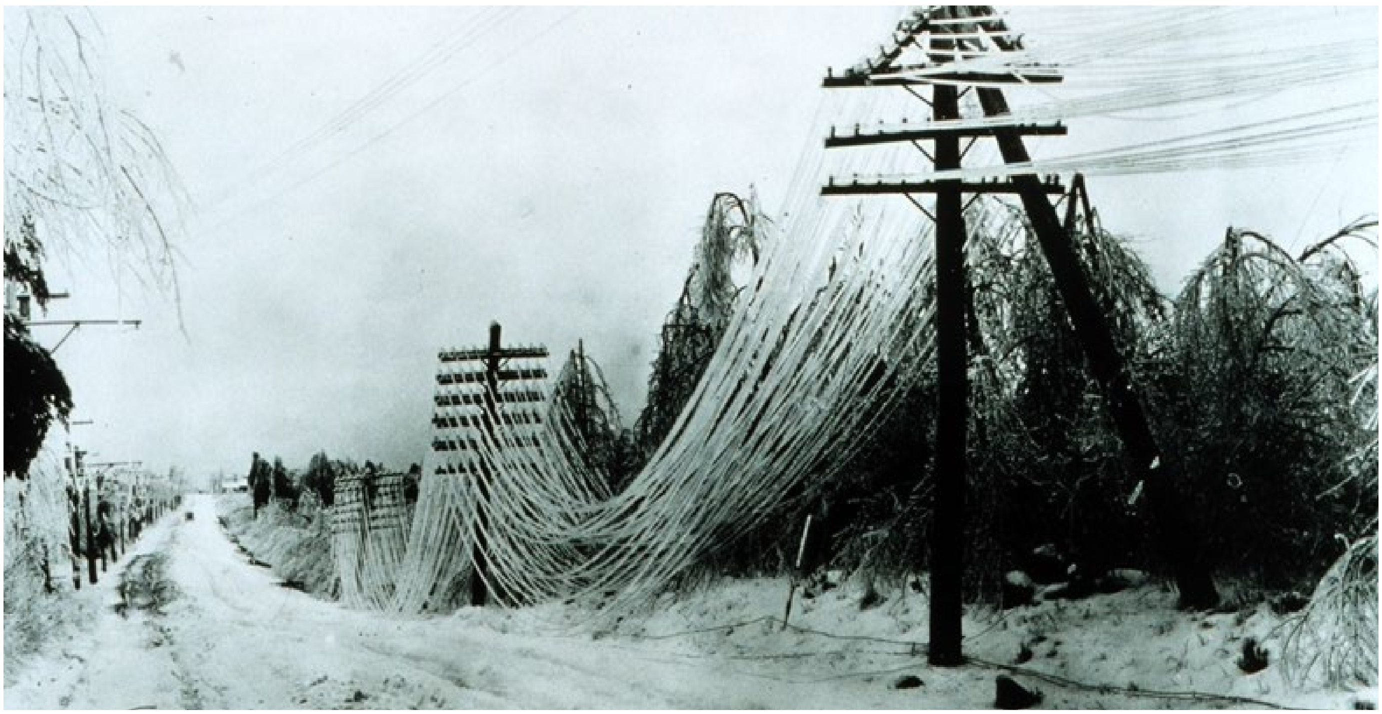
Many of the programs and initiatives useful during snowstorm, blizzard, freezing rain, and sleet events have significant overlap. Please see the Winter Weather Overview section for additional information.

# FREEZING RAIN AND SLEET STORMS

*Weather that produces freezing rain, sleet, or similar colder weather meteorological conditions.*

## *Hazard Description*

In most cases during the Michigan cold season, freezing rain, sleet, and snow all begin as snow in the clouds, with environmental air temperatures being a critical factor in determining eventual precipitation type. When air temperatures are not consistently subfreezing between the cloud and ground, snow temporarily falling through a warmer layer of air may melt back into liquid rain, but then refreeze into an ice pellet when it once again hits subfreezing air. It would then reach the ground as sleet. If the warm layer of air is deep enough, the melted snow may still be liquid when it hits any subfreezing surfaces below, forming as freezing rain on contact. Depending on the depth and uniformity of the warm layer there may be a mix of two or even all three of these precipitation types at the same time.



Power and telephone lines sagging after freezing rain. Source: NOAA Photo Library.

## *Hazard Analysis*

Freezing rain can cover trees, power lines, and roads with a sometimes-thick coating of ice, one reason extended periods of accumulating freezing rain are referred to as ice storms. Exposed roadways and sidewalks become slippery and treacherous. The accumulated weight of the ice may cause coated objects to break or collapse.

In contrast, falling and/or accumulating sleet shares some impact similarities with small hail, consisting of small ice pellets that bounce when hitting the ground. Sleet pellets can accumulate on surfaces (e.g., roads, roofs) but do not stick to trees and wires in the same way freezing rain does. Sleet accumulations are less than those of snow, typically limited to a couple of inches or less because the solid pellets are dense compared to snow's ice crystals. Generally considered less hazardous than freezing rain, it can still impact travel, add weight to structures, and quickly melt.

An additional hazard with some functional similarities to freezing rain is freezing fog. While both are the result of liquid droplets freezing on surfaces as a layer of ice, freezing fog is a fog cloud (stratus) droplet and not precipitation. It may coat materials that it settles on or that may move through it. In Michigan, it is typically less common than freezing rain. The frequency of ice and sleet storms varies somewhat by location across the state but generally occurs less often than snowstorm events and is spatially more uniform. Freezing rain and their associated ice storms are in general the most dangerous of these hazards and will be the primary focus of this chapter.

The combined number of ice storm, sleet, and freezing fog events are collectively described in the table below but are mostly from reports related to freezing rain. Relatively higher frequencies were observed in southern sections of the state (where intrusions of relatively warm air are more frequent) and across Upper Michigan, while relatively lower frequencies were observed across much of northern Lower Michigan. Similar to snowstorm-related events, greater economic impacts and numbers of injuries tend to occur in counties with more infrastructure and higher populations.

**Michigan Freezing Rain* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Freezing Rain Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 4 | $11,400,000 | | | 1 |
| Wayne | 5 | $21,000,000 | | | 1 |
| Livingston | 5 | $7,310,000 | | | |
| Oakland | 6 | $118,452,000 | | 1 | 2 |
| Macomb | 6 | $63,325,000 | | | |
| **5 County Metro Area** | **5 avg.** | **$178,487,000** | **$0** | **1** | **4** |
| Berrien | 5 | $30,000 | | | |
| Cass | 5 | $30,000 | | | |
| St. Joseph | 7 | $30,000 | | | |
| Branch | 7 | | | | 1 |
| Hillsdale | 7 | | | | |
| Lenawee | 6 | $3,555,000 | | | |
| Monroe | 6 | $6,565,000 | | | |
| Van Buren | 4 | $125,000 | | 1 | |
| Kalamazoo | 4 | $325,000 | | | |
| Calhoun | 5 | $1,530,000 | | | |
| Jackson | 5 | $2,030,000 | | | |
| Allegan | 5 | $2,500,000 | | | |
| Barry | 5 | $5,225,000 | | | |
| Eaton | 6 | $5,525,000 | | | |
| Ingham | 6 | $5,540,000 | | | |
| Ottawa | 6 | $3,500,000 | | | |
| Kent | 6 | $6,000,000 | | | |
| Ionia | 6 | $5,330,000 | | | |
| Clinton | 6 | $4,330,000 | | | |
| Shiawassee | 6 | $3,000,000 | | | |
| Genesee | 7 | $3,110,000 | | | |
| Lapeer | 6 | $4,075,000 | | | |
| St. Clair | 6 | $12,100,000 | | | |
| Muskegon | 4 | $2,200,000 | | | |
| Montcalm | 5 | $200,000 | | | |
| Gratiot | 4 | $1,250,000 | $5,000 | | |
| Saginaw | 11 | $4,020,000 | | | |
| Tuscola | 7 | $3,020,000 | | | |
| Sanilac | 4 | $3,030,000 | | | |
| Mecosta | 6 | $1,350,000 | $5,000 | | |
| Isabella | 6 | $1,350,000 | $5,000 | | |
| Midland | 9 | $50,000 | | | |
| Bay | 9 | $50,000 | | | |
| Huron | 4 | $25,000 | | | |
| **34 County Southern Lower Peninsula** | **6 avg.** | **$91,000,000** | **$15,000** | **1** | **1** |

(continued on next page)

**Part 2 of Freezing Rain* History for Michigan Counties – arranged by geography**

| COUNTY/AREA | Reported Freezing Rain Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | 4 | $1,200,000 | | | |
| Newaygo | 4 | $1,200,000 | | | |
| Mason | 2 | $200,000 | | | |
| Lake | 2 | $200,000 | | | |
| Osceola | 5 | $450,000 | $5,000 | | |
| Clare | 5 | $350,000 | $5,000 | | |
| Gladwin | 4 | $75,000 | | | |
| Arenac | 3 | $60,000 | | | |
| Manistee | 5 | | | | |
| Wexford | 5 | | | | |
| Missaukee | 2 | | | | |
| Roscommon | 5 | | | | |
| Ogemaw | 3 | $5,000 | | | |
| Iosco | 5 | $60,000 | | | |
| Benzie | 4 | | | | |
| Grand Traverse | 4 | | | | |
| Kalkaska | 4 | | | | |
| Crawford | 1 | | | | |
| Oscoda | 2 | | | | |
| Alcona | 3 | | | | |
| Leelanau | 4 | | | | |
| Antrim | 3 | | | | |
| Otsego | 3 | | | | |
| Montmorency | 3 | | | | |
| Alpena | 3 | | | | |
| Charlevoix | 3 | | | | |
| Emmet | 4 | | | | |
| Cheboygan | 4 | | | | |
| Presque Isle | 4 | | | | |
| **29 County Northern Lower Peninsula** | **4 avg.** | **$3,800,000** | **$10,000** | **0** | **0** |
| Gogebic | 7 | $110,000 | | | |
| Iron | 5 | $7,000 | | | |
| Ontonagon | 4 | $100,000 | | | |
| Houghton | 8 | $20,000 | | | |
| Keweenaw | 4 | $110,000 | | | |
| Baraga | 5 | $10,000 | | | |
| Marquette | 7 | $40,000 | | | |
| Dickinson | 8 | $30,000 | | | |
| Menominee | 5 | | | | |
| Delta | 7 | $20,000 | | | |
| Schoolcraft | 11 | $30,000 | | | |
| Alger | 5 | | | | |
| Luce | 7 | $10,000 | | | |
| Mackinac | 6 | | | | |
| Chippewa | 10 | | | | |
| **15 County Upper Peninsula** | **7 avg.** | **$487,000** | **$0** | **0** | **0** |
| **MICHIGAN TOTAL**** | **432** | **$316,774,000** | **$25,000** | **2** | **5** |
| **Michigan Annual Avg.** | **14.8** | **$11,591,034** | **$915** | **0.1** | **0.2** |

* Combines Storm Events Database categories for “Ice Storm”, “Sleet”, and “Freezing Fog”.

**One event may take place in multiple counties. State totals may be less than the sum of all counties.

In terms of property damage, major ice storm events have, according to NCEI records, caused over $316M in damages since 1996. Many storms are multi-county events and estimated damages from a wide area may be spread across counties in a manner considered as best estimates by NCEI. Outlier events nevertheless exist for certain counties. An April 2003 ice storm was particularly severe, responsible for a significant portion of the reported damages.

The following table highlights the monthly distribution of these events for the period of 1970-July 2021.

**Michigan's Ice and Sleet Storms, and Freezing Fog, Event Summaries by Month (1970-2021)**

| AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | **0** | **0** | **4** | **13** | **19** | **15** | **14** | **8** | **0** | **0** | **0** | **73** |
| **0%** | **0%** | **0%** | **5%** | **18%** | **26%** | **21%** | **19%** | **11%** | **0%** | **0%** | **0%** | **100%** |

(source: NCEI. Each listed date of occurrence (rather than each of the county event listings) was counted as one event)

All events during this period occurred between November and April, with only about one-eighth of the events involving sleet. All property/crop damage and all but one casualty listed in the NCEI database source were caused by ice storms (one of the casualties was associated with a freezing fog event).

### *Specific Impacts*

<u>Impact on the Public, Property, Facilities, and Infrastructure</u>
Widespread travel impediments or power failures may occur, interfering with residents' activities, comfort, and safety. People may be injured by slip and falls or by hypothermia/frostbite. Sheltering or warming centers may be required. Drivers may be trapped on roadways or injured in major interstate accidents. Some buildings are susceptible to structural failure from roof accumulation. Schools or businesses may be closed down. Downed power lines may lead to electrocution fatalities. Carbon monoxide poisoning is a concern when gas powered generators are in use.

<u>Impact on the Economic Condition of the State</u>
Direct economic impacts for the state would be regional and typically minimal unless power lines or roof collapse at major facilities led to extensive/lengthy shutdowns. Ice storms can cause significant economic losses for fruit and other agricultural sectors. Multiple cold weather impacts could occur depending on extreme temperatures or precipitation mix.

<u>Impact on Responders, Continuity of Operations, and Continued Delivery of Services</u>
Ice storms expose responders to dangerous conditions. Slippery roads and grounded aviation may delay response. Services that rely on electric power may have to switch over to generators (if available). Downed trees may make debris removal a high priority, especially to help allow utility and ambulance access.

<u>Impact on the Environment</u>
Damage to trees (or other plants) from the weight of accumulated ice may bring down limbs or cause collapse. Ice load may damage roots. If enough trees are affected, it may disrupt habitats and ecosystem diversity. Other effects include potential flooding from ice melt or the long-term impacts (e.g., wildfire, infestation) from excessive tree death. Transportation accidents involving hazardous materials may contaminate the environment.

### *Select Ice Storms, Sleet Storms, and Freezing Fog in Michigan*

Because freezing rain may be accompanied by nearby snowfall, some mixed precipitation events may be placed under other chapters. The important "Polar Vortex" of 2019 is included in the Extreme Cold chapter due to the mass threat it presented to residential heating. The following list is not meant to be comprehensive.

February 22-23, 2023 – Southern and Central Lower Peninsula
An ice storm impacted southern Lower Michigan while snow impacted further north. For the eastern part of the ice event, communities along and south of I-69 saw a wintry mix of snow, sleet, and freezing rain with widespread ice accumulations of ¼ -½ inches. Parts of Washtenaw exceeded ½ inch of ice. Icing impacts were widespread, with nearly 3,000 downed wires and over 500,000 customers without power in the DTE Energy area alone. In the more western part of the event, ice pellets accumulated to a depth of 1-2 inches along and slightly north of I-96. Freezing rain occurred mostly south of I-96, with ¼ - ½ inches of freezing rain in Van Buren County. A firefighter in Paw Paw died after being electrocuted by a downed power line. The most damaged counties were Wayne ($16M in damages), Oakland ($11M), and Washtenaw ($8M). Other counties affected by ice included Monroe, Lenawee, Livingston, Macomb, St. Clair, Barry, Allegan, Ingham, Van Buren, Kalamazoo, Calhoun, Jackson, and Eaton. Total property damages were $52M.

April 14-15, 2018 – Lower Peninsula
A late-season winter mix included high winds with rain that led to sleet and freezing rain across a wide area. Numerous vehicle accidents were reported. A head-on accident on M-21 shut the highway down in both directions. Ice accumulations varied, but were as much as ½ inch, and sleet accumulations reached 1-2 inches in some areas. Numerous flights were delayed or canceled. Several counties saw high damages, including Oakland and Washtenaw ($6M each) and Wayne and Macomb ($5M each). Total property damage estimates for the state were $36M, not including Monroe ($5M) and Bay ($2M) Counties, whose damages also included some lakeshore flooding. A total of 450,000 customers across Michigan experienced power outages.

April 26-27, 2017 – Central and Western Upper Peninsula
Freezing rain fell with damage reported in Gogebic, Houghton, Keweenaw, and Ontonagon Counties. Slick roads additionally affected Alger, Baraga, Iron, and Marquette Counties. Moderate to heavy ice accumulation caused extensive tree damage in the higher-elevation areas of Bessemer and Wakefield. Trails were damaged at the Porcupine Mountains State Park. Some school closures and power outages occurred. Total estimated property damages were $350K.

December 21-22, 2013 – Southeastern and South-Central Lower Peninsula
Existing moist air and an Ontario cold front produced an extensive area of freezing rain, leading to over 200,000 homes and businesses facing sometimes lengthy power outages heading into the Christmas holiday. Ice accumulations in some areas were ½ - ¾ inches thick. Unsafe travel conditions caused Shiawassee County to declare a local state of emergency. Total damages were estimated at $29M, across the counties of Genesee, Lapeer, Livingston, Macomb, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, and Tuscola. An additional $18M in damages were estimated within the central Lower Peninsula counties of Allegan, Barry, Calhoun, Clinton, Eaton, Ingham, Ionia, Jackson, and Kent. Total statewide damages in terms of estimated insured losses were reported at $60M. Unplowed snow and difficult to access properties (e.g., ice, debris) caused delays in the delivery of propane needed for residential heating.

February 20-21, 2011 – Lenawee and Monroe Counties
The end of a large snowstorm (producing 5-10 inches of snow across the majority of southeast Michigan) saw snow turn to ice near the Ohio border. Downed trees and power lines occurred from ice accumulations of ½-1 inch. Power outages lasted for up to five days. Property damage amounted to $1.5M in Lenawee County and $3.5M in Monroe County.

January 12, 2009 – Southern Lower Peninsula
The NWS issued a 17-county advisory for freezing fog. Such low hanging fog not only reduces visibility but can have its water droplets freeze when it comes into contact with cars, roads, and other surfaces.

March 1-2, 2007 – Southeast Michigan
A storm in Huron County resulted in ice accumulations up to 3 inches thick on power lines and trees. Most of the damage occurred in just three hours during the night. Strong winds gusted to 50 mph and brought down trees and utility poles over many miles. More than half of Huron County's population was without power, some for up to 6 days. Hundreds sought shelter and were assisted by the American Red Cross. Property damage amounted to $1.5M (mostly in Huron County). Hundreds of traffic accidents took place, including some that were serious and resulted in six injuries and one death. Counties such as Iosco, Oscoda, and Otsego were also impacted.

November 24, 2006 – Wayne, Washtenaw, and Monroe Counties
A high-pressure system set up a favorable situation for fog formation. Light winds off of Lake Erie and Lake St. Clair carried a marine layer of low clouds and dense fog inland across the Detroit area, mainly along and south of I-94. Visibilities were near zero at times during the rush hour traffic. Temperatures in the 20's (Fahrenheit) allowed the dense fog to freeze on area roadways, creating slippery conditions and numerous accidents. A semi-truck rollover accident at the junction of I-75 and I-275 resulted in one death. Clean-up operations at the scene were hampered by the fog.

February 16, 2006 – Central Lower Michigan
A major ice storm saw reports of ice accumulations up to 1 inch thick with widespread tree damage and thousands of power outages (some lasting several days). Numerous temporary shelters were opened due to the extreme cold in the wake of the storm. Several counties saw damage, including $1M each for Gratiot and Saginaw.

April 3-5, 2003 – West and Central Lower Michigan
One of the biggest ice storms to affect lower Michigan in the previous 50 years brought down thousands of trees and limbs as well as hundreds of power lines. Outages were widespread and lasted several days for many (some were without power for a week). The ice storm resulted in several million dollars of damage across the area. Most of the counties across the central and southern Lower Peninsula received a total of ½ - 1½ inches of ice. Damage totals amounted to $1M in Kent County, $1M in Lapeer County, $10M in St. Clair County, $50M in Macomb County, and $100M

in Oakland County, where one death and two injuries also occurred (due to falling trees and branches). Additional casualties stemmed from traffic accidents (about two dozen injuries and one death). Three persons died from carbon monoxide poisoning due to the use of poorly ventilated generators.

January 29-30, 2002 – Southern Lower Peninsula
Severe winter weather battered much of the region, bringing a foot or more of snow mixed with sleet and ice. Schools were closed, roads were flooded, and over 152,000 were left without power. Four persons were killed in weather-related traffic accidents in Kent, Saginaw, Midland, and St. Joseph Counties. Services such as American Automobile Association Michigan aided more than 2,850 motorists. Detroit Metropolitan Airport was forced to cancel more than 170 flight departures and 183 arrivals.

March 13-14, 1997 – Central and Southeast Michigan
An ice storm struck late at night causing numerous school closings due to widespread power outages, icy roads, and downed trees. North of Detroit saw mixed precipitation but still significant amounts of freezing rain with accumulations between ¾ - 1½ inches. Amounts ranged from 1½ - 2½ inches further south. Roughly 514,000 customers lost power (some up to 4 days). Major outages occurred in Jackson, Kalamazoo, Cass, Branch, St. Joseph, and Calhoun counties, as well as in Lansing. Many local communities opened shelters to accommodate residents unable to remain in their homes. Response efforts were severely hampered by snow and windy conditions the following day. Falling trees damaged dozens of cars and houses throughout the area. Wayne, Oakland, and Macomb County damages amounted to about $4M each. Washtenaw County damage tallies were $3M, Livingston County suffered $2M, and both Lenawee and Monroe Counties saw $1M.

January 1, 1985 – Southern Lower Michigan
A 13-county area saw freezing rain accumulating up to 1 inch thick and impacting trees, power lines, and roads. There were three deaths and eight injuries directly related to the storm. Approximately 13,000 homes and 260 businesses sustained damage (including some counted as destroyed), with losses estimated at nearly $25M. Another 160 businesses lost inventory as a result of the storm damage and power outages. Over 430,000 electrical customers were without power, some for as long as ten days. Several nursing homes and adult foster care facilities had to be evacuated after losing power or heat. At one time 28 public shelters were opened to nearly 1,000 residents. A Governor's Disaster Declaration (and State of Emergency) was issued for Allegan, Barry, Berrien, Calhoun, Eaton, Genesee, Ingham, Jackson, Kalamazoo, Lapeer, Livingston, Oakland, and Van Buren Counties. Total public and private damage from this ice storm was estimated at nearly $50M.

March 2-7, 1976 – Central Lower Michigan
An ice storm with accompanying high winds and tornadoes struck a 29-county area, causing widespread power outages and leading to over $56M in damage. A Presidential Major Disaster Declaration was granted for Allegan, Bay, Clare, Clinton, Genesee, Gladwin, Gratiot, Ionia, Isabella, Jackson, Kent, Lapeer, Macomb, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oakland, Oceana, Osceola, Ottawa, Roscommon, Saginaw, St. Clair, Sanilac, Shiawassee, Tuscola, and Wayne Counties.

### *Select Programs or Agencies*

Many of the programs and initiatives designed to mitigate, prepare for, respond to, and recover from freezing rain, sleet, snowstorms, and blizzards have significant overlap. Please see the Winter Weather Overview section for additional information.

# EXTREME COLD

*Periods of very low temperatures, especially when prolonged.*

## *Hazard Description*

Extreme cold in Michigan typically occurs from November to early April and is generally marked by air temperatures remaining near/below 0°F. These low temperatures are usually well forecast but are sometimes so extreme (or prolonged) that they jeopardize human life. The hazard frequently puts a strain on heating resources and may lead to utility outages/shortages that can magnify the impacts of outside temperatures.

## *Hazard Analysis*

Temperature variations are more disparate during the winter, with different parts of Michigan experiencing on average 3-50 (or more) days per year at or below 0° F. The state as a whole experiences between 90-180 (or more) days for which minimum temperatures are at/below freezing. Counties in the North Central and Upper Peninsula typically have more annual days of extreme cold than southern parts of the state, including periods that persist for multiple days in a row. The following table lists record lows for numerous weather stations across Michigan. These records are for specific stations and do not necessarily include all-time records for the counties or surrounding localities in the area. The all-time state record is in Vanderbilt (Otsego County) at -51°F on February 9, 1934. The majority of record low temperatures occurred in January and February. High temperatures are included for comparison/context. Record cold air temperatures generally ranged from -20°F to -45°F, often in interior northern areas.

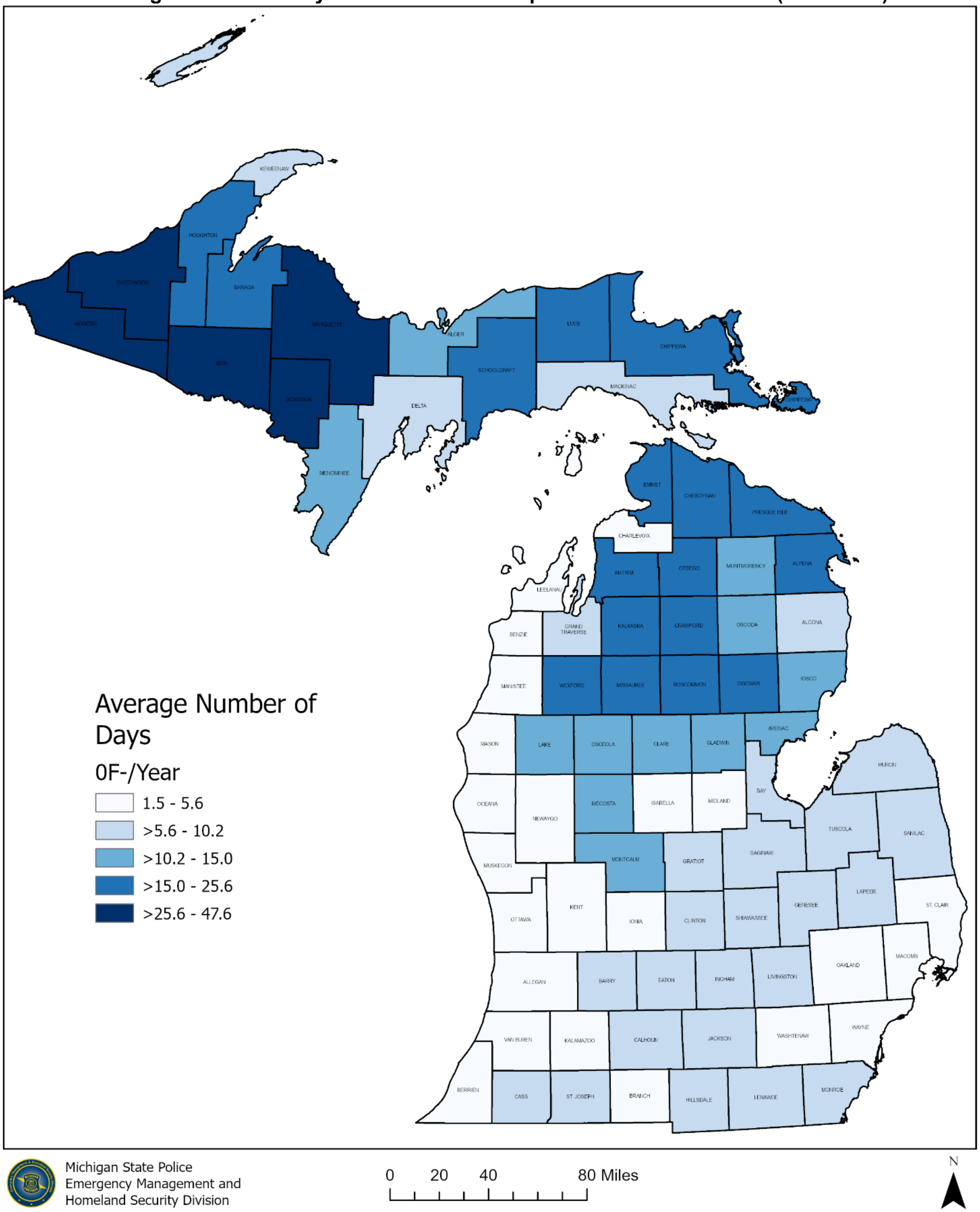
**Historic Temperature Records at Various Michigan Locations (through 2021)**

| **Southern Lower Peninsula** | **Record Low Temperature** | **Record High Temperature** |
|---|---|---|
| Adrian (Lenawee County) | -26°F (1/20/1892) | 108°F (7/14/1936, 7/24/1934) |
| Benton Harbor (Berrien County) | -21°F (1/12/1918) | 104°F (7/21/2002, 7/30/1999) |
| Coldwater (Branch County) | -29°F (1/31/2019) | 108°F (7/24/1934) |
| Ann Arbor (Washtenaw County) | -23°F (2/11/1885) | 105°F (7/24/1934) |
| Bloomingdale (Van Buren Co.) | -23°F (2/3/1996) | 105°F (7/5/1911, 7/13/1936) |
| Detroit (Wayne County) | -21°F (1/21/1984) | 105°F (7/24/1934) |
| Jackson (Jackson County) | -20°F (1/18/1976, 1/19/1994) | 103°F (7/15/1977) |
| Pontiac (Oakland County) | -22°F (2/5/1918) | 104°F (7/6/1988, 7/8/1936, 7/16/1988, 7/24/1934) |
| Flint (Genesee County) | -25°F (1/18/1976, 2/20/2015) | 108°F (7/8/1934, 7/13/1936) |
| Grand Rapids (Kent County) | -24°F (2/13-14/1899) | 108°F (7/13/1936) |
| Port Huron (St. Clair County) | -19°F (1/19/1994) | 103°F (7/9/1936) |
| Saginaw (Saginaw County) | -23°F (2/5/1918) | 111°F (7/9/1936) |
| Harbor Beach (Huron County) | -22°F (2/9/1934) | 105°F (7/10/1936) |
| Big Rapids (Mecosta County) | -36°F (2/11/1899) | 103°F (7/30/1916, 7/13-14/36) |
| **Northern Lower Peninsula** | **Record Low Temperature** | **Record High Temperature** |
| Houghton Lake (Roscommon Co) | -34°F (2/17/1979) | 103°F (6/19/1995) |
| Alpena (Alpena County) | -37°F (2/17/1979) | 106°F (7/13/1936) |
| East Tawas (Iosco County) | -29°F (2/1/1918, 2/20/1929) | 106°F (7/8-9/1936) |
| Gaylord (Otsego County) | -37°F (2/17/1979) | 101°F (7/11/1921, 7/30/1916) |
| Gladwin (Gladwin County) | -39°F (2/20/1979) | 105°F (7/13/1936) |
| Traverse City (Gd. Traverse Co.) | -37°F (2/17/1979) | 105°F (7/7/1936) |
| **Upper Peninsula** | **Record Low Temperature** | **Record High Temperature** |
| Hancock (Houghton County) | -30°F (2/9/1951, 2/10/1948) | 102°F (7/7/1988) |
| Ironwood (Gogebic County) | -41°F (1/17/1982, 2/12/1967) | 104°F (7/13/1936) |
| Munising (Alger County) | -33°F (2/25/1928) | 103°F (7/7-9/1936, 8/6/1947) |
| Sault Ste. Marie (Chippewa Co.) | -37°F (2/8/1934, 2/10/1899) | 98°F (7/3/1921, 7/30/1916, 8/5-6/1947) |

(source: NOAA NCEI)

Relatively warmest extreme lows tend to occur in counties bordering the Great Lakes, especially Lakes Michigan and Superior. It is important to note that there have been observed changes in the frequency of extreme low temperature events in recent decades associated with a trend towards a warmer climate. For example, annual extreme low temperatures (the coldest individual recorded temperature at a location in a given year) across much of the state have increased from 2°F to more than 8°F since 1950. Of the 31 extreme low temperature records for the 24 sites across the state listed in the records table, only five (5) have occurred during the past 30 years.

**Average Number of Days with Minimum Temperatures 0°F and Below (1991-2020)**



While latitude has an obvious impact on temperatures, proximity to the Great Lakes is another important consideration: water acts to reduce heating and cooling rates for land surfaces, resulting in relatively lesser extremes compared to inland areas. Ironwood (inland Gogebic County) for example has colder average temperatures during the winter than more northerly cities such as Houghton because it doesn't benefit from the tempering effects of Lake Superior.

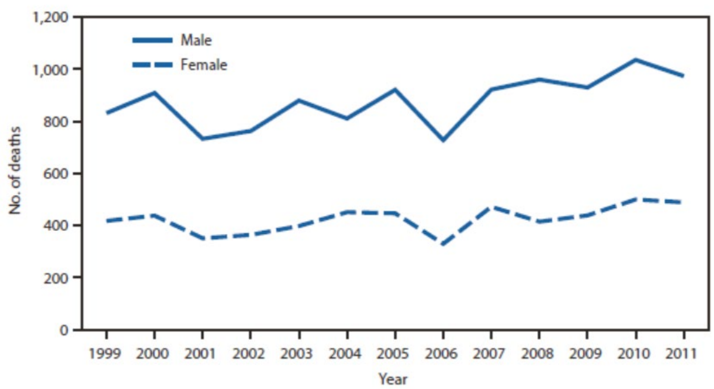
Cold temperatures may occur during blizzards and other storms, but extreme cold frequently happens around relatively calm winter weather (which allows maximum overnight heat loss from the surface) over snow-covered surfaces (which insulates against relatively warmer ground below). Colder, relatively denser air near the surface then collects and flows downhill to lower-lying areas of the landscape.

Deaths

More than 1,300 persons die each year in the US as a result of cold temperature-related causes (attributed to exposure to excessive natural cold as an underlying and contributing cause of death). This is substantially higher than the average of 175 heat-related deaths each year. It should be noted that a significant number of these deaths are not the direct result of freezing conditions. Rather, many are due to illnesses/diseases that are exacerbated by severe cold, such as heart attack, stroke, and pneumonia. Approximately 70% of weather-related fatalities in Michigan are attributed to exposure to the cold according to the NWS.

Hypothermia typically results from over-exposure to the cold and is generally thought to be clinically significant when core body temperature reaches 95°F or less. Hypothermia frequently occurs in conjunction with outdoor activities gone awry such as skiing, ice-fishing, snowmobiling, or camping. Treatment normally involves warming the victim (preferably performed by trained personnel). Most victims of this form of hypothermia tend to be generally healthy individuals who may lack experience in dealing with extreme cold temperatures and tend to be male.

**Number of Hypothermia-Related Deaths in United States by Gender: 1999-2011**




(source: National Vital Statistics System, mortality public use data files, 1999–2011)

Hypothermia can be linked to severe winter weather such as snowstorms or blizzards, such as when victims are trapped in stalled cars stuck on icy highways. However, many deaths are not associated with any particular storm event but are simply the result of unpreparedness or lengthy periods of cold weather. Elderly or otherwise vulnerable populations may experience problems when subjected to even moderate indoor cold stress (such as a poorly heated home). Hypothermia may not occur in these circumstances until days or perhaps weeks of continual exposure. Warming shelters and transportation for certain populations is a critical consideration.

Frostbite can also happen with extreme cold. It is rare for frostbite damage to directly result in death but may lead to amputation. Frostbitten areas should *not* be rubbed. When accompanied by wind, air temperatures can feel colder than the air temperature because of additional heat loss from the body and skin surfaces. Dehydration may also impact individuals, either due to pipes/wells becoming frozen or due to exertion (eating cold snow lowers core body temperatures and hastens hypothermia). Temperature alone is usually only one indicator of the weather's likely threat to human health.

Wind can make the air feel colder as it moves heat away from the body, exacerbating hypothermia and frostbite. Wind chill calculators can be found at http://www.wpc.ncep.noaa.gov/html/windchillbody_txt.html (see the end of the chapter for additional material regarding wind chill indexes, wind chill advisories, and other factors).

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
As already discussed, extreme cold can have a profound effect on public life safety. Nationwide statistics show extreme cold ranking behind only structure fires as a leading cause of fatalities. Looking beyond direct morbidity/mortality, greater energy use can also result in infrastructure failures due to the capacity limitations of utility systems. Warming centers may need to be operated. The main impacts upon facilities come from frozen pipes. These can range from small internal pipes within homes to large utility mains. Freezing can cause minor leaks or completely burst pipes with extensive water damage. Drinking water may be compromised whether on utility systems or wells. Schools and businesses are routinely impacted. Cold temperatures and thawing cycles are well known to have an impact on roadways and other infrastructure, which may become more brittle. General travel may become problematic and electric vehicles may not work as well.

Impact on the Economic Condition of the State
Businesses and organizers of outdoor events (e.g., sports, concerts) may be impacted by heating challenges, disrupted water service, or canceled events. General business productivity may be lowered. Many agricultural crops and livestock are vulnerable to losses because of extreme cold events (see the supplemental materials section of this chapter). Transportation and logistics hubs may be shut down. Deliveries may be delayed as vehicles stop working in the cold (e.g., dead batteries). Planes will need extensive deicing, and maritime traffic may be impacted by frozen waterways.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Freezing conditions may directly impact the health and effectiveness of responders, including the potential for dealing with impacts on overwhelmed or failed infrastructure. Special clothing and equipment maintenance is typically necessary. Frozen pipes may inhibit responders' access to water that is needed to fight fires. Some structure fires may become more common as people turn to extreme methods to heat their homes. Carbon monoxide poisoning may increase ambulance calls and hospital admissions. Schools and other governmental services may be closed.

Impact on the Environment
While Michigan's wildlife and habitat are in general adapted to winter, extreme conditions can hurt many plants and virtually all animals under poor conditions. This impact will vary based on the severity of the incident, its length, and time of the year. Thin-barked trees can crack. Waterways may become frozen and set the stage for future ice jams. Extremely frozen land may be impacted in ways that aren't apparent until thawed, especially if the ground was extensively wet before being frozen.

## *Select Episodes of Extreme Cold (Michigan)*

Air temperatures are noted in Fahrenheit unless otherwise stated. Separate wind chill values may be provided (see the supplemental materials section of this chapter for additional information regarding wind chill).

February 2021 – Northern Michigan
An Arctic air mass produced bitter cold wind chills across the region beginning February 6. Ironwood reported wind chills from -35°F to -40°F each morning February 7-9. Schools throughout Gogebic County were closed for two days. A very slight respite saw bitter wind chill readings improve to -25°F for some areas, but the 12-15 saw subsequent wind chills reach -35°F to -45°F during the nighttime and morning hours. Notably impacted counties included: Iron, Baraga, Ontonagon, Gogebic, Houghton, Delta, Keweenaw, Luce, Marquette, Menominee, Schoolcraft, and Dickinson.

January 28 to February 2, 2019 – Statewide Winter Emergency
This week-long event began for much of the state with a blizzard (snowfall ranging up to over a foot in depth as sustained winds began with gusts up to 40 mph). An extremely large number of schools closed throughout the state as a result, staying that way for most of the week. A combination of sustained sub-zero temperatures and strong winds produced dangerous wind-chill values (below -30°F were common throughout Michigan for multiple days, often dipping below -40°F). At least three deaths were attributed to weather exposure, with special shelters and over a hundred warming centers activated for several communities. Hospitals treated for carbon monoxide exposures resulting from makeshift efforts to heat homes. A fire occurred January 30 at a Consumer's Energy natural gas facility (Macomb County). Pressurization problems in large parts of the system led the utility, followed by the Governor, to ask both residential and industrial customers to voluntarily reduce their use of natural gas. By setting

thermostat levels to a recommended 65°F or below, and temporarily scaling back production activities at certain facilities, this collective effort helped to prevent a massive interruption in gas delivery that may have otherwise occurred. It should be noted that the problem did not involve the availability of natural gas per se, but constraints that the fire caused in the ability to deliver the gas (natural gas cannot be adequately and safely delivered without sufficient pressurization in the system).

Temporary electric failures occurred in some locations, affecting thousands of customers but not lasting for extended periods. Other infrastructure problems also arose from water main and pipe breaks, in places such as Lansing's Capitol Complex (Ingham County) and the northern half of the City of Newaygo (placed under a boil water advisory), and substantially lowered the water quality in Escanaba (Delta County). Many rivers experienced ice jams that threatened some areas with floods as well, such as Benzie County's Platte River near the Village of Honor (20 homes threatened) and Berrien County near M-139 (minor flooding near Riverfront Campground and in Niles). Excessive delays were reported at the Detroit Metropolitan Airport, as well as the Blue Water Transit bus system (St. Clair County) shutting down January 30-31. A State of Emergency declaration had taken effect on January 29 with non-essential State Government offices partially or fully closed for two to three days. There were numerous local states of emergency and other nearby states also declared. Michigan's State of Emergency expired after temperatures went back above zero.

Early January 2018 – Southeastern Lower Peninsula
From January 1-7, a prolonged cold spell affected Southeast Michigan, causing four persons to die in the Detroit Metro area. Low temperatures got as low as -15°F, and wind chill values went as low as -25°F. Flint set four new record temperatures during the period. The affected counties included Bay, Genesee, Huron, Lapeer, Livingston, Macomb, Midland, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, and Wayne.

Early January 2017 – Upper Peninsula
Very cold Arctic air from across Lake Superior resulted in very low wind chill values from January 3-7, in most Upper Peninsula counties. Wind chills at Ironwood (Gogebic County) were between -25°F and -35°F, and similar for Iron and Ontonagon Counties. Delta, Dickinson, and Marquette Counties were slightly warmer, with wind chill values down to a bitter -25°F at Iron Mountain, Escanaba, and K.I. Sawyer International Airport.

Mid-Late February 2015 – Northwest Lower Peninsula, then Upper Peninsula
February 13-14 saw frigid air enter the Traverse Bay area, causing wind chills from -30°F to -40°F. Some parts of the Upper Peninsula eventually went even colder. After a few milder days, an Arctic mass with gusty winds moved in on February 18, causing schools to close for three days across much of the Upper Peninsula. Wind chill values were later in the -25°F to -35°F range in various areas. Many counties in the Northern Lower Peninsula saw wind chills at -30°F to -40°F range on February 19, including -43°F near Cadillac (Wexford County). Subsequent warming was again followed by two other bouts of cold that closed schools. Southernmost Michigan did not feel these extremes.

January 2014 – Statewide
This particularly frigid winter often coincided with ice storms, power failures, and propane shortages that caused impacts to be more pronounced. Early January saw much of the Upper Peninsula endure wind chill values consistently between -30°F and -50°F. The worst was at Ironwood (-15°F one day with a wind chill reading of -54°F). Various Upper Peninsula schools were closed for two to three days and also later in the season. January 6 saw cold air further south, hitting -3°F at West Branch, Houghton Lake, Cassopolis, and Hillsdale. Detroit Metropolitan Airport bottomed out at -1°F January 6-7.

January 21-22, 2013 – Gogebic and Ontonagon Counties
Arctic air entered the area and wind chill values reportedly went at least as low as -4°F at Ironwood, on both mornings from January21-23. In neighboring Ontonagon County, wind chill values were estimated to be nearly as cold, from -35°F to -40°F. Area schools were closed because of the extreme cold.

April 27, 2012 – Lower Michigan – Late Freeze
A crop freeze caused extensive agricultural damage, particularly in the northwest fruit belt. Traverse City saw low temperatures of 25°F on April 27, 31°F April 28, and 26°F April 29. These temperatures were not greatly colder than normal lows, but a stretch of unprecedented warmth in mid-March with five consecutive 80°F days saw budding far ahead of schedule. The tart cherry crop was a total loss, while other orchard fruits such as sweet cherries, apples, pears, and peaches saw 90% losses of expected crop. Total estimated losses of $135M, by county: Leelanau $37.5M, Benzie and Grand Traverse $15M each, Antrim and Manistee $10M each, Berrien and Charlevoix $8M each, Emmet $5M, Cass $4M, and $1.3M each for Bay, Genesee, Huron, Lapeer, Lenawee, Livingston, Macomb, Midland, Monroe, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, and Washtenaw.

January 14-18, 2009 – Southeastern Michigan and Upper Peninsula
A persistent arctic air mass produced temperatures in Detroit from -3°F to -15°F below zero for four days (with wind chill values in the -5°F to -30°F range the majority of time). Wind chill values also plummeted to -20°F to -40°F from late evening on January 13 through the morning of January 16 in much of the Upper Peninsula.

February 9-11, 2008 – Upper Peninsula
Temperatures of -5°F to -15°F below zero combined with around 35 mph wind gusts and bitterly cold wind chill values down to -25°F to -40°F below zero over much of Upper Michigan from the night of February 9 into the morning of February 11, accompanied at times by blizzard conditions amid lake effect snow and blowing snow. Many schools were either canceled or delayed. Numerous dead batteries and fuel line freezes impeded transportation. An elderly Alzheimer's patient was found dead, five blocks from his home in Leland (Leelanau County).

February 3-6, 2007 – Southeast Michigan
A severe cold wave struck the region February 3-6. Temperatures went as low as -7°F at Saginaw and -5°F in Flint, and winds of 15-25 mph included gusts of up to 35 mph. Wind Chill Temperatures ranged from -15°F to -25°F for most of the incident, causing nearly every school district to cancel classes for one to two days. Hospitals reported numerous cold-related illnesses and frostbite cases. Area homeless shelters were filled to capacity. One death was attributed to the bad weather. Frozen pipes and water main breaks occurred throughout the area, with burst sprinkler pipes contributing. Total damages were estimated at $425K. Roughly 20,000 vehicle service calls were made.

January 2003 – Lower Peninsula
Sustained cold presented for much of January (never rising above freezing for a three-week period). Temperatures fell below zero for several nights. Frozen pipes and water main breaks occurred in many areas of Detroit and its suburbs. The cities of Flint (Genesee County) and Saginaw (Saginaw County) also had several reports of water main breaks. Several area schools canceled classes due to frozen pipes. Many homeless shelters were filled to capacity and area hospitals reported dozens of cases of frostbite. Three deaths were attributed to this cold spell (a homeless man found in a Detroit alley, a homeless man in Roseville (Macomb County), and an elderly Wayne County woman with Alzheimer's disease who had wandered from her home and was found frozen behind her garage).

December 21-29, 2000 – Southeast Michigan (including the Thumb area)
Heavy snow ended but then saw extreme cold settle into parts of Michigan. Temperatures never got out of single digits on December 22, with Detroit seeing a high of only 4°F. Flint saw an initial low of -5°F, with a Christmas morning low reaching -13°F. Ypsilanti and Chelsea High School pipes burst over the weekend. Several buildings at the University of Michigan also ruptured. Ice formation was extremely rapid on the Great Lakes and the connecting waterways. Several freighters got stuck in ice on both the Detroit River and Lake St. Clair, blocking the shipping channel and bringing dozens of ships to a halt. Ferry service on the St. Clair River between Michigan and Canada were interrupted due to ice jams.

December 1998 and January 1999 – Saginaw County, Southeast Michigan
December 30 saw a sprinkler pipe freeze and burst at Saginaw Valley State University ($500K in damages). Water was as deep as 3-4 inches in some offices when it was discovered. January brought more widespread events with Ann Arbor and Tecumseh seeing -13°F (-10°F in surrounding Washtenaw, Lenawee, and Wayne Counties). Three people died in Oakland County on January 4. Confirmed injuries of at least 29 people involved frostbite cases in Oakland and Wayne but represented only a small portion of affected people. Over 120 water main breaks occurred in Detroit. A large water ruptured in downtown Adrian, impacting 22,000 residents. Property damage was estimated at $1.3M.

January 17-19, 1997 – Southeast Michigan
The coldest weather of the winter resulted in two deaths from hypothermia: one in Bay City and the other (on January 12) in Warren. Low temperatures reached -6°F at Detroit Metropolitan Airport and -9°F at Flint's Bishop Airport.

February 3-5, 1996 – Upper Peninsula (Menominee County), Other Areas
Temperatures near Stephenson of -45°F, -44°F, and -41°F spanned three days. Other parts of the state were frigid, with Flint at or below 0ºF seven days in a row. A Detroit man wandered from his nursing home and died from the cold.

December 9, 1995 – Detroit and Upper Peninsula
Winds averaged 20-25 mph and resulted in wind chill temperatures of at least -30°F. Three deaths occurred from hypothermia in Detroit—two at street locations and one in a van. Separately and the next day, a man was found frozen to death by his disabled vehicle southeast of Ontonagon, where overnight wind chill temperatures reached -60°F.

December 1993 to May 1994 – Upper Peninsula and Northern Lower Peninsula
Gogebic, Ontonagon, Houghton, Marquette, Delta, Schoolcraft, Chippewa, Mackinac, Cheboygan, and Charlevoix Counites were part of Federal Disaster #1028 when record low temperatures caused the breakage of more than 3,200 water and sewer lines. Service to 18,700 homes was disrupted. Public costs were estimated at more than $12M.

December 1983 – Statewide
A massive area of arctic high pressure dominated much of North America during a historic cold wave dubbed the "coldest Christmas ever". Grand Rapids fell to -18ºF, setting an all-time monthly record low at the time. Nationwide costs were in the billions (including extensive citrus crop damages). Conservative Michigan damage estimates were over $5M.

### *Select Agencies or Programs*

Michigan Energy Assistance Program (MEAP), State Emergency Relief Program (SERP)
The MEAP administers statewide programs that provide energy assistance and self-sufficiency services to eligible low-income households. The SERP works in conjunction with the federal Low Income Home Energy Assistance Program (LIHEAP). The Weatherization Assistance Program is also available.

Additional information
See the Winter Hazards Overview for additional programs related to extreme cold.

### *Supplemental Material*

**Wind Chill Temperature Index and National Weather Service Windchill Advisories**
Colored portions of the wind chill chart that have darker shadings denote wind chill equivalents that can produce frostbite in 10 minutes or less. This index is a useful tool for looking beyond temperatures but is just one factor. For example, relatively drier air (common to winter weather) also allows a more rapid drop in temperature than is the case with warm summer air.

**Wind Chill Chart**

Temperature (°F)

| Wind (mph) / Calm | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 | -5 | -10 | -15 | -20 | -25 | -30 | -35 | -40 | -45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 36 | 31 | 25 | 19 | 13 | 7 | 1 | -5 | -11 | -16 | -22 | -28 | -34 | -40 | -46 | -52 | -57 | -63 |
| 10 | 34 | 27 | 21 | 15 | 9 | 3 | -4 | -10 | -16 | -22 | -28 | -35 | -41 | -47 | -53 | -59 | -66 | -72 |
| 15 | 32 | 25 | 19 | 13 | 6 | 0 | -7 | -13 | -19 | -26 | -32 | -39 | -45 | -51 | -58 | -64 | -71 | -77 |
| 20 | 30 | 24 | 17 | 11 | 4 | -2 | -9 | -15 | -22 | -29 | -35 | -42 | -48 | -55 | -61 | -68 | -74 | -81 |
| 25 | 29 | 23 | 16 | 9 | 3 | -4 | -11 | -17 | -24 | -31 | -37 | -44 | -51 | -58 | -64 | -71 | -78 | -84 |
| 30 | 28 | 22 | 15 | 8 | 1 | -5 | -12 | -19 | -26 | -33 | -39 | -46 | -53 | -60 | -67 | -73 | -80 | -87 |
| 35 | 28 | 21 | 14 | 7 | 0 | -7 | -14 | -21 | -27 | -34 | -41 | -48 | -55 | -62 | -69 | -76 | -82 | -89 |
| 40 | 27 | 20 | 13 | 6 | -1 | -8 | -15 | -22 | -29 | -36 | -43 | -50 | -57 | -64 | -71 | -78 | -84 | -91 |
| 45 | 26 | 19 | 12 | 5 | -2 | -9 | -16 | -23 | -30 | -37 | -44 | -51 | -58 | -65 | -72 | -79 | -86 | -93 |
| 50 | 26 | 19 | 12 | 4 | -3 | -10 | -17 | -24 | -31 | -38 | -45 | -52 | -60 | -67 | -74 | -81 | -88 | -95 |
| 55 | 25 | 18 | 11 | 4 | -3 | -11 | -18 | -25 | -32 | -39 | -46 | -54 | -61 | -68 | -75 | -82 | -89 | -97 |
| 60 | 25 | 17 | 10 | 3 | -4 | -11 | -19 | -26 | -33 | -40 | -48 | -55 | -62 | -69 | -76 | -84 | -91 | -98 |

Frostbite Times: 30 minutes; 10 minutes; 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

*Effective 11/01/01*

(source: https://www.weather.gov/safety/cold-wind-chill-chart)

Because daytime high temperatures typically decrease during the overnight hours, the corresponding drop in temperature can be greater when the humidity is low. Persons who are outdoors can rapidly find themselves in danger of hypothermia. Exposure to full sunshine on the other hand can increase heat index values by up to 15%. Conditions for each individual will vary with the duration of weather exposure, personal health, extent of acclimation, and clothing. Wet cotton in particular loses its insulation value when wet.

Although extreme cold can happen in any Michigan county there is some variation to the conditions under which wind chill advisories are issued, since it is the case that the warm season is longer in the southern part of the Lower Peninsula and there is a different phase of that area's population becoming acclimated to each year's winter weather. For southern Michigan, wind chill advisories are issued when wind chill temperatures reach -15ºF to -24ºF in Southern Lower Michigan, -20ºF to -29ºF in Northern Lower Michigan, and -25ºF to -34ºF in the Upper Peninsula of Michigan. Wind Chill Warnings, a more severe threat are issued when wind chill temperatures fall to -25ºF or colder in Southern Lower Michigan, -30ºF or colder in Northern Lower Michigan, and -35ºF or colder in the Upper Peninsula of Michigan.

**Temperature Timing**

The following table shows statistics describing the timing of observed 0°F and 90°F temperatures in terms of calendar dates during which the earliest, average, and latest dates in which temperatures were recorded at each location. Between those dates are shown the period in which such temperature extremes have regularly been observed. For example, the Adrian weather station had historically seen temperatures drop to 0°F or below as early as December 3 and as late as March 15, with an average occurrence on January 23.

**Timing of 0°F and 90°F Temperatures at Various Michigan Locations, 1991-2020**

Column Format: Earliest date of temperature, Average date of temperature, Latest date of temperature

| **Southern Lower Peninsula** | **Low Temperatures (<= 0℉)** | | | **High Temperatures (>=90℉)** | | |
|---|---|---|---|---|---|---|
| Adrian (Lenawee County) | Dec 3 | Jan. 23 | Mar 15 | May 15 | Jul 16 | Oct 1 |
| Benton Harbor (Berrien County) | Dec 8 | Jan 20 | Mar 13 | May 9 | Jul 18 | Oct 4 |
| Coldwater (Branch County) | Dec 3 | Jan 23 | Mar 13 | May 27 | Jul 10 | Sep 26 |
| Ann Arbor (Washtenaw County) | Nov 13 | Jan 28 | Mar 13 | May 20 | Jul 16 | Sep 26 |
| Bloomingdale (Van Buren Co.) | Dec 3 | Jan 24 | Mar 14 | May 16 | Jul 16 | Sep 27 |
| Detroit (Wayne County) | Dec 19 | Jan 24 | Mar 6 | May 16 | Jul 16 | Oct 8 |
| Jackson (Jackson County) | Dec 3 | Jan 23 | Mar 13 | May 27 | Jul 15 | Sep 26 |
| Pontiac (Oakland County) | Dec 10 | Jan 25 | Mar 9 | May 28 | Jul 17 | Oct 8 |
| Flint (Genesee County) | Dec 3 | Jan 25 | Mar 13 | May 18 | Jul 14 | Sep 26 |
| Grand Rapids (Kent County) | Dec 3 | Jan 26 | Mar 9 | May 15 | Jul 13 | Sep 26 |
| Port Huron (St. Clair County) | Dec 19 | Jan 23 | Mar 16 | May 15 | Jul 16 | Oct 8 |
| Harbor Beach (Huron County) | Dec 14 | Jan 31 | Mar 17 | May 29 | Jul 17 | Sep 26 |
| Big Rapids (Mecosta County) | Nov 15 | Jan 31 | Mar 28 | May 27 | Jul 16 | Sep 27 |

| **Northern Lower Peninsula** | **Low Temperatures (< 0℉)** | | | **High Temperatures (>90℉)** | | |
|---|---|---|---|---|---|---|
| Alpena (Alpena County) | Nov 28 | Feb 1 | Apr 6 | Apr 16 | Jul 13 | Oct 8 |
| East Tawas (Iosco County) | Dec 9 | Feb 2 | Mar 27 | May 18 | Jul 18 | Oct 9 |
| Gaylord (Otsego County) | Nov 10 | Feb 3 | Apr 8 | May 25 | Jul 14 | Sep 5 |
| Gladwin (Gladwin County) | Nov 29 | Jan 30 | Mar 27 | May 11 | Jul 14 | Oct 9 |
| Traverse City (Gd. Traverse Co.) | Dec 6 | Feb 5 | Mar 27 | May 9 | Jul 15 | Sep 26 |
| | | | | | | |
| **Upper Peninsula** | **Low Temperatures (< 0℉)** | | | **High Temperatures (>90℉)** | | |
| Hancock (Houghton County) | Nov 26 | Feb 3 | Apr 10 | May 20 | Jul 16 | Sep 11 |
| Ironwood (Gogebic County) | Nov 7 | Jan 27 | Apr 10 | May 29 | Jul 17 | Sep 12 |
| Munising (Alger County) | Dec 2 | Jan 26 | Mar 29 | May 25 | Jul 16 | Aug 31 |
| Sault Ste. Marie (Chippewa Co.) | Nov 10 | Jan 27 | Mar 27 | May 26 | Jul 16 | Sep 23 |

(source: NOAA NCEI)

**Michigan Extreme Cold* Data (Arranged by Geography, 1/1/1996 - 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Extreme Cold Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 15 | $500,000 | $1,300,000 | | 10 |
| Wayne | 22 | $275,000 | | 12 | 34 |
| Livingston | 15 | $25,000 | $1,300,000 | | 10 |
| Oakland | 16 | $25,000 | $1,300,000 | 5 | 14 |
| Macomb | 17 | $25,000 | $1,300,000 | 4 | 11 |
| **5 County Metro Area** | **17 avg.** | **$850,000** | **$5,200,000** | **21** | **79** |
| Berrien | 4 | | $8,000,000 | | |
| Cass | 5 | | $4,000,000 | | |
| St. Joseph | 4 | | | | |
| Branch | 4 | | | | |
| Hillsdale | 4 | | | | |
| Lenawee | 16 | $1,025,000 | $1,300,000 | | 10 |
| Monroe | 16 | $25,000 | $1,300,000 | | 10 |
| Van Buren | | | | | |
| Kalamazoo | | | | | |
| Calhoun | | | | | |
| Jackson | | | | | |
| Allegan | | | | | |
| Barry | | | | | |
| Eaton | | | | | |
| Ingham | | | | | |
| Ottawa | | | | | |
| Kent | 1 | $150,000 | | | |
| Ionia | | | | | |
| Clinton | | | | | |
| Shiawassee | 14 | $25,000 | $1,300,000 | | 10 |
| Genesee | 16 | $25,000 | $1,300,000 | | 11 |
| Lapeer | 15 | $25,000 | $1,300,000 | | 10 |
| St. Clair | 15 | $25,000 | $1,300,000 | 1 | 10 |
| Muskegon | | | | | |
| Montcalm | 1 | $100,000 | | | |
| Gratiot | | | | | |
| Saginaw | 15 | $525,000 | $1,300,000 | | 10 |
| Tuscola | 14 | $25,000 | $1,300,000 | | 10 |
| Sanilac | 16 | $25,000 | $1,300,000 | 1 | 10 |
| Mecosta | | | | | |
| Isabella | | | | | |
| Midland | 14 | $25,000 | $1,300,000 | | 10 |
| Bay | 15 | $25,000 | $1,300,000 | 2 | 10 |
| Huron | 14 | $25,000 | $1,300,000 | | 10 |
| **34 County Southern Lower Peninsula** | **6.0 avg.** | **$2,050,000** | **$27,600,000** | **4** | **121** |

(continued on next page)

| COUNTY/AREA | Reported Extreme Cold Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | 1 | | $2,000,000 | | |
| Newaygo | | | | | |
| Mason | | | | | |
| Lake | | | | | |
| Osceola | | | | | |
| Clare | | | | | |
| Gladwin | 4 | | | | |
| Arenac | 4 | | | | |
| Manistee | 3 | | $10,000,000 | | |
| Wexford | 3 | | | | |
| Missaukee | 4 | | | | |
| Roscommon | 5 | | | | |
| Ogemaw | 4 | | | | |
| Iosco | 4 | | | | |
| Benzie | 2 | | $15,000,000 | | |
| Grand Traverse | 3 | | $15,000,000 | | |
| Kalkaska | 3 | | | | |
| Crawford | 5 | | | | |
| Oscoda | | | | | |
| Alcona | 3 | | | | |
| Leelanau | 3 | | | 1 | |
| Antrim | 2 | | $10,000,000 | | |
| Otsego | 3 | | | | |
| Montmorency | 3 | | | | |
| Alpena | 3 | | | | |
| Charlevoix | 3 | | $7,500,000 | | |
| Emmet | 4 | | $5,000,000 | | |
| Cheboygan | 4 | | $5,000,000 | | |
| Presque Isle | 4 | | $5,000,000 | | |
| **29 County Northern Lower Peninsula** | **2.7 avg.** | **$0** | **$74,500,000** | **1** | **0** |
| Gogebic | 56 | | | | |
| Iron | 56 | | | 2 | |
| Ontonagon | 43 | | | | |
| Houghton | 59 | | | | |
| Keweenaw | 21 | | | | |
| Baraga | 43 | | | | |
| Marquette | 42 | | | | |
| Dickinson | 49 | | | | |
| Menominee | 34 | | | | |
| Delta | 38 | | | 1 | |
| Schoolcraft | 48 | | | | |
| Alger | 30 | | | | |
| Luce | 25 | | | | |
| Mackinac | 4 | | | | |
| Chippewa | 6 | | | | |
| **15 County Upper Peninsula** | **36.9 avg.** | **$0** | **$0** | **3** | **0** |
| **MICHIGAN TOTAL**** | **915** | **$2,800,000** | **$134,900,000** | **29** | **200** |
| **Michigan Annual Avg.** | **33.5** | **$102,454** | **$4,936,107** | **1.1** | **7.3** |

* Combines NCEI Storm Data categories for “Cold/Wind Chill”, “Extreme Cold”, and “Frost/Freeze”.
**One event may take place in multiple counties. State totals may be less than the sum of all counties.

**Agricultural Disaster Declarations Involving Cold and Heat (2012-2021)**

| ID# | Declared | Description | Counties | In Area 4 | In Area 3 | In Area 2 | In Area 1 |
|---|---|---|---|---|---|---|---|
| S3259 | 6-29-2012 | Snow, heat, rain, winds, hail, freeze, tornadoes, floods, lightning | 82 | 14 | 29 | 34 | 5 |
| S3306 | 7-25-2012 | Unseasonably early thaw, unseasonably warm nights, heat | 4 | 4 | 0 | 0 | 0 |
| S3380 | 9-5-2012 | Heat, frost, freeze, and drought | 5 | 0 | 0 | 5 | 0 |
| S3383 | | Freeze | 6 | 0 | 0 | 6 | 0 |
| S3384 | | Drought and heat | 3 | 0 | 0 | 3 | 0 |
| S3444 | 11-26-2012 | Unseasonably warm weather followed by frost and freezes | 3 | 3 | 0 | 0 | 0 |
| S3551 | 7-3-2013 | Rain, snow, and thaw/freeze effects ("winterkill") | 2 | 2 | 0 | 0 | 0 |
| S3584 | 9-11-2013 | Frost and freeze | 44 | 5 | 13 | 22 | 4 |
| S3622 | 1-23-2014 | Rain and colder-than-normal temperatures | 56 | 12 | 24 | 18 | 2 |
| S3623 | | Drought and colder-than-normal temperatures | 5 | 0 | 5 | 0 | 0 |
| S3636 | | Rain, drought, and cooler-than-normal temperatures | 25 | 0 | 22 | 3 | 0 |
| S3776 | 12-10-2014 | Freeze, frost, winds, extreme cold, record snowfall, ice, blizzards | 81 | 15 | 27 | 34 | 5 |
| S3806 | 3-25-2015 | Rain and colder-than-normal temperatures | 51 | 14 | 20 | 16 | 1 |
| S3807 | | Rain, drought, and colder-than-normal temperatures | 19 | 0 | 19 | 0 | 0 |
| S3914 | 10-14-2015 | Snow, freeze, frost, and extreme cold | 67 | 11 | 23 | 28 | 5 |
| S3934 | 11-18-2015 | Rain, floods, heat, landslides, mudslides, high winds, hail, lightning | 3 | 0 | 0 | 3 | 0 |
| S4216 | 9-1-2017 | Frost and freeze | 14 | 0 | 0 | 14 | 0 |
| S4256 | 11-21-2017 | Frost and freeze | 32 | 0 | 16 | 16 | 0 |
| S4266 | 12-21-2017 | Frost and freeze | 12 | 0 | 0 | 9 | 3 |
| S4376 | 8-8-2018 | Snow and freeze | 7 | 5 | 2 | 0 | 0 |
| **Total # Each Area Has Been Partially Affected by Declaration:** | | | | **10** | **11** | **14** | **7** |

(source: United States Department of Agriculture (USDA) Farm Service Agency (FSA); as described in Appendix A: Area 4 (Upper Peninsula), Area 3 (Northern Lower Peninsula), Area 2 (Southern Lower Peninsula minus Metropolitan Detroit), Area 1 (Metropolitan Detroit))

# FLOODING HAZARDS INTRODUCTION

More of Michigan's documented natural disaster damages, on average, come from water inundation than any other cause. This flooding overview provides information from the Storm Events Database primarily covering the categories of "flood", "flash flood", "heavy rain" and "lakeshore flood" (see accompanying table). An inland hydrological overview with associated maps is also provided. The three chapters in this section cover the following types of flooding, as well as some often related land mass hazards that don't fit neatly into other chapters (e.g., mudslides, erosion):

1. Inland flooding
    a. Fluvial (Riverine) and similar floods
        i. Related mudslides
    b. Pluvial and urban flooding
2. Shoreline flooding
    a. Great Lakes water levels
    b. Great Lakes storms and wave phenomena
        i. Related swimming hazards
    c. Shoreline erosion and recession
3. Dam and levee failures

Inland flooding is commonly categorized as being either fluvial or pluvial in nature. As used here, fluvial means floods associated with rivers and water bodies as they overflow. Early flood analysis often focused on the floodplain mapping of major rivers (or their tributaries) known to flood with fairly predictable seasonal water fluctuations. The term pluvial generally refers to flooding not associated with such water bodies, often driven by rain which simply collects in low-lying areas faster than it can soak into the ground. Although this can also happen in rural areas, pluvial flooding is frequently linked with the overwhelmed stormwater systems of cities. Two such disasters, DR-1346-MI (2000) and FEMA-4195-DR (2014), served as harbingers for more frequent "urban" flooding that demonstrated the significant damages that can occur even outside of well recognized floodplains.

Categorized here as a natural hazard, pluvial flooding is exacerbated by a breakdown in built water systems, such as inadequate or leaky pipes, missing backflow preventers, clogged drain openings, or poor planning/design standards. Dam and levee failures can also produce more technologically oriented flooding hazards, although precipitation is still a significant trigger during storm events. Unanticipated "blue sky" dam failures can be particularly dangerous as they may provide for little warning. Shoreline flooding along the Great Lakes will also be covered, as a result of either chronic high-water levels and/or acute storm surges. The potential for mudslides associated with saturated hilly ground will be touched upon, as will related erosion hazards affecting sand dunes and bluffs.

Michigan has experienced roughly 18 "flooding-related" declared disasters (disasters can involve multiple hazards and have varying impacts) since 1975 that have received both a Presidential Major Disaster Declaration and a Governor's Disaster Declaration. This averages to one such major flooding disaster roughly every 2.7 years. Additional events have resulted in only a Governor's Disaster Declaration, and many cases of localized flooding may receive only a county or other local declaration (or none at all).

**Overlap Between Flooding Hazards and Other Sections of the Hazard Analysis (Hazard Cascade)**
Floods may damage key facilities, either due to the physical impacts of water or debris hitting buildings or from water inundation (including into basements). Bridges and roads may be washed out. Electrical power may be directly affected or turned off for safety reasons. Sewer pumping and lift stations may go offline during a power/generator failure. Associated mudslides, erosion, and subsidence may temporarily or permanently alter the characteristics of the land in a manner that likewise injures people or damages infrastructure. Flood waters in urban or polluted areas tend to be contaminated with technological hazards such as chemicals and roadway residues. Agricultural areas contain fertilizers and pesticides. The bodies of drowned livestock or other animals may rot. Public health emergencies may result from stagnant or contaminated waters as a result of diseases (including from vector proliferation, such as mosquitoes) or hazardous materials. Human-related hazards such as terrorism, sabotage, or civil disturbances may cause water-related infrastructure to be destroyed or disabled, leading to flooding.

**Michigan Flood* Data (Arranged by Geography, 1/1/1996 - 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Flood Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Washtenaw | 36 | $9,045,000 | | | |
| Wayne | 113 | $1,329,300,000 | | | |
| Livingston | 22 | $1,504,000 | | | |
| Oakland | 37 | $408,706,000 | | 1 | |
| Macomb | 68 | $407,375,000 | | | |
| **5 County Metro Area** | **55.2 avg.** | **$2,155,930,000** | **$0** | **1** | **0** |
| Berrien | 39 | $16,777,000 | $100,000 | | |
| Cass | 14 | $1,251,000 | | | |
| St. Joseph | 7 | $1,380,000 | | | |
| Branch | 1 | $200,000 | | | |
| Hillsdale | 7 | $350,000 | | | |
| Lenawee | 35 | $950,000 | | | |
| Monroe | 37 | $12,980,000 | | 3 | |
| Van Buren | 11 | $4,693,000 | $250,000 | | |
| Kalamazoo | 15 | $18,160,000 | $260,000 | | |
| Calhoun | 14 | $6,835,000 | $335,000 | | |
| Jackson | 12 | $5,160,000 | $305,000 | | |
| Allegan | 21 | $15,190,000 | $7,325,000 | 2 | 4 |
| Barry | 16 | $7,310,000 | $700,000 | | |
| Eaton | 13 | $6,185,000 | $725,000 | | |
| Ingham | 13 | $11,560,000 | $375,000 | | |
| Ottawa | 22 | $53,365,000 | $1,905,000 | 2 | 3 |
| Kent | 26 | $4,680,000 | $510,000 | | |
| Ionia | 10 | $8,860,000 | $250,000 | | |
| Clinton | 14 | $6,560,000 | $375,000 | | |
| Shiawassee | 16 | $1,371,000 | | | |
| Genesee | 32 | $8,050,000 | | | |
| Lapeer | 17 | $9,820,000 | $1,000,000 | | |
| St. Clair | 31 | $16,170,000 | | | |
| Muskegon | 17 | $9,015,000 | $535,000 | | |
| Montcalm | 12 | $4,735,000 | $375,000 | | |
| Gratiot | 13 | $4,485,000 | $375,000 | | |
| Saginaw | 41 | $13,177,000 | $1,000,000 | | |
| Tuscola | 24 | $12,372,000 | | | |
| Sanilac | 12 | $3,785,000 | | | |
| Mecosta | 16 | $12,830,000 | $345,000 | | |
| Isabella | 18 | $78,740,000 | $21,375,000 | | |
| Midland | 21 | $329,270,000 | | | |
| Bay | 23 | $13,260,000 | $25,000 | 1 | |
| Huron | 17 | $464,000 | | | |
| **34 County Southern Lower Peninsula** | **18.7 avg.** | **$699,990,000** | **$17,445,000** | **8** | **7** |

(continued on next page)

| COUNTY/AREA | Reported Flood Events | Total Property Damage | Total Crop Damage | Deaths | Injuries |
|---|---|---|---|---|---|
| Oceana | 10 | $4,860,000 | $450,000 | | |
| Newaygo | 15 | $12,310,000 | $350,000 | | |
| Mason | 15 | $8,055,000 | $850,000 | | |
| Lake | 10 | $7,190,000 | $700,000 | | |
| Osceola | 13 | $8,450,000 | $575,000 | | |
| Clare | 9 | $4,375,000 | $275,000 | | |
| Gladwin | 15 | $18,036,000 | | | |
| Arenac | 15 | $4,698,000 | | | |
| Manistee | 15 | $5,719,000 | | | |
| Wexford | 12 | $1,182,000 | | | |
| Missaukee | 4 | $360,000 | | | |
| Roscommon | 4 | $504,000 | | | |
| Ogemaw | 5 | $800,000 | | | |
| Iosco | 6 | $1,448,000 | | | |
| Benzie | 6 | $345,000 | | | |
| Grand Traverse | 15 | $2,571,000 | | | |
| Kalkaska | 3 | $220,000 | | | |
| Crawford | 2 | $206,000 | | | |
| Oscoda | 4 | $203,000 | | | |
| Alcona | 7 | $404,000 | | | |
| Leelanau | 9 | $434,000 | | | |
| Antrim | 4 | $525,000 | | | 1 |
| Otsego | 2 | $203,000 | | | |
| Montmorency | 3 | $200,000 | | | |
| Alpena | 3 | $208,000 | | | |
| Charlevoix | 5 | $437,000 | | | |
| Emmet | 6 | $458,000 | | | |
| Cheboygan | 4 | $228,000 | | | |
| Presque Isle | 1 | $200,000 | | | |
| **29 County Northern Lower Peninsula** | **7.7 avg.** | **$84,829,000** | **$3,200,000** | **0** | **1** |
| Gogebic | 298 | $44,591,000 | | | |
| Iron | 23 | $5,065,000 | | | |
| Ontonagon | 20 | $9,049,000 | | | |
| Houghton | 43 | $122,120,000 | | 1 | |
| Keweenaw | 14 | $1,434,000 | | | |
| Baraga | 27 | $2,282,000 | $700,000 | | |
| Marquette | 61 | $25,757,000 | | 2 | |
| Dickinson | 29 | $588,000 | | | |
| Menominee | 21 | $2,435,000 | | | |
| Delta | 38 | $1,220,000 | | | |
| Schoolcraft | 10 | $202,000 | | | |
| Alger | 19 | $272,000 | | | |
| Luce | 9 | $200,000 | | | |
| Mackinac | 7 | $408,000 | | | |
| Chippewa | 8 | $345,000 | | | |
| **15 County Upper Peninsula** | **23.9 avg.** | **$215,968,000** | **$700,000** | **3** | **0** |
| **MICHIGAN TOTAL**** | **1413** | **$3,140,642,000** | **$42,355,000** | **12** | **8** |
| **Michigan Annual Avg.** | **51.7** | **$114,918,803** | **$1,549,806** | **0.4** | **0.3** |

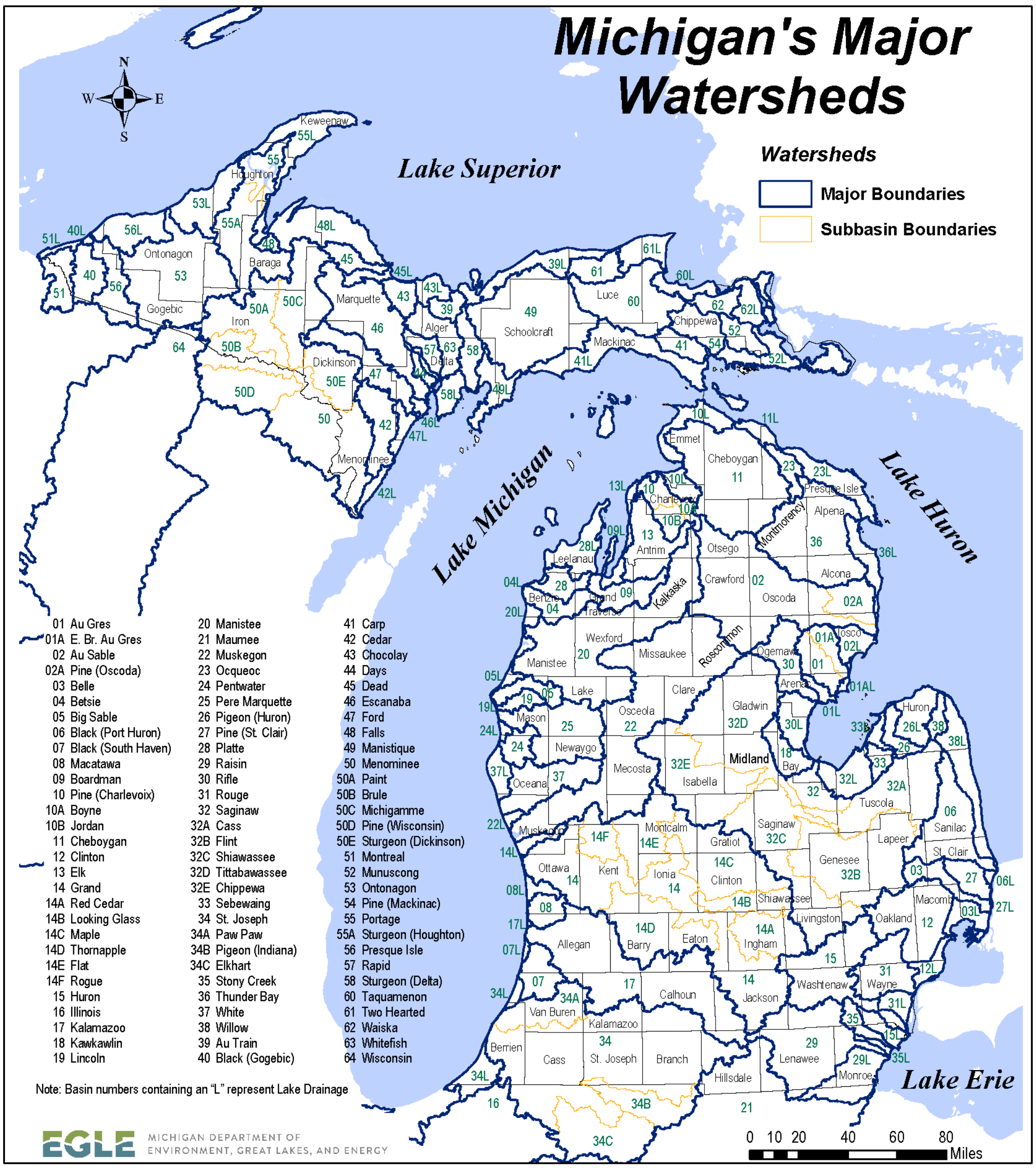
*Combines NCEI Storm Data categories for “Flash Flood”, “Flood”, “Heavy Rain”, “Lakeshore Flood”, and “Seiche”.

**One event may take place in multiple counties. State totals may be less than the sum of all counties.

## Michigan Hydrology

The Michigan Hydrologic Studies Program calculates flood discharges and conducts other types of hydrologic analyses that can be used in support of watershed management. Watersheds are defined as the land area that drains (or otherwise "sheds") the water that traverses across it for eventual deposit into a specific lake, river, or stream. Michigan watersheds can be divided in various ways depending on the location being studied. One general principle is that larger watershed areas tend to handle greater quantities of water runoff. There can be an almost infinite number of smaller areas within each watershed depending on topography and the base land size being studied. Additional hydrography resources and answers to frequently asked questions can be found HERE and HERE.

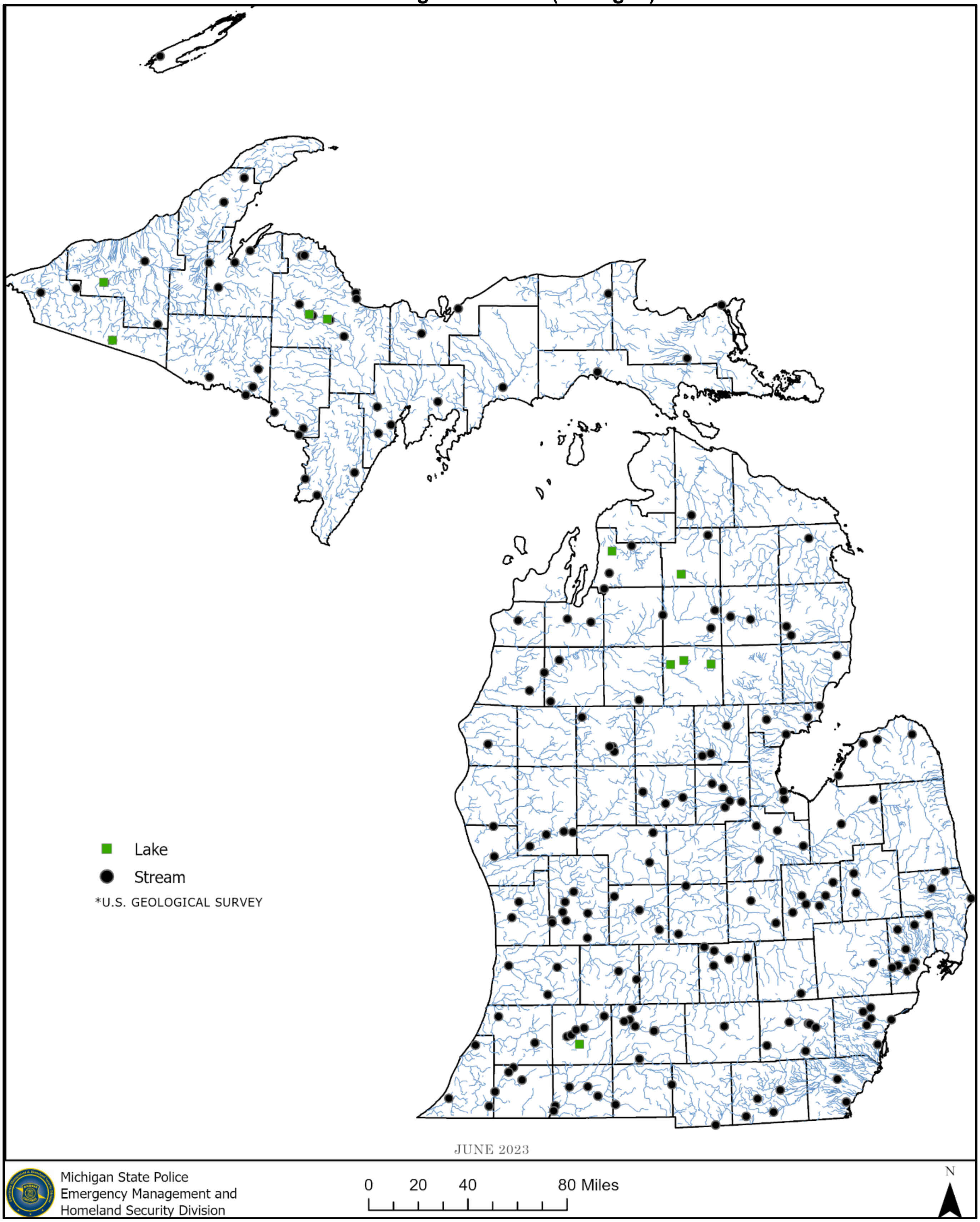
Virtually all waterways in Michigan eventually flow into the Great Lakes. A map showing 64 major watersheds is best viewed online. Higher risk areas within a watershed include floodplains and other specific types of relatively lower lying areas such as wetlands. Wetlands however should be generally viewed as beneficial resources that store water and help to alleviate extreme flooding. Although regulations have slowed the rate of wetland losses, Michigan's wetland resources continue to be degraded and lost at a rate that, while improving, is still faster than efforts to restore or create them. Areas with significant loss of wetlands tend to see consequences such as more flash flooding. Michigan's Wetlands Map Viewer can be found HERE, and information on its wetland monitoring and assessment strategy HERE.



(source: EGLE, revised April 28, 2019)

Gages are used by United States Geological Survey (USGS) and other organizations to assess water levels and flow rates for rivers, streams, and lakes. While gages can be placed at any location, their presence often indicates a waterway carrying an important need for study or monitoring.

**USGS Gage Locations (Michigan)**



# FLUVIAL AND PLUVIAL FLOODS

*Rising waters that cause the spilling of rivers above their banks, as well as the deposit, flow, and accumulation of water into low-lying areas, typically as a result of heavy precipitation or accumulated snowmelt.*

## *Hazard Description*

The flooding described in this chapter is divided into two broad categories depending on whether (1) rivers or other waterbodies are overflowing their banks, or (2) excessive precipitation is instead simply accumulating in low-lying areas. The former, often referred to as fluvial (or riverine) flooding, can inundate large geographic areas as waterways lose containment. Pluvial flooding instead occurs independent of an overflowing body of water (for example, excessive rain pooling in impervious or poorly drained areas). Pluvial flooding can occur in both city and rural settings but is often associated with extensively paved areas (i.e., "urban" flooding) and overwhelmed municipal water systems. Flooding events may involve both types of inundation, even if one predominates.

Flash flooding is caused by heavy or excessive rainfall in a short period of time, generally less than six hours, and can manifest within minutes or a few hours of excessive rainfall. Flooding associated with dam failures or Great Lake's shorelines is discussed in their chapters.

## *Hazard Analysis*

The periodic flooding of land adjacent to the normal course of a river, or the recharging of low-lying wetlands, can be a regular occurrence and part of natural cycles that people tolerate given the benefits water amenities provide. Some of Michigan's most popular cities are located near rivers and lakes despite being susceptible to enhanced flooding risk.

Flood-prone areas are found throughout the state. Fluvial flood sources include the connecting waters between the Great Lakes (e.g., Detroit River, St. Clair River, St. Marys River), inland lakes, and thousands of miles of tributaries that are part of 64 major watersheds touching some part of Michigan. Higher-elevation headwater areas have fewer flooding problems than the (typically) flat land next to a river, known as a floodplain. The term floodplain also carries a technical connotation that has come to mean the land area that will be inundated by the overflow of water resulting from a 100-year flood (i.e., a flood that has a 1% chance of occurring any given year).

Most riverine flooding occurs in the late winter or spring as the result of heavy rainfall and/or snowmelt (see the chapter on thunderstorms regarding precipitation trends). Flooding may occur in the immediate vicinity of a storm or where excess water that enters into connected rivers eventually combines downstream, known as a confluence area. Several factors come into play, including the speed with which water moves through a watershed (based on slope, saturation, soil type, frozen conditions, etc.) and the amount of excess capacity available in receiving channels.

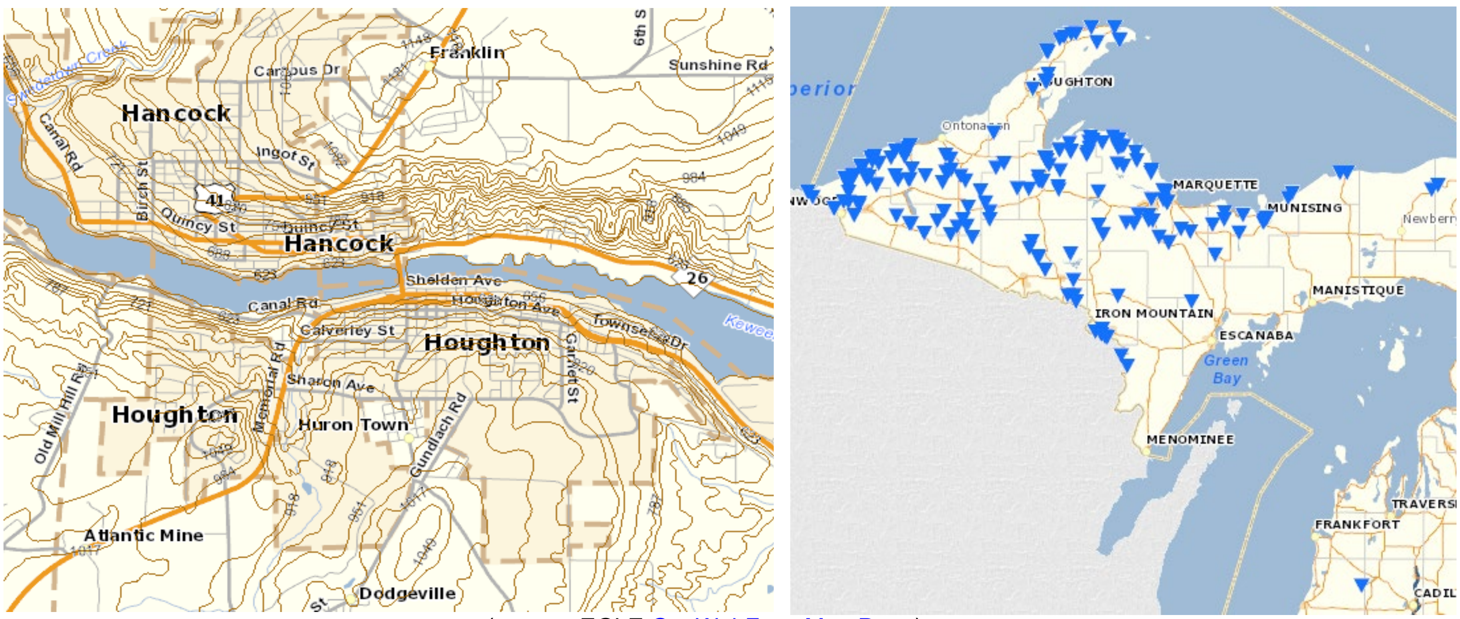
How quickly temperatures rise above freezing is important when considering snowmelt-driven flooding. Note that high-humidity air moving over a snowpack (typically leading to ground fog formation) can also significantly enhance melting and runoff rates. Ice jams may cause winter and early spring flooding as they create "natural dams" that have the ability to both temporarily flood upstream areas and eventually cause downstream flash floods when melting. Tree limbs or other trapped debris may similarly hold back and eventually release fluvial flood waters.

Pluvial flooding continues to be a problem in Michigan, particularly in the greater Detroit Metropolitan area where many highways are below grade and susceptible to heavy precipitation. Historically, the greatest frequency of pluvial flooding is during the summer season when heavy rain events are most common. Land development frequently increases flooding potential due to an increase in impervious surfaces, the loss of wetlands, or water systems/pipes that send rainwater into waterways at an accelerated rate. The Michigan Department of Environment, Great Lakes, and Energy (EGLE) estimates that about 6% of Michigan's land (roughly the size of the southeastern Michigan counties of Wayne, Oakland, Macomb, Washtenaw, and Monroe combined) is flood-prone, including about 200,000 buildings. For fluvial and pluvial flooding combined, the frequency of events follows an annual cycle, with the greatest numbers during the warm season (June and May are peak months) and lowest during the late fall through early winter months (the lowest overall frequency is during December). The southern half of the Lower Peninsula contains the areas with the most flood damage potential. Property damages can be extensive, averaging at least $100M per year from major events, as homes become flooded, culverts are washed out, and roads/bridges are damaged. Occasional deaths occur (about one death every two years, not counting Great Lakes/shoreline deaths).

Although detailed flooding maps are an eventual goal for all areas, the presence of digitized federal maps used to determine flood insurance rates is sometimes an indicator of locations with relatively higher flooding potential. A listing of floodplain maps can be viewed through FEMA's Map Service Center at https://msc.fema.gov/. It is important to note that a lack of a readily available digitized map for an area does not mean it is immune to flooding. Flood modeling is another potential source of information, but it should be kept in mind that different models may lead to different conclusions. One relatively new model is the First Street Foundation's climate tool, Risk Factor, which indicates 366,733 Michigan properties will have a greater than 26% chance of being severely affected by flooding over the next 30 years (representing roughly 12% of all properties in the state).

While many hazards interplay with flooding, "debris flows" such as mudslides should be especially considered depending on terrain. The steep downslopes of some hilly areas may become soaked and give way under the influence of both gravity and fast runoff rates. Local topographical maps are an important tool for helping emergency managers in identifying potential trouble areas. As an example, the Houghton/Hancock map illustrates locations of close relative proximity characterized by roughly 500-foot elevation differentials between them. The presence of waterfalls is another indicator of hilly areas. Most Michigan waterfalls are located in the western Upper Peninsula.

**Select Michigan Topographical and Waterfall Maps**



(source: EGLE GeoWebFace Map Page)

Beyond the potential for mudslides, more mundane erosion may be exacerbated by the cumulative effects of even minor flooding. A common example involves the erosion of land surrounding an undersized culvert or pipe, eventually causing a complete breakdown in the integrity of the land supporting the roadway/bridge that lies above it. Water mains, gas lines, or underground utility cables can also become exposed and vulnerable.

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

Floods can damage or destroy public/private property, including widespread residential impacts which may require evacuation and sheltering. They carry the potential to affect large portions of a community or region, making roads and bridges impassable and stranding cars. Power outages and drinking water supply/quality issues may emerge as infrastructure is damaged. Basement flooding and sewer back-ups may occur. Long-term collateral dangers include the outbreak of disease, widespread animal death, and the deposit of hazardous materials onto croplands or other areas. Fatalities and major injuries are uncommon in Michigan but possible.

Impact on the Economic Condition of the State

Floods can shut down businesses and services over a wide geographical area based on event severity, potentially crippling several economic components at one time (e.g., commercial, industrial, farming). Floodwaters may be slow to recede and produce lengthy/costly cleanups. Some governmental infrastructure may be directly impacted and need to be replaced, including along drains and sewer systems. Budgetary dollars that can be used for other purposes may need to be shifted to areas where flooding becomes chronic. Those who lose their homes may suffer significant financial losses, particularly among the uninsured.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responder vehicles may have limited alternate routes available amongst flood streets. Boats or helicopters may need to be deployed. High flow rates, water depth, and hidden hazards make search and rescue dangerous. Fire stations, police stations, and other key infrastructure may themselves become flooded, some of which (e.g., hospitals) are difficult to relocate to less susceptible areas. Almost all services carry the risk of being affected, especially if important assets (e.g., generators, pumping stations) are located in basements or otherwise compromised. Winter flooding from ice jams may make cleanup especially difficult.

Impact on the Environment
Water may become contaminated as it flows across a floodplain's streets, industrialized areas, or farmlands. Untreated sewage may be dumped into rivers when water systems are compromised or in localities with combined sewer systems. High bacterial counts may kill fish or create sanitary issues for communities depending upon the event. While the impact of flooding can sometimes have beneficial effects for certain types of wildlife or can recharge wetlands, many negative consequences also occur. Washed-out silt and debris may choke out the habitat as it accumulates downstream. The flow of some waterways may be permanently changed.

## *Select Flood Events in Michigan*

Water inundation is a relatively common hazard and even non-comprehensive listings for historical flooding will be lengthy. Smaller incidents with routine seasonal flooding (often near rivers subject to winter ice jams) won't typically be included even if local states of emergency have been declared. Such localized flooding may still create damages ranging into the millions, take lengthy times to recede, and close transportation routes or other facilities. Date ranges associated with the incidents below typically refer to only the precipitating event and not complete response and recovery times. Some flooding events are listed in chapters related to dam failures or Great Lakes shoreline flooding.

August 24, 2023 – Southeast Michigan (Primary Counties)
Early morning brought torrential rains, leading to street and highway flooding, submerged cars, and closed roads. Hundreds of homeowners reported water in their basements. The closure of Dingell Drive at Detroit Metro Airport, which along with nearby flooded road tunnels, cut off access to the McNamara terminal for several hours. Many flights were delayed or canceled. A lengthy closure of I-94 at I-275 was also reported. Numerous rainfall totals of 3-5 inches occurred mostly in the six-hour period from Midnight to 6 a.m. Water pumps at highways ran out of space to deposit water, with it sometimes simply flowing back into the system. A power outage also affected some pumps.

The evening then saw a second storm that brought more rain, high winds, and several tornadoes (see the Tornado Chapter). Canton Township was particularly hard hit by flooding, with up to 6 inches of rain and some creeks and rivers impacted. The highest total for this incident was 7.3 inches around Belleville (Wayne County). The Tyler Dam (Washtenaw County) was monitored due to washed-out banks on its downstream side but did not lose integrity (some parts of the county saw almost 5 inches of rain over three hours). A South Lyon police vehicle was severely damaged on a flooded road responding to a stranded motorist. Nearly 500,000 customers lost power at some point across the state due to tornadoes and high winds, including at the Estral Beach Wastewater Treatment Plant (Monroe County). A Governor's Declaration was made, not only due to the flooding but also as a result of the wind damage that affected much of the southern part of the Lower Peninsula. Chesterfield Township and the City of New Baltimore also experienced flooding and were later added to an overall series of state declarations (Executive Orders 2023-7 through 2023-10).

April 11, 2023 – Upper Peninsula (Houghton, Gogebic, Marquette, Ontonagon, Baraga, Iron, and Alger Counties)
Rising temperatures led to the rapid melting of snowpack after six months of well above-average winter precipitation, leading to widespread flooding. This overwhelmed some rivers and stormwater systems, caused culvert and embankment failures, created a minor sinkhole, and closed roads. There were sporadic power outages and Wakefield needed to bring in limited outside drinking water. A State Declaration was granted to seven requesting counties (Dickinson did not request but was also added). Preliminary damages estimates were over $31M, although subsequent heavy rain and snow between April 29 and May 2 also reflooded some of the same areas.

May 11-12, 2022 – Northern Michigan and Upper Peninsula (Mecosta and Marquette Counties)
A significant weather system quickly brought large amounts of rain that especially impacted two counties. Big Rapids (Mecosta) saw 4.5 inches of rain over a two-hour period, impacting roads, bridges, and a university campus. Property damages were $2.5M. The next day in Ishpeming (Marquette) saw heavy rainfall with 3-4 inches over three hours.

Sections of two county roads were closed and in one location cars became stranded in 2 inches of water. Reported property damages were $3M. State declarations were made for the counties.

February 17-18, 2022 – Monroe, Shiawassee, and St. Clair Counties
The City of Monroe was put under a flood warning when chunks of ice began piling up in the River Raisin. The river spilled over onto several streets, closing two main roads and affecting residential neighborhoods where some cars became trapped in the icy waters (one person was rescued). Several ice jams were present in the state around this time, including in Owosso with some basement and carpet damage for a closed middle school and the Curwood Castle Museum. Ice jams in late January and early February had earlier required assistance from the US and Canadian Coast Guards on the St. Clair River, leading to flood advisories.

June 25-26, 2021 – Ionia, Macomb, Oakland, Washtenaw, and Wayne Counties (Federal Disaster #4607)
Widespread rain of 3-5 inches fell across Metro Detroit over the weekend, reaching as high as 6-8 inches in some areas. Numerous roads and major highways became impassable, especially in Wayne and Washtenaw Counties. Some motorists became stranded and power outages occurred. Roughly 6,000 homes suffered minor damages while 15,000 suffered major damages. The Northville area saw particularly high property damages at $139M. A tornado also occurred in Ionia County.

February-July, 2019 – Ionia, Newaygo, Wayne, Tuscola, and Lake Counties (five separate Governor Disaster Declarations)
A busy year for floods began when winter weather contributed to ice jams in Ionia County. Roughly 25 structures were impacted with $400K in property damages. A compromised wastewater facility discharged raw sewage into the Grand River. March saw Newaygo County flood from rain, snowmelt, and frozen ground, closing 100 roads (30 completely washed out), impacting 50 homes, and causing $1.7M in property damages. May brought pluvial flash flooding to Wayne County, particularly in Dearborn Heights, where 5,000 basements flooded (property damages of $64M). Rain also impacted Tuscola County, which saw $4.2M in flooding-related property damages. July storms hit lightly developed Lake County, with 6-10 inches of rain and high winds that damaged roughly 50 homes.

June 16-19, 2018 – Gogebic, Houghton, and Menominee Counties (Federal Disaster #4381)
Historic rain fell mostly over a 6-hour period, with 72-hour totals as high (in inches) as 8.4 (Houghton), 7.8 (Gogebic), and 5.6 (Menominee). The area's topography led to flash flooding with sediment, rocks, and other debris washing down hills, especially in Houghton where buildings were damaged by direct force and scouring effects. A child died when a basement collapsed. Fifty miles of trails/snowmobile routes, also important to tourism, saw $20M in damages. Total damages for the three counties were over $100M, with roughly 40% attributed to roads (200 of which had been forced to close). Homes were counted as 172 with minor damage, 50 major, and 3 considered destroyed.

June 22-27, 2017 – Bay, Gladwin, Isabella, and Midland Counties (Federal Disaster #4326)
A storm event with 5-8 inches of rain led to flooding and also toppled trees and power lines. More than 1,900 homes were damaged and 57 were destroyed in Midland County. Public infrastructure impacts involved 193 roads and bridges that were damaged or destroyed ($116.4M in damage). In Bay County, 145 homes were damaged, and 50 roads and bridges were damaged or destroyed ($3M in damage). Isabella County calculated over 100 roads closed at the same time, plus at least $70M in property damage to area homes, roads, and bridges. Total property damages were estimated at $189M across all four counties, with $21M in crop damage in Isabella County.

July 11-12, 2016 – Gogebic County
Evening rainfall amounts of 3-6 inches fell across parts of the county, resulting in early morning flash flooding. Many areas of the road were washed out and impassable. Several people were stranded at Little Girls Point, and a county patrol car was swept up in flood waters at the Montreal River. Property damages were estimated at $6.15M.

August 11-13, 2014 – Metropolitan Detroit (Federal Disaster #4195 – Three counties)
A storm produced 4-6 inches of rain over four hours, overwhelming storm sewer systems and roadside pump stations. All major expressways in the central urban area were affected, with some closures creating massive transportation issues. An estimated 1,000 cars stalled and were abandoned (some rescues required). About 75,000 homes and businesses were damaged, 3,000 of which were major. Road and bridge damages saw losses calculated at $1.8B across the metropolitan area. Two deaths occurred. This event was similar to that of September 2000 (see below), but with severe transportation impacts on top of widespread basement flooding. Official FEMA damage estimates were

calculated as less severe than in 2000 because of changed standards that discounted huge amounts of damage for basements with unfinished areas. Bay, Genesee, and Saginaw counties also experienced significant road flooding.

April 12, 2014 – Newaygo and Osceola Counties
About 400 homes along the Muskegon River were impacted by flooding as rainstorms with snow caused river levels to greatly rise. About $4M in property damage was estimated in Newaygo and $3M in Osceola. Significant road damage also resulted. A Governor's Disaster Declaration was proclaimed for flooding and accompanying wind damages.

April-May 2013 – Multiple Counites (Federal Disaster #4121 – 16 counties, City of Grand Rapids, and City of Ionia)
Record flooding occurred from heavy rains as well as some snowpack melt. Hundreds of homes flooded, more than 300 roads closed, and preliminary damage assessments totaled more than $32M (including $7M in Ionia County). Many areas were impacted, not all of which were part of the federal declaration. Counties experienced roughly $3-5M in damages: Allegan, Barry, Calhoun, Clare, Clinton, Eaton, Gratiot, Houghton, Ingham, Isabella, Jackson, Kalamazoo, Lake, Mason, Mecosta, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, and Van Buren.

January 30, 2013 – Paris (Mecosta County)
A winter ice jam along the Muskegon River resulted in $4.6M in flooding damage. Over a dozen homes were evacuated near Rogers Heights. The area near Riverside Dr. and 183rd Ave. was especially impacted.

May 4, 2012 – Heavy Rains and Flash Flood (Genesee and Shiawassee Counties)
Half a foot of rain-stranded cars on roadways, saw numerous roads shut down (including sections of I-75 and I-69), bridges washed out, and the evacuation of some residents by boat. Genesee County property damage totaled $7.1M with the City of Swartz Creek and Township of Flint particularly hard-hit. An apartment building near Hill Road in Grand Blanc Township saw $1.7M in damage and had to be evacuated when it lost power and water levels left 30 of its cars almost completely submerged. Shiawassee County had $1.1M in property damage.

July 27-29, 2011 – Central Lower Peninsula (especially Ingham County)
Heavy rainstorms flooded roadways and residential areas within Lansing. Many homes had 4-5 feet of water in their basements. About $5M in property damage involved the Burchfield Drive area which required boat rescues. An apartment building was evacuated due to sewage backup (a shelter was opened). Eaton, Jackson, and Barry Counties were also affected. Total property damages were estimated at $6.75M (plus $400K in crop damage).

August 11-13, 2010 – Isabella County
Downtown Mt. Pleasant suffered flash flooding as at least 4 inches of rain fell over roughly three hours. Property damage estimates were $4M, $3M of which involved 39 Central Michigan University buildings. Repairs to campus ceilings, floors, walls, insulation, equipment, mechanical systems, and storm sewers were necessary. Some portions of the Central Michigan Community Hospital were impacted. Street flooding occurred in downtown Mt. Pleasant, and the intersection of Isabella and Baseline Roads was washed out (some roads saw over a foot of water across them).

June 2009 – Southwest Michigan (Ottawa and Allegan Counties)
Lake Michigan thunderstorms moved across already saturated ground, resulting in numerous flooded homes and streets. More than 2,000 homes were damaged in some way, with 57 damaged or washed-out roads. Ottawa County declared a local state of emergency with total damage estimates of $34M. Allegan County saw $4M in damages.

September 13, 2008 – Kalamazoo and Nearby Counties
Excessive rainfall and flooding led to a state of emergency in Kalamazoo County (Augusta saw 10.5 inches of rainfall). Many city roads were closed for several days, with damage to public infrastructure estimated at $11M, along with 466 homes and ten businesses flooded. Nearby counties were less extensively damaged, including Berrien County suffering roughly $750K in damage and $500K each for St. Joseph and Cass County.

June 6-13, 2008 – Southwest and Central Lower Peninsula (Federal Disaster #1777 – 11 counties)
Severe weather lasted several days, producing two flash floods amid 100 mph winds and three confirmed EF1 tornadoes. Rainfall totals were 7-12 inches, exceeding the "100-year" rainfall values of 3.5 inches in less than six hours. Flooding washed out roads and flooded crops. A federal disaster declaration was received for 11 counties. Some of the worst damages were in the counties of Allegan ($2M in property damage, $2M in crop), Mason ($3M property, $500K crop), Lake ($2M property, $500K crop), and Ottawa ($1M property, $1.5M crop). Two people died in Allegan when a car plunged off a washed-out road. Another person died in Ottawa County when they tried to remove boards from the Worley Drain Dam.

August 2-3, 2006 – Sanilac and Lapeer Counties
The Brown City area was especially hard hit, eventually receiving 10 inches of rain. Flash flooding began at 11 p.m., damaging many homes with 220 claims filed (total damages estimated at $1.55M). Waters reached three feet deep in a mobile home park. Crop damages were $1M in Lapeer County's North Branch area. Several homes were heavily damaged on the east side of Burnside Township, adding up to a total of about $300K in Lapeer County property damage.

May-June 2004 – Southern Lower Michigan (Federal Disaster #1527 – 23 counties)
Total rainfall over the Grand River basin from May 20 - June 3 was 4-7 inches, with some areas seeing 2-6 inches over a 36-hour period and submerging backyards under several feet of water. Roughly 100 homes in Macomb County had damages of around $100K each, with road and bridge damage estimates of $10M (overall Macomb damages were $100M). Clare, Gratiot, Isabella, Lake, Mason, Mecosta, Montcalm, Newaygo, Oceana, and Osceola Counties were pegged at $1M each.

April 11-17, 2002 – Western Upper Peninsula (Federal Disaster #1413 – Six counties)
Some areas received 100 inches of snowfall over two months, creating a snowpack holding as much as 11 inches of water. Record high temperatures during April 15-16 led to nearly two feet of snow melting. An additional 1.5 inches of rain contributed to flooding on rivers and lakes (the Black, Montreal, and Ontonagon Rivers went above the flood stage). Highways US-2, M-28, and M-64 were closed along with 25 lesser roads. Roughly 160 homes and businesses were part of an estimated $19M in damages. The Presque Isle Wildlife Dam partially failed when a 10-foot-wide earthen section gave way.

February 10-13, 2001 – Monroe County
The River Raisin crested, causing only moderate damage to basements but leading to three drownings when a pickup truck attempted to cross a flooded road (near the Saline River) and drove into a ditch filled with 10 feet of water.

February 9-10, 2001 – Multiple Counties
Rainfall and melting snow caused flooding in many areas, particularly Genesee County. Two major pumping stations were damaged, costing roughly $7M. Repair and flood-fighting costs for the County Drain Commission totaled nearly $600K, with the County Road Commission incurring $1.8M. A 200-resident mobile home park needed to be evacuated. A Governor's Disaster Declaration was granted. The rain had also threatened to overtop a Shiawassee County dam and the Peninsular Paper Dam (Washtenaw County). Homes were damaged in the City of Lansing.

September 10-11, 2000 – Wayne and Oakland Counties (Federal Disaster #1346)
Severe urban flooding brought sewer backups into basements. This was a large disaster in terms of the sheer amount of documented damages and serves to highlight the impacts and high costs associated with pluvial flooding in metropolitan areas. As an example, over 80,000 people planning to attend a Detroit Lions game were traveling to the stadium just as flood-prone areas began to swell. Hundreds of fans were forced to abandon their vehicles.

April 1998 – Alpena County
Rapid snowmelt and intense rainfall resulted in severe flooding, forcing residents from 80 homes in the City of Alpena to be evacuated. A total of 221 homes and five businesses were damaged by the floodwaters. Public damage totaled over $700K. A Governor's Emergency Declaration was granted to provide supplemental state assistance to the county.

June 20-21, 1997 – West Michigan (Governor's Disaster Declaration for Allegan and Ottawa Counties)
Rainfall hit Allegan, Ottawa, Barry, and Van Buren Counties. Flooding and winds were particularly severe in Allegan, which reported four injuries, five homes destroyed and 234 damaged, and 37 businesses damaged. Public damage totaled nearly $1.5M. Ottawa County saw 111 homes and five businesses impacted and $700K in public damages.

June 21-23, 1996 – Thumb Area (Federal Disaster #1128 – Seven counties)
Over 5 inches of rain fell in a 4-5 hour period in some areas, resulting in flash flooding that caused numerous road and bridge washouts and culvert failures. Over 2,700 homes and 40 businesses were affected. A tornado also struck nearby Frankenmuth in Saginaw County. Total public and private damage exceeded $25M, mostly flood-related.

May 1996 – Berrien County
Heavy rain caused widespread flash flooding that damaged nearly 100 miles of roadway, caused bridge/culvert washouts, collapsed basements, and undermined a railroad track. A dam in danger of overflowing had its impounded waters proactively drained. Public damage was estimated at $250K. A Governor's Disaster Declaration was granted.

April 1996 – Western/Southern Upper Peninsula
The melting of a heavy snowpack combined with rain caused flooding, especially in Menominee, Iron, and Delta Counties. Several roads and bridges were washed out, with 24 road closures at the height of the event. There were reports of numerous flooded basements. Public damages totaled almost $2M dollars.

July 7-8, 1994 – Lapeer, Sanilac, and Tuscola Counties (Governor's Disaster Declaration Granted)
Widespread flash flooding caused severe damage to roads, drainage systems, and at least 93 homes. Total public damages exceeded $1M.

July 2-3, 1992 – Gogebic County (Governor's Disaster Declaration Granted)
Over 6 inches of rain fell in a 24-hour period, causing severe damage to roads as rivers overflowed and culverts and bridges became clogged with debris. Some road washouts were up to 16-20 feet deep, stranding some residents.

June 1989 – Branch, St. Joseph, and Kalamazoo Counties (Governor's Disaster Declaration Granted)
Heavy rainfall over four days caused widespread flooding in Branch, St. Joseph, and Kalamazoo counties. Over 400 homes incurred flood damage and many local roads were washed out.

September 1986 – Central Lower Michigan (Federal Disaster #774 – 30 counties)
An intense storm produced rainfall ranging from 8-17 inches over 24 hours. Big Rapids received 19 inches over three days. The storm resulted in thousands of persons being evacuated. Five persons were killed and 89 injured (ten were killed from the indirect effects are included). Roughly 30,000 homes suffered basement and structural damage and 3,600 miles of roadways were impassable due to four primary bridge and hundreds of secondary road bridge/culvert failures. Eleven dams failed and 19 others threatened. Over $300M in damage resulted from the flood.

September 1985 – East Central Michigan (Federal Disaster #744 – Six counties)
As much as 7.45 inches of rain fell on hardest hit Genesee County. Damages were primarily caused by flooding rivers, although overburdened stormwater systems also swamped residential areas. Over 2,500 homes were damaged, as were roads, bridges, and agricultural lands. A Presidential Major Disaster Declaration was granted for Alcona, Genesee, Iosco, Lapeer, Saginaw, and Shiawassee Counties. Total public and private damages was estimated at $63M.

October 1, 1981 – Southern Lower Peninsula
Heavy rains resulted in over $250M in damages across 28 counties. All freeways in the Detroit Metropolitan area were closed for several hours. Roughly 300 washed-out sections of rural roads and 30 damaged bridges were noted. One fatality was reported. Over 500 persons were evacuated from their homes, 60 persons were rescued from a flooded motel in Farmington, and 485 families were assisted by the American Red Cross.

March 1982 – Berrien and Monroe Counties (Federal Disaster #654)
A combination of heavy rainfall and melting snow resulted in flooding with damages estimated at $12M. One death was directly attributed to the flooded conditions.

September 1975 – West Central / Central Lower Michigan (Federal Disaster #486 – 16 counties)
Strong rains caused widespread flooding and nearly $3M in public and private damage. A Presidential Major Disaster Declaration was granted for Allegan, Clare, Genesee, Gratiot, Ingham, Isabella, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, and Shiawassee Counties.

April 1975 – Southern Lower Michigan (Federal Disaster #465 – 21 counties)
Widespread storms caused flooding in Allegan, Barry, Berrien, Calhoun, Clinton, Crawford, Eaton, Genesee, Ingham, Ionia, Kalamazoo, Kent, Lapeer, Livingston, Macomb, Oakland, Ottawa, Saginaw, St. Clair, Shiawassee, and Van Buren Counties. Total public and private damages were nearly $58M. Some tornadoes also occurred.

April 1973 and December 1972 – Lower Peninsula (Federal Disasters #371 and #363)
Thawing conditions and severe storms resulted in a major disaster declaration for 14 counties, including Arenac, Bay, Macomb, Menominee, Monroe, Saginaw, St. Clair, Tuscola, Sanilac, St. Clair, and Van Buren. The Detroit Metropolitan region was also affected. Many of the same areas had already been majorly flooded just four months before.

April 4-11, 1947 – Central and Eastern Lower Michigan
April brought additional rain to multiple areas with already soaked ground (to include the Clinton, Detroit, Grand, Kalamazoo, Saginaw, and St. Clair Rivers, and the River Rouge). The city of Flint was particularly hard hit, with damages totaling $4M. Northville saw many homes with inundated first floors and filled basements.

March 24-27, 1904 – Central and Southern Lower Michigan
Rainfall on top of heavy snowpack and frozen soil especially impacted the Grand, Kalamazoo, Saginaw, and River Raisin basins. In Grand Rapids, 2,500 homes were damaged with 14,000 evacuees (damage estimates of $2M, not adjusted for inflation). Lansing saw $200K in damages and one fatality. Bay City saw some railroad bridges and dams undermined or washed away. An entire two square miles were inundated in Kalamazoo.

## *Select Agencies, Programs, or Laws*

FEMA and the National Flood Insurance Program
FEMA is responsible for mapping the country's flood risk through maps known as Flood Insurance Rate Maps (FIRM), one of the regulatory tools used by the NFIP. The NFIP makes flood insurance available in communities that have agreed to manage their floodplains in a manner geared towards minimizing future losses from flood damage. The NFIP is delivered directly by FEMA or through a network of companies that can write a policy under their own name (with FEMA still underwriting losses). FEMA provides information on how homeowners can understand flood zones and maps to help them decide if flood insurance is right for them.

Michigan also provides information on how residents can use the program. As of May 2020, there were 20,500 flood insurance policies in the state providing $4,074,845,000 in coverage. This figure reveals a roughly 20% decline in policies since 2010, and EGLE estimates that only 15% of all eligible flood-prone structures in Michigan have coverage. It should be noted that only 50% of all local Michigan communities participate in the NFIP, so there are also thousands of flood-prone structures not eligible for insurance through the program. As a participant in the NFIP, a community must adopt regulations that: 1) require any new residential construction and substantial improvements to existing structures, within the 100-year floodplain to have the lowest floor, including the basement, elevated above the 100-year flood elevation, 2) require non-residential structures to be elevated or dry floodproofed, and 3) require anchoring of manufactured homes in flood-prone areas. The community must also maintain a record of all lowest floor elevations or the elevations to which buildings in flood hazard areas have been floodproofed.

Flood Insurance Rate Map and the Risk MAP Program
Floodplain maps, including FIRMs, typically display areas that fall within a 100-year flood boundary (the term 100-year flood indicates that the area has a 1% chance of flooding in any given year, not that a flood will occur every 100 years). The term can be misleading because a "100-year" flood may still occur several times a century, due to both random chance, inaccuracies in complex modeling, or changes to an area (e.g., new development, weather patterns) since maps were created. More information regarding digitized FIRM availability for Michigan is available in the supplemental materials section at the end of this chapter.

Risk MAP, which focuses on mapping, assessment, and planning, is another flood-related FEMA program and a description of the process used to create flood maps. Its maps and other materials are generally divided between *regulatory* products and *non-regulatory* products. Regulatory products, such as FIRM, are intended to be used as the basis for official actions required by the NFIP. Michigan's website regarding map updates includes Risk MAP information on newer projects and data. The FEMA Flood Map Service Center used for obtaining maps can be found HERE.

Michigan Floodplain and Flood Hazard Management
Floodplain permitting review is done by the district floodplain engineer responsible for that portion of the state. A synopsis of Michigan's regulatory authority can also be found HERE. Part 31, Floodplain Regulatory Authority, is intended to ensure that the flow-carrying capacity of a watercourse is not obstructed in harmful ways and that its floodway portions are not used in residential construction. It and other select governmental authorities are described below:

*Floodplain Regulatory Authority, found in Water Resources, Part 31 of the Natural Resources and Environmental Act, 1994 PA 451*
Regulates occupation of the 100-year floodplain and ensures that proposed development in the floodway does not obstruct flood flows. A permit is required from EGLE for any occupation or alteration of the 100-year floodplain. In general, construction and fill may be permitted in the portions of the floodplain that are not floodway, provided local ordinances and building standards are met. Residential construction is specifically prohibited in the floodway.
Non-residential construction may be permitted in the floodway if it can be demonstrated that the project will not cause increased flood stages during flooding conditions up to and including the 100-year flood.

*Inland Lakes and Streams, Part 301 of the Natural Resources and Environmental Protection Act, 1994 PA 451*
Regulates all construction, excavation, and commercial marina operations on the State's inland waters. It ensures that proposed actions do not adversely affect inland lakes, streams, connecting waters, and the uses of all such waters. Structures are prohibited that interfere with the navigation and/or natural flow of an inland lake or stream.

*Land Division Act, 1996 PA 591, as amended by 1997 PA 87*
The Act requires review at local, county, and state levels to ensure that subdivided land is suitable for development. A proposed subdivision is reviewed for proper drainage by the County Drain Commissioner and for floodplain impacts by EGLE. Floodplain limits must be defined and prescribe minimum standards for new residential developments in areas within or affected by a floodplain.

*Wetlands Protection, Part 303 of the Natural Resources and Environmental Protection Act, 1994 PA 451*
Requires a permit from the EGLE for any dredging, filling, draining, or alteration of a wetland. This permitting process helps preserve, manage, and protect wetlands and the public functions they provide – including flood and stormwater runoff control.

*Natural Rivers Program, Part 305 of the Natural Resources and Environmental Protection Act, 1994 PA 451*
Through the natural rivers designation process, a Natural River District is established (typically 400 feet on either side of the riverbank) and a zoning ordinance is adopted. Within the Natural River District, permits are required for building construction, land alteration, platting of lots, cutting of vegetation, and bridge construction. These include building setbacks (in many cases prohibiting construction in the 100-year floodplain) and vegetative strip requirements.

*Manufactured Housing Commission Act, 1987 PA 96*
Provides regulation on the placement of manufactured homes and establishes construction criteria. Manufactured homes are prohibited from being placed within a floodway, as determined by EGLE. Manufactured homes sited within a floodplain must be elevated above the 100-year flood elevation and must install an approved anchoring system to prevent it from being moved from the site.

*Local River Management Act, 1964 PA 253*
Provides for the coordination of planning between local units of government as related to water management programs. Watershed councils conduct studies and have the authority to develop River Management Districts for the purpose of acquisition, construction, operation, and financing of water storage and other river control facilities. The provision to allow the acquisition of land adjacent to the river, for the purpose of management, aids in regulating the development of land prone to flooding.

United States Geological Survey Maps and Tools
The USGS is a Congressionally created science organization whose work is helpful in analyzing flooding. The USGS WaterWatch displays maps and graphs describing real-time and past streamflow conditions. Those who create free accounts can also sign up for WaterAlert, which sends users notifications for water conditions (e.g., pre-flood stages) they may wish to monitor. Other useful USGS tools include the Mapper for the National Water Information System, as well as the National Water Dashboard. A map for the network of stream gages that make some of this information possible is available in the Hydrological Overview that precedes this chapter. The USGS Flood Inundation Mapper allows communities to explore inundation maps showing where certain types of flooding would occur for select river/stream locations and conditions. Communities partner and work with the USGS to gather data and develop/validate a set of inundation maps. Once research is complete the information is loaded onto the USGS website where users can access the historical flood information and analyze potential loss estimates based on the severity of the flood.

United States Army Corps of Engineers (USACE) Advance Measures Program
The USACE has programs for technical planning and assistance. Advance Measures is part of Public Law 84-99. The program can be implemented as supplemental to state, tribal, or local governments in mitigating the potential damage or imminent threat of flooding. The governor or tribal leader will need to submit a request to USACE. The project must be engineeringly feasible and capable of being constructed prior to flooding. The type of project is intended to be temporary, and removal is a local responsibility. It can be 100% federally funded. Advance Measures also has a construction component under which USACE can provide assistance with permanent construction projects designed to mitigate potential flood damages. Such projects are funded on a 75% federal and 25% local cost-share basis. Construction projects require a written cooperation agreement between the USACE and the participating jurisdiction. The jurisdiction must agree to furnish all land, easements, and rights-of-way, agree to operate and maintain the project for 25 years, pay the 25% project cost-share, and provide interior drainage. Construction projects that could potentially be funded under the program include earthen levees, rock and/or sand-filled cribs, and concrete and/or steel sheet pile seawalls.

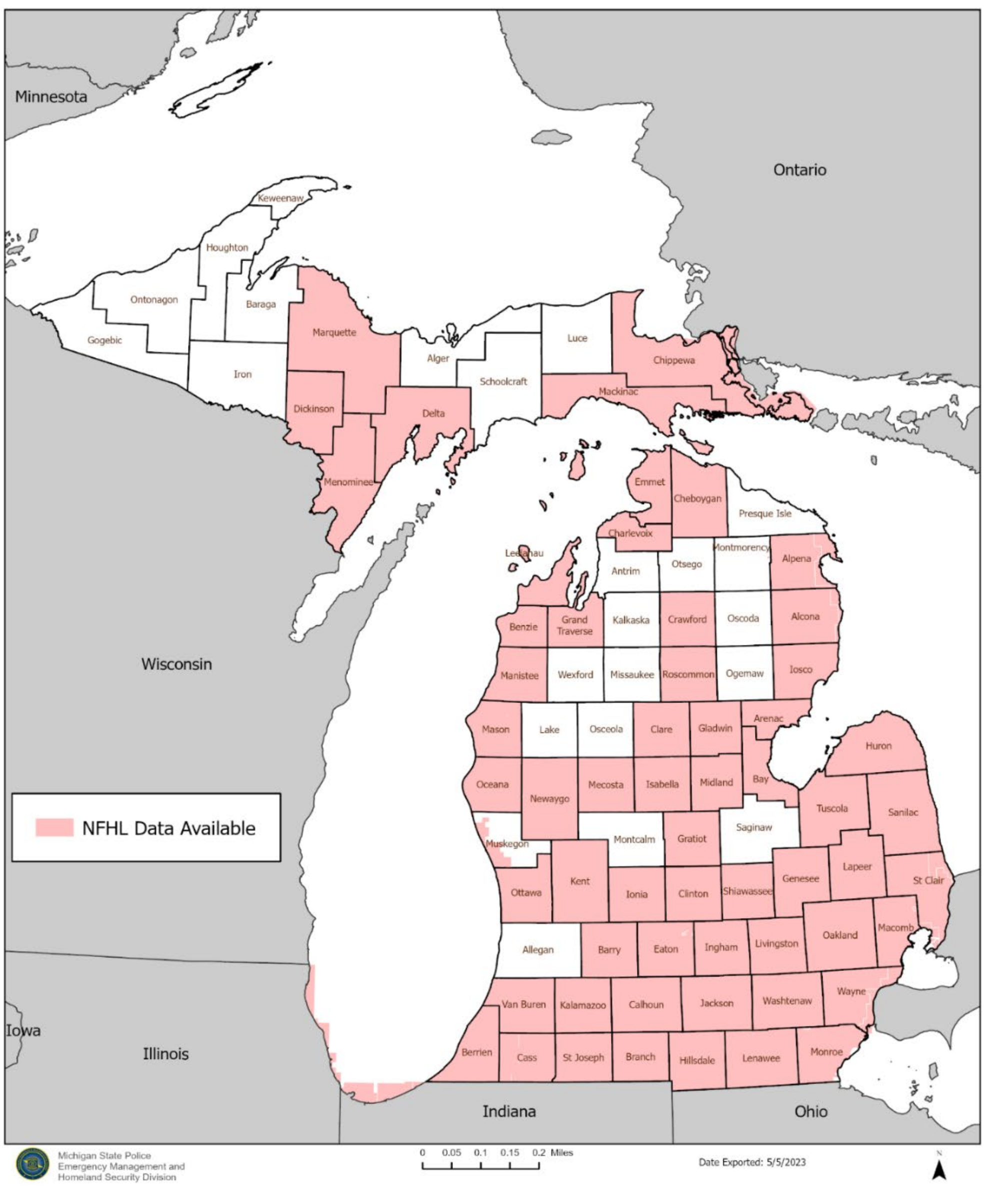
Michigan Silver Jackets
The Michigan Silver Jackets is a USACE-led program that focuses on interagency collaboration to reduce risks associated with flooding and other natural hazards. Participating agencies include several federal partners beyond USACE such as the USGS, FEMA, and NOAA, as well as state agencies such as EGLE and MSP/EMHSD.

Flood Mitigation Assistance (FMA)
Administered by MSP/EMHSD, the FMA grant program provides financial assistance to states and local communities to reduce flood damage risk for insurable structures under the NFIP. Cost share can be 100% federal but may require 25% local funding depending on the project. There are two types of FMA grants: 1) Capability and Capacity Building, which enhances the skills of grantees to improve flood mitigation assistance through multi-hazard mitigation planning, technical assistance, project scoping, and other activities, and 2) Project grants to fund eligible flood mitigation projects, with an emphasis on repetitively or substantially damaged structures insured under the NFIP.

## *Supplemental Material*

Digital Flood Insurance Rate Maps and Base Flood Elevations (BFEs)
The following map highlights areas where digitized FIRM is available. Many map products use data from FEMA's National Flood Hazard Layer (NFHL) and legends associated with the principles of BFE. A given BFE associated with a 100-year flood carries a 1% chance per year of flooding to the designated BFE level. As an example, if a BFE is 365 feet and the elevation of a structure's first floor is 363 feet above sea level, then a 100-year flood would be expected to create floodwaters that are two feet over the ground floor of that structure. The FEMA models for flooding divides these events into different degrees of severity based on their likelihood of annual occurrence. A few inches of water may be a "10-year" event in one area, but a "100-year" event somewhere else. Other time horizons exist, such as a 500-year floodplain. Please note, some flood studies were done decades ago and may no longer be accurate.

MICHIGAN DIGITAL FLOOD INSURANCE RATE (DFIRM)




(Source: FEMA NFHL, exported May 5, 2023)

# GREAT LAKES SHORELINE HAZARDS

*Hazards include shoreline flooding and erosion, meteotsunamis, seiches, waterspouts, ice shoves, and rip currents.*

## *Hazard Description*

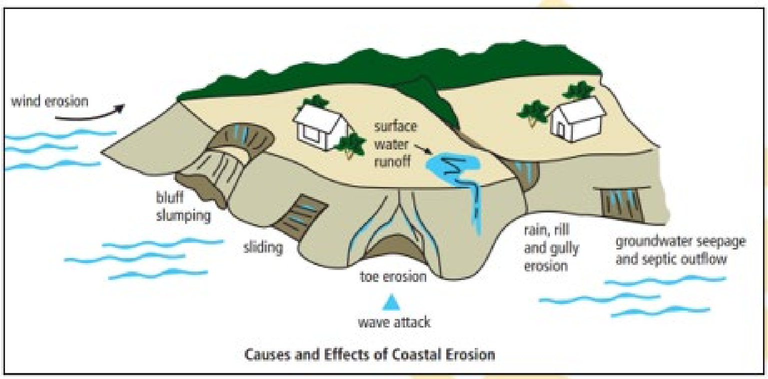
Largely surrounded by four Great Lakes, Michigan has the longest freshwater coastline in the world. Fluctuating water levels and waves constantly affect its many shoreline communities. Storm surges and coastal erosion can devastate buildings, roads, and other infrastructure during severe weather or more slowly over longer periods of time. Rough waters may damage property and put human life at risk, capsizing boats and creating rip currents. This chapter focuses on such hazards while trying not to duplicate materials found elsewhere in sections related to more generalized flooding. A brief analysis of Great Lakes water levels is included.

## *Hazard Analysis*

According to data from the Storm Event Database, a total of 46 significant and impactful flood events were observed on the shores of the Great Lakes between 1996 and 2022 (an average of slightly less than two per year). While such flooding events have occurred during every month, they are most common during the spring, early summer (April, May, and June), and fall (October and November). They are more common during periods of relatively high lake water levels, which contribute to erosion and exacerbate other shoreline hazards.

Shoreline Erosion

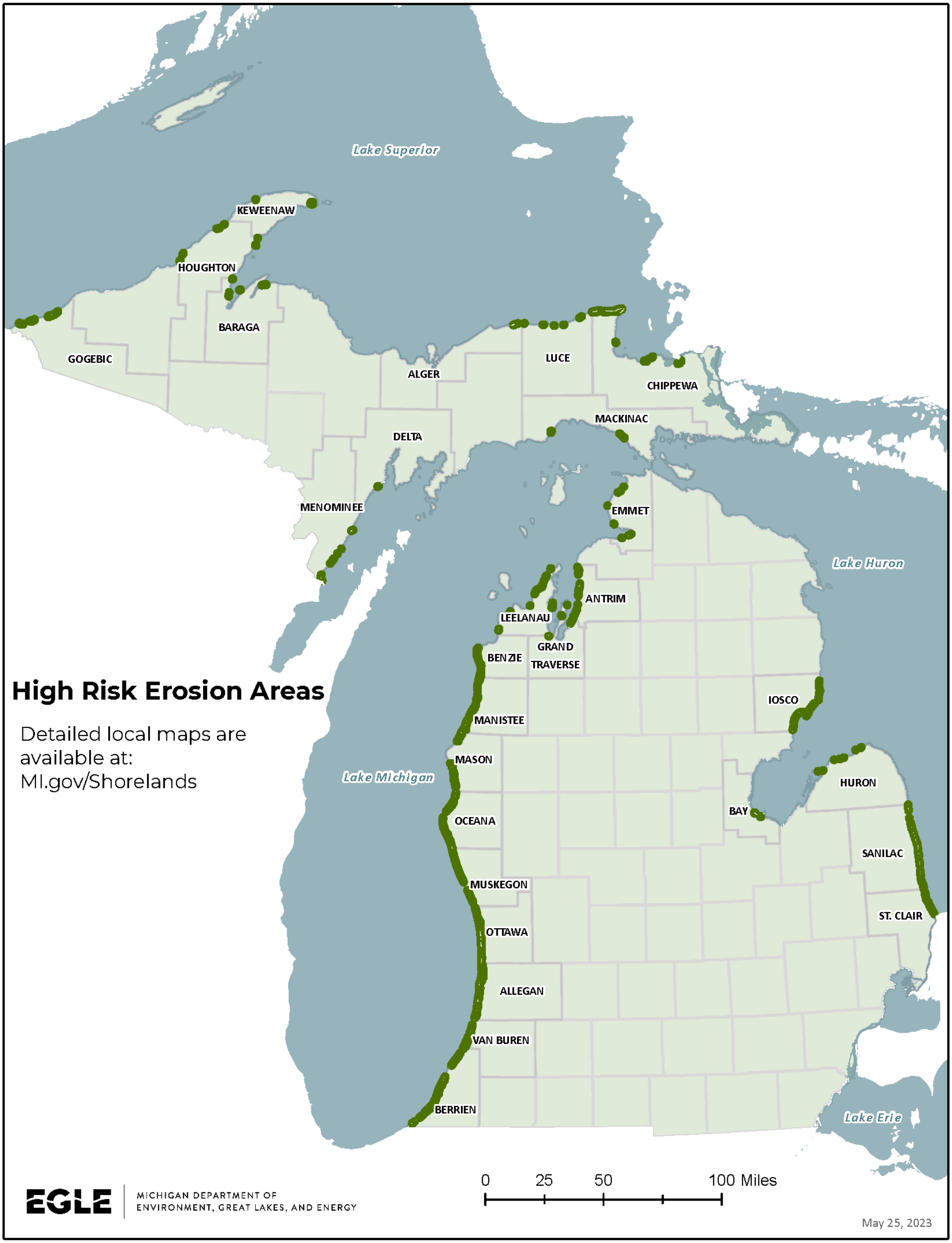
Shoreline erosion is a natural process, occurring during times of high, average, and even low Great Lakes water levels. Few systems other than some ocean coasts are exposed to more energy than the Great Lakes shoreline. Waves, currents, and changing water levels constantly reshape the coast. Wave action along bluffs, dunes, and cliffs can erode their bases and destabilize slopes. Surface runoff and groundwater seepage carry away materials and saturate bluffs (leading to slumping). Wind and frost also loosen and move sediment. Shoreline erosion may be slow and gradual, such as when sand is chronically blown off of dunes. It can also be dramatic, such as when large sections of bluffs may unexpectedly fall.




(source: USACE Living on the Coast booklet; picture: slope failure in Petoskey, MI)

Shoreline erosion can involve the loss of property where supporting sand/soil is removed by water and wind. Worst-case scenarios include inhabited structures where adjacent land is eroded away, exposing foundations, pipes, and septic systems. Such buildings reach a tipping point where they must be abandoned, as even a small weather event or the simple passage of time may lead to collapse. Other types of infrastructure may be impacted, such as shoreline trails or roadways that may crumble, sink, or fall.

The State regulates roughly eight percent of Michigan's coastline in areas that experience specific levels of erosion under the High-Risk Erosion Area (HREA) program (see additional information later in this chapter). As shown on the next page, the western shores of the Lower Peninsula are the most affected, although significant areas exist elsewhere in the State. The highest recorded average annual erosion rate in Michigan was 17.1 feet in Burt Township (Alger County, 2012 study). It is important to note that shorelines outside of designated HREAs still experience erosion and may be reclassified in the future due to the effects of climate change and other factors.


High Risk Erosion Areas
Detailed local maps are available at: MI.gov/Shorelands
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
KEWEENAW
HOUGHTON
BARAGA
GOGEBIC
ALGER
LUCE
CHIPPEWA
MACKINAC
DELTA
MENOMINEE
EMMET
ANTRIM
LEELANAU
GRAND TRAVERSE
BENZIE
MANISTEE
MASON
OCEANA
MUSKEGON
OTTAWA
ALLEGAN
VAN BUREN
BERRIEN
IOSCO
HURON
BAY
SANILAC
ST. CLAIR
0 25 50 100 Miles
EGLE
MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
May 25, 2023

Meteotsunamis and Other Weather Events

Weather can cause lake fluctuations lasting from hours to several days. For example, windstorms combined with differences in barometric pressure can “tilt” lake surfaces so that they become lower at one end as water is pushed higher to the other. Meteotsunamis and seiches both cause these effects but describe two distinct types of phenomena.

- Meteotsunamis, or meteorological tsunamis, produce a series of large water waves. They are associated with atmospheric disturbances (e.g., thunderstorms) where rapid changes in barometric pressure push against lake bodies as they travel across them. Generally smaller than tsunamis (which are generated by seismic activity), they can still create waves larger than 6 feet high that may affect long spans of shoreline. The progressive waves of meteotsunamis last from roughly two minutes to two hours. Many are too small to be directly damaging but may cause or exacerbate rip currents that imperil swimmers.

- A seiche is instead classified as a persistent wave that travels back and forth between two edges of an at least partially enclosed basin. They can be thought of as water sloshing back and forth in a very large tub. They are sometimes difficult to see and associated with slower changes in water levels as compared to meteotsunamis. Water level changes may still be quite profound. Winds are typically more important to a seiche motion, and its long-standing wave may take three to seven hours to shift between its lowest and highest levels. Lake Erie is well-known for seiche events, and from a Michigan perspective impacts Monroe County most frequently.

  Still, the focus of study, meteotsunamis, and seiches may also occur at the same time. Regardless of the mechanism, flooding becomes an obvious concern for shorelines on the high end of a tipped lake level. Lowered lake levels on the other end can also experience acute problems as water intakes become unexpectedly exposed. This may affect the water supply for critical facilities, including those used for nuclear power. Soils previously underwater may become weakened and set the stage for future erosion in the area.

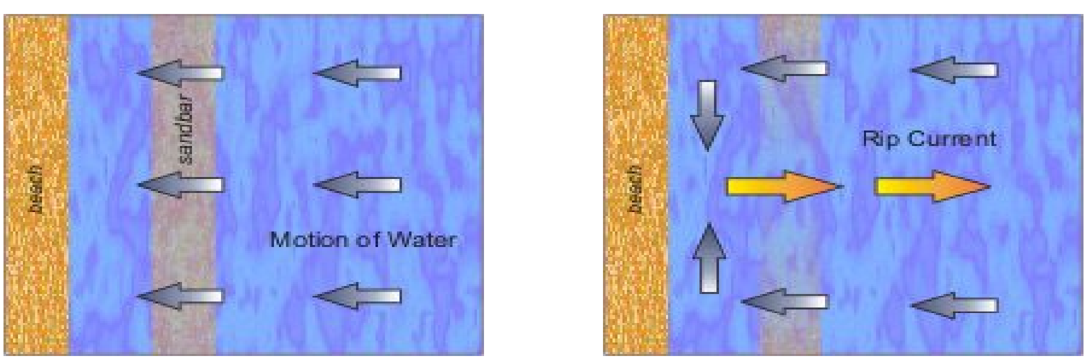
- Waterspouts share similarities with tornadoes, but from a technical standpoint, those that are associated with non-severe convective clouds are not truly tornadic. They are typically weaker phenomena that involve contact with water, threatening marine traffic, port areas, and lake-spanning bridges. Unless tornadic they usually begin to dissipate as they move onto land.

- Ice shoves, also referred to as ice surges and other names, occur when sometimes massive amounts of free-floating Great Lakes ice are pushed inland after breaching the shore by high winds and other factors. This phenomenon may form quickly, reportedly becoming piled as high as 40 feet even as they push further inland and invade shoreline homes. Some areas appear to be more susceptible, such as on Saginaw Bay and counties near Keweenaw Bay, Green Bay (Wisconsin), and similar areas.

Rip Currents (and Other Dangerous Near-Shore Currents)

Rip currents can be life-threatening to swimmers and are especially prevalent in Lake Michigan (see next page). They are naturally created when the wind drives waves toward the shore of sandy beaches, accumulating excess water between the shoreline and a sand bar. This water then moves along the shoreline until exiting as a rip channel back to the lake.

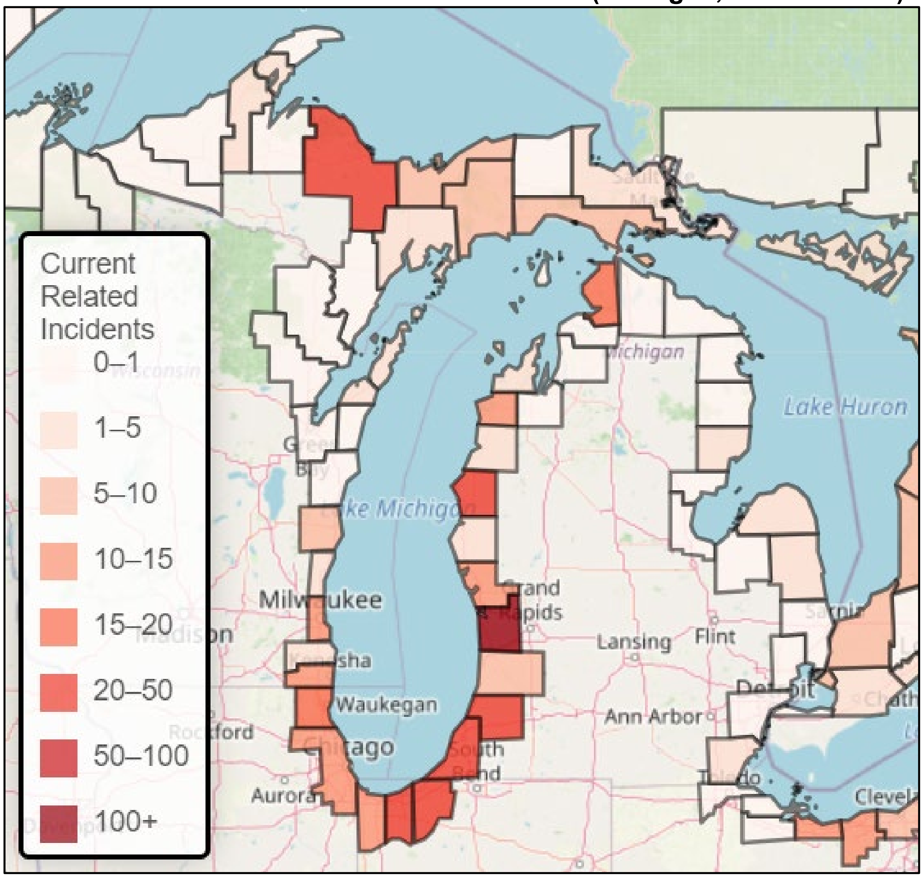
**Rip Current Formation**




This narrow flow of water can sweep swimmers far out into lakes even as it may dampen incoming waves and create an illusion of relative calm. Many even strong swimmers drown from rip currents, with statistics showing Michigan near or at the top each year. Information on how to survive a rip current can be found HERE.

Structural rip currents can also form adjacent to human-made structures (e.g., break walls, jetties, piers) via different mechanisms. Structural rip currents cause more incidents and are typically more difficult to escape. Swimmers should avoid entering channels, river outlet areas, and other dangerous locations. The lower half of Lake Michigan sees the majority of drownings. Marquette County has a long shoreline and is above-average risk.

**Great Lakes Water Current Related Incidents (Michigan, 2002-Present)**




(source: NWS, accessed July 27, 2023)

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
While not of the same destructive potential as hurricanes, many Michigan shoreline hazards may still damage homes, roads, and other infrastructure in a manner sometimes similar to flooding and/or high winds. Public beaches and marinas may be impacted in a variety of ways. Casualties may occur, including to boaters and swimmers. The State's nuclear power plants are located on the Great Lakes. Water systems (e.g., drinking, wastewater) may be vulnerable. The state has important locks, pipes, and several bridges that traverse the Great Lakes. Cultural resources may be impacted.

Impact on the Economic Condition of the State
Cargo shipping and ferry services can be impacted when port areas become flooded or channels become shallow. Loads may need to be lightened or expensive dredging projects employed. Developed commercial areas could be endangered. Perceptions of Michigan beaches being dangerous may impact tourism. Damaged international bridges or locks could carry significant economic impacts. Although ecosystem changes on the Great Lakes are not a focus of this chapter, changes in water level or ice cover can impact the fishing industry.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Storm conditions or damaged roads may delay personnel or cause rerouting. Responders may be imperiled, especially those in watercraft or on ice. Thin ice on the Great Lakes may cause an increase in ice fishing-related rescues involving submerged cars or breakaway ice. Continued delivery of services should not be impacted except in remote areas (e.g., islands, single bridged areas). High-level state government would be relatively unaffected.

Impact on the Environment

Flooding and erosion can be part of natural processes and are necessary for the health of plants and animals that depend on coastal environments. Not all impacts should be viewed as deleterious (especially outside of developed areas), but development itself can be damaging. Attempts to slow erosion by installing "hardened" shorelines (e.g., groins, revetments, seawalls) can disrupt coastal processes, negatively impacting the environment and shifting risk to other locations. Increasingly fast Great Lakes water level shifts have become problematic. Shorter periods of ice formation on the Great Lakes may impact aquatic habitats. Low water levels may see stakeholders needing to manage revealed or dredged contaminated sediments. Ships that run aground or capsize may release hazardous cargo or fuel.

### *Select Shoreline Hazard Events in Michigan*

Provided examples are for representative purposes and are not meant to be comprehensive. Flooding events affecting the Great Lakes shoreline also impact other areas of the State and may be included in related chapters.

July 18, 2023 – Waterspout (Lake Huron)
A waterspout formed near Mackinac Island, prompting alerts for boaters to seek safety. It moved at roughly 12 mph with no injuries reported. It is included in this listing due only to its proximity to the frequently car-laden Mackinac Bridge.

June 26, 2021 – Cliff Collapse (Alger County)
A section of the Pictured Rocks National Park unexpectedly crashed into Lake Superior, just outside the range of nearby boaters. A 200-foot chunk of materials from the cliff face generated a large wave. There was a similar collapse in 2019 when kayakers narrowly escaped injury from falling rocks between Miners Beach and Mosquito Beach.

April 4, 2020 – Shoreline Collapse (Emmet County)
A piece of land the size of a football field fell into Lake Michigan, taking a section of a large bike trail along with it. An engineering study showed that past high shoreline water levels, combined with a poorly drained uphill area, destabilized the slope and left it vulnerable to persistent wind and wave action. The shoreline trail will be difficult to repair.

October 2019 – Lakeshore Area Flooding (various Lake Michigan and Lake Huron locations)
Strong winds resulted in coastal flooding and beach erosion. Water levels rose over the docks at Northport Marina (Leelanau County). A boat house was also flooded. Part of the break wall at Empire Beach was destroyed. A previous restoration effort from earlier flooding was ruined in Glen Haven with shoreline fences ruined. High water levels and 30-40 mph winds produced large waves resulting in flooding across Bay, Tuscola, and Huron Counties. The water level at Essexville peaked at 71 inches above the chart datum. Lakeshore flooding affected homes and roads in Harbor Beach, Caseville, and Sebewaing. Shoreline erosion occurred at Port Crescent State Park and Port Hope. Significant damage to seawalls was reported in Lakeport. Extensive flooding also worked inland from Lake Michigan into New Buffalo (Berrien County). Some road closures were noted. Total property damages for the events were over $500K.

May 8-9, 2019 – Shoreline Flooding (Monroe and Wayne Counties)
High Lake Erie water levels coupled with easterly winds of 20-30 mph led to lakeshore flooding. Toledo water levels peaked at 86 inches, with Fermi and Gibraltar peaking at 78 inches and 76 respectively. Estral Beach saw some homeowners stranded in their homes from flooding, with firefighters assisting in evacuations. Several other beachfront communities were also inundated by water, including Frenchtown and Monroe Townships, LaSalle, and Luna Pier.

April 15, 2018 – Shoreline Flooding (Monroe and Bay Counties)
Strong winds and heavy precipitation ranging from rain, freezing rain, and snow caused flooding around the western shores of Lake Erie and Saginaw Bay. Monroe County property damages were estimated at $5M, including shoreline roads in LaSalle Township. Some homes in Luna Pier and North Shores saw evacuations. In Bay County, property damages were estimated at $2M, with water reaching some homes in Bangor Township.

October 24, 2017 – Lake Superior Seiche (Marquette County)
Heavy winds resulted in a seiche on Lake Superior. Minnesota was chiefly affected, but the Granite Island buoy north of Marquette measured a 28.8-foot wave, the tallest ever recorded with modern instruments on Lake Superior. Two people were reportedly swept off the Black Rocks at Presque Isle Park and believed drowned.

2014 to 2016 – Lake Erosion (Houghton County)
Facilities at F.J. McLain State Park were notably impaired after severe Lake Superior storms in 2014 and 2015 resulted in erosion that damaged park roadways, utilities, and embankments related to a dozen lakefront campsites. Continued erosion eventually threatened an additional 18 campsites at the park, which were closed for safety reasons.

October 31, 2014 – Halloween Storm
Severe weather saw Lake Michigan wind speeds of 60 mph produce a 21.7-foot wave according to a buoy near Holland. New Buffalo (Berrien County) saw a retaining wall destroyed, exposing the foundation of a later demolished lakeside home. Lake Superior reported 7.9-foot waves, and a buoy at the southern end of Lake Huron recorded 15.4-foot waves.

2013 (and earlier) – Low Lake Levels
Low water levels in Lakes Michigan, Huron, and Erie persisted after the fastest Great Lakes decline in nearly 150 years. Between the summer of 1997 and the spring of 2003, the middle Great Lakes (Michigan, Huron, and Erie) each dropped by almost five feet. Lakes Michigan and Huron remained below their long-term annual average until 2014.

May 13, 2013 – Ice Shove (Bay County)
An ice shove impacted the shoreline near Linwood, with giant hills of ice estimated up to 20 feet tall occurring near damaged homes. Ice shoves are regularly reported in this area of Saginaw Bay.

October 15, 2011 – High Surf (Berrien County)
Strong winds produced rough waters inside a New Buffalo break-wall seeing 8-10 feet waves (cresting to 14 feet at the shoreline). One person died and two others were rescued when their kayak capsized.

September 3, 2010 – Rip Current (Berrien County)
Waves as high as 16 feet caused extremely strong rip currents, sweeping a man away who had become separated from his rubber raft. Conditions capsized a rescue craft, injuring four responders and forcing their mission to be called off.

August 5, 2010 – Rip Currents (Marquette and Alger Counties)
Two teenaged swimmers drowned in high waves and rip currents near Presque Isle as winds gusted to over 30 mph at times. A father and son drowned in similar conditions in Grand Marais Harbor.

August 15, 2009 – Rip Current (Mackinac County)
Two persons died near the Pointe Aux Chenes sand dunes (northwest of St. Ignace) when a teenager was carried into deeper water by rip currents and his 66-year-old grandfather attempted to rescue him.

June 8, 2008 – Road Erosion (Allegan County)
Two deaths occurred after a car fell 50 feet into a water-filled ravine. The occupants were delivering newspapers along Lakeshore Drive, in the 2700 block west of Fennville. The road had been washed out where a creek and culvert had been overwhelmed by runoff from a heavy thunderstorm the night before. See also the 1985-1986 listing below.

August to September 2007 – Water Level Recession (Muskegon County)
Dredging was needed at Great Lakes ports due to low water levels. A super-freighter became stuck in the mouth of Muskegon Harbor (reportedly the second large ship that had recently run aground at the same location).

October 28-29, 2006 – Lake Erie Seiche
Two days of 30-40 mph winds created an eight-foot difference in water levels between the ends of Lake Erie, with Michigan coastal areas seeing water pushed away. Monroe waters were four feet below the level they had been merely two days before, rapidly exposing and weakening land in some areas. Eastern parts of the lake experienced flooding.

July 4, 2003 – Meteotsunami, Rip Current (Berrien County)
The holiday saw seven persons drown near Sawyer from events initially described as undertow but later categorized as meteotsunami-induced riptides. Researchers postulated that the one-time wave of a meteotsunami can create effects lasting for hours, creating a hidden danger even when waters might look relatively calm after a storm has passed.

November 10-11, 1998 – Great Lakes Storms (Statewide)
One of the strongest ever Great Lakes storms generated 15–20-foot waves on Lake Michigan and 8–15-foot waves along the western Lake Superior shoreline (causing considerable beach erosion in both locations). Persistent high winds affected the water level of Saginaw Bay, pushing roughly five feet of water into Lake Huron. This temporary loss of water for the shallow bay exposed up to one-half of its bottom bed (water rose to its previous level later in the day). Wind gusts of 50-80 mph were common, with a peak gust of 95 mph reported on Mackinac Island. In Frankfort (Benzie Co.), on the Lake Michigan shoreline, 80-90 mph gusts destroyed a hangar at the City-County Airport ($500K in damage) and damaged six private planes. The walls of a church under construction in Troy were destroyed. A warehouse in Flint lost its roof, with another damaged. A boat storage rack collapsed in Mt. Clemens (Macomb Co.) causing about $500K in damage to 20 boats. The roof was blown off a hardware store in Lake City (Missaukee Co.). One person died and over 500,000 Lower Peninsula electric customers lost power from downed trees and lines.

May 31, 1998 – Lake Michigan Seiche (Muskegon County, Much of Lower Peninsula)
A derecho moved across Lake Michigan producing widespread wind gusts of 60-90 mph, producing a seiche and sinking a tugboat in White Lake Channel north of Wabaningo. All hands were saved but estimated boat repairs were $20K. The wave action responsible for sinking the tug was just one small addition to widespread inland damage.

1997-1998 – High Lake Levels and Shoreline Floods
The high-water period in 1997-1998 resulted in the Great Lakes being at or near record levels, contributing to shoreline damage in locations such as New Buffalo (Berrien County). The USACE implemented its Advance Measures Program to assist more than 20 Michigan shoreline jurisdictions with flood/erosion mitigation.

April 6-7, 1997 – Great Lakes Storm (West and Central Lower Michigan)
An intense low-pressure system with 50-70 mph wind gusts and 10-15 feet waves moved across Lake Michigan, causing widespread damage and lakeshore erosion before moving inland. Private damage was estimated at $5M, with specific damages reported in the counties of Clinton, Ionia, Kent, Montcalm, Muskegon, Osceola, Ottawa, and Van Buren. The winds downed numerous trees and power lines, caused roof and structural damage to many buildings, and resulted in 200,000 power outages. The USACE estimated that severe beach erosion involved as much as 20 feet of beach loss in some areas. The erosion was due in part to unusually high Great Lakes water levels, which were nearly 38 inches above average at the time. One injury was also reported.

1985-1986 – High Lake Levels and Shoreline Floods
Record-high lake levels in 1985-1986 combined with storms to damage community shores, including around Saugatuck Township (Allegan County). A large section of Lakeshore Drive crumbled away, resulting in detours and other access problems for area homes. Various incidents culminated in a Governor's Disaster Declaration for 17 shoreline counties.

November 10, 1975 – Lake Superior Storm
The sinking of the freighter Edmund Fitzgerald took place during a strong storm producing winds exceeding 60 mph and wave heights reaching nearly 20 feet. A total of 29 crewmen died.

1972-1973 – High Lake Levels and Shoreline Floods
High water levels caused flooding in over 30 counties during this period, resulting in more than $50M in public and private damage. Thousands of persons were forced to evacuate their homes. Similar high water-level flooding had also occurred in the early 1950s and late 1960s, also resulting in millions of dollars worth of damage.

November 11, 1940 – Lake Michigan Seiche (Including Mason County)
Enormous waves were generated by winds reaching speeds of up to 75 mph. The resulting seiche and its push of water caused considerable damage to the northern shores of Lake Michigan. Five vessels and 66 lives were lost. A car ferry was damaged and driven ashore in Ludington.

July 13, 1938 – Swimmer Fatalities (Allegan County)
During an otherwise calm day, a three-meter wave struck the Holland State Park, causing five swimmers to drown.

July 4, 1929 – Swimmer Fatalities (Ottawa County)
After a storm had passed, a six-meter wave unexpectedly surged over a pier at Grand Haven State Park, sweeping persons into the Lake as the water retreated. Strong rip currents carried away several persons, killing a total of ten.

### *Select Laws, Agencies, or Programs*

Many programs and initiatives that pertain to flooding are also applicable to shoreline flooding and will not be covered here (see applicable chapters). This section will focus on areas unique to this chapter, such as erosion and beach alerts.

The EGLE Shorelands Protection and Management
Part 323, Shorelands Protection and Management (Natural Resources and Environmental Protection Act (NREPA), 1994 PA 451) directs EGLE to identify hazardous and fragile coastal areas and to regulate the impact of past and future development. It addresses three coastal areas: 1) HREAs, identified as shorelines receding at an average long-term rate of at least one foot per year over a minimum period of 15 years, 2) flood risk areas, vulnerable to inundation from the Great Lakes, and 3) environmental areas, necessary for the preservation of fish and wildlife.

- A HREA is designated following recession rate studies and can change over time. EGLE has identified 125 municipalities along the Great Lakes coast that have shorelines HREAs, covering approximately 250 miles of shoreline. Presently, about 7,500 individual property owners are affected by shoreline setback requirements. Relevant administrative rules require 1) a 30-year setback for small, readily moveable permanent structures having a foundation size of 3,500 square feet or less, and 2) a 60-year setback for all other permanent structures, including waste treatment systems. The readily-moveable provision allows the structure to be moved landward if the home is ever threatened with erosion damage. Under Part 323, the regulatory program for HREAs may be administered by local units of government.

- The Flood Risk Area Program requires new construction in the 100-year floodplain of the Great Lakes to be elevated to prevent property damage. The permitting responsibility for flood risk areas is handled at the local level due to the overlap of regulations found in Part 323, the NFIP, and the building codes.

- Part 323 Environmental Areas include sensitive fish and wildlife habitat along the shorelands of the Great Lakes, including connecting waterways and river mouths. About 607 parcels of land were designated as environmental areas from 1976 to 1985, representing approximately 275 linear miles of essential habitat. The statute identifies uses that require EGLE review, including dredging, filling, grading, other alterations of the soil, alterations of the natural drainage, alteration of vegetation utilized by fish or wildlife, or both, including timber harvest in identified colonial bird nesting areas and the placement of permanent structures.

Coastal Management Program
Michigan was among the first states to have its coastal program approved (1978) and places a high emphasis on coastal resilience. The foundations of the program are to (1) improve the administration of existing state shoreline statutes (2) provide substantial technical and financial assistance to local partners for creative coastal projects, and (3) improve governmental coordination to reduce time delays, duplication, and conflicts in coastal management decision-making (federal consistency). The program provides financial support for state resource and management programs for work in the coastal zone boundary, including Shoreland Protection and Management (including HREA), Submerged Lands, Critical Dune Areas, Wetlands, Inland Lakes and Streams, and Floodplain Management. Financial assistance to communities includes pass-through grants for planning, low-cost construction projects, and capacity building.

United States Army Corps of Engineers
The USACE maintains a strong Michigan presence, including at its Detroit District headquarters. Several coastal-related programs exist with opportunities for engineering services provided. Their website provides additional useful information as it relates to many of the coastal processes discussed in this chapter.

Great Lakes Research Center (GLRC) (Michigan Technological University)
The GLRC research includes work related to flooding and erosion. Mapping for erosion risk is calculated differently than what is required for official HREAs, providing additional data and informing communities of how their shorelines have changed over time. Short-term erosion rates can show the more recent effects of high water.

National Weather Service Forecasting and Alerts
The NWS issues rip current advisories and hosts a Great Lakes Beach Forecast web map. The State also maintains a page related to warnings. Forecasting meteotsunamis remains a challenge but is the focus of active research.

State Beach Warnings
The State Beach Guard website provides updates on beach conditions. The state also publicizes laws related to when swimmers may enter the water from the beach when flags are present. This flag warning system at state-designated swim beaches has four categories (see webpage for additional details):

United States Coast Guard (USCG)
The USCG issues press releases and other alerts related to shoreline hazards, including due to unsafe ice conditions. The headquarters for the Great Lakes is the Ninth Coast Guard District, which helps to coordinate ice-cutting, rescue operations, and other missions across the three sectors that surround Michigan.

## *Supplemental Material*

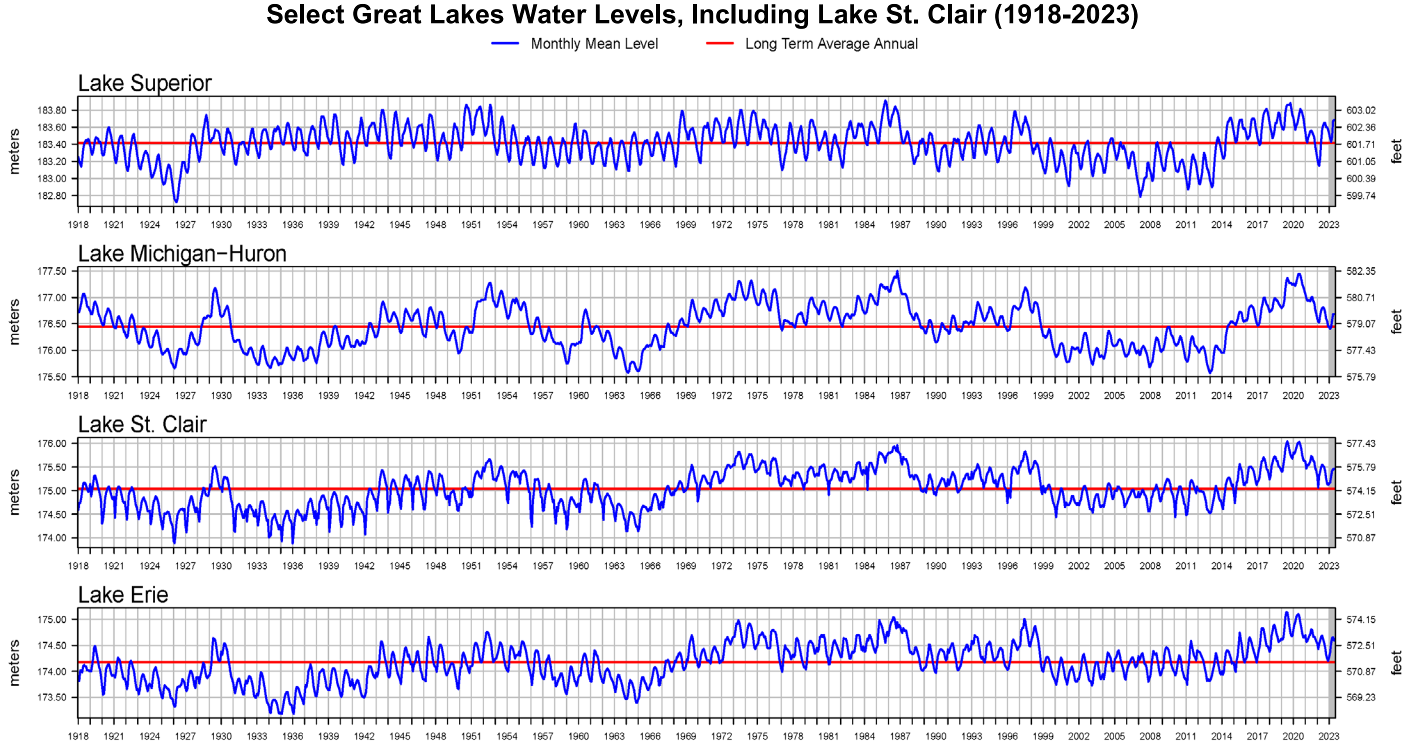
**Great Lakes Water Levels**
Great Lake waters go through complex cycles of highs and lows. The Lake Superior basin, which is the headwaters for the lakes, plays an important role as its surrounding snowpack melts. Rises in water levels may not be immediately evident due to the length of time it takes geographically large land areas to deliver runoff from precipitation into the lakes (including from areas outside of Michigan). A multitude of countervailing factors also exist. Evaporation rates influenced by temperature, wind, and ice cover all play major roles.

Some human-related factors include (1) diversion of water for human use (e.g., drinking water, agriculture, manufacturing), (2) regulation of water levels via dams and other control structures, (3) dredging of connecting waterways for navigation purposes, and (4) the covering of land surfaces with impervious materials. These can delay, hasten, or remove water that would ordinarily flow into the Great Lakes. However, apart from Lake Ontario, they currently have a relatively minimal impact on overall water levels in the lakes.

Seasonal fluctuations take place superimposed over long-term trends. Such seasonal changes average about one foot on Lakes Superior, Michigan, and Huron, and one and one-half feet on Lake Erie. Differences in water level extremes over longer term historical periods vary for each lake. Records indicate maximum differences of nearly four feet on Lake Superior to over six and one-half feet on Lakes Michigan and Huron.

During the past decade, water levels increased from near-record lows in 2013 to above normal levels in 2014 following a severe winter with long-duration heavy ice cover (reducing evaporative loss) and above-normal precipitation. This started a path towards near-record high levels in 2019 and 2020. During those two years, periods of prolonged onshore winds mostly associated with passing high and low pressure systems (generally not problematic during normal water levels) led to a high frequency of shoreline flooding for many parts of Michigan. Detailed information on Great Lakes water levels can be best viewed online, or by using the NOAA Lake Level Viewer or Great Lakes Dashboard.

**Select Great Lakes Water Levels, Including Lake St. Clair (1918-2023)**




(source: USACE)

Many climate experts foresee the potential for more frequent and faster swings between the highs and lows of Great Lakes water levels in the future.

# DAM AND LEVEE FAILURES

*The failure or collapse of a water control structure, resulting in downstream flooding.*

## *Hazard Description*

A dam is a barrier that stretches across a river or other body of water, constructed to hold back and raise upstream water levels. Impounded waters may be used for agriculture, energy generation, flood control, recreation, or as a municipal water supply. Water may be diverted through constructed structures or other engineering methods. Dams may be subjected to flooding events such as excessive rain, leading to unintended overtopping or other dam failures. Poor construction, improper operation, lack of maintenance, hazard cascade, seismic activity, and sabotage may also be primary or contributing factors. Loss of life and extensive property/environmental damage may occur both upstream and downstream of the event due to an uncontrolled release of water and liquid-borne solids.

Other flood control structures may also fail. A levee/dike is often a compacted earthen structure at least partially made up of soil types impervious to water. Their sides tend to be sloped and require maintenance to prevent seepage. A berm is a small levee, usually designed to handle low-velocity floodwaters for a limited period of time. Formal floodwalls are typically made of reinforced concrete or masonry walls set upon a solid underground foundation. They may exceed 20 feet in height, but the vast majority of those in Michigan are relatively short.

## *Hazard Analysis*

Many of Michigan's first dams were relatively small efforts related to gristmills and older industries, the remnants of which may still exist. The late 19th Century also saw private hydroelectric efforts upon waterways. As many dams aged, changing economics led to some being abandoned. Rebuilding aged dams is not economically feasible for many owners, even if they still generate income. The costs and consequences of removing any dam can be substantial.

The National Inventory of Dams has roughly 92,000 dams in its database with an average age of 61 years. The majority of these dams are "low hazard" (see below), but about 17% are "high hazard". EGLE has documented approximately 304 dam failures in Michigan between 1888 and 2020.

Michigan regulates its dams under Part 315 (Dam Safety) and Part 307 (Inland Lake Levels) of the NREPA. Its dams are classified into three hazard potential categories based on the *possible impacts* that may result from their failure (the physical condition of the dams themselves is rated separately).

- A "Low Hazard Potential Dam" means a dam where failure may cause damage limited to agriculture, uninhabited buildings, structures, or township or county roads, where environmental degradation would be minimal, and where danger to individuals is slight or nonexistent.

- A "Significant Hazard Potential Dam" means a dam where failure may cause damage limited to isolated inhabited homes, agricultural buildings, structures, secondary highways, short line railroads, or public utilities, where environmental degradation may be significant, or where danger to individuals exists.

- A "High Hazard Potential Dam" means a dam where failure may cause serious damage to inhabited homes, agricultural buildings, campgrounds, recreational facilities, industrial or commercial buildings, public utilities, main highways, or class I carrier railroads, or where environmental degradation would be significant, or where danger to individuals exists with the potential for loss of life.

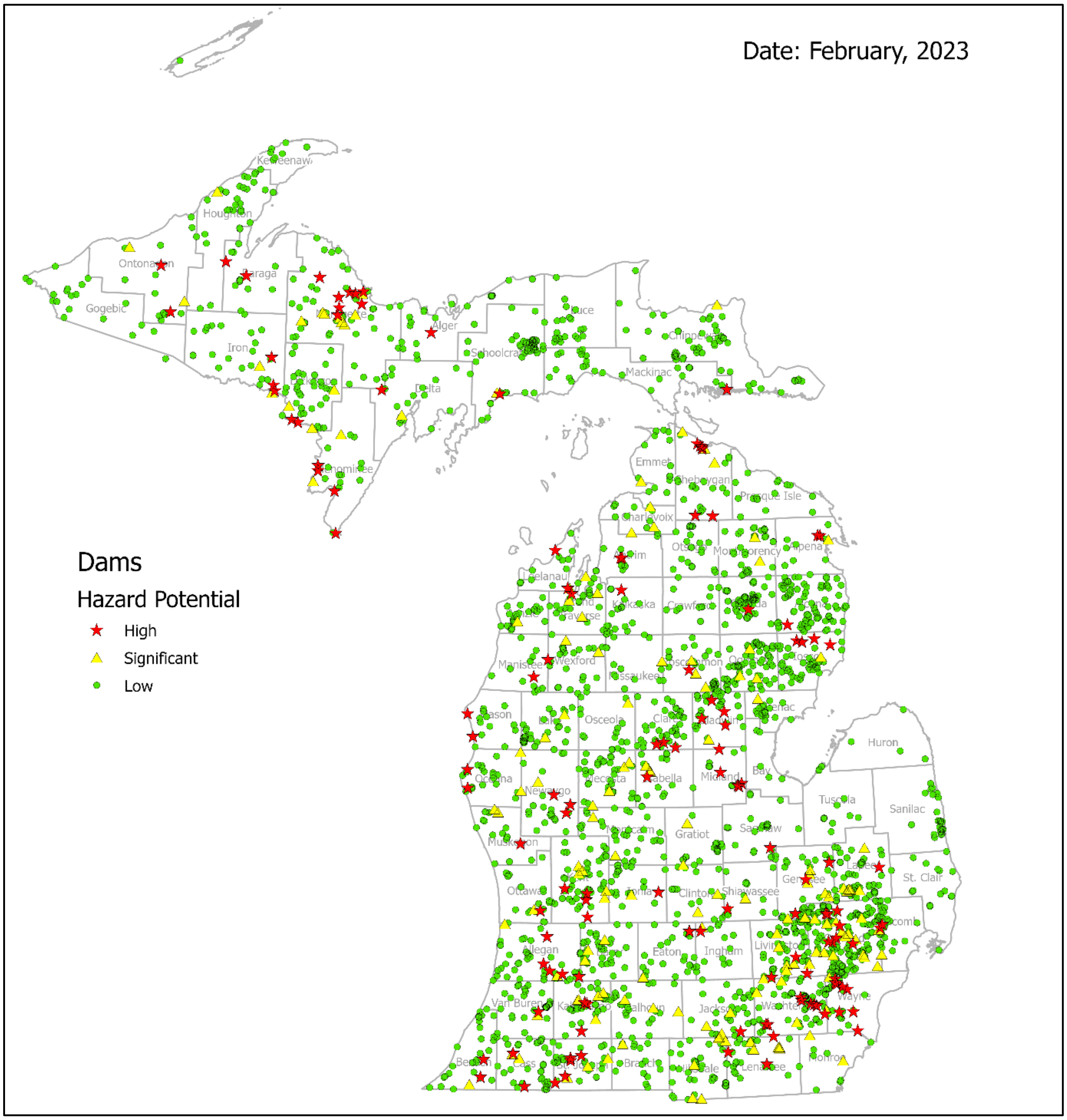
A pocket guide from FEMA uses similar nomenclature and criteria:

- "Low Hazard Potential" – No probable loss of human life and low economic and/or environmental losses (typically limited to the property of the dam owner).

- "Significant Hazard Potential" – No probable loss of human life but possible economic loss, environmental damage, disruption of lifeline facilities, or other impacts.

- "High Hazard Potential" – Loss of one or more human life is probable.

The locations and categories of Michigan-regulated dams are shown below. High-hazard potential dams are listed by county later in this chapter. An interactive web map can be accessed by clicking HERE.




(source: EGLE DSP)

It should be noted that a “high” hazard status does not always indicate the kind of deadly flood risk that some laypersons may envision. For example, rural areas may contain high-hazard potential dams even though no inhabitable structures are nearby. The “high” risk potential from a dam failure may instead be due to environmental impacts or the effects on the integrity of important roads. Just one potential impact type being identified as sufficiently elevated will raise the category level for an entire dam.

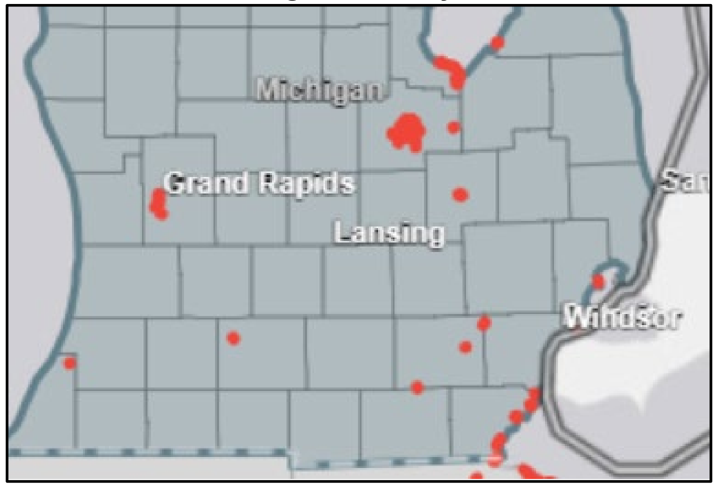
Local emergency managers should look beyond their own borders, as upstream dam failures in other counties can significantly impact far-away areas. Dam failures can be more severe than riverine flooding due to the potential size of a sudden flash flood and subsequent wave action. Failures not caused by weather (so-called “sunny day failures”) often occur with no warning and may be the result of cascading effects from other hazards. Variable population and critical infrastructure locations also mean that not all dams will create the same level of risk. The risk of flooding from a specific dam failure can be estimated from past occurrences or can be calculated in abstract probabilistic terms. A challenge in using the former method is that risk will be estimated on a fairly infrequent number of past occurrences (perhaps none). When there is an incident, it may also be of relatively minor impact based on scope and outcome. A community with no history of dam failure may wish to examine the histories of similar dams (based on age, construction, size, and maintenance), even if out of state, and use the information to estimate potential chances of failure by proxy.

While dam risks vary widely, Michigan's recent history suggests a frequency of roughly two failures per year, on average, with most involving small impacts and rural locations. Although none of the 304 recorded dam failures in Michigan were catastrophic in terms of massive loss of life, damage to property from large events can still be substantial. Both the 2018 and 2023 Michigan Infrastructure Report Card from the American Society of Civil Engineers gave Michigan's dams a grade of C-, citing more than $225 million necessary to address aging dams. Roughly 12% of Michigan dams have a high or significant hazard potential rating. Roughly 67% of its dams are over 50 years old, and 271 dams are over 100 years old. As of July 2023, the average age all of all Michigan dams in the NID database is 79 years.

The National Levee Database indicates thirteen Michigan counties with levee systems (including floodwalls): Bay (7), Berrien (1), Calhoun (2), Genesee (3), Huron (2), Kent (5), Lenawee (1), Macomb (1), Monroe (5), Saginaw (21), Tuscola (1), Washtenaw (2), and Wayne (7). Some levee systems share political borders, leaving the official state count at 56 (average age 36 years).

Some of these are USACE levee systems, with the remaining locations indicating non-federal ownership locally constructed, operated, and maintained. A downtown Grand Rapids floodwall has the largest estimated consequences from failure. The database continues to be updated, and information should be confirmed when used for local planning purposes.

**Michigan Levee Systems**




(source: USACE, map as of July 25, 2023)

Although not the focus of this chapter, it should be noted that other, temporary flood barriers can carry hidden dangers. These vary in quality, and may include sandbags, inflatable barriers filled with water, or anchored metal-plank walls. The force of suddenly flooding water from their failure may prove deadlier than the natural flows that would have otherwise occurred. Dam-like structures may also be constructed by wildlife instead of humans, and natural obstacles can arise through the accumulation of ice, logs, or debris. These may create flooded upstream areas until they melt or dislodge, suddenly releasing waters downstream. Agencies may also wish to build awareness to risks involving any "low head" dams in their area. These small dams of short height can pose a significant risk of death to swimmers and kayakers depending on water conditions. They are sometimes referred to as "drowning machines".

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
High fatalities have not been reported from Michigan dam failures, but the potential for mass casualties is always present. Historically significant incidents have caused varying levels of evacuation, population displacement, road/bridge closures, and property damage. Failed dams that do not cause flash floods may still create issues for area hydrology and infrastructure. For example, hydroelectric dams may need to be shut down in the event of a breach, causing impacts on an area's power supply. Drinking water and stormwater systems may fail, including well water. Upstream lakes may become quickly depleted as their waters drain away, creating erosion and lowering property values for homes not otherwise damaged by the event. Recreational activities, hunting, and fishing can be impacted.

Impact on the Economic Condition of the State
The economic impacts of dam failure are similar to those of floods (refer to requisite chapters). Some companies may need to temporarily cease production, which may lead to impacts throughout the larger supply chain. Dams with hydroelectric power facilities also support Michigan's production activities and related jobs.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Dam failures may cause flash flooding, which is especially dangerous for responders. Waters often conceal open manholes, electrical currents, weakened structures, sharp objects, animal carcasses, chemicals, and bacteria/mold. The force of flowing water can overwhelm even specially trained personnel, as well as structures and vehicles. Roads necessary for debris removal, repair, and rescue operations may be impassable or require lengthy alternate routes. Infrastructure failures can inhibit the operations and services of many public agencies and firms. Supply delivery will be strained. Area facilities may need to temporarily relocate, sometimes at a reduced capacity.

Impact on the Environment
Besides levels of immediate and visible natural destruction, failures have the potential to harm natural ecosystems by pushing accumulated sediment forcefully downstream and throughout associated floodplains. Such previously settled sediments may also be contaminated. A failure may push water onto agricultural land, which then carries fertilizers and pesticides into other areas. Ecosystems may be severely damaged, especially those for aquatic and amphibious species, including organisms closely connected to those species within food webs. Any formerly impounded area may quickly drain and compromise upstream flora and fauna.

### *Select Dam Failures in Michigan*

May 19, 2020 – Gladwin, Midland, and Saginaw Counties (Federal Disaster 4547-DR)
A heavy storm began on May 18, delivering up to 6-8 inches of rain in areas of the Tittabawassee River watershed. Flooding occurred in counties such as Gladwin, Midland, Saginaw, Iosco, and Arenac (which became part of state and federal emergency and disaster declarations). Run-off waters placed a heavy load upon the Secord and Smallwood Dams in Gladwin County, which were damaged but not breached. A breach occurred the next day at the downstream Edenville Dam, east of its powerhouse and spillways, resulting in an uncontrolled release into Sanford Lake. This was in turn followed by the overtopping of the downstream Sanford Dam about two hours later. The contents of Wixom Lake inundated areas as it progressed through Midland County, where floodwaters reached nine feet deep in parts of the City of Midland. Saginaw County also saw flooding, but area marshlands absorbed enough flow to blunt some effects. Serious impacts occurred in the Village of Sanford, the City of Midland, and townships along the Tittabawassee River, destroying roughly 130 homes and causing about $320M in property damage.

Evacuations were complicated by multiple nursing homes in Saginaw and Midland Counties and involving hundreds of senior citizens (one Midland facility had roof damage and 18 inches of floodwater). At least 500 persons made use of temporary shelter facilities, complicated by Coronavirus 2019 (some evacuees chose to sleep in their vehicles to reduce exposure). Many evacuated persons found shelter with friends, but 280 families were put up in hotel lodging. In Saginaw County, all four bridges across the Tittabawassee River were closed. In Midland County, all major highways had flood closures, some for multiple days, with a county total of 138 closed roadway segments. Damaged community facilities included the Midland library, historic county courthouse, Northwood University, Midland Center for the Arts, Sanford Centennial Museum, and the Dow Botanical Gardens. Schools were also disrupted. Up to nine feet of flood water swept into the bottom level of Midland Hospital, closing their morgue and relocating their dispatch services. The City of Midland's wastewater infrastructure was inundated. Five sewer pump stations failed when they were completely submerged. Sixteen temporary pumps were used, and potable water stations were set up. Power failures occurred as cables were damaged, and there were additional impacts on gas, phone, and internet lines (one area network hub was completely lost). Drained lake areas created an erosion risk as former shorelines threatened to crumble.


Tobacco River flow being restored to its normal course as repair progressed at the Edenville Dam, 2021

It should be noted that the Edenville Dam had been identified as carrying substantial risk, but its failure occurred before improvements or enforcement actions could be completed. The private owner of the Secord, Smallwood, Edenville, and Sanford Dams declared bankruptcy in the aftermath of the incident. An area non-profit entity, the Four Lakes Task Force (FLTF), now works on behalf of Gladwin and Midland Counites in accordance with Part 307 of NREPA (see below). State Courts have ruled that the FLTF is now the recognized County Delegate Authority for purposes of acquiring, repairing, and operating the four dams. A preliminary report on the incident can be found by clicking HERE; information on the recovery phase HERE.

April 15, 2014 – Roscommon County
During the annual spring thaw, water levels were high in the area, and the Wraco Lodge Dam on Wolf Creek gave way, sending flood waters across several major roads and resulting in approximately $60K in property damage. The resulting road closures included Old-27 near the Clare County Line, Waco and Rollway Roads, Newaygo and Townline Roads, and County Road 402. Floodwaters were inches away from reaching the level of the US-127 bridge.

October 6, 2012 – Dam Failure and Flash Flood (Grand Traverse County)
East of the town of Grawn, a temporary dam and de-watering structure had been in place alongside the Brown Bridge Dam on the Boardman River, to assist in drawing down the small lake behind the dam (Brown Bridge Pond) before the dam's permanent removal. This temporary dam failed and caused the release of all remaining water, causing road closures and home evacuations within the hour. A total of 53 homes sustained varying degrees of damage. Docks, small footbridges, and some small outbuildings were destroyed. Total damages were estimated at $1.8M.

May 31, 2010 – Kent County
Severe storms and heavy rainfall battered the Rockford area, where a retaining wall washed out and numerous homes flooded. Property damage from the storm was estimated at $200K. Many roads were also inundated or washed out.

September 13, 2008 – Berrien County
Heavy rainfall struck as the remnants of Hurricane Ike and Tropical Storm Lowell reached the southern portion of Michigan. Totals across Berrien and Cass Counties eventually exceeded 12 inches, causing an earthen portion of the Niles Dam to breach. Downstream residents were evacuated as a precaution. Primary impacts were to the area's roads and lasted for several days.

May 14-15, 2003 – Upper Peninsula Flooding and Cascading Dam Failure (Marquette County)
A series of dikes and dams failed during intense flooding, starting with the Silver Lake Basin reservoir (the headwaters of the Dead River). By 11 a.m. the next day, accumulated waters had overtopped the Tourist Park Dam, which then failed structurally at 12:30 p.m., with water eventually eroding a new channel on the dam's left side. Excessive water flowed downstream and eventually flooded low-lying areas in the City of Marquette. A local state of emergency was declared, with damages estimated at about $3.2M (of which $1M was caused to the failed dike and downstream dams themselves). The Governor ordered the evacuation of persons living along waterways in the Dead River Basin area and its tributaries downstream of Silver Lake. Although the US Small Business Administration issued a "Declaration of Economic Injury," no federal Disaster Declaration was approved for the event. The fact that some of the dams stayed intact, despite cascading water flows from upstream, helped to preserve Marquette neighborhoods that might have otherwise been overwhelmed.

April 17, 2002 – Upper Peninsula Flooding and Dam Failure (Gogebic County)
A pattern of flooding and dam failures occurred in the Upper Peninsula several years in a row. April 17 saw a partial failure of the Presque Isle Wildlife Dam (aka Wood Dam), creating a markedly increased water flow and a flash flood warning for downstream Marenisco Township. The City of Wakefield separately experienced floods due to heavy rains and rapid spring snowmelt, with their water/wastewater treatment and electric plants in danger of inundation and shutdown. The Michigan State Police Post was evacuated due to flooding. In Gogebic County, 48 homes were destroyed, 91 suffered major damage, and 27 minor damage. Seven businesses were destroyed with 11 damaged. A Presidential Disaster Declaration was issued.

September 1986 – Central Lower Michigan (Federal Disaster #774 – 30 counties)
A slow moving low-pressure system produced 8-17 inches of rainfall over a 60-mile wide/180-mile-long area over a 24-hour period. In Big Rapids, 19 inches of rain fell from September 9-12. The storm resulted in thousands of persons being evacuated due to flooding. Five persons were killed and 89 injured (up to ten were killed if indirect effects are included). Roughly 30,000 homes suffered basement and structural damage and 3,600 miles of roadways were made impassable due to the failure of four primary bridges and hundreds of secondary road bridges and culverts. Eleven dams failed with 19 others threatened. Thirty counties were included in the Presidential Major Disaster Declaration: Allegan, Arenac, Bay, Clare, Clinton, Genesee, Gladwin, Gratiot, Huron, Ionia, Isabella, Kent, Lake, Lapeer, Macomb, Manistee, Mason, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, Sanilac, Shiawassee, Tuscola, and Van Buren. The flood resulted in over $300M in damages.

1939 & 1969 – Lenawee County
Many small dams were originally built to run mills. The Rollin Mill Dam was destroyed when it was struck by a tornado in 1939. The dam was not rebuilt. The Globe Mill Dam (River Raisin) was washed out by flooding in 1969 and later rebuilt. Some older historical dams throughout the state were simply abandoned if they were no longer needed.

### *Select Laws, Agencies, and Programs*

Michigan Dam Safety Program
Part 315 of NREPA, 1994 PA 451, Dam Safety, provides for the rating and inspection of state dams. Dams over six feet tall that create impoundment surface areas of five acres or more are regulated by Part 315. Regulated dam owners are required to maintain an Emergency Action Plan if their dams are rated as being of a high or significant hazard potential. Part 307, Inland Lake Levels, is also used by EGLE's Dam Safety Program (DSP) to regulate certain other dams (Part 307 describes the authority to maintain lakes and operate dams). Additional information can be found on EGLE's website, as well as in the February 2021 Michigan Dam Safety Task Force report. The report collects information from three sources: an outside review of EGLE's DSP, an independent forensic investigation into the 2020 Edenville and Sanford dam failures, and an evaluation of the surviving portion of the Edenville Dam.

Dam Risk Reduction Grant Program
This new state program administered by EGLE aims to provide private owners with the needed resources for proper management of existing dams to help minimize risks associated with dam failures. Stakeholders could apply for grants beginning in 2022. Information includes a program handbook as well as eligibility requirements.

US Army Corps of Engineers and National Inventory of Dams
The USACE maintains a congressionally authorized database that includes information for all High and Significant Hazard Potential Dams, as well as many Low Hazard Potential Dams. See the primary flooding chapter for more information on USACE available resources.

Federal Energy Regulatory Commission (FERC) and Federal Programs
Hydroelectric dams are not regulated under Part 315 of NREPA (above) and are instead FERC licensed dams. An overview of their role in overseeing non-federal hydropower generation can be found HERE. Also at the federal level, the Dam Safety and Security Act of 2002 addresses the safety and security of dams. The Act includes resources for the development and maintenance of a national dam safety information network and the creation of a strategic plan by the National Dam Safety Review Board. Information on the National DSP can be found HERE.

High Hazard Potential Dams (HHPD) Grant Program
This federal program provides technical, planning, design, and construction assistance for the rehabilitation of certain high hazard potential dams under the National DSP (33 USC 467f, §5006). Grants address the needs of eligible dams where a hazard mitigation plan is in place and other federal criteria are met. EGLE is the authorized State Administrative Agency. Program related details and maps are included in the MHMP.

### *Supplemental Materials*

EGLE maintains a database of all dams that are: (1) regulated by Michigan's dam safety laws, (2) hydropower dams regulated by FERC, and (3) a few unregulated dams that would be rated as High or Significant Hazard Potential Dams because their failure could result in loss of life.

The state's high hazard potential dams are listed on the table beginning on the following page. An interactive web map can be accessed by clicking HERE.

**County Dam Count, Including High and Significant Hazard Potential Dams**
(Michigan, February 10, 2023)

| County | High Hazard | Significant Hazard | Total | County | High Hazard | Significant Hazard | Total |
|---|---|---|---|---|---|---|---|
| Alcona | 1 | 0 | **73** | Lake | 0 | 2 | **36** |
| Alger | 1 | 0 | **21** | Lapeer | 1 | 6 | **59** |
| Allegan | 5 | 2 | **46** | Leelanau | 2 | 1 | **14** |
| Alpena | 2 | 1 | **11** | Lenawee | 3 | 5 | **32** |
| Antrim | 2 | 0 | **13** | Livingston | 3 | 7 | **60** |
| Arenac | 0 | 1 | **18** | Luce | 0 | 0 | **21** |
| Baraga | 2 | 0 | **14** | Mackinac | 1 | 0 | **26** |
| Barry | 0 | 3 | **39** | Macomb | 2 | 1 | **27** |
| Bay | 0 | 0 | **5** | Manistee | 2 | 0 | **12** |
| Benzie | 0 | 1 | **27** | Marquette | 9 | 8 | **65** |
| Berrien | 2 | 1 | **29** | Mason | 2 | 0 | **14** |
| Branch | 0 | 1 | **19** | Mecosta | 0 | 4 | **38** |
| Calhoun | 0 | 3 | **25** | Menominee | 4 | 2 | **19** |
| Cass | 2 | 2 | **41** | Midland | 4 | 0 | **13** |
| Charlevoix | 0 | 3 | **14** | Missaukee | 0 | 1 | **15** |
| Cheboygan | 6 | 3 | **26** | Monroe | 0 | 2 | **9** |
| Chippewa | 0 | 1 | **56** | Montcalm | 0 | 2 | **34** |
| Clare | 3 | 0 | **40** | Montmorency | 0 | 2 | **32** |
| Clinton | 0 | 2 | **20** | Muskegon | 1 | 2 | **17** |
| Crawford | 0 | 0 | **14** | Newaygo | 3 | 1 | **23** |
| Delta | 1 | 1 | **21** | Oakland | 8 | 15 | **145** |
| Dickinson | 2 | 3 | **38** | Oceana | 2 | 2 | **22** |
| Eaton | 3 | 1 | **25** | Ogemaw | 0 | 3 | **66** |
| Emmet | 0 | 1 | **14** | Ontonagon | 2 | 2 | **17** |
| Genesee | 3 | 7 | **34** | Osceola | 0 | 1 | **16** |
| Gladwin | 5 | 1 | **34** | Oscoda | 1 | 0 | **54** |
| Gogebic | 0 | 0 | **20** | Otsego | 0 | 0 | **20** |
| G. Traverse | 1 | 4 | **27** | Ottawa | 1 | 1 | **23** |
| Gratiot | 0 | 2 | **19** | Presque Isle | 0 | 0 | **15** |
| Hillsdale | 0 | 5 | **45** | Roscommon | 1 | 3 | **31** |
| Houghton | 0 | 1 | **31** | Saginaw | 1 | 0 | **25** |
| Huron | 0 | 0 | **4** | Saint Clair | 0 | 0 | **16** |
| Ingham | 1 | 1 | **14** | Saint Joseph | 5 | 3 | **31** |
| Ionia | 1 | 1 | **22** | Sanilac | 0 | 0 | **27** |
| Iosco | 4 | 1 | **48** | Schoolcraft | 1 | 1 | **50** |
| Iron | 3 | 2 | **27** | Shiawassee | 0 | 1 | **13** |
| Isabella | 1 | 3 | **21** | Tuscola | 0 | 0 | **14** |
| Jackson | 1 | 4 | **36** | Van Buren | 1 | 1 | **37** |
| Kalamazoo | 4 | 5 | **42** | Washtenaw | 8 | 4 | **64** |
| Kalkaska | 1 | 0 | **22** | Wayne | 8 | 1 | **37** |
| Kent | 4 | 5 | **56** | Wexford | 0 | 2 | **26** |
| Keweenaw | 0 | 0 | **9** | **TOTAL** | **137** | **158** | **2475** |

**MICHIGAN HIGH HAZARD POTENTIAL DAMS**

| County | High Hazard Dam Name | NID ID# | Hydraulic Height (feet) | Purpose | River |
|---|---|---|---|---|---|
| Alcona | Alcona Dam | MI00150 | 54 | Hydro | Au Sable River |
| Alger | Au Train Dam | MI00152 | 38 | Hydro | Au Train River |
| Allegan | Allegan City Dam | MI00489 | 14 | Retired Hydro | Kalamazoo River |
| | Lake Doster Dam | MI00723 | 34 | Recreation | Trib. to Silver Creek |
| | Menasha Dam | MI00522 | 21.6 | Hydro Recreation | Kalamazoo River |
| | Monterey Lake Dam | MI00472 | 20 | Recreation | Pigeon Creek |
| | Trowbridge Dam | MI00604 | 30.2 | Retired Hydro | Kalamazoo River |
| Alpena | Four Mile Dam | MI00170 | 35 | Hydro | Thunder Bay River |
| | Norway Point Dam | MI00189 | 62 | Hydro | Thunder Bay River |
| Antrim | Bellaire Dam | MI00435 | 18 | Retired Hydro | Intermediate River |
| | Cedar River Dam | MI00516 | 22 | Retired Hydro | Cedar River |
| Baraga | Ford Dam | MI00129 | 26 | Recreation | Plumbago Creek |
| | Prickett Diversion Dam | MI00193 | 55 | Hydro | Sturgeon River |
| Berrien | Berrien Springs Dam | MI00538 | 31.5 | Hydro | Saint Joseph River |
| | Buchanan Dam | MI00157 | 28 | Hydro | Saint Joseph River |
| Cass | Adamsville Hydroelectric Dam | MI00729 | 10.5 | Hydro | Christiana Creek |
| | Upper Mill Dam | MI00035 | 14 | Recreation | Dowagiac Creek |
| Cheboygan | Cornwall Creek Dam | MI00246 | 31.2 | Recreation | Cornwall Creek |
| | Little Black River Structure A | MI00040 | 27.5 | Flood & Stormwater | Little Black River |
| | Little Black River Structure B | MI00042 | 22 | Flood & Stormwater | Little Black River |
| | Little Black River Structure C | MI00047 | 17 | Flood & Stormwater | Trib. to S Br Little Black River |
| | Little Black River Structure D | MI00066 | 19 | Flood & Stormwater | South Br Little Black River |
| | Wildwood Lake Dam | MI00249 | 21 | Recreation | Bradley Creek |
| Clare | Lake 13 Dam | MI00044 | 19 | Recreation | Runyon Creek |
| | Shamrock Lake Dam | MI00622 | 19.8 | Recreation | Tobacco River |
| | Surrey Lake Dam | MI00116 | 16 | Recreation | Elm Creek |
| Delta | Escanaba #4 Dam | MI00167 | 69 | Hydro | Escanaba River |
| Dickinson | Big Quinnesec Falls Dam | MI00103 | 82 | Hydro | Menominee River |
| | Little Quinnesec Falls Dam | MI00826 | 65 | Hydro | Menominee River |
| Eaton | Carrier Creek Structure A | MI00980 | 21 | Flood & Stormwater | Carrier Creek |
| | Carrier Creek Structure B | MI00981 | 17 | Flood & Stormwater | Carrier Creek |
| | Myers-Henderson Detention Pond | MI00901 | 11 | Flood & Stormwater | Miller Creek |
| Genesee | Hamilton Dam | MI00060 | 22 | Water Supply | Flint River |
| | Holloway Dam | MI00064 | 30 | Recreation | Flint River |

| County | High Hazard Dam Name | NID ID# | Hydraulic Height (feet) | Purpose | River |
|---|---|---|---|---|---|
| | Linden Mill Dam | MI00062 | 9.5 | Retired Hydro | Shiawassee River |
| Gladwin | Chappel Dam | MI00525 | 32 | Retired Hydro | Cedar River |
| | Edenville Dam | MI00549 | 56.7 | Hydro | Tittabawassee River |
| | Lake Lancer Dam | MI00471 | 36 | Recreation Other | Sugar River |
| | Secord Dam | MI00547 | 57 | Recreation | Tittabawassee River |
| | Smallwood Dam | MI00548 | 36 | Hydro | Tittabawassee River |
| Grand Traverse | Union Street Dam | MI00511 | 20 | Recreation | Boardman River |
| Ingham | Moores Park Dam | MI00094 | 21 | Hydro | Grand River |
| Ionia | Webber Dam | MI00206 | 33 | Hydro | Grand River |
| Iosco | Cooke Dam | MI00161 | 54 | Hydro | Au Sable River |
| | Five Channels Dam | MI00168 | 60 | Hydro | Au Sable River |
| | Foote Dam | MI00169 | 55 | Hydro | Au Sable River |
| | Loud Dam | MI00178 | 55 | Hydro | Au Sable River |
| Iron | Michigamme Falls Dam | MI00184 | 70 | Hydro | Michigamme River |
| | Peavy Falls Dam | MI00191 | 75 | Hydro | Michigamme River |
| | Way Dam | MI00205 | 50 | Hydro | Michigamme River |
| Isabella | Lake Isabella Dam | MI00434 | 38.5 | Recreation | Chippewa River |
| Jackson | Brooklyn Dam | MI00121 | 22 | Retired Hydro | River Raisin |
| Kalamazoo | Lower Comstock Dam | MI00136 | 18 | Recreation | Comstock Creek |
| | Middle Comstock Dam | MI00137 | 21 | Recreation | Comstock Creek |
| | Morrow Dam | MI00146 | 25 | Hydro | Kalamazoo River |
| | Sunset Lake Dam | MI00144 | 8.4 | Recreation | Gourdneck Creek |
| Kalkaska | Rugg Pond Dam | MI00518 | 22.5 | Retired Hydro | Rapid River |
| Kent | Ada Dam | MI00501 | 31 | Hydro | Thornapple River |
| | Cascade Dam | MI00502 | 31 | Hydro | Thornapple River |
| | Grand Rapids West Side Dam | MI00508 | 23.5 | Retired Hydro | Grand River |
| | LaBarge Dam | MI00503 | 32 | Hydro | Thornapple River |
| Lapeer | Mill Creek Structure | MI00105 | 25 | Flood & Stormwater | North Branch Mill Creek |
| Leelanau | Leland Dam | MI00510 | 19 | Retired Hydro | Trib. to Lake Michigan |
| | Meeuwenberg Dam | MI00439 | 39 | Recreation | Trib. to Cedar Lake |
| Lenawee | Addison Mill Pond Dam | MI00710 | 25 | Retired Hydro | Bean Creek |
| | Atles Mill Dam | MI00588 | 13 | Recreation | River Raisin |
| | Lake Adrian Dam | MI00594 | 29.4 | Water Supply | Wolf Creek |
| Livingston | HiLand Lake Dam | MI00602 | 14.2 | Recreation | Portage River (Hell Creek) |
| | Nichwagh Lake Dam | MI00598 | 14.7 | Retired Hydro | Trib. to Huron River |
| | Woodland Lake Dam | MI00606 | 16.9 | Recreation | South Ore Creek |
| Mackinac | Cedarville Operation Tailings Basin Dam | MI02671 | 10 | Tailings | Trib. to Lake Huron |

| County | High Hazard Dam Name | NID ID# | Hydraulic Height (feet) | Purpose | River |
|---|---|---|---|---|---|
| Macomb | Lower Stony Lake Dam | MI00685 | 30.1 | Recreation | Stony Creek |
| | Upper Stony Lake Dam | MI00686 | 19.1 | Recreation | Stony Creek |
| Manistee | Hodenpyl Dam | MI00174 | 90 | Hydro | Manistee River |
| | Tippy Dam | MI00200 | 80 | Hydro | Manistee River |
| Marquette | Carp Intake Dam | MI00158 | 54 | Retired Hydro | Carp River |
| | Carp River Dam | MI00159 | 60 | Retired Hydro | Carp River |
| | Hoist Dam | MI00175 | 85 | Hydro | Dead River |
| | Lake Sally Dam | MI00468 | 15 | Other | Ely Creek |
| | McClure Dam | MI00183 | 64 | Hydro | Dead River |
| | Ogden Lake Dam | MI00841 | 5.8 | Other | Ely Creek |
| | Silver Lake Basin Dam | MI00197 | 36 | Other | Dead River |
| | Tilden Recirculation Basin | MI00611 | 100 | Water Supply | Trib. to Schweitzer Creek |
| | Upper Dam No 2 | MI00181 | 62 | Hydro | Dead River |
| Mason | Hamlin Lake Dam | MI00236 | 21.6 | Recreation | Big Sable River |
| | Ludington Pumped Storage | MI00180 | 170 | Hydro | None |
| Menominee | Chalk Hill Dam | MI00160 | 38 | Hydro | Menominee River |
| | Grand Rapids Dam | MI00022 | 32 | Hydro | Menominee River |
| | Lower Menominee River Dam | MI00532 | 29 | Hydro | Menominee River |
| | White Rapids Dam | MI00207 | 52 | Hydro | Menominee River |
| Midland | Midland Storage Basin | MI00965 | 16.5 | Flood & Stormwater | None |
| | Number 6 Brine Pond Dam | MI02675 | 12 | Other | Trib. to Titabawasee River |
| | Sanford Dam | MI00550 | 36 | Hydro | Tittabawassee River |
| | Tertiary Pond Dam | MI02676 | 14.7 | Other | Trib. to Titabawassee |
| Muskegon | Muskegon County Resource Recovery Center | MI00613 | 18.6 | Other | Black and Mosquito Creeks |
| Newaygo | Croton Dam | MI00162 | 60 | Hydro | Muskegon River |
| | Hardy Dam | MI00171 | 120 | Hydro | Muskegon River |
| | White Cloud Dam | MI00526 | 18.9 | Retired Hydro | White River |
| Oakland | Clarkston Dam | MI00240 | 34 | Retired Hydro | Clinton River |
| | Dawson Millpond Dam | MI00718 | 9 | Retired Hydro | Clinton River |
| | Heron Dam | MI00692 | 23.1 | Recreation | Thread Creek |
| | Lake Louise Dam | MI00255 | 12 | Recreation | Kearsley Creek |
| | Lake Neva Dam | MI00614 | 17 | Recreation | Cedar Creek |
| | Oxbow Dam | MI00263 | 15 | Recreation | Huron River |
| | Pontiac Lake Dam | MI00265 | 21 | Other | Huron River |
| | Wildwood Lake Dam | MI00276 | 20.3 | Recreation | Thread Creek |
| Oceana | Holiday Lake Dam | MI00436 | 27 | Recreation | Golden Creek |
| | Upper Silver Lake Dam | MI00016 | 25 | Recreation | Au Sable Creek |

| County | High Hazard Dam Name | NID ID# | Hydraulic Height (feet) | Purpose | River |
|---|---|---|---|---|---|
| Ontonagon | Bond Falls Dam | MI00153 | 46 | Hydro | Middle Branch Ontonagon River |
| | Victoria Diversion Dam | MI00203 | 120 | Hydro | W Br Ontonagon River |
| Oscoda | Mio Dam | MI00186 | 50 | Hydro | Au Sable River |
| Ottawa | Buttermilk Creek Detention Dam | MI04010 | 12 | Flood & Stormwater | Buttermilk Creek |
| Roscommon | Lake James Dam | MI00347 | 16 | Recreation | Denton Creek |
| Saginaw | Misteguay Creek 4 | MI00067 | 29 | Flood & Stormwater | Misteguay Creek |
| Saint Joseph | Constantine Hydro Dam | MI00535 | 30 | Hydro | Saint Joseph River |
| | Mottville Dam | MI00187 | 20 | Hydro | Saint Joseph River |
| | Portage Plant Dam | MI00374 | 16.3 | Retired Hydro | Portage River |
| | Sturgis Dam | MI00534 | 41 | Hydro | Saint Joseph River |
| | Three Rivers Dam | MI00395 | 16 | Hydro | Saint Joseph River |
| Schoolcraft | Manistique Papers Dam | MI00377 | 25 | Retired Hydro | Manistique River |
| Van Buren | Maple Lake Dam | MI00388 | 24 | Retired Hydro | S Br Paw Paw River |
| Washtenaw | Argo Dam | MI00559 | 15 | Retired Hydro | Huron River |
| | Barton Dam | MI00560 | 29 | Hydro | Huron River |
| | Ford Manchester Dam | MI00391 | 24.6 | Retired Hydro | River Raisin |
| | Geddes Dam | MI00561 | 24.5 | Retired Hydro | Huron River |
| | Manchester Mill Dam | MI00715 | 18 | Retired Hydro | River Raisin |
| | Peninsular Paper Dam | MI00500 | 19.7 | Retired Hydro | Huron River |
| | Rawsonville Dam | MI00194 | 54 | Hydro | Huron River |
| | Superior Dam | MI00558 | 32 | Hydro | Huron River |
| Wayne | Detroit Metro Airport Stormwater Pond 6 | MI02682 | 16 | Flood & Stormwater | Frank & Poet Drain |
| | Flat Rock Dam | MI00556 | 15.9 | Retired Hydro | Huron River |
| | French Landing Dam | MI00557 | 35 | Hydro | Huron River |
| | Nankin Mill Dam | MI00365 | 17 | Retired Hydro | M Br River Rouge |
| | Newburgh Dam | MI00396 | 29 | Retired Hydro | M Br River Rouge |
| | Phoenix Dam | MI00397 | 24 | Retired Hydro | M Br River Rouge |
| | Waterford Dam | MI00399 | 19 | Retired Hydro | M Br River Rouge |
| | Wilcox Dam | MI00398 | 22 | Retired Hydro | M Br River Rouge |

(source: EGLE DSP, August 4, 2023)

# ECOLOGICAL HAZARDS INTRODUCTION

The following ecological related natural hazards are covered in this section:

1. Extreme Heat
2. Drought
3. Wildfires
4. Invasive Species

These hazards deal with changes to biological ecosystems and are common in climatological-related disaster groupings. Extreme cold could be placed here but has more in common with winter storms (see the Winter Hazards Overview).

Higher temperatures have become more prevalent during the recent period of climate change, as evidenced by both overall increases to annual trend lines as well as acute instances of extreme heat. Many densely populated areas tend to retain heat due to building materials such as concrete and asphalt, making urban cities particularly susceptible.

Drought is a complex phenomenon exacerbated in part by high temperatures. Persistent droughts may continue to impact ecosystems for many years. Croplands can also be affected. The hazard is modified for many Michigan locations depending on their proximity to the Great Lakes.

Wildfire risk is in turn increased by high temperatures and drought. While prescribed burns can have beneficial effects for some species, wildfires in general carry a high potential to destroy large swaths of land. It may take several decades for forests to fully recover. Ash and debris may contaminate air and water in areas that didn't experience fires.

Changing temperatures directly impact flora and fauna, with ecosystems becoming unfit for some native species even as they begin to accommodate others. Such changes allow for invasive species to expand their range in Michigan's land and waters, threatening historical ecosystem balance. Entire forests and even the Great Lakes can be impacted.

**Overlap Between Ecological Hazards and Other Sections of the Hazard Analysis (Hazard Cascade)**
Extreme heat can quickly exacerbate drinking water shortages and lead to a public health emergency (especially if also impacted by drought). Faltering crops or weakened livestock may create food shortages. Underwatered livestock may eventually succumb and die, and improperly disposed of carcasses can lead to pollution and disease.

Computer servers and technological control equipment need cool environments for proper operation. Some of these devices are part of the electric grid, which may already be stressed by high air conditioning needs. Power plants themselves need controlled environments, and particular consideration should be given to nuclear facilities whose cooling waters may become warm enough to induce fish kills in associated lakes and streams.

Extreme heat can impact transportation systems. Vehicles overheat and break down. Particularly severe events have been known to melt/buckle roadways, both for cars and airport runways. Drought-induced low waters may require dredging and impact maritime shipping. Invasive species may directly or indirectly clog water inlets.

Response to hazardous material and structure fires will be complicated by worker fatigue and potential shortages of water used for firefighting purposes. Empirical evidence exists for greater civil unrest during times of higher temperatures. Arsonists or terrorists may intentionally ignite wildfires.

# EXTREME HEAT

*Periods of very high temperatures, especially when prolonged.*

## *Hazard Description*

Extreme heat typically occurs in Michigan from May to September and is generally marked by temperatures above 90°F. These high temperatures are usually well forecast but are sometimes so extreme (or extend for long periods of time) that they still jeopardize human life. The hazard frequently puts a strain on air-conditioning and may lead to power outages/shortages that can greatly magnify the impacts of outside temperatures. Nighttime temperatures are an important consideration for people without air conditioning, as the human body needs time to recover from extreme heat.

## *Hazard Analysis*

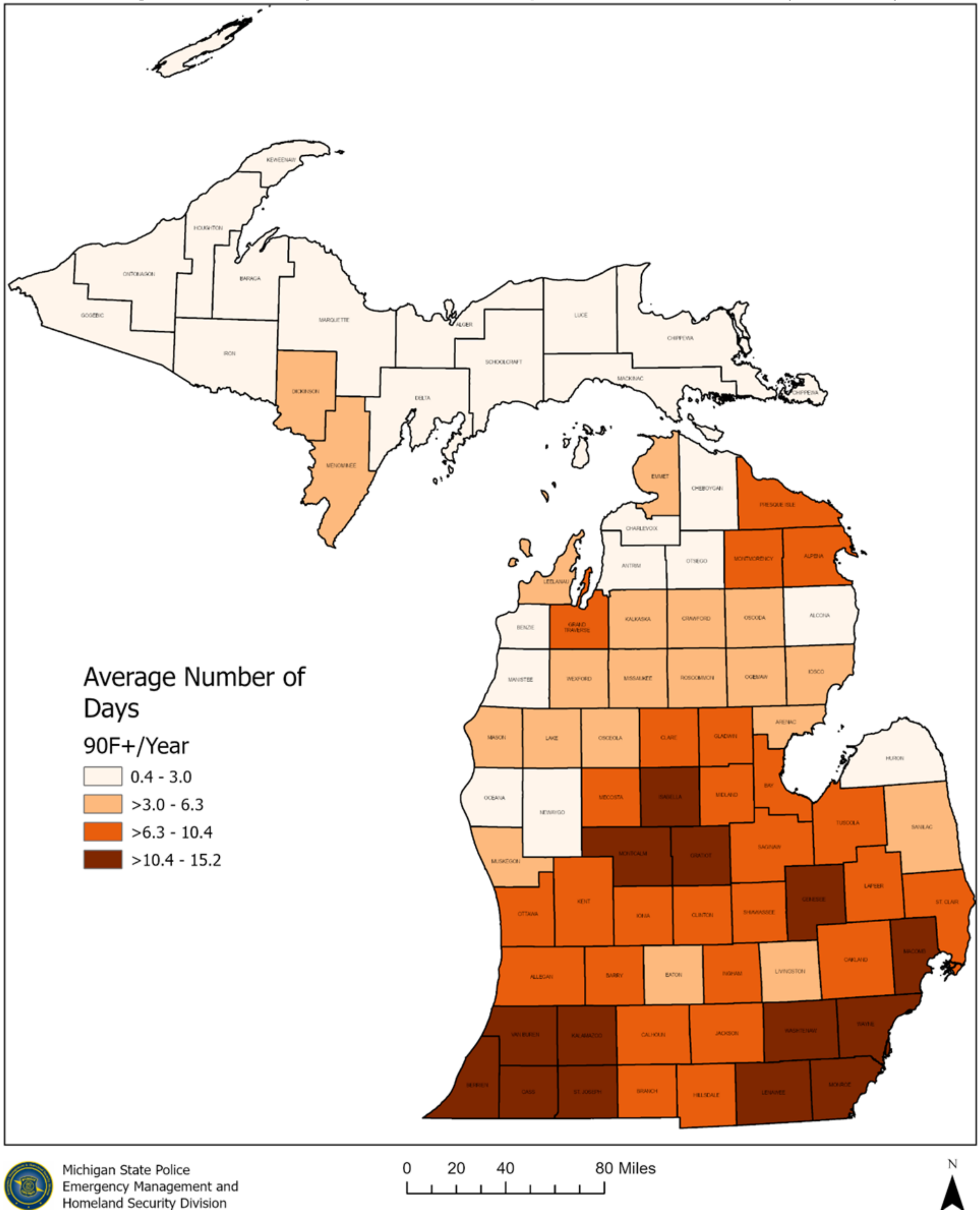
Prolonged high temperatures are often referred to as "heat waves" and occur in every part of the state. Counties in the southern half generally have a higher frequency for these events, with urban areas often seeing relatively higher temperatures due to heat-absorbing materials (e.g., concrete, asphalt, tar, glass). The following table lists record highs for numerous weather stations across Michigan. These records are for specific stations and do not necessarily include all-time records for the counties or surrounding localities in that area. The all-time state record is from Mio (Oscoda County) and Stanwood (Mecosta County) at 112°F (July 13, 1936). It should be noted that the majority of record-high temperatures occurred in July. Low temperatures are included for comparison/context.

**Historic Temperature Records at Various Michigan Locations (through 2021)**

| **Southern Lower Peninsula** | **Record Low Temperature** | **Record High Temperature** |
|---|---|---|
| Adrian (Lenawee County) | -26°F (1/20/1892) | 108°F (7/14/1936, 7/24/1934) |
| Benton Harbor (Berrien County) | -21°F (1/12/1918) | 104°F (7/21/2002, 7/30/1999) |
| Coldwater (Branch County) | -29°F (1/31/2019) | 108°F (7/24/1934) |
| Ann Arbor (Washtenaw County) | -23°F (2/11/1885) | 105°F (7/24/1934) |
| Bloomingdale (Van Buren Co.) | -23°F (2/3/1996) | 105°F (7/5/1911, 7/13/1936) |
| Detroit (Wayne County) | -21°F (1/21/1984) | 105°F (7/24/1934) |
| Jackson (Jackson County) | -20°F (1/18/1976, 1/19/1994) | 103°F (7/15/1977) |
| Pontiac (Oakland County) | -22°F (2/5/1918) | 104°F (7/6/1988, 7/8/1936, 7/16/1988, 7/24/1934) |
| Flint (Genesee County) | -25°F (1/18/1976, 2/20/2015) | 108°F (7/8/1934, 7/13/1936) |
| Grand Rapids (Kent County) | -24°F (2/13-14/1899) | 108°F (7/13/1936) |
| Port Huron (St. Clair County) | -19°F (1/19/1994) | 103°F (7/9/1936) |
| Saginaw (Saginaw County) | -23°F (2/5/1918) | 111°F (7/9/1936) |
| Harbor Beach (Huron County) | -22°F (2/9/1934) | 105°F (7/10/1936) |
| Big Rapids (Mecosta County) | -36°F (2/11/1899) | 103°F (7/30/1916, 7/13-14/36) |
| **Northern Lower Peninsula** | **Record Low Temperature** | **Record High Temperature** |
| Houghton Lake (Roscommon Co) | -34°F (2/17/1979) | 103°F (6/19/1995) |
| Alpena (Alpena County) | -37°F (2/17/1979) | 106°F (7/13/1936) |
| East Tawas (Iosco County) | -29°F (2/1/1918, 2/20/1929) | 106°F (7/8-9/1936) |
| Gaylord (Otsego County) | -37°F (2/17/1979) | 101°F (7/11/1921, 7/30/1916) |
| Gladwin (Gladwin County) | -39°F (2/20/1979) | 105°F (7/13/1936) |
| Traverse City (Gd. Traverse Co.) | -37°F (2/17/1979) | 105°F (7/7/1936) |
| **Upper Peninsula** | **Record Low Temperature** | **Record High Temperature** |
| Hancock (Houghton County) | -30°F (2/9/1951, 2/10/1948) | 102°F (7/7/1988) |
| Ironwood (Gogebic County) | -41°F (1/17/1982, 2/12/1967) | 104°F (7/13/1936) |
| Munising (Alger County) | -33°F (2/25/1928) | 103°F (7/7-9/1936, 8/6/1947) |
| Sault Ste. Marie (Chippewa Co.) | -37°F (2/8/1934, 2/10/1899) | 98°F (7/3/1921, 7/30/1916, 8/5-6/1947) |

(source: NOAA NCEI)

**Average Number of Days with Maximum Temperature 90°F and Above (1991-2020)**




Record temperatures generally ranged from 101°F to 111°F. These fall within NWS "Extreme Caution" (90-104°F) and "Danger" (105-129°F) categories. There are some regional patterns within the state, with latitude having an obvious impact. The proximity to the Great Lakes is another consideration, with lower record temperatures being observed in areas within a mile or two of shorelines. For most areas of the Lower Peninsula more than a few miles inland, the extreme values are in the 115-120°F range. Upper Michigan is generally lower (100-110°F).

Temperatures can be exacerbated by sunny days, with relative humidity also playing an especially important role in how heat stress impacts human beings. Temperature alone is only one indicator of the weather's total threat to human health, see this chapter's supplemental materials section for information on the NWS Heat Index.

While high humidity makes high temperatures feel worse for people, extreme heat and dry soils often exist together due to relationships between surface air temperature and evaporation. This means that areas with relatively coarse sandy or gravelly soils that hold relatively less water have a greater risk for high air temperatures than areas with fine or moderate textured soils. For example, many of the all-time high-temperature records across the state were set on very dry landscapes in 1934 and 1936, both during and following periods of extreme drought and in areas with coarse soils.

Indoor temperatures can easily exceed outdoor temperatures, especially in multiple-story buildings or cars (glass greatly increases temperatures on sunny days). Urban heat island effects may be particularly pronounced. While the impacts of heat may be less in rural areas, residents may not be located near designated cooling shelters. Beyond air conditioning, using only fans to move air is effective until temperatures reach the mid-90s, at which point they will *not* prevent heat-related illnesses (the blowing air would be too close to the person's own body temperature). Relocating to a cooler environment such as a basement can be effective, as may a cool bath if better options do not exist.

Deaths and Illness

According to the NWS, an average of 168 deaths per year in the US were attributable to extreme heat over the 30-year period from 1993 to 2022. The Michigan Department of Health and Human Services (MDHHS) estimates between one and five deaths per year, on average, in the state due to extreme heat. Heatstroke and heat exhaustion may also occur. Heatstroke symptoms include high body temperature (can reach 106°F or higher), dry skin, inadequate perspiration, paleness or reddening, confusion/irritability, and seizures. Victims may become delirious, stuporous, unconscious, or comatose. Cooling is essential to prevent permanent neurological damage or death. Heat exhaustion is a less severe condition but can still cause dizziness, weakness, and fatigue. It is often the result of a bodily fluid imbalance from increased perspiration. Restoring fluids and cooling down is important so that it does not lead to heatstroke. Heat syncope may additionally occur, typically when people are not acclimated to being in higher temperatures.

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

Urban areas often contain vulnerable populations with special considerations, such as lack of air conditioning amidst heat island effects. Any required stair use will become difficult due to physical mobility limitations or trapped stairwell heat. Some foods and medicines require refrigeration. The elderly and children may be especially susceptible, as are workers who must be outside (e.g., farming, construction). Cooling centers may be needed, including those allowing for pets. Increased use of air conditioning may result in electric brownouts or system failures. Backup generators may be lacking. Water use may be regulated if drought is also present. Athletic events, parades, and festivals may be affected. Although not as widely reported compared to southern states, extreme heat can have a damaging impact on Michigan infrastructure such as roads and airport runways. Climate-related migration may occur, both within and into the state, affecting population distribution and housing.

Impact on the Economic Condition of the State

Businesses and organizers of outdoor events (e.g., sports, concerts) may be impacted by cooling challenges, inadequate water service, or canceled events. General business productivity may be lowered, and those that rely on outdoor workers may need to be stopped completely. Many agricultural crops and livestock are vulnerable to losses because of extreme heat events (see the supplemental materials section of this chapter). Tourism may be negatively impacted, but will vary based on the type of any associated recreation (beach going may be increased for example).

Impact on Responders, Continuity of Operations, and Continued Delivery of Services

Heat may directly impact the health and effectiveness of responders, especially when wearing heavy uniforms or personal protective equipment. Heat increases the risk of fires and may increase the risk of civil disobedience. If blackouts occur or air conditioners break down many businesses may need to close, including those supplying important government services. Public transportation (such as bus stations) may be impacted. A loss of climate control at prisons may be particularly problematic.

Impact on the Environment

Increased power consumption (e.g., air conditioners) may result in more pollution. The number of surface-level ozone days may increase. Many types of plants and wildlife, including fish, are negatively impacted by extreme temperatures. Nuclear plants, as applicable, need to monitor the temperatures of water used for cooling purposes before discharge so as not to affect aquatic life. Agricultural areas may use more pumped water as irrigation is increased. The risk of damaging wildfires will be increased. Long-term, macro-level environmental damage from a warming climate includes the melting of glaciers, the thermal expansion of ocean waters, and increased sea levels/erosion. Invasive species may become more prominent even as other species become extinct.

### *Select Heat Waves Affecting Michigan*

Brief synopses of recent significant historical heat waves or unusual temperature patterns that have affected Michigan. The listing is not meant to be comprehensive. Temperatures are in Fahrenheit unless otherwise noted. See also the chapter on drought.

Spring, 2023 – Lower Peninsula and Western Lower Peninsula
A spring heat wave brought early high temperatures to many areas of the state, with nearly the entire lower peninsula hitting near or above 90°F on June 1. Conditions were also extremely dry. The western side of the state saw the highest temperatures, with Muskegon breaking time of year records several days in a row. Kalamazoo had at least five days in a row between 90°F and 93°F. Holland also hit 93°F during this time, and Mt. Pleasant 92°F. Average temperatures for early June would typically have been in the middle 70°s.

June 30-July 5, 2018 – Southeast Michigan and Northern Lower Michigan
A heat wave impacted southeast Michigan June 30 - July 5, producing high temperatures in Detroit between 90°F and 96°F. Heat-related emergency room visits peaked on July 1, remaining elevated through the rest of the heat wave. June also ended hot for northern Lower Michigan. Highs were well into the 90°s, including 99°F at Alpena and 98°F at Traverse City and Gaylord. Heat indices exceeded 105°F across most of northern lower Michigan, and some locations exceeded 110°F (114°F near Indian River). An estimated 25-30 people visited local hospitals due to heat-related illnesses.

July 14-19, 2013 – Southeast Michigan (Wayne, Oakland, Macomb, Washtenaw, Genesee, and Saginaw Counties)
A six-day heat wave impacted Southeast Michigan from July 14 through 19, with high temperatures ranging from the upper 80°s to mid-90°s. Heat indices were mostly in the 90°s, but area hospitals reported an increase of 173 heat-related illnesses during this time, including 80 in Wayne, 50 in Oakland, and 25 in Macomb County.

June 28-July 7, 2012 – Southeast Michigan (Wayne, Oakland, Macomb, Washtenaw, Genesee, and Saginaw Counties)
Temperatures began near 100°F, with heat indices slowly rising to 100°F - 110°F and leading to hospitalizations. June 29 ended up not being as hot, with high temperatures up to the mid 90°s and dry air helping to keep heat indices short of 100°F. This was followed however by an extended period in July, with temperatures topping out around 100°F on multiple days. Detroit set a record high on July 4, reaching 102°F. Heat indices peaked around 110°F on July 4 and July 6. Over 700 heat-related emergency room visits were reported statewide. Southeast Michigan tallies included 39 heat injuries in Wayne County, 28 in Oakland, 20 in Macomb, 13 in Genesee, 10 in Saginaw, and five in Washtenaw.

July 17 - 22, 2011 – Southeast Michigan (Oakland and Wayne Counties)
A heat wave helped to cap off a record warm month in Detroit, with heat indices above 100°F. A 37-year-old Highland Township man with an enlarged heart died of hyperthermia. A 60-year-old man died in Wayne County, found in his car with the windows rolled up. A 57-year-old man died of hyperthermia in his Redford Township group home.

July 4, 2010 – Southeast Michigan
A heat wave lasted for five days across the greater Detroit Metropolitan area. An elderly man without air conditioning died in Grosse Pointe Farms (Wayne County), and a middle-aged homeless woman died of hyperthermia in her car in Waterford Township (Oakland County). High temperatures were all in the low 90°s each day, with heat indices in the upper 90°s, but evening temperatures did not go below 70°F to help people recover from the daytime heat.

Summer, 2006 –Southeast Michigan (Midland County)
Roughly 315 heat-related "injuries" occurred this summer, with 75 on May 29 and 240 in late July/early August (including six known cases of heat stroke). Midland hit 98°F on Memorial Day, and parades caused many to swoon and be treated for dehydration and heat exhaustion. A 5-day period of temperatures at or above 90°F saw the heat index average between 105°F and 110°F in the Detroit area. A large number of cooling centers were opened.

Late June and early July 2002 – Metro Detroit
It was reported that 25 persons were treated for heatstroke at the beginning of July, 15 of whom were in Wayne County and five each were from Oakland and Macomb Counties. On June 28, two very young children had died in Southfield (Oakland County) as a result of being left alone in a parked car when outdoor temperatures were in the 90°s. The heat index during the first four days of July was above 10°F.

June-August 2001 – Midwest and Central Plains
High temperatures and humidity sent heat stress index readings well above 100°F for many days, forcing communities to open cooling centers. Heat-related deaths occurred in many areas despite these measures. Three elderly residents in a Detroit-area nursing home died in June with five more hospitalized from heat-related stress. The deaths prompted state legislation to require Michigan nursing homes to have air conditioning in resident rooms and common areas. August 1 saw heat indices at 105°F for some southern Lower Peninsula counties and 110°F in similar areas on August 8. The National Climatic Data Center reports one death and 200 "injured" from excessive heat during early August.

July 1999 – Midwest and East Coast
A wide-ranging heat wave resulted in an estimated 256 heat-related deaths in 20 states (including one in Kent County in Michigan). Most of the deaths occurred in urban areas in the Midwest, where temperatures soared above 90°F for much of the month and humidity levels were oppressively high. Numerous persons with heat-related problems (ranging from dehydration to heatstroke) were treated at hospitals in Detroit and other cities across the state.

July 1995 – Central and Eastern United States
A July 11-27 heat wave caused 1,021 deaths (465 of those occurring in the Chicago metropolitan area alone). Many of the deaths were low-income elderly persons living in residential units not equipped with air conditioning. Local utilities in Chicago were forced to impose controlled power outages because of excessive energy demands. Water suppliers saw very low levels of water in storage. The heat also caused the loss of tens of millions of cattle and poultry throughout the Midwest. Michigan was relatively spared but still experienced 28 heat-related fatalities that year, most of them occurring in July. Detroit saw its highest average temperature at 74.5°F (August was even higher at 77.1°F).

Summer 1988 – Central and Eastern United States
A wide-ranging drought/heat wave caused an estimated $40B in damages from agricultural losses, disruption of river transportation, water supply shortages, wildfires, and related economic impacts across the country. The heat wave was particularly long in Michigan, with 39 days with 90°F or worse heat. Temperatures in Southeast Michigan topped the 100°F mark on five occasions, including a peak of 104°F. Reported deaths ranged between 5,000-10,000, with varying interpretations of "heat-related" fatalities making it difficult to provide precise estimations.

July 1936 – Michigan
Heat wave temperatures exceeded 100°F up to seven days in a row (e.g., Detroit had seven days, Alpena had six, and Traverse City had five). The temperature peaked at 112°F in Mio and set a state record. Cooling technology was in its infancy, and the heat led to deaths for even some healthy adults. Many relied on "old time" iceboxes, leading to spoiled food and some illness. Statewide, 570 people died from heat-related causes, including 364 in Detroit.

### *Select Agencies, Programs, or Laws*

Michigan Department of Health and Human Services
Information on four types of heat-related illnesses, along with tips on how to stay healthy, are included on this MDHHS web page. Links to similar resources available from the Occupational Safety and Health Administration and the Centers for Disease Control are also included.

Resilience Analysis and Planning Tool (RAPT)
The RAPT tool has a specially dedicated page for extreme heat that can help emergency managers visualize and understand population demographics useful in prioritizing vulnerable populations in both rural and urban settings. The RAPT can also be used to identify community cooling centers in order to prioritize locations.

Michigan Energy Assistance Program, State Emergency Relief Program
The MEAP administers statewide programs that provide energy assistance and self-sufficiency services to eligible low-income households, useful for residential climate control. The SERP works in conjunction with the federal LIHEAP. The Weatherization Assistance Program is also available.

Environmental Protection Agency (EPA)
The EPA provides many resources on its Adapting to Heat webpage. This includes information on comprehensive heat response planning, infrastructure improvements (e.g., green roofs, cool pavements), and educational resources such as the Excessive Heat Events Guidebook.

HEAT.gov (Part of the National Integrated Heat Health Information System)
This website is part of an NWS initiative with the goal of providing timely and science-based information related to extreme heat in collaboration with a variety of stakeholders. HEAT.gov shows maps and other real-time updates for what parts of the country are under extreme heat advisories, watches, and warnings (see below).

Michigan High School Athletic Association (MHSSA)
The MHSSA provides material for student-athletes that may also be useful to the broader population. These include model policies for outdoor activities taking place in high heat and humidity, as well as a printable heat index card.

### *Supplemental Material*

Material on heat indices, temperature timing, agricultural damage, and other information is provided.

**Heat Index and Heat Advisories**
Evaporation of perspiration is a primary natural cooling mechanism for the human body. However, evaporation of moisture (and the latent cooling that results) does not occur as rapidly when the surrounding air already has a relatively high moisture content (humidity) and inhibits the body's efforts to cool itself. Calculators that account for this can be found online, such as the following Heat Index (HI) calculator at http://www.wpc.ncep.noaa.gov/html/heatindex.shtml.

**NWS Heat Index**

Temperature (°F)

| Relative Humidity (%) | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 80 | 81 | 83 | 85 | 88 | 91 | 94 | 97 | 101 | 105 | 109 | 114 | 119 | 124 | 130 | 136 |
| 45 | 80 | 82 | 84 | 87 | 89 | 93 | 96 | 100 | 104 | 109 | 114 | 119 | 124 | 130 | 137 | |
| 50 | 81 | 83 | 85 | 88 | 91 | 95 | 99 | 103 | 108 | 113 | 118 | 124 | 131 | 137 | | |
| 55 | 81 | 84 | 86 | 89 | 93 | 97 | 101 | 106 | 112 | 117 | 124 | 130 | 137 | | | |
| 60 | 82 | 84 | 88 | 91 | 95 | 100 | 105 | 110 | 116 | 123 | 129 | 137 | | | | |
| 65 | 82 | 85 | 89 | 93 | 98 | 103 | 108 | 114 | 121 | 128 | 136 | | | | | |
| 70 | 83 | 86 | 90 | 95 | 100 | 105 | 112 | 119 | 126 | 134 | | | | | | |
| 75 | 84 | 88 | 92 | 97 | 103 | 109 | 116 | 124 | 132 | | | | | | | |
| 80 | 84 | 89 | 94 | 100 | 106 | 113 | 121 | 129 | | | | | | | | |
| 85 | 85 | 90 | 96 | 102 | 110 | 117 | 126 | 135 | | | | | | | | |
| 90 | 86 | 91 | 98 | 105 | 113 | 122 | 131 | | | | | | | | | |
| 95 | 86 | 93 | 100 | 108 | 117 | 127 | | | | | | | | | | |
| 100 | 87 | 95 | 103 | 112 | 121 | 132 | | | | | | | | | | |

**Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity**

Caution    Extreme Caution    Danger    Extreme Danger

**HI up to 89°F** = **Caution** (fatigue possible with prolonged exposure and/or physical activity)

**HI 90°F to104°F** = **Extreme Caution** (sunstroke, muscle cramps and/or heat exhaustion possible with prolonged exposure/activity)

**HI 105°F to 129°F** = **Danger** (sunstroke, muscle cramps, heat exhaustion is likely with prolonged exposure and physical activity)

**HI above 130°F** = **Extreme Danger** (heat stroke or sunstroke is highly likely with prolonged exposure and/or physical activity)

The HI table shows a modified temperature based on relative humidity and other factors (it assumes shady conditions with a light wind). Actual indoor conditions may vary, trapping heat in some locations and making them more dangerous. Although the resulting heat calculations may at first seem exaggerated, they are still less than what is voluntarily felt inside a sauna set at 140°F. Persons entering a hot car will often be placing themselves into even worse conditions than those listed on the table. The most common such automobile-related fatalities involve babies under 1 year old, due in part to a child's body temperature being able to rise much faster than adults. Parking in the shade with windows cracked open does *not* provide sufficient cooling to safeguard human or pet health on a hot day.

In Michigan, *heat advisories* will be announced by the NWS when the calculated HI is expected to exceed 100°F for three consecutive hours, and can be extended into the nighttime if low temperatures are in the 70°s or higher. The ability to sleep in lower temperatures is an important consideration when the human body attempts to recover from excessive daytime heat. An *excessive heat warning* will be issued if the calculated HI will be at least 105°F for three or more hours. People vary in their capacity to both tolerate extreme heat and can find themselves in circumstances that threaten their health (or others under their care) even if no official temperature advisory has been issued.

**Temperature Timing**

The following table shows the timing of observed 0°F and 90°F temperatures by the date for which the *earliest*, *average*, and *latest* temperatures were recorded at each location. Between those dates are shown the period in which such temperature extremes have regularly been observed. For example, the Adrian weather station has historically seen temperatures at or above 90°F as early as May 15 and as late as October 1, with an average occurrence on July 16.

**Timing of 0°F and 90°F Temperatures at Various Michigan Locations, 1991-2020**

Column Format: Earliest date of temperature, Average date of temperature, Latest date of temperature

| **Southern Lower Peninsula** | **Low Temperatures (<= 0℉)** | | | **High Temperatures (>=90℉)** | | |
|---|---|---|---|---|---|---|
| Adrian (Lenawee County) | Dec 3 | Jan 23 | Mar 15 | May 15 | July 16 | Oct 1 |
| Benton Harbor (Berrien County) | Dec 8 | Jan 20 | Mar 13 | May 9 | July 18 | Oct 4 |
| Coldwater (Branch County) | Dec 3 | Jan 23 | Mar 13 | May 27 | Jul 10 | Sep 26 |
| Ann Arbor (Washtenaw County) | Nov 13 | Jan 28 | Mar 13 | May 20 | Jul 16 | Sep 26 |
| Bloomingdale (Van Buren Co.) | Dec 3 | Jan 24 | Mar 14 | May 16 | Jul 16 | Sep 27 |
| Detroit (Wayne County) | Dec 19 | Jan 24 | Mar 6 | May 16 | Jul 16 | Oct 8 |
| Jackson (Jackson County) | Dec 3 | Jan 23 | Mar 13 | May 27 | Jul 15[t] | Sep 26 |
| Pontiac (Oakland County) | Dec 10 | Jan 25 | Mar 9 | May 28 | Jul 17 | Oct 8 |
| Flint (Genesee County) | Dec 3 | Jan 25 | Mar 13 | May 18 | Jul 14 | Sep 26 |
| Grand Rapids (Kent County) | Dec 3 | Jan 26 | Mar 9 | May 15 | Jul 13 | Sep 26 |
| Port Huron (St. Clair County) | Dec 19 | Jan 23 | Mar 16 | May 15 | Jul 16 | Oct 8 |
| Harbor Beach (Huron County) | Dec 14 | Jan 31 | Mar 17 | May 29 | Jul 17 | Sep 26 |
| Big Rapids (Mecosta County) | Nov 15 | Jan 31 | Mar 28 | May 27 | Jul 16 | Sep 27 |

| **Northern Lower Peninsula** | **Low Temperatures (< 0℉)** | | | **High Temperatures (>90℉)** | | |
|---|---|---|---|---|---|---|
| Alpena (Alpena County) | Nov 28 | Feb 1 | Apr 6 | Apr 16 | Jul 13 | Oct 8 |
| East Tawas (Iosco County) | Dec 9 | Feb 2 | Mar 27 | May 18 | Jul 18 | Oct 9 |
| Gaylord (Otsego County) | Nov 10 | Feb 3 | Apr 8 | May 25 | Jul 14 | Sep 5 |
| Gladwin (Gladwin County) | Nov 29 | Jan 30 | Mar 27 | May 11 | Jul 14 | Oct 9 |
| Traverse City (Gd. Traverse Co.) | Dec 6 | Feb 5 | Mar 27 | May 9 | Jul 15 | Sep 26 |
| | | | | | | |
| **Upper Peninsula** | **Low Temperatures (< 0℉)** | | | **High Temperatures (>90℉)** | | |
| Hancock (Houghton County) | Nov 26 | Feb 3 | Apr 10 | May 20 | Jul 16 | Sep 11 |
| Ironwood (Gogebic County) | Nov 7 | Jan 27 | Apr 10 | May 29 | Jul 17 | Sep 12 |
| Munising (Alger County) | Dec 2 | Jan 26 | Mar 29 | May 25 | Jul 16 | Aug 31 |
| Sault Ste. Marie (Chippewa Co.) | Nov 10 | Jan 27 | Mar 27 | May 26 | Jul 16 | Sep 23 |

(source: NOAA NCEI)

**Michigan Extreme Heat* Data (Arranged by Geography, 1/1/1996 – 4/30/2023)**

(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Extreme Heat Events | Deaths | Injuries |
|---|---|---|---|
| Washtenaw | 14 | | 17 |
| Wayne | 16 | 3 | 541 |
| Livingston | 14 | | 4 |
| Oakland | 17 | 5 | 194 |
| Macomb | 15 | | 60 |
| **5 County Metro Area** | **15.2 avg.** | **8** | **816** |
| Berrien | | | |
| Cass | | | |
| St. Joseph | | | |
| Branch | | | |
| Hillsdale | | | |
| Lenawee | 14 | | 2 |
| Monroe | 14 | | 2 |
| Van Buren | | | |
| Kalamazoo | | | |
| Calhoun | | | |
| Jackson | | | |
| Allegan | | | |
| Barry | | | |
| Eaton | | | |
| Ingham | | | |
| Ottawa | | | |
| Kent | 1 | | |
| Ionia | | | |
| Clinton | 1 | | |
| Shiawassee | 13 | | 5 |
| Genesee | 13 | | 23 |
| Lapeer | 13 | | 1 |
| St. Clair | 13 | | 7 |
| Muskegon | | | |
| Montcalm | | | |
| Gratiot | 1 | | |
| Saginaw | 13 | | 19 |
| Tuscola | 13 | | 1 |
| Sanilac | 12 | | 1 |
| Mecosta | | | |
| Isabella | 1 | | |
| Midland | 13 | | 3 |
| Bay | 13 | | 1 |
| Huron | 12 | | 1 |
| **34 County Southern Lower Peninsula** | **4.7 avg.** | **0** | **66** |

(continued on next page)

| COUNTY/AREA | Reported Extreme Heat Events | Deaths | Injuries |
|---|---|---|---|
| Oceana | | | |
| Newaygo | 1 | | |
| Mason | | | |
| Lake | | | |
| Osceola | | | |
| Clare | | | |
| Gladwin | 2 | | |
| Arenac | 2 | | |
| Manistee | 2 | | |
| Wexford | 2 | | |
| Missaukee | 2 | | |
| Roscommon | 2 | | |
| Ogemaw | 2 | | |
| Iosco | 2 | | |
| Benzie | 2 | | |
| Grand Traverse | 2 | | |
| Kalkaska | 2 | | |
| Crawford | 2 | | |
| Oscoda | 2 | | |
| Alcona | 2 | | |
| Leelanau | 2 | | |
| Antrim | 2 | | |
| Otsego | 2 | | |
| Montmorency | 2 | | |
| Alpena | 2 | | |
| Charlevoix | 2 | | |
| Emmet | 2 | | |
| Cheboygan | 2 | | |
| Presque Isle | 2 | | |
| **29 County Northern Lower Peninsula** | **1.6 avg.** | **0** | **0** |
| Gogebic | 3 | | |
| Iron | 3 | | |
| Ontonagon | 3 | | |
| Houghton | 4 | | |
| Keweenaw | 2 | | |
| Baraga | 3 | | |
| Marquette | 3 | | |
| Dickinson | 3 | | |
| Menominee | 3 | | |
| Delta | 2 | | |
| Schoolcraft | | | |
| Alger | 3 | | |
| Luce | 1 | | |
| Mackinac | 1 | | |
| Chippewa | 1 | | |
| **15 County Upper Peninsula** | **2.3 avg.** | **0** | **0** |
| **MICHIGAN TOTAL**** | **318** | **8** | **882** |
| **Michigan Annual Avg.** | **11.6** | **0.3** | **32** |

* Combines NCEI Storm Data categories for “Excessive Heat” and “Heat”.

**One event may take place in multiple counties. State totals may be less than the sum of all counties.

**Agricultural Damages**
Heat waves often exacerbate drought conditions, resulting in significant agricultural losses. For example, the summer heat of 1980 worsened the effects of a drought that ultimately caused over $20B in agricultural damage. A drought and heat wave in 1999 caused a nationwide total of more than $1B in damage (mainly to agricultural crops in the eastern US).

**Agricultural Disaster Declarations Involving Heat and Cold (2012-2021)**

| ID# | Declared | Description | Counties | In Area 4 | In Area 3 | In Area 2 | In Area 1 |
|---|---|---|---|---|---|---|---|
| S3259 | 6-29-2012 | Snow, heat, rain, winds, hail, freeze, tornadoes, floods, lightning | 82 | 14 | 29 | 34 | 5 |
| S3306 | 7-25-2012 | Unseasonably early thaw, unseasonably warm nights, heat | 4 | 4 | 0 | 0 | 0 |
| S3380 | 9-5-2012 | Heat, frost, freeze, and drought | 5 | 0 | 0 | 5 | 0 |
| S3383 | | Freeze | 6 | 0 | 0 | 6 | 0 |
| S3384 | | Drought and heat | 3 | 0 | 0 | 3 | 0 |
| S3444 | 11-26-2012 | Unseasonably warm weather followed by frost and freezes | 3 | 3 | 0 | 0 | 0 |
| S3551 | 7-3-2013 | Rain, snow, and thaw/freeze effects (“winterkill”) | 2 | 2 | 0 | 0 | 0 |
| S3584 | 9-11-2013 | Frost and freeze | 44 | 5 | 13 | 22 | 4 |
| S3622 | 1-23-2014 | Rain and colder-than-normal temperatures | 56 | 12 | 24 | 18 | 2 |
| S3623 | | Drought and colder-than-normal temperatures | 5 | 0 | 5 | 0 | 0 |
| S3636 | | Rain, drought, and cooler-than-normal temperatures | 25 | 0 | 22 | 3 | 0 |
| S3776 | 12-10-2014 | Freeze, frost, winds, extreme cold, record snowfall, ice, blizzards | 81 | 15 | 27 | 34 | 5 |
| S3806 | 3-25-2015 | Rain and colder-than-normal temperatures | 51 | 14 | 20 | 16 | 1 |
| S3807 | | Rain, drought, and colder-than-normal temperatures | 19 | 0 | 19 | 0 | 0 |
| S3914 | 10-14-2015 | Snow, freeze, frost, and extreme cold | 67 | 11 | 23 | 28 | 5 |
| S3934 | 11-18-2015 | Rain, floods, heat, landslides, mudslides, high winds, hail, lightning | 3 | 0 | 0 | 3 | 0 |
| S4216 | 9-1-2017 | Frost and freeze | 14 | 0 | 0 | 14 | 0 |
| S4256 | 11-21-2017 | Frost and freeze | 32 | 0 | 16 | 16 | 0 |
| S4266 | 12-21-2017 | Frost and freeze | 12 | 0 | 0 | 9 | 3 |
| S4376 | 8-8-2018 | Snow and freeze | 7 | 5 | 2 | 0 | 0 |
| **Total # Each Area Has Been Partially Affected by Declaration:** | | | | **10** | **11** | **14** | **7** |

(source: USDA FSA; as described in Appendix A: Area 4 (Upper Peninsula), Area 3 (Northern Lower Peninsula), Area 2 (Southern Lower Peninsula minus Metropolitan Detroit), Area 1 (Metropolitan Detroit))

# DROUGHT

A period of abnormally dry weather sufficiently long enough to cause a serious hydrological imbalance.

### *Hazard Description*

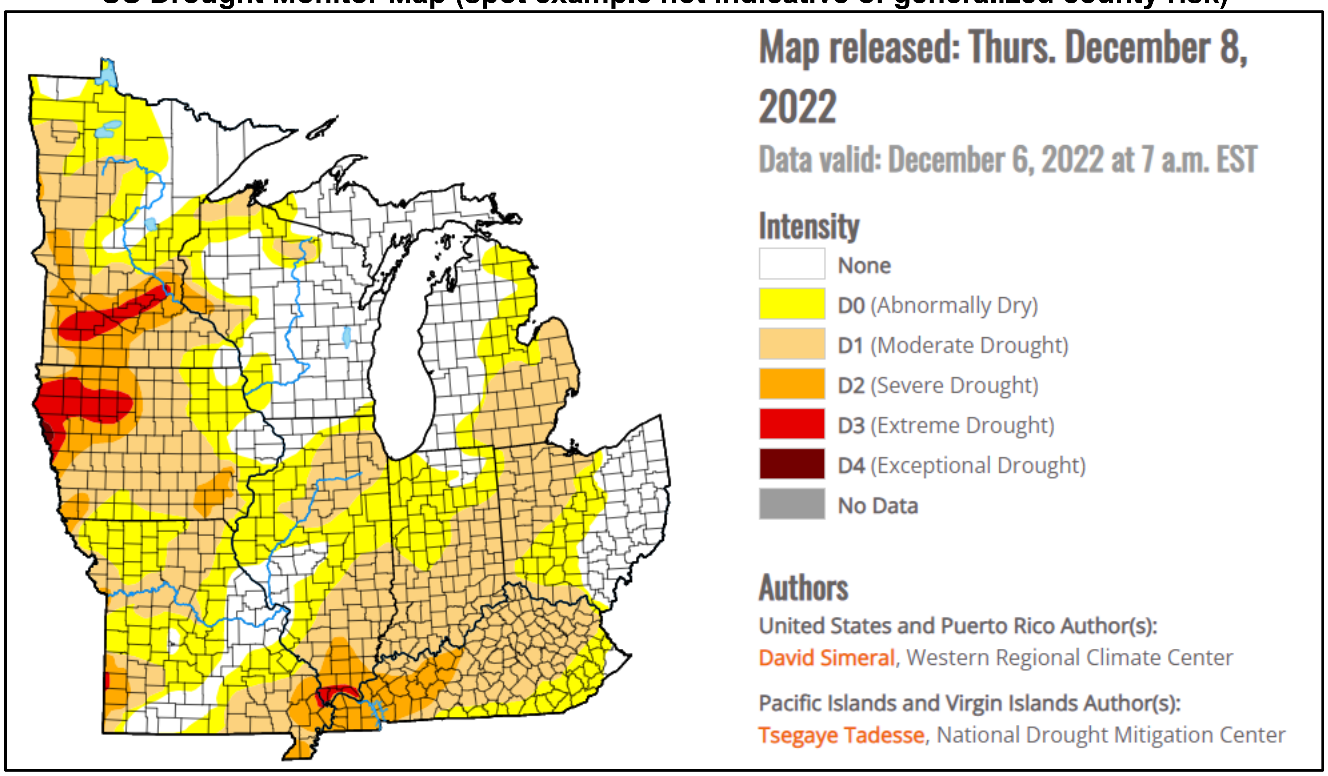
In contrast to hazards with well-defined thresholds, drought is a relative condition caused by a natural reduction in the amount of available water over an extended period of time (usually a season or more in length). Effects may accumulate slowly, typically without exact beginning or end points. This lack of clearly visible and universally accepted standards can make confirming drought conditions difficult. Large geographic areas may be impacted and made more severe based on location, duration, and the water needs of humans and natural/agricultural landscapes.

Droughts may be described in different ways. For example, a meteorological drought is based on the degree of dryness, or the departure of actual precipitation from an expected average or normal amount based on monthly, seasonal, or annual time scales. A hydrologic drought involves the effects of precipitation shortfalls on stream flows and reservoir, lake, and groundwater levels. An agricultural drought involves deficiencies in precipitation and soil moisture with respect to the water needs of crops.

### *Hazard Analysis*

There are many drought-related indices, which include river and stream flows, precipitation deficits or surpluses (e.g., the Standardized Precipitation Index), soil water balances relative to plant growth (e.g., the Crop Moisture Index), and hydrological balances (e.g., the Surface Water Supply Index), among others. Additional indices are catalogued by the Integrated Drought Management Programme. Drought conditions and impacts in the US are jointly monitored by the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, the NOAA, and the USDA. The US Drought Monitor (DM) is a common source for drought-related maps. It attempts to capture an overall assessment of drought severity as it collectively considers multiple types of drought.

**US Drought Monitor Map (spot example not indicative of generalized county risk)**




(source: US Drought Monitor, accessed Dec. 12, 2022)

The provided DM map is included as a past example and should not be interpreted as indicative of typical county risk.

The DM uses five general categories to describe drought/dryness: abnormally dry (D0), which describes areas that may be going into or coming out of drought, and four levels of existing drought: moderate (D1), severe (D2), extreme (D3) and exceptional (D4). Additional distinctions address short-term dryness (1–3-month duration) and long-term dryness (6-60 months), as well as “type” categories: agricultural impacts on crops, pastures, and grasslands are denoted by an ‘A’, and hydrologic effects on water supplies such as rivers, groundwater, and reservoirs are denoted by an ‘H’.

### US Drought Monitor Classification Categories

| Cat. | Description | Possible Impacts | Palmer Drought Index | USGS Weekly Streamflow, CPC Soil Moisture Model, Objective Short & Long-term Drought Indicator Blends | Standardized Precipitation Index (SPI) |
|---|---|---|---|---|---|
| D0 | Abnormally Dry | Going into drought: short-term dryness that slows planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered. | -1.0 to -1.9 | 21st to 30th percentiles | -0.5 to -0.7 |
| D1 | Moderate Drought | Some damage to crops and pastures; streams, reservoirs, or wells are low; some water shortages are developing or imminent; voluntary water-use restrictions requested. | -2.0 to -2.9 | 11th to 20th percentiles | -0.8 to -1.2 |
| D2 | Severe Drought | Crop or pasture losses likely; water shortages are common; water restrictions are imposed. | -3.0 to -3.9 | 6th to 10th percentiles | -1.3 to -1.5 |
| D3 | Extreme Drought | Major crop/pasture losses; widespread water shortages or restrictions. | -4.0 to -4.9 | 3rd to 5th percentiles | -1.6 to -1.9 |
| D4 | Exceptional Drought | Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells create water emergencies. | -5.0 or less | 0th to 2nd percentiles | -2.0 or less |

(source: Drought Monitor)

Michigan drought analysis can be accomplished by examining different types of drought and severity by region. Addressing agricultural droughts first, they can carry significant economic losses through lower yields and/or decreased crop quality.

Agricultural Disaster Declarations Involving Drought (Michigan, 2012-2021)

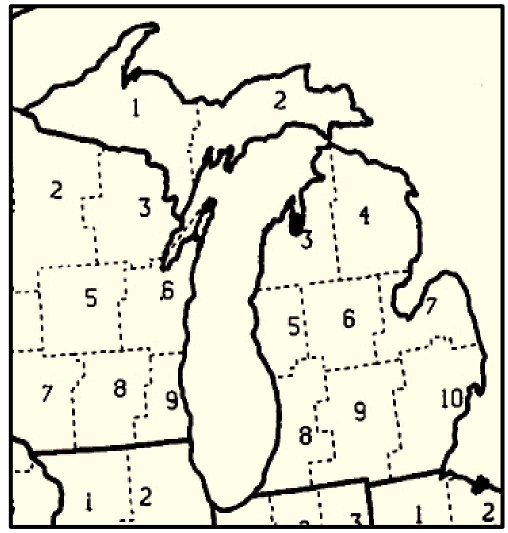
| ID# | Declared | Description | Counties | In Area 4 | In Area 3 | In Area 2 | In Area 1 |
|---|---|---|---|---|---|---|---|
| S3275 | 7-12-2012 | Drought | 5 | 0 | 0 | 5 | 0 |
| S3303 | 7-25-2012 | Drought | 10 | 0 | 0 | 10 | 0 |
| S3332 | 8-08-2012 | Drought | 1 | 0 | 0 | 1 | 0 |
| S3344 | 8-15-2012 | Drought | 2 | 0 | 0 | 2 | 0 |
| S3370 | 8-29-2012 | Drought and heat | 83 | 15 | 29 | 34 | 5 |
| S3380 | 9-05-2012 | Heat, frost, freeze, and drought | 5 | 0 | 0 | 5 | 0 |
| S3384 | | Drought and heat | 3 | 0 | 0 | 3 | 0 |
| S3623 | 1-23-2014 | Drought and colder-than-normal temperatures | 5 | 0 | 5 | 0 | 0 |
| S3636 | | Rain, drought, and cooler-than-normal temperatures | 25 | 0 | 22 | 3 | 0 |
| S3807 | 3-25-2015 | Rain, drought, and colder-than-normal temperatures | 19 | 0 | 19 | 0 | 0 |
| S3936 | 11-25-2015 | Drought, rain, hail, and high winds | 24 | 5 | 19 | 0 | 0 |
| S4132 | 1-09-2017 | Drought | 51 | 5 | 25 | 16 | 5 |
| **Total # Each Area Has Been Partially Affected by Declaration:** | | | | **3** | **6** | **9** | **2** |

(source: USDA FSA; as described in Appendix A: Area 4 (Upper Peninsula), Area 3 (Northern Lower Peninsula), Area 2 (Southern Lower Peninsula minus Metropolitan Detroit), Area 1 (Metropolitan Detroit))

For example, corn yields in Michigan declined 20 bushels/acre in 2012 due to a widespread regional drought that growing season. A 2001 drought caused the destruction of one-third of the state’s fruit and vegetable crops. Even relatively short but excessively dry weather during water-sensitive crop growth stages may lead to agricultural drought conditions that do not significantly impact other landscapes. A substantial portion (one-third) of Michigan’s recent agricultural disaster declarations have involved drought impacts.

Michigan's 10 Climate Divisions (CDs) are useful for analyzing drought. The following divisions are arranged by county:

Division 1: Baraga, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Marquette, Menominee, Ontonagon
Division 2: Alger, Chippewa, Delta, Luce, Mackinac, Schoolcraft
Division 3: Antrim, Benzie, Charlevoix, Emmet, Grand Traverse, Kalkaska, Leelanau, Manistee, Missaukee, Wexford
Division 4: Alcona, Alpena, Cheboygan, Crawford, Montmorency, Iosco, Ogemaw, Oscoda, Otsego, Presque Isle, Roscommon
Division 5: Lake, Mason, Muskegon, Newaygo, Oceana
Division 6: Clare, Gladwin, Gratiot, Isabella, Mecosta, Midland, Montcalm, Osceola
Division 7: Arenac, Bay, Huron, Saginaw, Sanilac, Tuscola
Division 8: Allegan, Berrien, Cass, Kalamazoo, Kent, Van Buren, Ottawa
Division 9: Barry, Branch, Calhoun, Clinton, Eaton, Hillsdale, Ingham, Ionia, Jackson, Shiawassee, St. Joseph
Division 10: Genesee, Lapeer, Lenawee, Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, Wayne



The following table summarizes 127 years of drought records as expressed by the Palmer Drought Severity Index (PDSI), by month, for all 10 of Michigan's CDs.

**Drought Months in Michigan, by Climate Division**
Drought Severity Based Upon PDSI
Select Index Values Shown (January 1895 through December 2021)

| **Climate Division** | Months without Drought | Months with any drought | % Months with drought | % Months with drought | % Months with drought | % Months with drought | % Months with drought | % Months with drought |
|---|---|---|---|---|---|---|---|---|
| PDSI: | (>=0) | (< 0) | <= -2 | <= -3 | <= -4 | <= -5 | <= -6 | <= -7 |
| **1** | 46.3% | 53.7% | 19.0 | 8.4 | 3.7 | 1.5 | 0.4 | 0.1 |
| **2** | 46.2% | 53.8% | 18.5 | 9.4 | 2.5 | 0.5 | 0.0 | 0.0 |
| **3** | 48.2% | 51.8% | 18.6 | 6.4 | 2.1 | 0.6 | 0.2 | 0.0 |
| **4** | 50.7% | 49.3% | 19.4 | 10.0 | 4.3 | 1.0 | 0.1 | 0.0 |
| **5** | 48.7% | 51.3% | 18.2 | 6.4 | 1.8 | 0.4 | 0.1 | 0.0 |
| **6** | 55.4% | 44.6% | 15.7 | 6.1 | 2.3 | 0.9 | 0.1 | 0.0 |
| **7** | 54.5% | 45.5% | 14.4 | 6.2 | 2.0 | 0.7 | 0.2 | 0.0 |
| **8** | 52.8% | 47.2% | 16.9 | 6.7 | 2.2 | 0.7 | 0.3 | 0.0 |
| **9** | 56.8% | 43.2% | 14.1 | 6.2 | 3.2 | 1.2 | 0.3 | 0.0 |
| **10** | 56.1% | 43.9% | 15.9 | 8.2 | 3.9 | 2.2 | 1.0 | 0.0 |

(source: NOAA Climate at a Glance)

The PDSI values shown are for select threshold ranges, with the most extreme drought events shown on the right. The lowest (worst) PDSI value of -7.33 occurred in January 1977 in CD1. The data suggest that northern portions of the state (CDs 1, 2, 3, 4, and 5) are slightly more drought-prone than southern sections of the state. Overall, the statistical differences between Michigan's CDs are not large, due at least in part to the PDSI's strong dependence on an area's precipitation normals. These summary indicators for CDs may also vary considerably from actual conditions on individual farms within a particular area.

Observed Michigan precipitation has increased in recent decades (see Thunderstorms Overview). Severe drought has also, in general, become rare during the past 20-30 years. Given this and a trend towards greater landscape water content, drought, and associated impacts have tended to become less frequent and less severe than in earlier decades. No recent events have reached the same level of intensity as Michigan's severe historical droughts nor have there been any observed extended events during the past decade. Despite this near-term trend of decreasing drought risk, long-term projections of future climate in the region suggest warming temperatures, greater rates of evapotranspiration, more erratic precipitation, and lower soil moisture levels during the warm season. In particular, shorter-duration seasonal droughts are expected to worsen during the summer, even though overall annual precipitation rates may increase.

This mix of countervailing trends and projections presents a complicated picture. With sufficient planning and water infrastructure, projected changes may actually be beneficial from a drought-related perspective for a period of time. They are still expected to worsen significantly in the longer-term, after a period of indeterminant (but several) decades.

## *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

Droughts may cause water shortages used for drinking, power generation, and recreation. A reduction in the quantity and quality of agricultural crops may lead to food shortages. Property values may be impacted by soil or water feature loss. Water restrictions and limitations among residents may change lifestyle patterns (e.g., lawn watering, and car washing). Stream flows can fall below 50% of their normal levels during moderate and severe drought conditions, reducing the navigability of waterways and altering the relationship between water levels/locations and built facilities (boardwalks, docks, fishing sites, etc.). Some municipal systems and infrastructure may find the maintenance of water quality and supply to be more difficult and expensive. Urbanized areas can be vulnerable to drought due to the sheer number of users that are competing for available water resources. Drought associated with high heat may be especially problematic in dense inner-city areas with urban heat islands. Illness from associated heat and other health-related problems may arise from diminished sewage flows and increased pollutant concentrations in surface water.

Impact on the Economic Condition of the State

Drought may result in substantial adverse impacts on the state's agricultural and tourist sectors, which are especially important to Michigan's rural economy. In addition to declines in crop and livestock productivity, drought may cause the erosion of topsoil (with an associated loss in land value and tax base). Many businesses directly use water in their products (bottled water, soft drinks) or as part of industrial processes. An increase in costs for affected products and services might be expected to arise from severe drought impacts. Water-born transport and freight can impact supply chains, even outside of Michigan (e.g., Mississippi River water levels).

Impact on Responders, Continuity of Operations, and Continued Delivery of Services

Water availability can be expected to affect a community's capacity to fight wildfires and major structure fires depending on circumstances. Extreme conditions may require accessing private ponds or other water sources. The high temperatures sometimes associated with drought may impact first responders, even in non-firefighting situations (e.g., routine policing). Services and operations that rely upon the availability of large amounts of quality water may find that their activities are constrained or made much more expensive. Conflicts between water users can arise, with restrictions and limitations in severe cases leading to social unrest.

Impact on the Environment

Drought can impact water bodies, including inland lakes and the Great Lakes themselves, contributing to periods of chronic low-water levels. Hydrological impacts include the potential loss of important wetlands. Extended rainfall deficits may cause groundwater depletion and reductions in water quality. Drought may also impact plant and animal life through a reduction in drinking water and loss of biodiversity. Drought is a contributor to wildfire risk. Air quality can be reduced by an increase in dust and pollutants in the air. Soil quality and quantity are also diminished due to enhanced erosion, especially around freshly exposed areas near lowered lakes and streams. Wood-related industries may be hampered by reduced timber productivity, increased insect infestations, and other factors. Aquatic species may decline as water quantity and quality degrades.

## *Significant Droughts in Michigan*

Many hazards that are brief and result in acute impacts (e.g., tornadoes, ice storms, power outages) are relatively easy to historically list. Droughts on the other hand may take several seasons to become problematic or impactful, persist for long periods, and often take years to fully resolve. Significant drought has become relatively rarer for Michigan in the past 20-30 years. The following list is not comprehensive but attempts to include many of the most notable Michigan droughts since the 1930's "Dust Bowl" era. References to CDs may be used (see previous page).

2012: National, including Michigan

Drought conditions developed rapidly during the late winter and early spring of 2012. They were preceded by an unusually mild winter including five consecutive months of above-normal temperatures back to October 2011 and below-normal seasonal snowfall totals. Overwintering vegetation came out of dormancy much earlier due to a heat wave in the middle of March which also started earlier vegetative watering. Hot and dry weather persisted for much of June through early August. Given the abnormally early start of the growing season, drought conditions developed rapidly across the central and southern Midwest and spread into Michigan during June. By mid-July, the percentage of the state experiencing drought conditions and/or abnormal dryness as defined by the DM had grown to 82%. The area of severe or worse drought conditions expanded to 21%, and extreme drought conditions made their first appearance in a narrow area of southern Lower Michigan along the Indiana border. By early August, three-month precipitation deficits ranged from 1-3 inches over central sections of the state to over six inches across southern sections (normally among the wettest periods of the year). Plant available soil moisture levels in the top five feet of the soil profile of affected areas during the same period fell to levels generally 1-5 inches below normal. At that peak time of the drought, 81% of the Midwest region was classified as abnormally dry. Michigan also saw at least three major heat waves: the third week of June, the first week of July, and the third week of July, the second of which was the most severe and included many temperature readings over 100°F.

The impacts of the 2012 drought varied greatly across Michigan. The largest overall agricultural losses were observed across the southern three tiers of counties in the Lower Peninsula, especially along the Indiana border. For some of the estimated 40% of Michiganders who relied on well water, the drought led to reduced capacity or failed wells, leaving affected homeowners without drinking or toiletry water. The groundwater level in some areas of the state dropped up to 40 feet by mid-summer. In areas where groundwater is relatively less abundant, links between well failure and nearby agricultural irrigation were observed, as irrigation wells are typically drilled much deeper than most home wells and have high pumping capacities, resulting in a potentially significant cone of depression in the local water table. Economic losses in the state's agricultural sector associated with the drought were at least partially masked by relatively high commodity prices. For some individual crops, however, losses were significant. Corn production across the state dropped more than 17 million bushels relative to 2011, with a market value loss of more than $100M. Forage crops were also severely impacted, with a 43.3% reduction in production. Low feed supplies led to higher-than-normal prices, with mixed grass/alfalfa hays selling for $300-$380 a ton by year's end. The reduced feed inventory and increased pressure for acres from commodity crops (corn, soybeans, and wheat) hindered producers' efforts to replenish hay stocks. Low feedstocks and high feed prices also caused many livestock feeders to eliminate breeding herds. A natural disaster declaration was made on August 29 for all of Michigan's 83 counties due to the drought and excessive heat that began on March 1, 2012.

<u>2005-2007: Northern Michigan (also Great Lakes Water Levels and Muskegon County)</u>
The Upper Peninsula suffered from drought conditions that started in mid-2005 and persisted with few interruptions through 2009 in its western half. Most parts of Michigan experienced only occasional moderate impacts throughout these years. Northern Michigan, especially the Upper Peninsula, was the most strongly impacted. In 2007, the hay crop in the Eastern Upper Peninsula was only 50% to 70% of normal, and the resulting lack of feed led some farmers to downsize their cattle herds. Forests became stressed. In the northern tip of the Lower Peninsula, near-constant irrigation by the proprietors of farms and golf courses was needed. Corn and bean crops were severely impacted. A burning ban was also issued for most of the state to reduce the risk of wildfires. The statewide drought level in 2005 reached a low point of -3.53 PDSI in October, and drought levels remained moderate (D2) during 2007. CDs 2, 8, and 9 reported at least six consecutive months of drought conditions during 2005, including -3.78 (CD8) and -3.38 (CD9). The western Upper Peninsula only saw four months of drought in 2005 (reaching a low of -3.25 in September) but then saw long-term drought conditions begin in mid-2006 and remain until March of 2008, followed several months later by another year of sustained drought from August 2008 through July 2009. CD2 experienced a long drought period that began in May 2005, almost exclusively remaining through August 2007.

This was also a period of low water levels in the Great Lakes, although there is debate as to how much this was caused by overall drought conditions. A super-freighter became stuck in the mouth of Muskegon Harbor during late summer, 2007, and was reported as the second large ship to run aground within the month, at the same location. Shipping officials stated that additional dredging was needed in Great Lakes ports because of the low water levels.

<u>1998-2003: National, including Michigan</u>
Droughts caused considerable damage to several areas of the US during this time period. A 2001 drought and heat wave impacting Michigan damaged or destroyed approximately one-third of the state's fruit, vegetable, and field crops, resulting in a USDA Disaster Declaration for 82 of the state's counties. In addition, the event caused water shortages in many areas in southeast Michigan, forcing local officials to issue periodic water use restrictions. The summer of 2002 was also very hot and dry, with several record highs set in September throughout eastern Michigan. During the first half of the month, hundreds of communities across the area were under water restrictions. The hardest hit by the drought was the agricultural industry. September yields across most of the area were estimated at under 50% and many eastern Michigan counties were declared agricultural disaster areas. The drought status lasted through mid-2003.

<u>April 1988 - September 1988: National, including Michigan</u>
One of the worst on record, for many areas of Michigan the 1988 drought was as severe as the 1934 "Dust Bowl" era or worse. It was preceded by a drier than normal winter before a prolonged anomalous weather pattern effectively prevented the flow of moisture from the Gulf of Mexico into Michigan and other areas. Total precipitation across much of the Great Lake's region during April 1 – June 30 was less than half normal. From May 1 – June 30, Flint recorded

just 0.97 inches of rain, and Saginaw and Detroit both recorded their driest June of the century. The drought was also accompanied by extreme heat (see the related chapter). During June, the entire state was categorized by the PDSI as "Extreme Drought" (the worst possible category). Impacts from the drought varied by sector. Urban water restrictions were implemented to maintain adequate pressure in fire hydrants. Rural homeowners with wells sometimes needed to extend their well points or drill new ones. Agriculture was particularly impacted during critical crop growth stages, resulting in record or near-record reductions from normally expected crop yields. Stream flows in many areas of Michigan rapidly fell to less than 50% of median levels by May and neared or exceeded all-time lows and/or dried up by early summer. Low regional stream flows impaired barge transportation on the Ohio and Mississippi Rivers. The movement of many commodities was shifted to railroads and Great Lakes ports. In June, USACE was requested to consider directing an increase in the amount of water diverted from Lake Michigan into the Illinois River (the project did not happen). The nationwide economic impact of the 1988 drought was estimated at $60B, ranking it the costliest national drought event ever.

<u>September 1976-July 1977: National, including Michigan</u>
This drought impacted much of the US and severely hit Northern Michigan. Extreme drought conditions in the Upper Peninsula contributed heavily to the large wildfire that struck the Seney area in 1976. The drought had involved a significant reduction in rainfall (6-8 inches below normal) in the area, and the water table in the Seney National Wildlife Refuge dropped a full foot, exposing old vegetation, peat, and muck to the drying forces of intense sunlight. The loss of forest resources was staggering. At a statewide level, the drought lasted for 11 consecutive months, from September 1976 to July 1977, and reached a low point in January 1977, with a PDSI of -5.29 (D4). Although CD1 only had nine months of drought, it set its all-time lowest PDSI record with a -7.33 in January 1977. Other northern Michigan CDs similarly had shorter but exceptional drought levels, with CD2 hitting a -5.14 PDSI in December 1976 and CD6 reaching -5.61 in July 1977. CD4 reached a -5.37 PDSI low and CD3 reached a -5.06 low, both during January 1977.

<u>November 1962-December 1964: Michigan (statewide)</u>
Every part of Michigan experienced at least eight continuous months of drought. Statewide drought levels lasted for 26 consecutive months, from November 1962 to December 1964. CDs 8, 9, and 10 saw even longer drought durations, nearly three years long. The overall drought index statewide reached exceptional D4 levels in November 1963 and stayed there for five months, with the worst point reached in February 1964 (PDSI of -5.97). Within the three southernmost CDs, southwestern Michigan stayed within the extreme D3 classification level with a low PDSI value of -4.22 in February 1964. The central and eastern portions of the southern Lower Peninsula reached exceptional D4 drought levels, with CDs 9 and 10 both reaching their low points in February 1964 with respective values of -6.15 and -6.40.

<u>July 1955-February 1956: Northeastern Michigan</u>
Statewide, an eight-month drought period was measured with PDSI values that reached the severe D2 level, with a low value of -3.37 reached in September of 1955. CDs 2, 3, 4, and 5 all felt this drought for a period of at least six consecutive months, with the longest stretch of uninterrupted drought occurring in CD4, lasting for an entire year from July 1955 through June 1956 and reaching a low point with exceptional D4 drought severity involving a PDSI of -5.00 in February 1956. CDs 2 and 3 reached the extreme D3 drought level, and CD5 reached a severe D2 level during this event.

<u>October 1947-December 1949: Northern Michigan</u>
A serious drought within CDs 1, 2, and 4 lasted for two years. The northeastern Lower Peninsula saw 17 continuous months of drought from August 1948 to December 1949, culminating in the extreme D3 level with a PDSI of -4.68. The eastern Upper Peninsula was also very heavily struck, during 13 consecutive months from October 1947 to October 1948, and that final month saw the area's all-time lowest PDSI at -5.65. CD1 suffered the longest of any area in this event, with droughts during almost the entire period of October 1947 to April 1949. The PDSI there got as low as -5.74 in October 1948 and stayed at that exceptional D4 drought level until the end of that year.

<u>1930s: National, including Michigan</u>
The "Dust Bowl" droughts were the backdrop for John Steinbeck's book *The Grapes of Wrath*. Widespread exceptional drought conditions from years without rain were exacerbated by poor land management practices. Great clouds of dust and sand, carried by the wind, covered everything. Millions of acres of farmland became useless, forcing hundreds of thousands of people to leave their farms. Although exact figures were not kept, some researchers estimate that nearly $1B (in 1930s dollars) was provided in assistance to victims of the Dust Bowl drought.

In Michigan, this period took the form of a most severe statewide drought condition from August 1930 to August 1931, followed by a less extreme but longer-lasting period from August 1933 to May 1935, in which the general pattern involved Michigan's south and western areas seeing the hardest conditions, and finally a period of more limited problems between

1936 and April 1940. The most extreme conditions occurred in early 1931 when all-time record-low Palmer Index values occurred for 8 out of Michigan's 10 climate divisions. The lowest Palmer Drought Index values ranged from -6.06 (CD5) to -6.98 (CD10). The all-time low statewide PDSI of -7.73 occurred in February 1931. The areas that experienced the more prolonged conditions of drought were also the most heavily agricultural areas of the state, in the southern Lower Peninsula. Nevertheless, the entire state was struck very hard. The CD8 experienced 27 consecutive months of drought between July 1930 and September 1932.

### *Select Agencies, Programs, or Laws*

State of Michigan
Drought monitoring for the state is a multi-agency, collaborative effort. Depending on the nature and extent of the situation, a state-level task force may be set up to promote cooperation, coordination, and good information flow among participating agencies.

United States Department of Agriculture
The USDA has a variety of programs designed to provide assistance to farmers and other agricultural enterprises adversely impacted by natural disasters, including drought. The USDA FSA can provide emergency loans to farmers, ranchers, and agricultural business operators who have suffered property loss or economic injury. Emergency loans are made to qualified applicants in those counties designated by FEMA as eligible for Federal disaster assistance under a Presidential Disaster Declaration, or those that have been specifically designated in a Secretary of Agriculture disaster declaration. Eligible applicants in counties contiguous to declared or designated counties may also qualify. The USDA Natural Resources Conservation Service can provide technical and financial assistance to farmers and agriculture operators for land and water conservation-related efforts aimed at recovering from the adverse impacts of drought and other natural disasters.

National Integrated Drought Information System
This multi-agency partnership provides a Michigan-specific webpage and also lists the activities associated with regional Drought Early Warning Systems (DEWS) networks. The DEWS activities focus on five key areas: monitoring, forecasting, planning/preparedness, outreach, and interdisciplinary research.

United States Geological Survey
The USGS is the primary federal agency that collects and analyzes streamflow data, a good index of the relative severity of drought. Its Water Watch product for Michigan is one of many available maps and tools. Additional information related to USGS stream gages can be found in the Flooding Overview section of this publication.

Michigan State University (MSU) Extension
The MSU Extension weather page includes video forecasts especially geared towards agricultural producers when conditions may impact their operations. Extension also provides information as part of efforts to help mitigate farm stress and create resilient agriculture.

National Drought Mitigation Center and International Drought Information Center (IDIC)
The NDMC and IDIC, located at the University of Nebraska-Lincoln, are research programs and central coordinating points for drought-related programs and initiatives. The NDMC Drought Risk Atlas provides historical drought information and a web-based tool to visualize and assess drought risk.

The Center for Food Security and Public Health
Located at Iowa State University, the Center helps to coordinate rural community-oriented web sources on topics such as drought. It includes material specifically related to drought's effects on crops and livestock.

# WILDFIRES

*An uncontrolled fire in forested areas, brushlands, and prairies.*

### *Hazard Description*

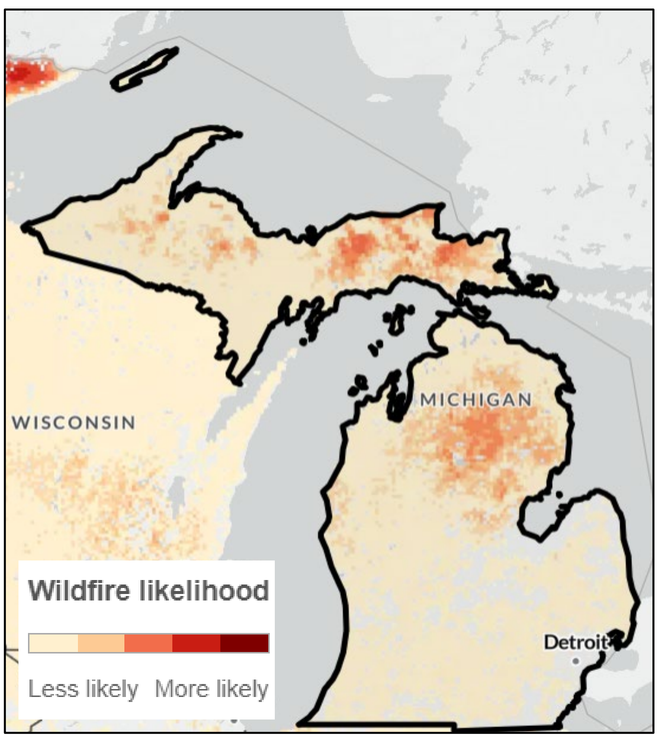
Wildfires are most frequently associated with forests but can be more broadly thought of as any unplanned or uncontrolled fire in areas predominated by combustible vegetation. Many grasslands, bushlands, and mixed ecosystems fall into this loose definition, although swamps and more rocky areas may present natural firebreaks depending on seasonal and other conditions. Timber type, drought, dead wood, and high winds/temperatures are contributing factors. Croplands and structures may become engulfed depending on where the fire spreads. While sometimes a natural phenomenon (e.g., lightning), human-related factors may directly or indirectly be a source of ignition.

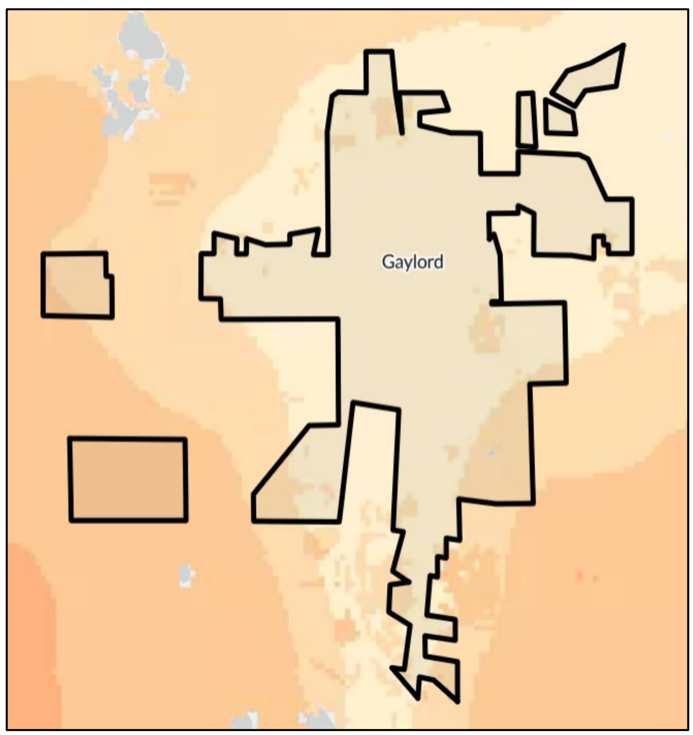
### *Hazard Analysis*

Michigan was roughly 95% forested prior to Euro-American settlement, with forests now still covering roughly 53% of the State's total land area (roughly 20 million acres). Michigan has nearly 4 million acres of official state forest land that sees management practices such as harvesting and replanting. Forests may be described based on a predominant species, ecological classification, or resource use (e.g., timberlands). This vast forest system is a boon for the environment, recreation, and industry. Despite these benefits, every forest holds the potential for wildfire.

This danger is particularly relevant to many rural/remote areas of development outside of city cores, although urban forestry and city park systems should also be properly managed. Some plants are particularly flammable due to high resin and other factors (e.g., junipers, pines, firs, spruces). The National Wildfire Coordinating Group (NWCG) (and others) utilize highly detailed modeling to predict how different types of land may burn under specific scenarios.

The USDA has created wildfire analysis resources and customized tools. Below are screenshots for the state and the community of Gaylord as examples. The tool indicates that populated areas in Michigan have, on average, greater wildfire likelihood than 14% of other states. Populated areas in Gaylord have, on average, greater wildfire likelihood than 42% of communities in the US.

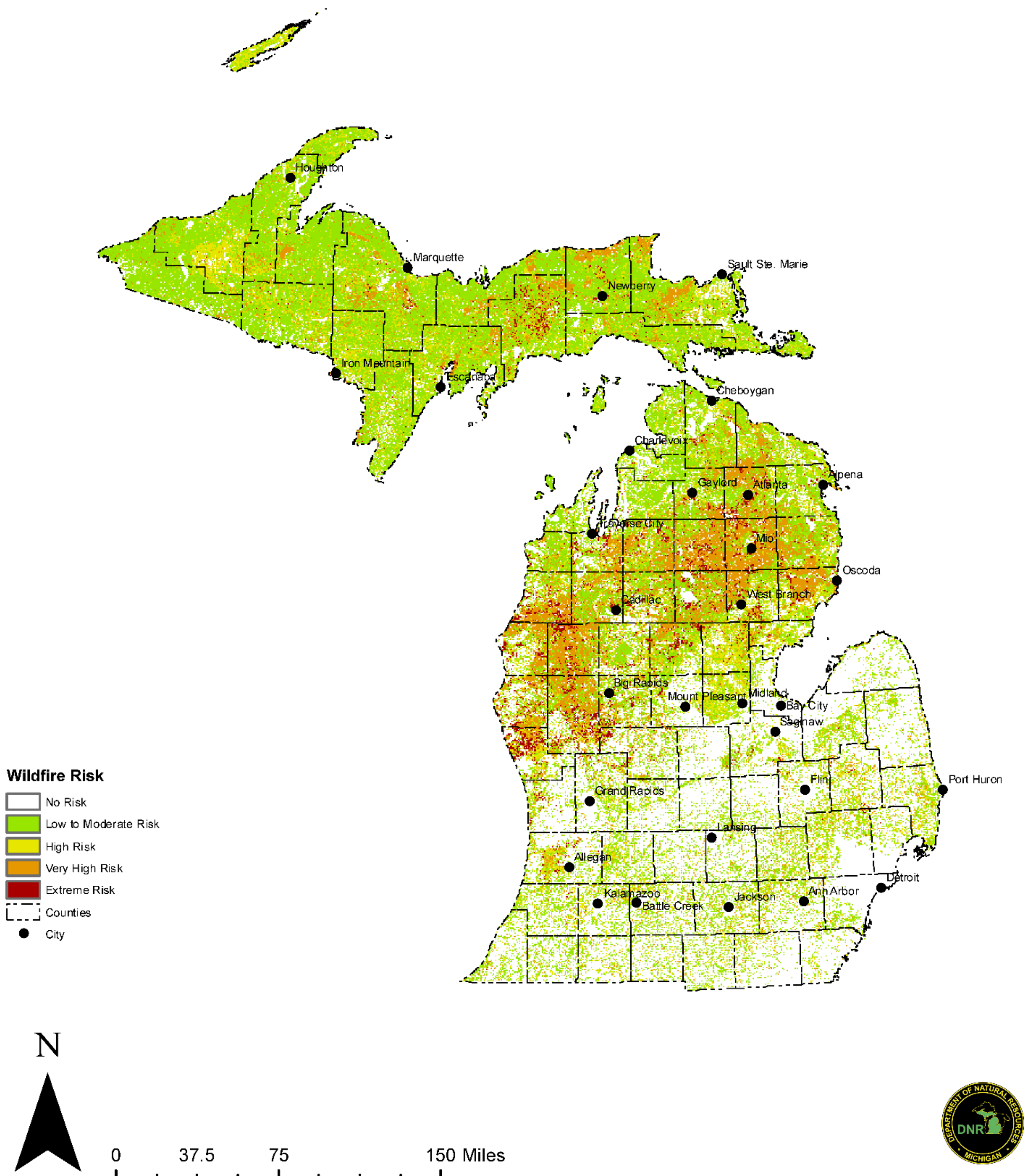



(source for both images and accompanying statistics: USDA Wildfire Risk to Communities screenshot, June 12, 2023)

A statewide wildfire risk map from the Department of Natural Resources (DNR) is included on the following page.

# Wildfire Risk




Source: Michigan Department of National Resources
Forest Resources Division, May 2023

While prairie areas can be flammable and must be considered, the bulk of near-term historical occurrences shows that forests present a relatively greater danger. Based upon a 2004 inventory by the USDA, the percentage of forested land cover is the highest across the entire Upper Peninsula (more than 75% of the total land area) and the Lower Peninsula counties of Cheboygan, Crawford, Kalkaska, Lake, Montmorency, Oscoda, Otsego, Presque Isle, and Roscommon. Wildfires and their smoke readily cross political boundaries, and local emergency managers should familiarize themselves with fire risks present in other counties, neighboring states, and Canada. Areas of poor tree health, especially due to recent insect infestation or disease, may result in standing dead timber.

Conditions that make areas susceptible to wildfire mean nearby regions may see multiple fires at one time or in quick succession. Areas of poor tree health, including insect infestation or disease, may result in standing dead timber. Some fires may take several days to completely extinguish, which may complicate sheltering even for those whose homes remain untouched. Monitoring operations are frequently required to ensure fires are not rekindled.

Debris burning is the leading cause of DNR response to wildfires. Lightning strikes caused fewer fires but were associated with the greatest number of acres burned (potentially because they may start in difficult to access remote areas). Equipment such as vehicles may start fires from hot/sparky exhaust or engine blocks hovering over grass and leaves.

**DNR Responded Wildfires (Attributable Cause)**

Number of Michigan Events & Acres Burned (2006-2021)

| **Activity/Cause** | **By # of Events** | **By Acres Burned** |
|---|---|---|
| Debris burning | **30.1%** | 20.3% |
| Undetermined / Misc. | 25.7% | 17.4% |
| Equipment | 13.7% | 4.2% |
| Campfires | 8.5% | 2.1% |
| Lightning | 5.1% | **52.1%** |
| Powerline | 4.9% | < 1% |
| Arson | 4.0% | 1.6% |
| Children Fires | 2.6% | < 1% |
| Railroad Fires | 2.1% | < 1% |
| Structural fires | 1.4% | < 1% |
| Smoking | 1.3% | < 1% |
| Fireworks | < 1% | < 1% |

(source: Michigan DNR, 2022)

Prescribed burning is an important management tool used by the DNR and other organizations. They may become uncontrolled due to inherent risk, unforeseen conditions, or attempted burns by poorly trained or unauthorized parties.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure

The destructive properties of wildfire are described in the historical examples (below). Isolated structures or entire towns may be put at risk. Sheltering may be required. Fires may close roadways and air travel due to flames or smoke. Electric power may be impacted, sometimes intentionally (to protect firefighters). Property damages are largely driven by the amount of developed areas affected. Michigan events in recent decades have not resulted in human deaths but have done so in the past. Impacts can also be widespread from smoke, ash, and debris that may travel far away via air and water. Exposure to smoke may be especially problematic for certain cohorts (e.g., people with asthma, the elderly).

Impact on the Economic Condition of the State

The state economy as a whole is typically not affected, with the timber industry being a notable exception. Agriculture and tourism can also see moderate localized impacts. Smaller communities in rural areas may see more significant or longer-lasting effects. Costs for successfully responding to fires can still be significant, especially for areas where they are common and budgets need to be shifted.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services

Wildfires involve special training and equipment. Heat, smoke, and remote locations present risks that may make areas inaccessible or ground planes and helicopters used in operations. Equipment staging, coordination, and communications may be impacted by multiple fires over large areas. Normal services are typically restored within a few days unless specific governmental structures catch fire or are part of an evacuation area.

Impact on the Environment

Large tracts of vegetative land may be completely destroyed and take years to recover. The extent of tree damage will vary based on factors such as time of exposure, bark thickness, prior tree health, and whether fires remained on the ground or reached treetops. Wildfires may also cause dramatic changes to the ecosystem, permanently altering the prevalence of some species while allowing for the rapid introduction of new ones. It is worth noting that many Michigan plants were historically dependent on natural fire cycles. The jack pine and mesic prairies are examples, some of which face challenges due to a lack of routine fires. All forms of wildlife may be impacted, through injury, death, or loss of habitat (some animals likewise rely on ecosystems with cyclical fires). Wildfires can be a significant source of particulates in the atmosphere that absorb and scatter solar radiation. They also produce many gases, including carbon monoxide, carbon dioxide, and methane. Both factors have various impacts on animal health, plant growth, and climate conditions.

## *Select Michigan Wildfires*

According to DNR and United States Forest Service (USFS) records, over 5.8 million acres of Michigan forest were burned between 1910-1949 (145,000 acres per year). By comparison, those same organizations were involved in suppressing over 46,100 wildfires that burned 390,000 acres between 1950-1996 (8,300 acres per year). That historical reduction was just the start of modern firefighting techniques and prevention. Some 19th-century events are listed below to demonstrate the true potential of unchecked wildfires. More successful response efforts should not be taken to mean conditional risk has been reduced, particularly as the State's climate changes.

June 3, 2023 – Crawford and Iosco Counties

Dry conditions and an errant campfire near Grayling burned 2,400 acres (most of the damage to state lands), leading to road closures and evacuations. Multiple agencies responded, including agencies from Wisconsin. A county state of emergency was declared, and a five-mile temporary flight restriction was put in place. A utility closed their substation as a precaution. A separate Iosco County fire burned roughly 300 acres before being contained.

June 2023 – Entire State (Canadian Wildfire Smoke)

June saw Canada surpassing its record for the largest area burned by wildfires in a single year. The fires also produced record levels of carbon emissions, with unhealthy smoke levels drifting into Michigan that eventually affected every county. Detroit and other parts of the state were reported as having "the worst air quality in the world" on various days.

May 1, 2018 – Crawford, Wexford, and Newaygo Counties

Three separate wildfires included one near Grayling, estimated at 44 acres that shut down a stretch of I-75 for almost two hours. The "Bond Mill Pond Fire" (Haring Township) was estimated at 79 acres (mostly state forest lands) with several residents evacuated. The USFS provided helicopter support and dumped 1,600 gallons of water before being grounded due to high winds. A fire near Newaygo was estimated at 105 acres in size, with two residents evacuated.

June 29 to July 1, 2016 – Chippewa County

An 82-acre fire in Munuscong was the largest of at least three wildfires responded to that week. No injuries were reported, and no structures were threatened. The USFS also battled a 35-acre fire in the Hiawatha National Forest.

July 30, 2015 – Marquette County

A 100-acre wildfire in Humboldt started in an area where winter logging had occurred, fueled by warm weather and strong winds. At least $150K worth of cut timber was destroyed, with no injuries reported.

May 20 to 31, 2012 – Luce County "Duck Lake Fire"

Lightning strikes started wildfires in the Newberry area and the Seney National Wildlife Refuge. The fire spread rapidly toward Lake Superior, closing some major roads and forcing evacuations in the Pike Lake, Bodi Lake, Culhane Lake, and Little Lake Harbor areas. Over 130 structures were burned (including a store and motel) within the fire's 21,069 acres before it was fully contained (areas smoldered well into June). About $12M in property damage and $600K in resources were expended. A Governor's state of disaster was declared for Luce and Schoolcraft Counties.

May 18 to 26, 2010 – Crawford ("Meridian Boundary Fire") and Kalkaska ("Range 9 Fire") Counties

An out-of-control debris fire burned 8,800 acres, taking several days to reach 95% containment. Six residences were damaged and 12 destroyed, with 36 outbuildings destroyed or damaged, resulting in total property damages of $825K. May 18 also saw a controlled burn go awry in adjacent Kalkaska County. The fire burned 1,100 acres of mostly grassy areas at Camp Grayling but also destroyed 4 seasonal homes in Blue Lake Township.

May 20-26, 2009 – Marquette (“Black River Falls Wildfire”) and Baraga (“Pinery Wildfire”) Counties
A wildfire started when a wind-damaged pine tree fell across a power line, burning 811 acres as it destroyed 21 homes as part of $4M in property damage. Personnel and equipment costs were $100K. A separate fire in Baraga burned 685 acres, with $50K in property damage from a destroyed mobile home and impacted cemetery and trail areas. Firefighting costs were $125K. Both fires took several days to fully extinguish.

April 24, 2008 – Crawford County (“Four Mile Road Fire”)
Fire erupted near Grayling under dry conditions, potentially started by sparks from a passing train. The fire quickly expanded, crossing I-75 (closed for several hours) and eventually burning 1,300 acres. Power outages occurred. Fifty homes were evacuated, with about a half-dozen cabins lost and $287K in damage sustained by the Grayling Game Club. A gas station and motel were threatened but spared. Total property damages were estimated at $750K, and DNR response costs and timber damages were about $619K. Periods of rain helped suppress the fire.

August 2007 – Luce County “Sleeper Lake Fire”
A lightning strike started a remote wildfire that still required the evacuation of some residents three separate times. More than 220 personnel were needed to battle and suppress the 19,000 acre fire. A Governor’s State of Emergency was declared.

April 27-30, 2007 – Baraga County
A prescribed burn by the USFS lost control, consuming 1,300 acres. Over 120 firefighters battled the blaze and helped to evacuate 30 homes in the Covington area. No injuries or structural damages were reported.

April 30-May 1, 2006 – Oscoda County
A Hughes Lake wildfire was started by brush burning in a fire pit. The fire spread at rates nearing two mph with flame heights reaching 300 feet. Stands of jack pine contributed to the intensity of the fire. Approximately 5,950 acres of timber and brushland burned. Sixteen mostly seasonal structures and seven vehicles were destroyed. A number of evacuations were ordered, some as far west as M-18 in southeast Crawford County (most residents returned within a few days). An American Red Cross shelter in Luzerne hosted seven persons. Total damage to property was conservatively estimated at $600K. At its height, almost 300 personnel were involved in fighting the fire, including crews from New Mexico and Montana. Costs incurred in fighting the fire were in excess of $800K.

May-June 2000 - Oscoda and Houghton Counties
Prolonged dry conditions set the stage for a May wildfire near Mio which consumed 5,200 acres in the Huron-Manistee National Forest before being contained a week later. Nearly 300 firefighters and two aerial water tankers were deployed with roughly 30 people evacuated. About a month later, a brush fire at a blueberry farm in Torch Lake Township burned over 350 acres before being contained the next day. Firefighters from the DNR and 15 local fire departments, plus two aerial water tankers, were called to fight the blaze. Over 20 homes and cottages were evacuated.

May 2-7, 1999 – Marquette (Federal FSA-2261, “Tower Lake Complex Fire”), Mackinac, and Oscoda Counties
Aerial firefighting assets were brought in as a wildfire near Champion burned 5,625 acres, destroying at least eight structures, and forcing the evacuation of 450 persons in the broader vicinity (including Van Riper State Park). The fire burned ten bridges and forced the closure of US-41 and M-95 near Champion and Michigamme for several days. Timber losses were $12.8M, with property losses at $960K. During this general timeframe, a fire near Epoufette burned 850 acres over several days while another 850-acre fire burned parts of the Huron-Manistee National Forest in Oscoda. Nearly 40 wildfires were fought in the Northern Lower Peninsula during the first week of May.

May 1990 - Crawford County (“Stephan Bridge Road Fire”)
A wildfire burned 76 homes and 125 other structures, 37 vehicles and boats, and over 5,900 acres of forestland resulting in property losses of $5.5M near Grayling. The timber losses totaled another $700K. The fire originated from a controlled burn, started on snow-covered ground, and was presumed extinguished until rekindled seven weeks later. Strong winds at one point saw the rate of spread at 277 feet per minute. One firefighter was injured from smoke inhalation.

July 1988 – Escanaba (Delta County)
A wildfire caused the evacuation of 60 families and the closure of Highway US-2. Two firefighters were injured.
May 1986 - Marquette County
Multiple wildfires burned 7,000 acres and forced the evacuation of 4,000 people at Sawyer Air Force Base.

May 1980 - Oscoda County “Mack Lake Fire”
A wildfire potentially caused by a prescribed burn destroyed 24,000 acres (including 44 homes/buildings) and forced the evacuation of 1,500 people. One firefighter was killed. Total property and timber losses were $2M.

August-September 1976 - Seney (Schoolcraft County)
The fire was at least partially started by lightning, although smoldering areas from controlled burns exacerbated the situation. The fire started on federal property but eventually also encompassed state and private lands (74,000 acres total). Fire suppression and damage costs exceeded $8M.

May 1968 – Crawford and Kalkaska Counties
The "Fletcher Road Fire" was started by a pipeline welding crew. The fire crowned (reaching treetops) in over 75% of the area and jumped across Fletcher Road, burning at a fast rate of approximately two mph. Tree mortality was almost total within an area of 4,216 acres. A million-dollar gas refinement facility was protected by responder efforts.

July 1911 – Au Sable-Oscoda Fire (Iosco, Cheboygan, Crawford, and Otsego Counties)
Enormous wildfires ravaged the towns of Oscoda and Au Sable, whose 1,800 residents were evacuated by train and steamboat. At Cheboygan, a huge pile of sawdust had been burning for weeks and was beyond control. A railroad suffered heavy losses near Grayling, including 40 cars and two bridges. Property damages were estimated at $100K in Alpena, $300K in Waters, and $500K in Oscoda and Au Sable. Total damages were over $1.5M, along with significant timber losses. At least 500 evacuees were sheltered at Tawas City and East Tawas.

October 1908 – Metz Fire (Presque Isle County)
Droughts exacerbated wildfires converging on Metz. Some evacuees tried to flee by train but found the tracks blocked by fire. A burned-out culvert wrecked the train as they returned, killing 14 passengers. Two other deaths were reported.

Summer 1896 – Ontonagon Fire
A wildfire overtook the town of Ontonagon, with more than 340 buildings burned. Human injuries included one death, although many animals died. Parts of the population needed to relocate to neighboring communities.

August-September 1881 - Thumb Area
Several small fires started for land clearing purposes were fanned by winds, eventually joining together and burning over a million acres until reaching Lake Huron. Property loss exceeded $2M and 282 were killed over six days.

October 1871 - Lower Peninsula
Summer drought created dry tinder, including from logging debris. Many smaller fires smoldered until strong winds generated a widespread catastrophe that burned 2.1 million acres and killed 200 people. An area north of Saginaw Bay was hardest hit. Primarily taking place October 8-19, the fires weren't completely extinguished for over a month. A separate catastrophic fire in Peshtigo occurred during this same time, touching upon Menominee County.

### *Select Laws, Agencies, or Programs*

Michigan Natural Resources and Environmental Protection Act
Part 15 of NREPA (1994 PA 451) assigns responsibility for the prevention and suppression of forest fires to the DNR Director, who may also enter into agreements with other entities to control forest fires. The Act also establishes requirements for burning permits and allows the Governor to issue wildfire-related burning prohibitions.

Michigan Department of Natural Resources Forest Resources Division
The DNR Forest Resources Division directs and coordinates wildfire prevention, containment, and suppression activities on all non-federal lands in the state, as well as certain Tribal lands (under contract with the US Bureau of Indian Affairs). The Division actively works toward reducing the State's vulnerability to wildfires by: 1) participating in multi-state and interagency hazard mitigation efforts, 2) aiding local communities in developing zoning and subdivision control ordinances that adequately address wildfire mitigation, 3) regulating the days and times people are granted permits to burn debris, 4) conducting research on wildfire prevention, containment, and suppression activities, and 5) developing wildfire hazard assessments to aid community and property owners in determining their vulnerability to wildfires. More information is available on their forest management and fire conditions web pages (including a fire danger map).

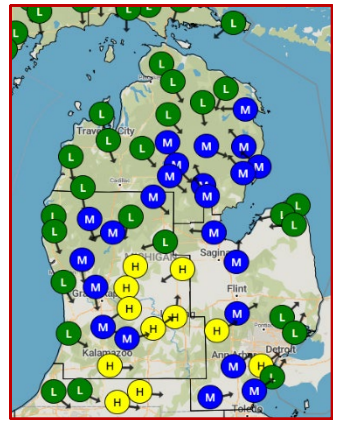
Roscommon Equipment Center (REC) and Forest Fire Experiment Station
The DNR's REC provides fire agencies across the nation with specialized firefighting equipment. Agencies may submit project proposals on their website. Services also include technical assistance and testing.

Great Lakes Forest Fire Compact
This partnership between the states of Michigan, Wisconsin, and Minnesota also includes the Canadian provinces of Ontario and Manitoba. Its purpose is to promote collaboration and effective wildfire control via mutual aid.

Mutual Aid Box Alarm System (MABAS)
A user-driven system designed in part to streamline fire services coordination across Michigan, MABAS is used for both day-to-day mutual aid and for large-scale events such as major fires (including wildfires) that may overwhelm local resources. Illinois, Indiana, Wisconsin, and several other Midwest states have implemented the MABAS program.

National Wildfire Coordinating Group and National Interagency Coordinating Center (NICC)
Both the NWCG and NICC are important coordinating groups, with Michigan assigned to the Eastern Area Coordinating Center's outlook dashboard. The separate Michigan Interagency Wildland Fire Protection Association uses social media to highlight red flag warnings and other alerts.

National Weather Service and Red Flag Warnings
The NWS Storm Prediction Center creates fire weather outlooks and other products. Monitoring and alerting services for Michigan are divided into five regions:




- Upper Michigan – Issued by NWS Marquette
- Northern Michigan – Issued by NWS Gaylord
- Southeast Michigan – Issued by NWS Detroit/Pontiac
- Southwest Michigan – Issued by NWS Grand Rapids
- Northern Indiana – Issued by NWS North Webster

Regional boundaries can be found on the MesoWest Great Lakes Fire & Fuels map (screenshot from June 15, 2023), which includes five counties monitored out of Indiana. Importantly, the NWS issues red flag watches and warnings when wildfire risk is especially dangerous due to high temperatures, low humidity, and gusty winds. Burn bans or restrictions on permits will be enforced along with other precautions.

United States Forest Service and United States Geological Survey Fire Danger Forecast
A joint effort of the USFS and USGS, the Fire Danger Forecast project focuses on research and development of digital map products suited for monitoring and forecasting fire potential and allows for historical lookbacks.

Air Quality Index (AQI) and AirNow
Particulate matter ($PM_{2.5}$), whether from wildfire smoke or other sources, is monitored by a combination of local, state, and federal entities. Available tools include state AQI maps, city ratings from AirNow, and EnviroFlash notifications.

Fire Adapted Communities and Firewise USA
The US Forest Service promotes community efforts to identify wildfire risks so prudent adaptation steps can be implemented, including through the use of mitigation assistance teams. The separate Firewise USA program educates stakeholders (e.g., homeowners, planners, builders, emergency managers, government officials) on design practices that minimize wildfire impacts. Workshops discuss the integration of "firewise" home and landscape as part of verified community planning. Both initiatives distribute publications and tools related to wildland-urban interfaces.

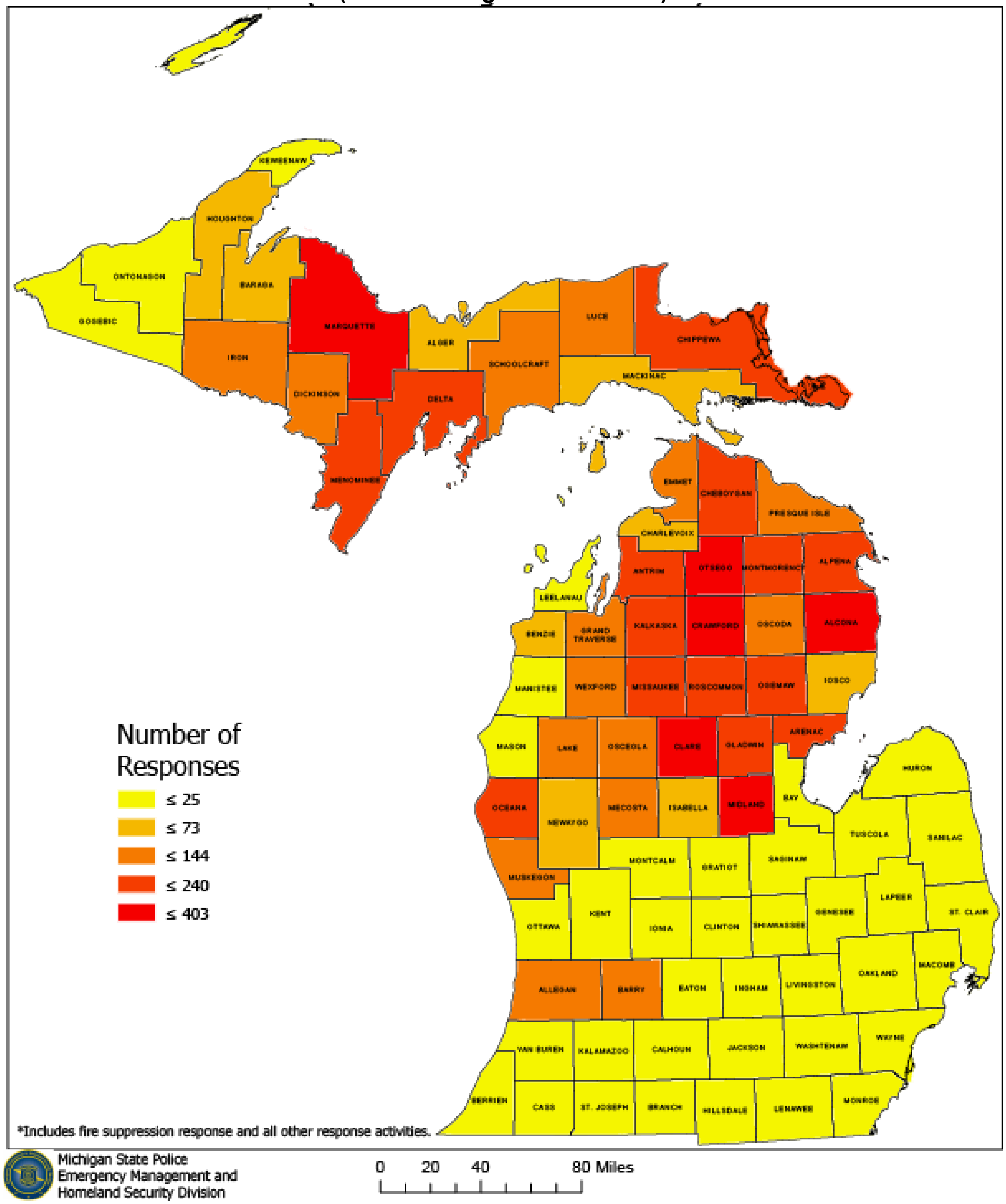
## *Supplementary Materials*

Supplementary material includes information regarding DNR fire response, by county breakdowns of selected data, and general information regarding wildfire fuel categories and modeling.

Data displayed on the following DNR fire response map does not include wildfires suppressed by the USFS on federal lands or those fires responded to by only local fire departments. While some risk trends emerge from the map, it is primarily provided to show general DNR activity. Information provided on the map is also included in a table highlighting the number of acres burned during these responses. It should be noted that there is a relatively smaller DNR fire force in the southern Lower Peninsula, driven by factors such as need, which also skews data. Local fire departments respond to hundreds of wildfires per year and are instrumental in keeping the wildfire threat for southern Michigan in check.

The separate "Wildfire History for Michigan Counties" table also has limitations as it is based on data taken from the NWS, which is not as robust as their information for hazards such as storms, tornadoes, and high winds. The table greatly undercounts the many smaller wildfire events that take place each year but is provided for completeness and to allow for comparisons from similar data sources across multiple natural hazards. It is anticipated that damage totals by hazard will see the National Risk Index (NRI) become a primary data source as the tool is further refined and grows.

## DNR Fire Response* 2006-2022
## (Not including Federal Lands)



## DNR Responses and Acres Burned, DNR Jurisdiction Land Only: 2006-2022

(rows condensed to allow table to fit onto one page)

| County | All Fire Count | Number of Wildfires/Year | All Acres | Average Annual Acres |
|---|---|---|---|---|
| Alcona | 278 | 16.4 | 1,212 | 71.3 |
| Alger | 54 | 3.2 | 208 | 12.2 |
| Allegan | 111 | 6.5 | 422 | 24.9 |
| Alpena | 240 | 14.1 | 293 | 17.2 |
| Antrim | 207 | 12.2 | 186 | 11.0 |
| Arenac | 156 | 9.2 | 549 | 32.3 |
| Baraga | 73 | 4.3 | 1,951 | 114.7 |
| Barry | 99 | 5.8 | 403 | 23.7 |
| Bay | 25 | 1.5 | 181 | 10.7 |
| Benzie | 44 | 2.6 | 199 | 11.7 |
| Berrien | 6 | 0.4 | 6 | 0.4 |
| Branch | 3 | 0.2 | 155 | 9.1 |
| Calhoun | 2 | 0.1 | 4 | 0.2 |
| Charlevoix | 61 | 3.6 | 122 | 7.2 |
| Cheboygan | 192 | 11.3 | 333 | 19.6 |
| Chippewa | 152 | 8.9 | 1,021 | 60.1 |
| Clare | 387 | 22.8 | 605 | 35.6 |
| Clinton | 4 | 0.2 | 52 | 3.1 |
| Crawford | 327 | 19.2 | 18,348 | 1,079.3 |
| Delta | 152 | 8.9 | 484 | 28.4 |
| Dickinson | 127 | 7.5 | 481 | 28.3 |
| Emmet | 108 | 6.4 | 233 | 13.7 |
| Gladwin | 226 | 13.3 | 513 | 30.2 |
| Gogebic | 11 | 0.7 | 16 | 1.0 |
| Grand Traverse | 110 | 6.5 | 459 | 27.0 |
| Gratiot | 4 | 0.2 | 94 | 5.5 |
| Houghton | 40 | 2.4 | 38 | 2.2 |
| Huron | 4 | 0.2 | 722 | 42.5 |
| Ingham | 6 | 0.4 | 39 | 2.3 |
| Ionia | 3 | 0.2 | 42 | 2.5 |
| Iosco | 64 | 3.8 | 1,012 | 59.5 |
| Iron | 144 | 8.5 | 816 | 48.0 |
| Isabella | 69 | 4.1 | 349 | 20.5 |
| Jackson | 5 | 0.3 | 73 | 4.3 |
| Kalamazoo | 6 | 0.4 | 53 | 3.1 |
| Kalkaska | 156 | 9.2 | 1,617 | 95.2 |
| Kent | 12 | 0.7 | 108 | 6.4 |
| Keweenaw | 19 | 1.1 | 191 | 11.2 |
| Lake | 97 | 5.7 | 455 | 26.8 |
| Lapeer | 19 | 1.1 | 235 | 13.8 |
| Leelanau | 19 | 1.1 | 146 | 8.6 |
| Lenawee | 6 | 0.4 | 137 | 8.1 |
| Livingston | 22 | 1.3 | 350 | 20.6 |
| Luce | 91 | 5.4 | 39,427 | 2,319.3 |
| Mackinac | 72 | 4.2 | 190 | 11.2 |
| Manistee | 13 | 0.8 | 67 | 4.0 |
| Marquette | 403 | 23.7 | 1,907 | 112.2 |
| Mason | 11 | 0.7 | 97 | 5.7 |
| Mecosta | 104 | 6.1 | 292 | 17.2 |
| Menominee | 201 | 11.8 | 532 | 31.3 |
| Midland | 270 | 15.9 | 338 | 19.9 |
| Missaukee | 151 | 8.9 | 334 | 19.6 |
| Monroe | 4 | 0.2 | 512 | 30.1 |
| Montcalm | 13 | 0.8 | 161 | 9.5 |
| Montmorency | 206 | 12.1 | 2,759 | 162.3 |
| Muskegon | 95 | 5.6 | 710 | 41.7 |
| Newaygo | 52 | 3.1 | 286 | 16.8 |
| Not Applicable | 4 | 0.2 | 1 | 0.0 |
| Oakland | 5 | 0.3 | 33 | 1.9 |
| Oceana | 196 | 11.5 | 589 | 34.7 |
| Ogemaw | 165 | 9.7 | 1,497 | 88.1 |
| Ontonagon | 20 | 1.2 | 93 | 5.5 |
| Osceola | 142 | 8.4 | 299 | 17.6 |
| Oscoda | 89 | 5.2 | 202 | 11.9 |
| Otsego | 357 | 21.0 | 448 | 26.4 |
| Ottawa | 9 | 0.5 | 34 | 2.0 |
| Presque Isle | 111 | 6.5 | 349 | 20.5 |
| Roscommon | 184 | 10.8 | 505 | 29.7 |
| Saginaw | 1 | 0.1 | 4 | 0.2 |
| Sanilac | 10 | 0.6 | 31 | 1.8 |
| Schoolcraft | 114 | 6.7 | 3,977 | 233.9 |
| Shiawassee | 4 | 0.2 | 42 | 2.5 |
| St. Clair | 13 | 0.8 | 246 | 14.5 |
| St. Joseph | 2 | 0.1 | 16 | 0.9 |
| Tuscola | 8 | 0.5 | 494 | 29.1 |
| Van Buren | 18 | 1.1 | 48 | 2.8 |
| Washtenaw | 7 | 0.4 | 55 | 3.3 |
| Wayne | 2 | 0.1 | 42 | 2.5 |
| Wexford | 128 | 7.5 | 764 | 45.0 |
| **Totals** | **7,125** | **419.2** | **92,291** | **5,428.9** |

Data from NCEI related to wildfires has acknowledged limitations and is underreported. It is provided in this chapter as supplementary information and to enable direct data comparisons versus other hazards.

**Michigan Wildfire* Data (Arranged by Geography, 1/1/1996 - 4/30/2023)**
(see Appendix A for information related to geographic groupings)

| COUNTY/AREA | Reported Wildfire Events | Total Property Damage | Total Crop Damage | Injuries |
|---|---|---|---|---|
| Washtenaw | | | | |
| Wayne | | | | |
| Livingston | | | | |
| Oakland | | | | |
| Macomb | 2 | $20,000 | | |
| **5 County Metro Area** | **0.4 avg.** | **$20,000** | **$0** | **0** |
| Berrien | | | | |
| Cass | | | | |
| St. Joseph | | | | |
| Branch | | | | |
| Hillsdale | | | | |
| Lenawee | | | | |
| Monroe | | | | |
| Van Buren | | | | |
| Kalamazoo | | | | |
| Calhoun | | | | |
| Jackson | | | | |
| Allegan | | | | |
| Barry | | | | |
| Eaton | | | | |
| Ingham | | | | |
| Ottawa | | | | |
| Kent | | | | |
| Ionia | | | | |
| Clinton | | | | |
| Shiawassee | | | | |
| Genesee | | | | |
| Lapeer | | | | |
| St. Clair | | | | |
| Muskegon | | | | |
| Montcalm | | | | |
| Gratiot | | | | |
| Saginaw | | | | |
| Tuscola | 1 | | | |
| Sanilac | | | | |
| Mecosta | | | | |
| Isabella | | | | |
| Midland | | | | |
| Bay | | | | |
| Huron | | | | |
| **34 County Southern Lower Peninsula** | **0.03 avg.** | **$0** | **$0** | **0** |

(continued on next page)

| COUNTY/AREA | Reported Wildfire Events | Total Property Damage | Total Crop Damage | Injuries |
|---|---|---|---|---|
| Oceana | | | | |
| Newaygo | | | | |
| Mason | | | | |
| Lake | | | | |
| Osceola | | | | |
| Clare | | | | |
| Gladwin | | | | |
| Arenac | | | | |
| Manistee | | | | |
| Wexford | | | | |
| Missaukee | | | | |
| Roscommon | 1 | | | |
| Ogemaw | | | | |
| Iosco | 1 | $40,000 | | |
| Benzie | | | | |
| Grand Traverse | | | | |
| Kalkaska | 1 | $125,000 | | |
| Crawford | 2 | $1,575,000 | | |
| Oscoda | 2 | $600,000 | | |
| Alcona | | | | |
| Leelanau | | | | |
| Antrim | | | | |
| Otsego | | | | |
| Montmorency | | | | |
| Alpena | | | | |
| Charlevoix | | | | |
| Emmet | | | | |
| Cheboygan | | | | |
| Presque Isle | | | | |
| **29 County Northern Lower Peninsula** | **0.2 avg.** | **$2,340,000** | **$0** | **0** |
| Gogebic | | | | |
| Iron | | | | |
| Ontonagon | 1 | | | |
| Houghton | 1 | $200,000 | | |
| Keweenaw | 1 | $10,000 | | |
| Baraga | 2 | $50,000 | | |
| Marquette | 7 | $5,006,000 | $1,000,000 | 4 |
| Dickinson | | | | |
| Menominee | | | | |
| Delta | 1 | $20,000 | | |
| Schoolcraft | 2 | | | |
| Alger | 1 | | | |
| Luce | 2 | $12,040,000 | | |
| Mackinac | | | | |
| Chippewa | | | | |
| **15 County Upper Peninsula** | **1.2 avg.** | **$17,326,000** | **$1,000,000** | **4** |
| **MICHIGAN TOTAL**** | **28** | **$19,686,000** | **$1,000,000** | **4** |
| **Michigan Annual Avg.** | **1** | **$720,328** | **$36,591** | **0.15** |

*Uses NCEI Storm Data for "Wildfire" category. **One event may take place in multiple counties. State totals may be less than the sum of all counties.

**Fuel Categories and General Modeling Considerations**
Anything that can burn is fuel for a wildfire, but some types of vegetation generally present greater risks than others. Fuel type and changing status is a major consideration in varying models produced by MesoWest, the NWCG, and others. For general educational purposes, one older but easier to understand “fuel category” grouping is provided from FEMA publication 386-2 (Understanding Your Risks). Its summarized fuel categories include:

LIGHT FUEL CATEGORY – Covers any of the following general descriptions of vegetation in an area:

1. Predominantly marsh grasses and/or weeds.

2. Mosses, lichens, and low shrubs are the predominant ground fuels but have no overstory and/or occupy less than one-third of the site.

3. Grasses and/or forbs predominate. Any woody shrubs will occupy less than one-third of the site. An open overstory of conifer and/or hardwood trees may be present.

4. Brush, shrubs, tree reproduction, or dwarf tree species predominate, but this is only considered light fuel if the average height of woody plants is less than six feet, and they occupy less than one-third of the site.

5. Deciduous broadleaf tree species predominate, and the area has not been thinned or partially cut (which would create a higher-risk fuel source called slash).

6. Conifer species predominate, but the primary ground fuels are grasses and forbs. If the primary ground fuels are duff and litter, branch wood, and tree boles, then the area can only be considered "light fuel" if pine needles are two or more inches in length, the overstory is not decadent, and only a nominal accumulation of debris.

MEDIUM FUEL CATEGORY – Covers any of the following general descriptions of vegetation in an area:

1. Mosses, lichens, and low shrubs are the predominant ground fuels, and an overstory of conifers occupies more than one-third of the site.

2. Grasses and/or forbs predominate, with woody shrubs occupying between one-third and two-thirds of the site.

3. Brush, shrubs, tree reproduction, or dwarf tree species predominate, and woody plants are either greater than six feet in height or cover more than one-third of the site.

4. Conifer species predominate, and the understory is dominated by lichens, mosses, low shrubs, woody shrubs, and/or reproduction. If primary ground fuels are duff and litter, branch wood, and tree boles, and pine needles are less than two inches long, then the overstory must not be decadent with only a nominal accumulation of debris.

HEAVY FUEL CATEGORY – Covers any of the following general descriptions of vegetation in an area:

1. Deciduous broadleaf tree species predominate in an area that has been thinned or partially cut, leaving slash as the major fuel component.

2. Conifer species predominate, with duff and litter, branch wood, and tree boles as the primary ground fuels, and an overstory that is overmature and decadent, with a heavy accumulation of dead tree debris.

3. Slash is the predominant fuel in the area (counts as heavy fuel at any level of loading, regardless of whether settling has been significant or slight, and whether foliage is attached or falling off).

This particular FEMA publication also combined fuel categories with assessments of local topography to then determine overall risk categories. Additional factors used in tools and models often include weather conditions and human factors such as the number of people residing, visiting, or traveling through an area. Some people may increase fire risks through camping activities or carelessness while others (e.g., community spotters) may reduce risks. The location of fire-fighting personnel, equipment, and water sources are just a few of the many factors that can be considered.

# INVASIVE SPECIES

*A non-native species that would cause harm upon establishing itself in Michigan.*

## Hazard Description

The interface between emergency management and invasive species is considered on a case-by-case basis. For purposes of this publication, an invasive species is defined as being non-native (alien) to Michigan and establishing itself, or threatening to establish itself, in a manner that causes harm to ecosystems or the economy. The term “nuisance” may be associated with these species, but not all nuisance animals/plants are invasive simply because of their behavior. Broader definitions vary, with some species (e.g., salmon, pheasants) not native to the state being viewed as desirable and naturalized. *This chapter highlights select invasive species that may negatively impact Michigan, not all of which overlap with emergency management.* Invasive organisms (i.e., microbial pathogens) are not covered in this chapter.

## Hazard Analysis

Invasive species enter the state through migration or as assisted by human activity. Not all invasives entering Michigan are able to establish a breeding population and may simply die off after a period of time. This is especially true for species that find the ecosystem inhospitable. A changing climate may allow specific species to survive where they had not been able to before, intensifying the need for stakeholders to build improved prevention/detection systems and to coordinate response.

Direct human involvement may be accidental (unknown transport of species), negligent (pets/gardens), or even purposeful. Tourism and multimodal trade activities are common sources. This includes invasives in shipping containers of food or other materials, or as carried on animals or even people. Trucks, rail, airplanes, and boats all have areas where species may temporarily shelter. The purposeful introduction could be for nefarious or benevolent reasons. For example, non-native species are widely used in agriculture, to prevent erosion, to provide fishing/hunting opportunities, or to even combat other species. There exists a risk for beneficial species to have unintentional impacts.

Invasives can become successful if no natural controls (e.g., predators, disease) exist, allowing them to out-compete native populations or otherwise establish a foothold. Examples include the mundane to the exotic, many of which have become naturalized to the point where people simply assume they are native. This includes crabgrass, dandelions, and German cockroaches. Some invasive species are legally designated by the state as being prohibited or restricted.

## Specific Impacts

Impact on the Public, Property, Facilities, and Infrastructure

Property owners’ trees or ornamental plants may be affected. Dying trees may be more fire-prone or susceptible to windstorms, potentially causing utility line or property damage. Local food supplies may be affected. Some species may clog water inlets or alter municipal water quality. Although invasive species primarily cause ecological damage, direct threats to public safety may occur. Some species may be toxic or produce disease. Impacted trees may fall and cause injury. Carp jumping out of the water have knocked people out of boats.

Impact on the Economic Condition of the State

Government and households may suffer economic harm. Millages may be raised for local spray or other control programs. Forestry, agriculture, and horticulture industries have been significantly impacted in the past. Local farmer’s markets or some fairs may be situationally affected. Ballast water issues have the potential to impact Great Lake’s shipping. Impacts on water may damage the fishing industry, tourism, and recreational sectors. Invasive Carp carry the potential to be especially damaging to the Great Lakes.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services

Responders are not routinely involved with invasive species. Continuity of Operations would be unaffected. Some delivery of services could be situationally impacted, especially as related to food programs or water management.

Impact on the Environment

Invasive species typically alter the existing ecosystem and may decrease both terrestrial and aquatic biodiversity. Extreme cases may lead to deforested land or native species extinction. Habitat change can create soil erosion, increase flooding, or contribute to forest fires. Invasive species may encourage harmful algal blooms and worsen their effects on aquatic ecosystems. The Great Lakes, inland rivers, and inland lakes may experience detrimental consequences.

**Invasive Species of Concern in Michigan:**
Invasive species examples are primarily categorized here between those on a watch list and those already established in the state. Michigan's official 2022 watch list includes species that have never been confirmed in Michigan's wild or have a limited known distribution. They would pose a significant threat to the ecosystem or economy if established.

**Michigan Watch List (printable)**

Aquatic Plants
- Brazilian elodea (Egeria densa)
- European frog-bit (Hydrocharis morsus-ranae)
- European water-clover (Marsilea quadrifolia)
- Hydrilla (Hydrilla verticillata)
- Parrot feather (Myriophyllum aquaticum)
- Water chestnut (Trapa natans)
- Water hyacinth (Eichhornia crassipes)
- Water lettuce (Pistia stratiotes)
- Water soldier (Stratiotes aloides)
- Yellow floating heart (Nymphoides peltata)

Terrestrial Plants
- Asiatic sand sedge (Carex kobomugi Ohwi)
- Chinese yam (Dioscorea oppositifolia L.)
- Himalayan balsam (Impatiens glandulifera)
- Japanese chaff flower (Achyranthes japonica)
- Japanese stiltgrass (Microstegium vimineum (Trin.) A. Camus)
- Kudzu (Pueraria montana var. lobata)
- Mile-a-minute weed (Persicaria perfoliata)

Insects and Tree Diseases (Tree diseases list the name of the associated pathogen or fungus)
- Asian longhorned beetle (Anoplophora glabripennis)
- Balsam woolly adelgid (Adelges piceae)
- Beech leaf disease (Litylenchus crenatae and potential associates)
- Hemlock woolly adelgid (Adelges tsugae)
- Spotted lanternfly (Lycorma delicatula)
- Thousand cankers disease (Geosmithia morbida)

Mammals
- Nutria (Myocastor coypus)

Fish and other Aquatic Animals


- Carps
  - Bighead carp (Hypophthalmichthys noblis)
  - Black carp (Mylopharyngodon piceus)
  - Grass carp (Ctenopharyngodon idella)
  - Silver carp (Hypophthalmicthys molitrix)
- Crayfish
  - Marbled crayfish (Procambarus virginalis)
  - Red swamp crayfish (Procambarus clarkii)
- New Zealand mud snail (Potamopyrgus antipodarum)
- Northern snakehead (Channa argus)

Although all species on Michigan's Watch List should be monitored, special attention is given to invasive carp in the supplemental materials section of this chapter. Additional resources for broader study can be found at misin.msu.edu and invasive.org. The USDA also maintains a website highlighting both native pests and invasives. Examples of invasive species not on Michigan's watch list include the Khapra Beetle, which normally prefers the more conducive climates of Texas or Oklahoma. One of the world's most destructive pests of stored grain, Michigan agricultural specialists confiscated a bag of seeds infested with the insects from an Iraqi traveler in 2018. Customs and Border Patrol agents likewise detected six illegal giant African snails at Detroit Metropolitan Airport in 2023.

Despite best efforts, many invasive species have become entrenched in Michigan's ecosystem and must now be managed (where possible). In some instances (e.g., Dutch elm disease) no effective treatment is available and the planting of different trees is necessary. Some species have become so historically entrenched (naturalized) that they are treated by most as a permanent part of the ecosystem and relatively ignored. Considerable effort may be put into species management where the spread may be halted or potentially reversed.

**Recent Examples Within Michigan**

Dreissenid Mussels (including Zebra and Quagga Mussels) (family Dreissenidae)
By firmly attaching to hard surfaces, dreissenid mussels have clogged water-intake pipes and fouled hard-shelled animals such as clams and snails. Zebra mussels have reduced plankton populations as they filter large volumes of water for food, impacting food resources for fish such as smelt, chub, and alewife. The transfer of suspended materials to lake bottoms via mussel waste also leads to increased water clarity, which while aesthetically pleasing allows for additional sun penetration and promotes the overgrowth of aquatic plants.

Emerald Ash Borer (EAB) (Agrilus planipennis)
Adult EAB feeding on ash foliage causes little damage even as their larvae in the inner bark disrupt the tree's ability to transport nutrients. Many ash trees lose up to 50% of their canopy in a year, killing it in 2-3 years. Fallen trees have caused extensive property damage. A quarantine area was imposed by the state in 2002, but by 2018 EAB had spread to 79 Michigan counties and the quarantine was lifted. Firewood hygiene practices can still be employed to limit the spread of insects and diseases.

Russian Boar (Sus scrofa Linnaeus)
Russian boars go by many names, including feral swine, and they may mate with domestic pigs. They became established in Michigan by escaping from captivity and through intentional release. Typically associated with wetlands, mixed forests, and agricultural landscapes, these opportunistic omnivores consume almost anything including crops, bird eggs, insects, seedlings, nuts, and even young domestic livestock or fawns. Feeding habits put them in direct competition for resources with deer, bear, turkey, squirrel, and waterfowl. They may destroy vegetation or cause erosion as they root for food with their tusks. They may be aggressive towards humans and can transmit disease. Banned by state law in 2012, they are now most typically found in only three northern counties.

Sea Lamprey (Petromyzon marinus)
Lampreys have eel-like bodies and use a large round mouth rimmed with teeth to attach themselves to prey. For 12-18 months of their life cycle, they feed on fish and may die from excessive blood loss or infection. With no natural predators in the Great Lakes, they eventually decimated other fish species after their introduction, including lake trout, lake white fish, and lake herring. The reduction of these other key predator fish allowed the small alewife, another invasive species, to explode in population and create a domino effect of ecological impacts. Scientists found a chemical in 1958 that selectively killed lamprey larvae and have since employed numerous other techniques. The Great Lakes Fishery Commission currently administers a largely successful control program.

Spongy Moth (Lymantria dispar) (formerly Gypsy Moth)
Feeding spongy moth caterpillars may defoliate trees, producing debris and frass which can coat areas and disrupt human outdoor activities. They rarely pose problems to healthy forests themselves. Male and female moths are of different colors, and while females do not fly, small caterpillars can be blown by the wind to other trees. Gypsy moth egg masses and pupae can be unknowingly transported on firewood, vehicles, and recreational gear.

## *Select Programs, Agencies, and Laws*

Michigan Invasive Species Program
This broad program is jointly run by several state departments. Program response is summarized in state management plans.

Aquatic Specific Tools and Mutual Aid Agreements
Tools include maps highlighting where select aquatic species have been found. A Mutual Aid Agreement with eight states and the provinces of Quebec and Ontario was developed to provide support and resources for cooperatively responding to invasive species in the Great Lakes.

Michigan Invasive Species Coalition and Cooperative Invasive Species Management Areas (CISMAs)
This coalition provides support to regional and local groups working to control invasive species within the state, including with resources from MSU. Some partnerships work within a defined region of the state. Each CISMA is governed by a steering committee that identifies priorities within a strategic plan.

Animal and Plant Health Inspection Service (APHIS)
The APHIS mission is an integral part of the USDA's efforts to ensure safe and affordable food, including through programs with an invasive species nexus. Useful resources include web pages devoted to pests and diseases as it oversees agricultural commodity import requirements.

United States Geological Survey
Services from USGS related to invasive species range from detection and initial assessment to the testing of control methods. Offices conducting research relevant to Michigan species are located in Ann Arbor (the Great Lakes Science Center) and Wisconsin (the Upper Midwest Environmental Science Center). A web tool for exploring USGS invasive species research is available HERE.

National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory
This agency includes research on aquatic invasive species. Their Ecosystem Dynamics (EcoDyn) branch develops models to forecast the impacts of multiple stressors (e.g., invasive species, climate, and nutrients) on Great Lakes water quality, food webs, and fisheries. Harmful algal blooms are not always technically invasive themselves but can have their toxic effects worsened by certain invasives.

### *Supplemental Materials*

Invasive carp merit further consideration due to their potential impact on the Great Lakes. Four different carp species are of varying concern: bighead, black, grass, and silver. Some species can grow to 60-100lbs (or more). Silver carp leaping several feet out of water have collided with people on smaller boats, causing injury and creating a drowning risk. Grass carp are of relatively lower concern but have been found in small numbers in some Great Lakes because they had been introduced to nearby waterways going back to the 1970s (for aquatic plant control). Most often found in Lake Erie, Michigan prohibits grass carp possession (some states allow for sterile stocking).

Currently, on Michigan's state watch list, some of these fish made their way into the Mississippi River from flooded Arkansas fish farms during the 1970s. Alarms were raised after they continued to swim upstream as they would bring great harm to the lake habitat and water quality if left unabated. Impacts would include significant disruptions of the food chain supporting other Great Lakes fish.

The USACE and other participants constructed a temporary electronic dispersal barrier in Illinois in 2002. A more permanent barrier followed in 2005, stretching two rows of electrodes across a canal approximately 220 feet apart. The electrodes pulse specific amounts of electric current into the water, designed to behaviorally force fish to swim away while still being harmless to people.


Sanitary and Ship Canal Dispersal Barrier System (source: USGS)

Potential evidence of invasive carp was detected beyond the electric barrier in 2009, leaving only a single lock/dam on the Calumet River between the detected location and Lake Michigan. The Illinois DNR responded by dumping 2,200 gallons of a fish-specific toxin into the canal. While producing roughly 90 tons of dead fish only one carp was found in the area. In 2010 a 19-pound bighead carp was found in Lake Calumet, seeming to confirm Deoxyribonucleic acid (DNA) evidence that the carp had breached the barrier on the Chicago Sanitary and Ship Canal. A silver carp was later caught on the Lake Michigan side of the electric barriers in 2017, roughly nine miles from Lake Michigan. In August 2022, another silver carp was captured in Lake Calumet, seven miles from Lake Michigan. At this time, there is no evidence of any live bighead, silver, or black carp in the Great Lakes.

The most recent version of Michigan's invasive carp plan can be found HERE.

# GEOLOGICAL HAZARDS INTRODUCTION

Michigan's overall geologic risks are relatively low, although some portions of the state still demonstrate reasons for caution. Landslide danger, broadly defined here as types of mass wasting, is largely a function of topography and slope conditions not commonly found in the state. Notable exceptions include sliding dunes on the shores of the Great Lakes, (covered under the Shoreline Hazards chapter), and mudslides (covered under Flooding).

The geological-related natural hazards highlighted in this section include:

1. Ground Movement
    a. Earthquakes
    b. Subsidence
2. Ground Impacts (celestial hazards affecting the ground and atmosphere)
    a. Meteorites and Other Space Objects
    b. Space Weather

While earthquake and subsidence risks have obvious geological impacts, celestial hazards impacting the ground (and atmosphere) may not immediately come to mind. The physical impact of a large meteorite hitting the ground is relatively straightforward, but manmade objects such as satellites can be easily overlooked. Space Weather, such as a large solar mass ejection from our Sun, would only directly devastate the ground in catastrophic scenarios. However, even "more routine" space weather can also induce electrical currents in the ground, impacting infrastructure such as buried pipelines and above-ground power grids.

**Overlap Between Geological Hazards and Other Sections of the Hazard Analysis (Hazard Cascade)**
The most serious of regional earthquakes might damage some utility infrastructure in the southern part of the state, including oil and natural gas pipelines. Some localized flooding or subsidence could result from broken water mains. Seismic activity from worst-case scenarios could cause the collapse of buildings and other structures, but this is unlikely for Michigan even if a catastrophic event occurred involving the New Madrid fault line. Associated transportation accidents might result in hazardous material spills. Damaged roads or bridges may delay first responders or require their rerouting.

The effects of meteorites on the Earth are typically minor, but an impact of sufficient size could hit a city similar to the largest of bombs. Such an impact would carry no radiation but could still destroy key infrastructure, cause mass casualties, and create fires. Extreme-sized objects hitting the Great Lakes could generate large waves.

Space weather impacts may cause power outages or corrode pipelines. Times to power restoration could in worst-case scenarios take months or longer to restore (this would be extremely rare). The operability of Global Positioning System (GPS) based navigation may be impacted for automobiles, airplanes, and seagoing vessels. The radio capabilities of first responders may be affected and the internet impacted.

# EARTHQUAKES

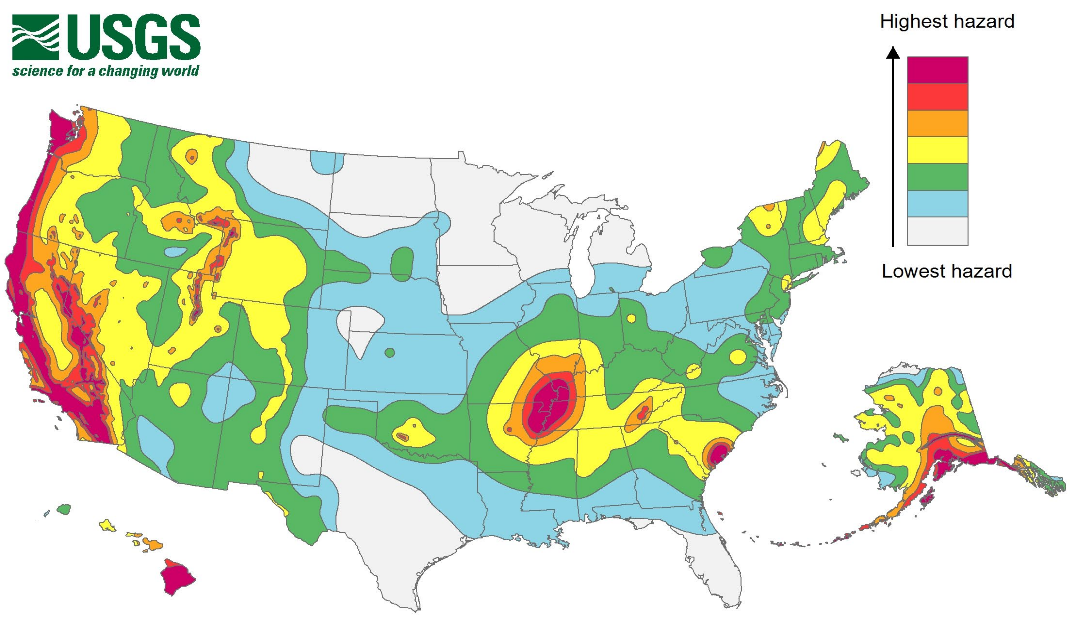
*A shaking or trembling of the ground/earth's crust caused by tectonic activity or other seismic forces.*

## *Hazard Description*

Earthquakes tend to occur along fractures (fault lines) in the earth's crust, producing seismic waves and ground tremors ranging in intensity from slight rumblings to great shocks. The duration of an earthquake may be brief to several minutes or come in a series over a period of days or weeks. They generally occur without warning because no reliable prediction indicators exist. The initial ground movement of an earthquake is seldom the direct cause of injury or death, with more casualties arising from structural collapse, landslides, falling objects, or vehicle incidents/train derailments occurring in the immediate aftermath of a quake. Underground infrastructure can also be impacted and/or subsidence may occur.

## *Hazard Analysis*

Michigan sits in a stable part of the continent, containing fault lines that are generally considered inactive. No severely destructive earthquake has ever been documented in the state, which is considered at relatively lower risk for major events. Minor earthquakes have occurred. The USGS has categorized areas of the country into levels of hazard risk based on criteria such as fault line proximity, bedrock type, and other factors. An online USGS seismic hazard map for Michigan varies slightly from the one shown below based on the way data is measured. The NRI also has a related map that highlights estimates of annual losses.




2018 Long-term National Seismic Hazard Map

While major earthquakes do not originate in Michigan, the state may still experience impacts from larger seismic events that occur farther away. This has included earthquakes emanating from the lower St. Lawrence Valley/Timiskaming areas of Quebec and northern Illinois. Direct impacts upon Michigan from such events would not be expected to be severe. The nearest "highest hazard" area is the New Madrid Seismic Zone, which extends from Cairo, Illinois through New Madrid, Missouri to Marked Tree, Arkansas. A catastrophic earthquake happening there in the future could cause some lesser impacts in Michigan, likely limited to southern counties. The state might need to shelter refugees coming from this area in the case of a major quake.

Due to the infrequency and historically low intensity of earthquake activity in Michigan, seismic hazard risks are unlikely at the forefront for most local designers/developers, who are not required to build to the same standards as truly high-risk areas (e.g., California). Some of Michigan's communities may therefore be vulnerable to major seismic events. Emergency managers and county planners may wish to consider strengthening critical infrastructure to better resist seismic activity, especially in the southern part of the state and on poorly consolidated sediments. Buried pipelines may be particularly susceptible.

It should be noted that areas around active mines and quarries may experience seismic effects as a result of blasting activities and subsidence, as well as due to stress concentrations around underground mines (including abandoned mines, like those found in the Upper Peninsula). See the related chapter on subsidence for more information.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
Impacts occur in the short and long run, beginning with immediate damage and injuries/fatalities depending on location, severity, and aftershocks. General infrastructure and utilities could be impacted, resulting in shortages or higher prices for energy and food. Worst case scenario earthquakes would constitute a national emergency (e.g., Hurricane Katrina).

In Michigan, there is moderate potential for limited property damage to occur in some counties as a result of small, local earthquakes or those of a regional nature. The damage would likely be no more than minor inconveniences for homeowners and businesses and severe in only unusual and isolated circumstances. At greatest risk in Michigan are pipelines, chimneys, and buildings that are poorly designed and/or constructed, and unsecured shelving, furniture, mirrors, gas cylinders, etc. within structures that could fall and cause injury.

Impact on the State Economy
Impacts from events originating in Michigan should be nominal. A major out-of-state earthquake could interrupt the state's energy supply. A sustained interruption, or even a sharp rise in prices, could substantially impact key economic sectors. Building supplies would be in high demand, slowing some aspects of recovery efforts.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
If an event involves structural collapse, some search and rescue activities may need to occur involving specially trained personnel and specialized equipment. Earthquake-related infrastructure failures, in particular damage or disruption to transportation corridors or anything involving hazardous materials, may inhibit efficient and safe response to the incident and may interfere with the ability to access resources needed for incident response activities. Services may be impacted, especially if water lines, fuel pipelines, or rail lines are damaged.

Impact on the Environment
Beyond direct damage to topography, significant earthquakes may negatively impact natural resources, disrupting wildlife habitats, toppling trees, releasing trapped lake bottom gases, or redirecting surface or groundwater. Secondary environmental impacts caused by an event may involve the release of hazardous materials from damaged infrastructure or transportation incidents. Michigan should be generally safe from severe impacts, but it would be especially prudent to monitor pipelines for spills/releases.

### *Historical Record of Earthquakes/Tremors Affecting Michigan*

Earthquake records can be classified in many ways, including by magnitude and intensity. The well-known Richter scale has been in use since the 1930s, making it a convenient tool for maintaining general historical lists. It is, however, now considered to be an outdated method for measuring the strength of earthquakes and not always used by those who study the phenomena. Some experts prefer to discuss earthquakes in terms of their intensity and thus have turned to using the Modified Mercalli Intensity (MMI) scale, which is discussed further at the end of this chapter.

Minor earthquakes of magnitude <5 (on the Richter scale) have occurred in southern Michigan, and many small earthquakes (M < 3.5) have occurred in western Lake Erie and along the Detroit and St. Clair rivers. These earthquakes created intensities that can be felt and measured with the MMI scale, as high as V or possibly up to a low VI, causing only very minor damage. Most "damage" associated with the 2015 Scotts (Galesburg) event was along the Kalamazoo River, and a gas leak is reported to have occurred at a business southeast of Galesburg.

The following table lists known earthquakes that were *felt* within Michigan based on available data. The included 1947 event, with an epicenter near Coldwater, was the strongest of those originating in Michigan (still only causing light damage, mainly affecting residential structures in the area). Other Michigan quakes of magnitude 4.0 or higher are highlighted in red. It should be noted that explosive blasting, subsidence, mine collapse, ice quakes (i.e., cryoseism), and even meteors/meteorites can all cause tremors that can register on seismic monitoring equipment. Many people may mistake their loud noises or vibrations as being earthquakes.

**Earthquakes/Tremors Felt in Michigan**

| Date | Origin | Magnitude |
|---|---|---|
| 12-16-1811(x3) | New Madrid, MO | 7.3 |
| 01-23-1812 | New Madrid, MO | 7.0 |
| 10-20-1870 | Charlevoix, QUE | 6.6 |
| 09-19-1884 | Lima, OH | 4.8 |
| 09-01-1886 | Charleston, SC | 7.7 |
| 10-31-1895 | Charleston, MO | 6.7 |
| 05-26-1909 | Sandwich, IL | 5.1 |
| 03-01-1925 | La Malbaie, QUE | 7.0 |
| 08-12-1929 | Attica, NY | 5.2 |
| 11-01-1935 | Timiskaming, QUE | 6.2 |
| 03-02-1937 | Anna, OH | 5.0 |
| 030-9-1937 | Anna, OH | 5.4 |
| 03-13-1938 | Gibraltar, MI | 3.8 |
| 03-14-1938 | Gibraltar, MI | N/A |
| 03-09-1943 | Lake Erie, OH | 4.5 |
| 09-05-1944 | Massena, NY | 5.8 |
| 08-10-1947 | Coldwater, MI | 4.7 |
| 11-09-1968 | El Dorado, IL | 5.5 |
| 09-15-1972 | Rock Falls, IL | 4.5 |
| 04-03-1974 | Lancaster, IL | 4.7 |
| 02-02-1976 | Pt. Pelee, ON | 3.4 |
| 07-27-1980 | Sharpsburg, KY | 5.1 |
| 08-20-1980 | Harrow, ON | 3.2 |
| 01-31-1986 | Perry, OH | 5.0 |
| 07-12-1986 | St. Mary's, OH | 4.6 |
| 06-10-1987 | Lawrenceville, IL | 5.2 |
| 11-25-1988 | Saguenay, QUE | 5.9 |
| 09-02-1994 | Central Michigan | 3.4 |
| 09-25-1998 | Sharon, PA | 5.2 |
| 04-18-2008 | West Salem, IL | 5.4 |
| 02-10-2010 | Elgin, IL | 3.8 |
| 06-23-2010 | Val-Des-Monts, QUE | 5.4 |
| 12-30-2010 | Kokomo, IN | 3.8 |
| 08-23-2011 | Mineral, VA | 5.8 |
| 05-02-2015 | Scotts (Galesburg), MI | 4.2 |
| 06-30-2015 | Burlington, MI | 4.4 |
| 04-19-2018 | Amherstburg, ONT | 3.4 |
| 06-10-2019 | Timberlake, OH | 4.0 |
| 08-21-2020 | Detroit Beach, MI | 3.4 |
| 06-17-2021 | Bloomingdale, IN | 3.8 |
| 10-23-2001 | Prairie Lake, MI | 2.9 |
| 07-07-2022 | Luna Pier, MI | 2.4 |


USGS map showing areas that experienced tremors from the May 2, 2015, earthquake near Galesburg. "Did You Feel It?" is a USGS resource that collects. information on any impacts people may experience.

(sources: MSU Earthquake Information Center/East Lansing Seismic Station, USGS Earthquake Catalog)

### *Select Programs, Agencies, or Laws*

United States Geological Survey Earthquake Hazards Program and Earthquake Catalog
The USGS maintains a searchable database of earthquake events, along with a website that provides numerous types of analytical information and data products useful in assessing locational risk.

National Response Framework (NRF)
The NRF would coordinate federal assistance for a catastrophic earthquake (or similar disaster) through the Department of Homeland Security. The NRF outlines the responsibilities of federal agencies in disaster response and/or recovery.

National Earthquake Hazards Reduction Program (NEHRP)
The NEHRP is a multistakeholder partnership that administers EQprogram.net, an online resource intended for use by State Earthquake Program Managers. Available content includes materials from past annual meetings.

### *Supplemental Material*

Although numerous intensity *scales* have been developed to evaluate the effects of earthquakes, the one most currently used in the US is the MMI scale, sometimes simply referred to as “MM” for Modified Mercalli. It assigns intensities from a list of 10 categories using a Roman numeral scale ranging from I (least intense) to X (most intense).

| Intensity | Shaking | Description/Damage |
|---|---|---|
| I | Not felt | Not felt except by a very few under especially favorable conditions. |
| II | Weak | Felt only by a few persons at rest,especially on upper floors of buildings. |
| III | Weak | Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated. |
| IV | Light | Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. |
| V | Moderate | Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. |
| VI | Strong | Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. |
| VII | Very strong | Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. |
| VIII | Severe | Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. |
| IX | Violent | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. |
| X | Extreme | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. |

(source: USGS)

For naturally occurring earthquakes, some areas of southern Michigan, and perhaps extending up to the thumb region, could experience effects as high as Intensity V. Most of the rest of the state would likely experience no greater than Intensity IV effects. Such events may cause alarm but should not result in routine direct injury.

# SUBSIDENCE

*The lowering or collapse of the land surface due to the removal of subsurface ground support.*

## *Hazard Description*

Sinkhole formations are a type of natural subsidence, such as where groundwater gradually dissolves sub-surface soluble materials and creates underground cavities capable of collapse. While such processes can be slow and happen largely out of sight, their outcomes may manifest themselves in a sudden or dramatic fashion, with cars and buildings falling into sometimes enlarging surface holes. Earthquakes, flooding, and other natural processes may also be triggers. Human-caused subsidence can be related to activities such as groundwater withdrawal, the drainage of organic soils (such as peat), and underground mining. Leaking water from broken water mains is another cause.

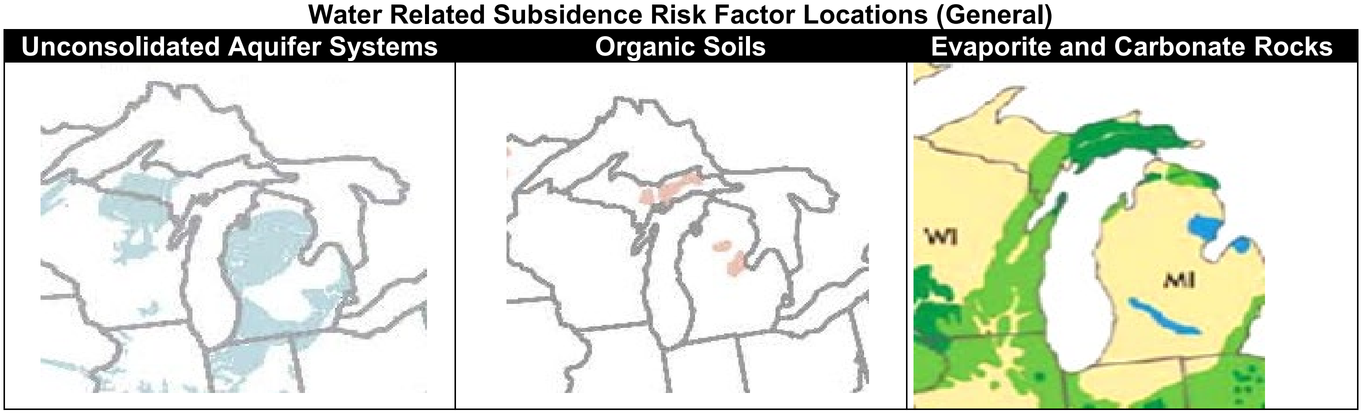
## *Hazard Analysis*

Newly emerging sinkholes tend to garner the most subsidence-related media attention in Michigan. Their costs over the past 15 years have been estimated at $300M at the national level (annually), although tracking of the hazard is limited and actual damages may be higher. Michigan contains some geologic features (e.g., karst formations) that are strongly associated with subsidence, as well as extensive aquifer systems and areas susceptible to both soil erosion and compaction. The state's water infrastructure system is subject to frequent freeze-thaw cycles and may become cracked, leaking underground. Some parts of Michigan also have a rich mining history with abandoned mines that are potentially vulnerable to collapse (over 800 underground mines with more than 2,300 shafts or other surface openings).

**Water-Related Subsidence**

Three distinct processes account for many types of water-related subsidence: the compaction of aquifer systems, the drainage and subsequent oxidation of organic soils, and the dissolution and collapse of susceptible rock. More detailed maps for some of these factors are available later in the chapter.

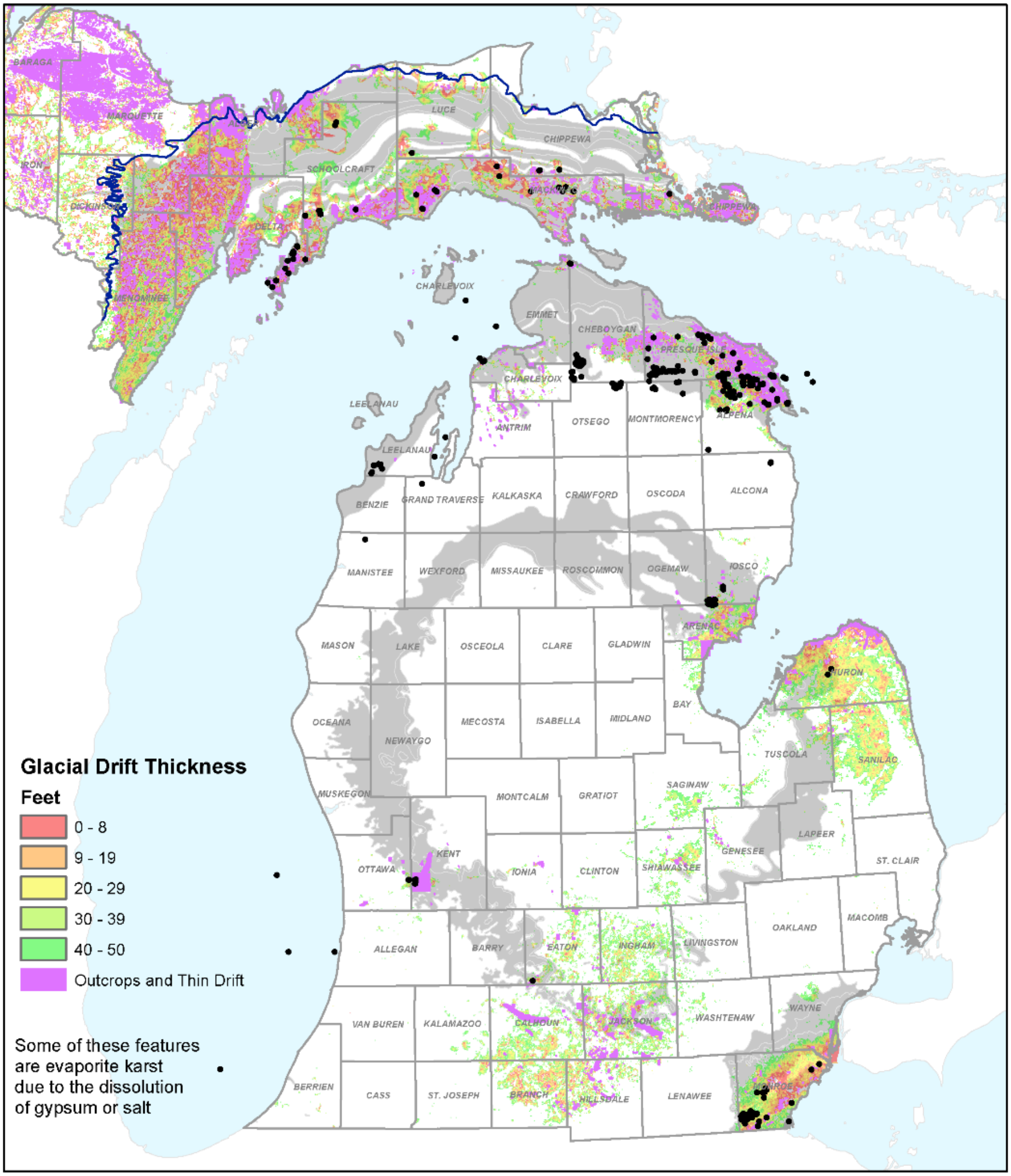
**Water Related Subsidence Risk Factor Locations (General)**




(source: USGS, *Ground Water and the Rural Homeowner, Pamphlet, 1982)*

Compaction of aquifers occurs when groundwater is depressurized or removed, creating empty pore space that was once filled with water. The empty space can then collapse in on itself due to the weight of overlying rock or sediment. This subsidence may be partially recoverable if the aquifer is recharged and pressures rebound, or an aquifer may become permanently reduced in capacity (and the subsidence is also permanent). Organic soils (rich in organic carbon) may be drained for agriculture or other purposes, potentially causing subsidence. Compaction, desiccation, and erosion from wind and water are other important soil factors for consideration.

Collapsing cavities are commonly triggered by the lowering of groundwater levels due to changes in underground hydrology, the enhanced percolation of groundwater, or exogenous water pumping. Risk tends to be associated with specific rock types such as soluble carbonates, including limestone, and associated with "karst" landscapes. Salt deposits are also highly soluble. Current mapping of carbonate bedrock does not include all karst features (i.e., sinkholes, caves), but may be indicative of areas with a higher risk for newly emergent sinkholes. This is particularly true where land cover over these rock types is relatively thin. Areas colored in purple on the following map (2015) represent the highest areas of concern, followed by red and then orange.




# KNOWN OR SUSPECTED KARST FEATURES IN MICHIGAN

PRECAMBRIAN_LINE

Known or Suspected Karst Feature

Carbonate Bedrock Formation

Ty Black & John Esch

Note: Not all carbonate bedrock formations are completely carbonate, some have mixed lithlogies. Not all carbonate bedrock formations are likely to produce karst features, some are more soluble than others. Not all carbonate bedrock formations have associated known karst features. Many carbonate forrmations are overlain by thick glacial drift which limits the potential for karst development.

Geologic and landscape features aside, broken water mains/pipes and the improper discharge of stormwater are the most frequent causes of water-related subsidence reported in Michigan. It most commonly occurs with sandy or silty ground where water discharge or leaks wash away fine particles (causing voids that can result in collapse). Flooding from excessive rain or snowmelt can also play a role in sinkhole formation.

**Mine Related Subsidence**
Much of the historical mining in Michigan took place before the establishment of modern laws and regulations, and not all mine sites, including mine openings and underground workings, were properly sealed or secured. Collapses have occurred in unsuspected areas decades after mining ceased. Underground mining has occurred in the state for coal, metals such as copper, iron, and nickel (including minor amounts of gold and silver), and evaporite minerals such as salt (halite), potash, and gypsum. General locations for select historical mining operations can be found below, but it should be stressed that any listings are not meant to be comprehensive. This publication should also not be viewed as a resource for identifying mining facilities that may still be in operation. The state maintains some such listings available for nonferrous metals (e.g., copper, gold), iron, and coal.

**Copper**. The "Copper Country" area generally crosses Gogebic, Ontonagon, Houghton, and Keweenaw counties. Based on *known* locations of past underground copper mines, the following jurisdictions have significant levels of properties and infrastructure that are currently in use within or near such areas:

Houghton County, including some areas near highways US-41 and M-26: Adams Township, Calumet Township, Elm River Township, Franklin Township, City of Houghton, Osceola Township, Portage Township, and Quincy Township.

Keweenaw County, including some areas near Highway US-41/M-26: Allouez Township, Eagle Harbor Township, Grant Township, and Houghton Township.

Ontonagon County, including some areas near highways M-64 and M-107: Carp Lake Township, Greenland Township (including some areas near Highway M-38), Matchwood Township, and Rockland Township (including some areas near Highway US-45).

**Iron ore.** Michigan has three iron ranges: 1) the Gogebic Range, which extends from Gogebic County into Wisconsin, 2) the Marquette Range, in Marquette County; and 3) the Menominee Range, in Dickinson and Iron counties. Based on *known* locations of past underground iron mines, the following jurisdictions have significant levels of properties and infrastructure that are currently in use within or near such areas:

Baraga County: Spurr Township, including some areas near Highway M-28.

Dickinson County: Breitung Township (including some areas near Highway US-2), Felch Township (including some areas near Highway M-69), Iron Mountain, Norway, Norway Township (including some areas near Highway US-2), and Waucedah Township (including some areas near Highway US-2).

Gogebic County: Bessemer, Bessemer Township, Ironwood, Wakefield (including some areas near Highway M-28), and Wakefield Township (including some areas near Highway US-2).

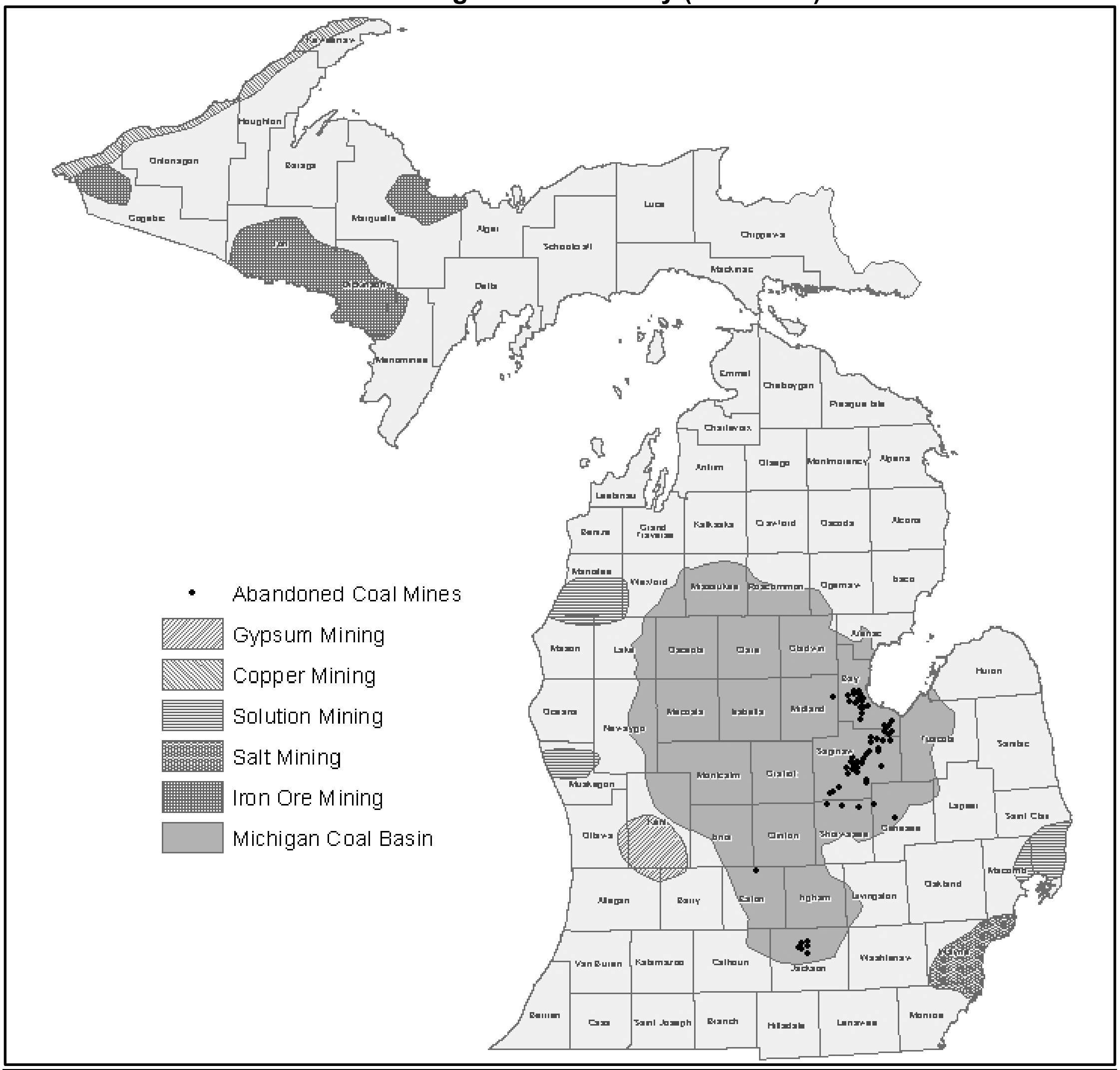
Iron County: Caspian, Crystal Falls, Crystal Falls Township (including some areas near highways US-2 and US-141), Gaastra, Hematite Township, Iron River (including some areas near Highway M-189), Iron River Township, Mastodon Township, and Stambaugh Township (including some areas near Highway M-189).

Marquette County: Champion Township, Ely Township, Forsyth Township (including some areas near Highway M-35), Humboldt Township (including some areas near Highway US-41/M-28), Ishpeming (including some areas near Highway US-41/M-28 and Business Route 28), Ishpeming Township, Michigamme Township (including some areas near Highway US-41/M-28), Negaunee (including some areas near Highway US-41/M-28 and Business Route 28), Republic Township, Richmond Township, and Tilden Township.

**Salt.** Much of the Lower Peninsula contains extensive salt beds. These formations are over 3,000 feet thick in some locations and are composed of alternating layers of salt and other minerals. Active salt mines still exist in Detroit, where there are also large abandoned caverns. Most salt "mining" locations in the state employ a brine solution method where fresh water is injected through a pipe into deep shafts that end in salt beds that are then drawn upwards and dried.

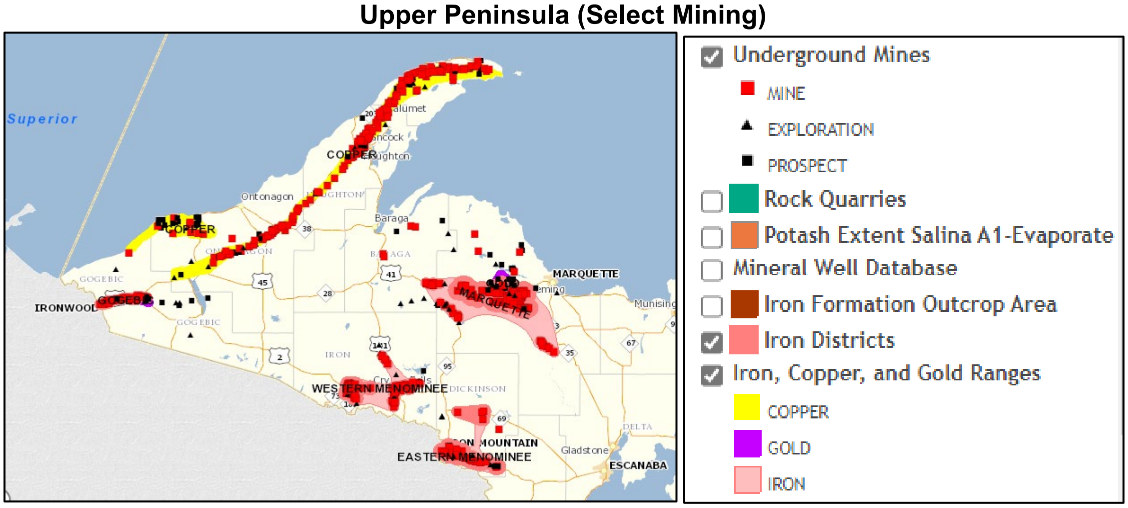
The following map can be used to provide a rough overview of where select mining occurred in the state. More accurate information is now available online. A screenshot example of the Upper Peninsular is provided. The State's inventory of historical and abandoned mines may not be complete, and information on some locations is inaccurate, lacking, or absent.

**Select Mining Related Activity (Historical)**




(source: EGLE - Oil, Gas, and Minerals Division (OGMD), 2010)

**Upper Peninsula (Select Mining)**




(source: EGLE GeoWebFace, accessed July 14, 2023)

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
Some instances of subsidence may cause private property damage (typically cars) or injuries. Subsidence-related damage is generally not covered under a standard homeowner's insurance policy. Michigan has typically seen public infrastructure such as roadways and water mains affected. Many forms of infrastructure may be vulnerable including buildings, transportation routes, water supply lines, urban sewage lines, and pipelines for oil and gas. Most past incidents have had a limited effect on the general public.

Impact on the State Economy
Overall economic impacts of subsidence in Michigan have not been significant. A worst-case incident might result in a major oil pipeline collapse, causing large-scale environmental impacts and expensive response and recovery activities. Information on Michigan's mineral industry is available from the USGS.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Areas that involve deep spaces can endanger personnel and equipment. Roadway disruptions may slow first responders or interrupt the delivery of other services. Mine rescue operations can be complex.

Impact on the Environment
Subsidence by definition alters the environmental surface, with most Michigan alterations occurring on a small scale. In cases of subsidence related to groundwater withdrawal, there can be a permanent reduction in an aquifer's total storage capacity. Depending on location, subsidence may result in the release of contaminants such as sewage or hazardous materials being transported by pipes.

### *Select Subsidence Incidents*

The following examples are meant to give a representative sample of the hazard and are not meant to be exhaustive.

April 13, 2023 – Ishpeming (Marquette County)
An abandoned mine's fill material shifted during a flood, causing an 80-foot sinkhole to form and closing a roadway. Nearby power lines experienced no movement, but some public water services were temporarily affected.

June 16-17, 2018 – Houghton County
Storms producing as much as seven inches of rain led to heavy flooding. Most storm damages were directly related to flooding, but 60 sinkholes were reported across the Keweenaw Peninsula, some of which impacted roadways.

December 24, 2016 – Fraser (Macomb County)
The Macomb Interceptor Drain collapsed, causing a 100-foot-wide and 250-foot-long sinkhole that led to the evacuation of 22 homes and $75M in damages. The Governor declared the site a disaster area. The sinkhole was eventually determined to have resulted from an operational error in 2014 that had put small fractures in the pipe. Surrounding dirt slowly filtered into the cracks and was swept away, creating space around the pipe and leading to collapse.

March 28, 2014 – Detroit (Wayne County)
A sinkhole 16 feet deep and 30 feet wide opened at the intersection of Linwood and Monterey Avenues, most likely caused by an underground sewer riser collapsing. The road remained blocked off until repairs were completed.

January 18, 2014 – Detroit (Wayne County)
A gaping sinkhole appeared near the Renaissance Center, forming when a manhole structure leading down to the water main collapsed and filled with water. The opening was about eight feet wide and several feet deep, resulting in the closure of two westbound lanes on East Jefferson. Repairs took over a week to complete due to the proximity of underground telecommunications lines and electrical wiring.

August 18, 2011 – Detroit (Wayne County)
A partially collapsed sewer eroded dirt beneath Beaubien Street. An automobile driving over the road was the last stress the buckling pavement could handle, which took a nosedive into the collapsed road (shattering a water main in the process and causing the sinkhole to completely fill with water). Two women and an infant were successfully rescued.

March 23, 2011 – Ann Arbor (Washtenaw County)
A crack in a concrete retention system caused a 40-foot sinkhole to occur outside an underground parking structure's construction site, closing two businesses for the day. The apparent cause was the poor condition of the retention wall, sandy soils, and thawing ground which together seemed to create an underground cavity that bubbled up vertically.

January 21, 2011 – Detroit (Wayne County)
A man was injured when the front end of his truck went into a 10-foot-wide sinkhole caused by a water main break on Detroit's west side. The 52-year-old victim was taken to a local hospital, where he was treated for minor injuries.

October 4, 2010 – Stephenson (Menominee County)
A 600-foot-long crevice on undeveloped land suddenly opened on the ground surface. In some places it was only a foot wide and a few inches deep, but in other locations more than two feet wide and five feet deep. Vibrations were felt by nearly all residents. The executive director of the Delta Conservation District speculated in newspaper reports that the cause may have been the result of rock fracturing below the surface (areas containing fractured rock formations can result in fissures and sinkholes as the result of pressures generated by the annual freeze-thaw process).

May 20, 2010 – Detroit (Wayne County)
A sinkhole large enough to swallow a car closed portions of West Lafayette Street in downtown Detroit. The street began to crumble away after crews punctured a water line when working to demolish the historic Lafayette Building.

August 2004 - Sterling Heights (Macomb County)
A sewer line break caused a section of 15 Mile Road to collapse, prompting residents in six homes to evacuate and the street to close for several weeks. Two sinkholes formed and eventually merged, forming one hole 150 long and 45 feet wide. Roughly 15 homes lost water service for several hours, with 1,000 customers losing power due to utility poles that needed to be removed. Raw sewage (up to seven million gallons daily) was diverted into the Mount Clemens sewage treatment plant to prevent wastewater from entering basements or polluting county drains and streams. Repairs were estimated at $53M.

March 2004 - Detroit (Wayne County)
A sinkhole about 20 feet wide and 14 feet deep opened in the westbound lanes of Six Mile Road. Faulty water main work started six months earlier had washed away the underneath soil.

April 2001, August 2000 – Gaastra (Iron County)
Over 3,000 cubic yards of soil caved in at the abandoned Baltic Mine Pit, just four feet from the city sewer line feeding the wastewater treatment plant. A similar collapse had occurred earlier. It should be noted that when the sewer line was first installed there was 100 feet of ground between the sewer line and the edge of the mining pit. From 1984 to 2001, the annual recession rate at the site was nearly six feet per year. Concerns arose that another incident would cause the sewer line to break, contaminating nearby water wells and the Iron River, as well as potentially collapsing County Road 424. The city received grant funding to relocate the vulnerable piping.

February 9, 2000 – Detroit (Wayne County)
A 15-foot sinkhole opened up on Seneca near Mack, swallowing up a half-ton pickup truck. The truck's two occupants escaped serious injury. Officials believed a leaking underground pipe caused the subsidence.

July 1999 - Iron Mountain (Dickinson County)
An abandoned mineshaft caved in, exposing a 50-foot diameter by 1,600-foot-deep shaft. The cave-in occurred directly adjacent to the Cornish Pumping Engine and Mining Museum, a popular tourist attraction. The structure was in danger of collapsing into the opening until temporary stabilization measures were taken. A Governor's Emergency Declaration was granted to provide state assistance in securing the site and permanently capping the opening.

June 1999 - Milan (Monroe County)
Northbound traffic on US-23 at Milan was diverted for approximately ten hours after the pavement sank eight inches over a 30-foot stretch of highway. The subsidence and traffic diversion caused traffic to back up for several miles throughout the day. A definitive cause was not established, but a leaking storm sewer was suspected.

October 1984 - Jackson County
The abandoned Andrews Street Coal Mine partially collapsed, causing a detached residential garage and vehicle to fall into a shallow sinkhole. It was unclear if the mine location was noted on applicable maps at the time. A $12K emergency reclamation project was instituted.

May 3, 1940 –Iron Mountain (Dickinson County)
A 150-foot-long section of highway collapsed into a nearby pit belonging to the Chapin Mine. When the mine ceased operations in 1932 its water pump had been given to the county, causing water to accumulate in the mine. Unequal hydraulic pressures on each side of the water-surrounded road were suspected to have eventually caused the collapse. Five nearby parked vehicles fell into the pit.

October 29, 1927 – Hancock (Houghton County)
Seven persons were killed at Quincy Mine No.2 when an air burst sent rocks down a shaft, entombing the workers below at a reported depth of 4,300 feet. The cause of the air blast was not determined.

February 21, 1918 – Crystal Falls (Iron County)
Water and sand flooded parts of the Amasa-Porter Mine, causing a cave-in responsible for the deaths of 17 people. Pumps began to clear the area, but a second rush of water swept through the mine days later and ended rescue operations.

May 13, 1912 – Ironwood (Iron County)
The ceiling of the Norrie Mine's $19^{th}$ level gave way, catching 13 workers in its collapse and killing six. One rescued man died a week later.

## *Select Laws, Agencies, or Programs*

Michigan Department of Environment, Great Lakes, and Energy - Oil, Gas, and Minerals Division
The OGMD regulates most forms of mineral mining in Michigan with regulatory authority granted under the Michigan NREPA (1994 PA 451). The Division's activities include issuing permits for mining operations, maintaining records on mining areas, and regulating mine reclamation.

County Mine Inspectors
Several counties that have had underground mining operations (excluding coal) have mine inspectors who can provide information on matters related to abandoned facilities. Information about the locations and subsurface conditions of mines is not guaranteed to be comprehensive, as some historical mine locations have been lost to time. Many private property owners with mines also do not wish to publicize them in order to minimize trespass.

Michigan Underground Abandoned Mine Inventory
Information was compiled in conjunction with Michigan Technological University under contract with the Geological Survey Division of the DNR. The inventory was conducted over several years during the 1990s and is generally considered as incomplete. Data was distributed to county mine inspectors and is included on EGLE's GeoWebFace.

Mine Data Retrieval System of the Mine Safety and Health Administration (MSHA)
The MSHA is part of the US Department of Labor. Its database of mine locations is not always accurate for Michigan but can serve as a starting point for identifying operational mines in local areas.

Michigan State University
The Natural Features Inventory from MSU has studied the portion of the Niagara Escarpment (Upper Peninsula) that contains numerous karst sinks, springs, and caves. It has also identified sinkhole communities in other parts of the state.

## METEORITES AND OTHER IMPACTING OBJECTS

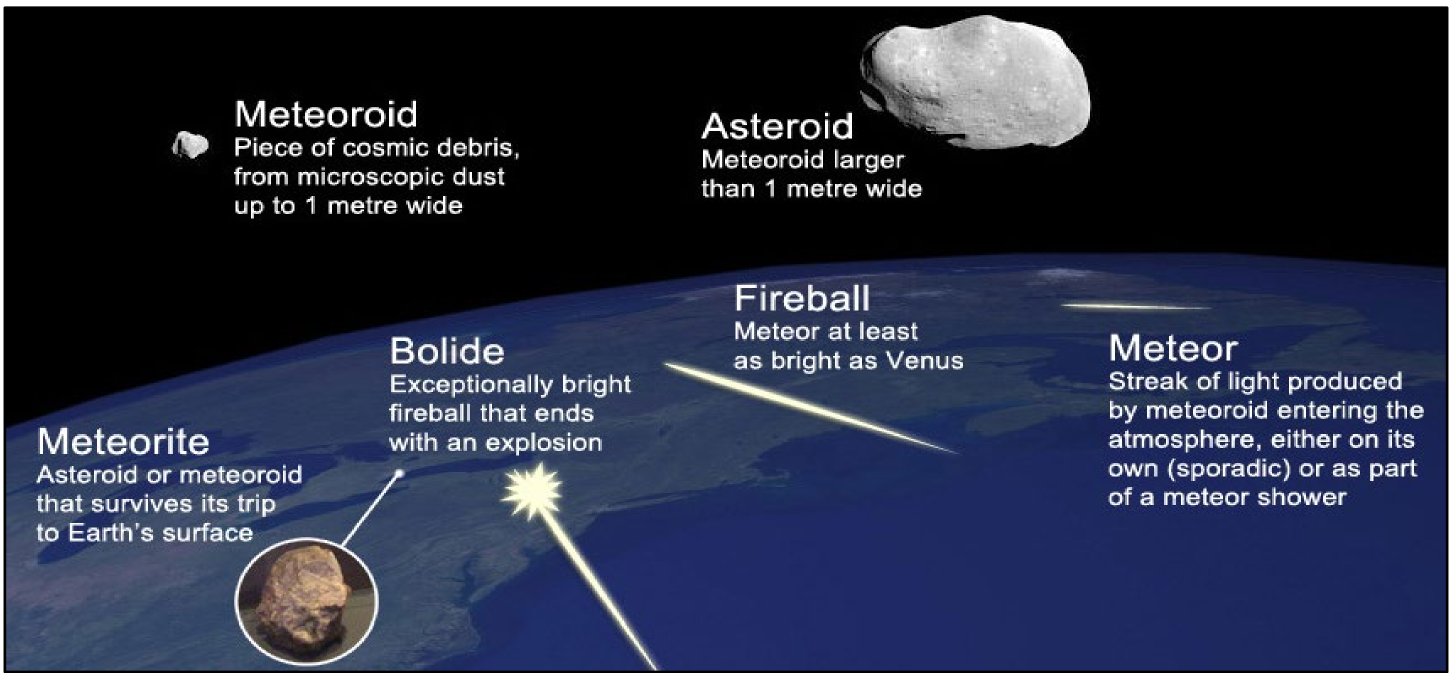
*A meteorite, satellite, or similar object that physically hits or otherwise impacts the planet.*

### *Hazard Description*

Meteoroids are small rock/metallic bodies in outer space that have typically broken away from larger asteroids. As a scientific distinction, a *meteoroid* that enters the Earth's atmosphere is then called a *meteor*. Any parts of meteors that end up physically hitting the surface are then called *meteorites*. The remnants of falling space stations and satellites may also fall to Earth as their orbits decay. Airplane crashes are covered under transportation and terrorism-related chapters.

### *Hazard Analysis*

Most meteors are tiny and generally burn up harmlessly in the atmosphere. Some are large enough to be seen and informally called "shooting stars". Audible sonic booms may be heard, attracting attention and causing concern. Some meteors are also referred to as *bolides.* Depending on the context when used, a bolide may simply refer to an exceptionally bright meteor or may also be used to describe a meteor that explodes in the atmosphere. Exploding bolides may still create strong wind effects or blast forces even as they are largely vaporized prior to impact. An example from a 2013 meteor (bolide) event in Russia saw at least 1,000 persons injured as a result of windows shattered by its atmospheric shock wave. Such extraterrestrial objects can create intense heat and in worst-case scenarios produce more energy than nuclear bombs.



(Credit: Scott Sutherland/NASA. Although a good approximation, sizing scales and descriptions may vary by source.)

Meteorites may also cause damage when they physically strike the Earth's surface, depending on mass, speed, and other factors. Most are small due to ablation, with the majority landing harmlessly in oceans or remote areas and never found. Although they may appear fiery while in the sky, meteorites are typically cool in temperature by the time they hit the ground and pose little threat for starting fires in most locations. Extraterrestrial objects that impact populated areas or are sufficiently sized carry the potential to cause harm, including impact craters, seismic events, large waves, and flooding.

Asteroids and comets causing truly catastrophic disasters are rare and highly unlikely to occur in Michigan except during very long timeframes. From a practical standpoint, local emergency managers will only monitor such objects after groups such as the National Aeronautics and Space Administration (NASA) have been able to locate a detectible-sized incoming object of concern. While the scientific community has made advances in monitoring larger objects, most meteoroids would be difficult to track in a manner that allows for any warranted alarms. The only warning communities may receive is when they see lights in the sky or hear sonic booms. Many people will unfortunately go outside or get near windows when this happens. While harmless during most minor events, such behavior can increase casualties when damaging impacts do occur. It is very difficult for the naked eye to determine how close such falling objects actually are.

Space stations and satellites carry far less damage potential and generally have monitored orbits. More advanced notice is therefore possible and significant media coverage is common. Preliminary impact zones in particular can be tremendously large, and debris may be spread over sizeable areas. Such objects have carried hazardous materials in the past, including radioactive components, so the general public should avoid debris. Response and recovery teams may be activated.

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
Most typical extraterrestrial impacts should present only minor public concern. The pattern of recent nearby events has involved very limited damage to life or property. Although rare, sufficiently massive or fast-moving objects can have effects similar to large bombs or nuclear blasts. Underground sheltering can be employed if enough notice is able to be given, but many imminent impacts may allow for only short (or no) notice. Major earthquakes or other seismic activities could occur. The Great Lakes could create massive wave events and severe flooding under the right conditions.

Impact on the Economic Condition of the State
Any expenditures made during typical events should be nominal for the state. Catastrophic-level events within Michigan would be crippling to its economy but are unlikely to occur. The potential for dust in the atmosphere could impact agriculture and other industries. Major out-of-state events could be similar to those seen by a significant nearby earthquake, causing supply chain issues and a shortage of goods.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
A small incident should not create significant risk for responders unless the impact is upon a structure that may collapse. The presence of hazardous materials should be expected with space-vehicle components and considered when chemical facilities have been heavily damaged. Catastrophic impact incidents are extremely rare but may result in simultaneous infrastructure failures, sheltering requirements, search and rescue, and firefighting efforts.

Impact on the Environment
Most environmental impacts from routine meteor/meteorite events are minimal to non-existent. Hazardous materials may be a concern (see above). Rarer events could devastate the ground via explosive actions in the atmosphere or the physical impacts of asteroids creating huge craters and extensive dust. Weather patterns could be affected. Entire areas would be destroyed, and the physical features of the Great Lakes could be changed. Cataclysmic events are highly unlikely to occur except over timeframes typically estimated over millions of years. Such events could lead to mass extinctions on the planet.

### *Select Events*

A particularly well-known asteroid hit present-day Mexico roughly 66 million years ago, creating a 110-mile diameter crater and dust cloud that contributed to the end of the dinosaur era. Some ancient events are included to show the wide range of threats posed. This listing is not meant to be exhaustive.

February 15, 2023 – Texas, Meteor and Found Meteorites
NASA issued a statement for a meteoroid roughly two feet in diameter and weighing 1,000 pounds entering the atmosphere. Law enforcement agencies took calls for loud booms. The news reported its meteor exploded with the force of eight tons of Trinitrotoluene (TNT) at an altitude of 21 miles. Some meteorite fragments were found, with no direct injuries reported.

December 18, 2018 – Kamchatka, Russia, Meteor
A meteor exploded into a large fireball roughly 16 miles above the Bering Sea, unleashing energy that was calculated to be 10 times that of the "Little Boy" bomb dropped on Hiroshima in 1945. The area was uninhabited. Major events of this type are estimated to occur 2-3 times per century.

March-April, 2018 – Tiangong-1 Space Station Alert
The Chinese space station's orbit decayed and was projected to partially survive reentry (some parts potentially weighed 220 pounds). Tiangong-1's fuel, hydrazine, also posed a contamination risk. Likely paths showed a higher chance of debris falling within mid-latitude zones, including southern Michigan. The debris ultimately landed in the South Pacific Ocean.

January 16, 2018 – Southern Michigan Bolide and Livingston County Meteorites
A bright meteor was seen with some reports of sonic booms. A seismic measurement of magnitude 2.0 was reported near New Haven (Macomb County) at approximately the same time, providing a potential indication of how loud the sound was. A strewn field in Hamburg Township included only very small (102-gram) fragments. There was no reported damage.

February 15, 2013 – Chelyabinsk, Russia, Bolide with Shock Wave
A bright bolide exploded in the air, creating a shock wave that shattered windows throughout a wide section of Chelyabinsk. Some doors also buckled, with most injuries caused by flying glass. Destruction could have been worse as meteorite fragments weighing about 0.75 tons were later retrieved from nearby Chebarkul Lake (40 miles away). The total impact energy was calculated by NASA to be the equivalent of about 440 kilotons of TNT.

September 20, 2007 – Southern Peru, Meteorite
Residents of a remote mountain village heard an explosion and found a 43-foot-wide crater near Lake Titicaca. A 1.5-magnitude earthquake was detected. The impact was unusual for several reasons, including the high altitude where the impact took place, the presence of reported boiling water within the crater, and several persons being temporarily overcome by noxious odors. While some conjectured the illnesses were psychosomatic, others speculated the meteor struck the highly elevated ground in an uncharacteristically “hot” manner, vaporizing arsenic in the groundwater. Others believe that a sulfur-bearing compound within the meteorite itself was instead vaporized and inhaled.

March 26, 2003 – “Park Forest Meteorites” in Suburban Chicago, Illinois
Hundreds of small meteorites fell across residential areas in the suburbs of Chicago. The original meteoroid was calculated to have weighed between one and seven thousand kilograms (kg) (possibly more) before it broke apart in the atmosphere. About 30kg of meteorite fragments were recovered, the largest of them weighing 5.26kg. Numerous holes were punched through windows, roofs, and ceilings, including at a fire station.

Feb 1, 2003 – National, Space Shuttle Columbia Explosion Debris Fields
The Space Shuttle Columbia broke apart violently when returning from a mission, creating an alert for falling debris across the southwestern US. More than 2,000 debris impact sites were eventually reported. NASA issued warnings that the shuttle debris could contain hazardous materials and should be left to authorities.

September 1, 1997 – Salem Township (Washtenaw County), Meteorite
Numerous persons reported sonic booms and a bright daylight meteor that broke up into at least three parts. One meteorite struck a residential roof in Salem Township as a family worked in their backyard. A loud noise from the garage found it full of drywall dust and a dented car roof. The meteorite was roughly six inches long, four inches wide, one inch thick, and weighed 1.5kg.

July 15 to 24, 1994 – International, Comet Shoemaker-Levy 9
Comet Shoemaker-Levy 9 crashed into Jupiter after being broken into 21 fragments by gravitational forces. The comet’s debris vaporized, releasing heat that temporarily exceeded the surface temperature of the Sun (energy estimates exceeded thousands of 50-megaton nuclear bombs). Resultant spots in Jupiter’s atmosphere were sized comparable to the Earth.

January 1978 – International, Cosmos 954 Satellite
The Soviet satellite was being monitored by federal agencies and found to have a decaying orbit. The projected crash was estimated as having only an 8% chance of occurring on land, but such satellites were known to be powered by small nuclear reactors. Decontamination response plans were initiated. The satellite eventually crashed in Canada.

June 30, 1908 – Russia, Tunguska Event
A large object blasted into the atmosphere above this Siberian area. Although the object was evidently destroyed in the air (leaving no impact crater), its destructive force was estimated as equivalent to 5-30 megatons of TNT. Roughly 80 million trees were flattened over 830 square miles. Cornell University researchers concluded the event was “very likely” a comet impact (with most of its mass in the form of easily dissipated ice). Unusual levels of acid rain followed. Estimates about the frequency of this type of event vary from once every thousand years to once per century.

Approximately 450 million years ago – Cass County, Michigan, Near Surface/High Energy Shock Event
Evidence of a past hypervelocity impact was found in Calvin Township. The Calvin 28 cryptoexplosive disturbance left a roughly 5-mile diameter impact area located near the village of Vandalia and the Indiana State Line.

Approximately 1.8 billion years ago – Sudbury, Ontario, Asteroid or Comet
One of the largest known events took place in present-day Ontario, leaving found impact effects that measure 155 miles in diameter. Debris ejected from the site was thrown into parts of what would be the US. The heat generated by the impact would have killed any person within at least 500 miles of the impact site, including throughout Michigan.

### *Select Agencies, Programs, or Laws*

National Aeronautics and Space Administration & Planetary Defense Coordination Office
NASA works in part to detect hazardous asteroids and comets to better track them. Their overall defense-related coordination efforts can be found at https://www.nasa.gov/planetarydefense/overview. They also maintain a catalog of recent meteorite strikes.

National Near-Earth Object (NEO) Preparedness Strategy and Action Plan
This 2018 plan was a result of extensive coordination between NASA, FEMA, and other agencies. It seeks to improve US preparedness for NEO hazards by enhancing detection, improving modeling, and developing technologies for NEO deflection and disruption.

The Double Asteroid Redirect Test (DART)
NASA's DART, the world's first full-scale mission to test technology for defending Earth against potential asteroid or comet hazards, was launched in 2021. This involved the first demonstration of a kinetic impact technique to change the trajectory of an asteroid in space. See https://www.nasa.gov/planetarydefense/dart for more information.

United States Space Force (USFF)
The USFF employs Ground-Based Electro-Optical Deep Space Surveillance sites to monitor deep-space objects, continuing the work of the United States Air Force (USAF). A USAF report from a 2008 asteroid strike Interagency Deliberate Planning Exercise estimated that an asteroid detected at a distance equivalent to that of the Earth's Moon would provide 8 hours of warning for coastal area evacuation (to mitigate against a projected ocean impact).

### *Supplemental Material*

Extraterrestrial objects of differing composition enter our atmosphere at varying speeds, hurtling towards a spinning planet at seemingly random locations below. Some scientific study believes that more meteorites may strike near the equator, and while scientific opinion varies, it can be stated that the US represents less than 2% of the planet's total surface. From this perspective, any one incident is *statistically* unlikely to directly impact our country. The types and conditions associated with each event can of course vary extensively and may still produce national emergencies.

Risk estimates can be calculated in different ways, frequently resulting in diverging opinions.* One example method for Michigan is to calculate the proportion of total surface area occupied by state land (approximately $2.9 \times 10^{-4}$, or 0.00029), multiplying this factor against an estimated frequency for global events. This produces the following estimates, on average, for different types of impacts upon Michigan's land surface area and assuming random event distribution:

- About one to five impacts per year that are larger than 100 grams (golf ball size) – This may kill an individual that is struck, but since most land is not occupied by a person it would still be exceptionally rare.

- About one impact per century involving an object of more than 100kg (220 pounds), and about one impact every 1,700 years involving an object of more than 1,000kg (about 2,200 pounds) – These types of events would result in loud sounds and bright flare-ups in the sky, leaving a field of fragments strewn across an area that is miles across. Actual damages are likely to be only moderate unless an urban area or critical facility is struck.

- About one impact every 350,000 years involving an object of more than 100,000kg (about 220,000 pounds). This type of impact could resemble an atomic blast, exploding brightly and producing effects that would cause extensive building damage and flatten forested lands.

Asteroid impacts are more damaging than meteoroids due to their larger size. Asteroids and comets that have identified paths close to Earth's orbit are classified as NEOs. While the majority pose little concern, those with high risk receive further study. Some may be categorized using the Torino Impact Hazard Scale or placed onto an Asteroid Watch Dashboard. Previously uncatalogued objects are sometimes only found after a relative "near miss" that passes the planet. Additional information on asteroids and comets can be found HERE.

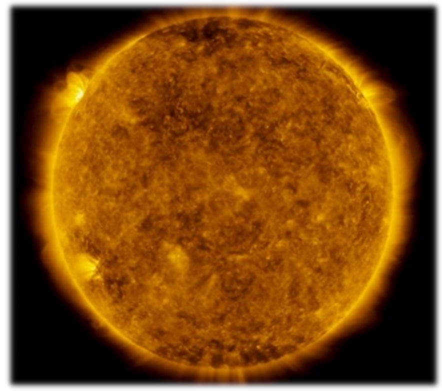
* The MSP/EMHSD does not endorse any one particular modeling method or conclusion among the variety presented by the scientific community. Provided examples are for preliminary educational purposes and base level understanding before broader consideration.

## SPACE WEATHER

*Solar emissions that interact with the space surrounding the Earth, which may damage orbiting satellites, interfere with communication and navigation systems, disrupt utility operations, or cause other terrestrial impacts.*

### *Hazard Description*

Space weather describes the patterns of solar emissions from the Sun, often referred to as "solar winds". This electromagnetic radiation is continually interacting with the space surrounding our planet, typically in a relatively benign manner. This can be thought of as "calm" space weather.



Sun Image, NASA, May 202

Periodic intense flare-ups, or "storms", distribute highly charged plasma particles that may significantly impact our planet. Coronal mass ejections (CME) and solar flares may ultimately cause failures of communication satellites, navigation systems, electric power grids, and even pipelines. The famous Carrington Event of 1859 (described below) caused telegraph systems around the world to malfunction, sometimes starting fires or giving people shocks. Today's storms carry the potential to be particularly damaging because of society's ever-growing reliance upon electricity and computers.

### *Hazard Analysis*

Storms are commonly described as three general types: (1) Geomagnetic Storms, (2) Solar Radiation Storms, and (3) Radio Blackouts. Although different, they can happen at the same time or have overlapping effects.

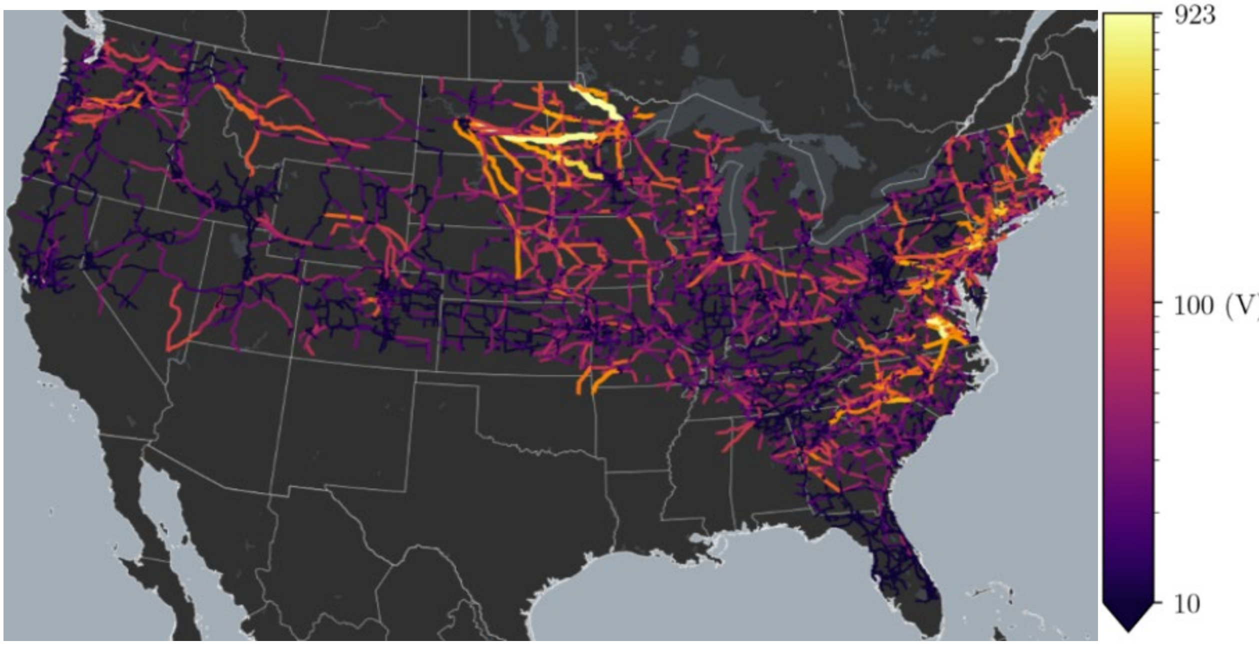
**Geomagnetic Storms** can produce strong disturbances to the Earth's magnetic fields and are typically caused by a CME. Auroras become brighter and can be seen closer to the equator during this time. Storms can induce currents that impact electric transmission equipment, including transformers. The CMEs typically travel from the Sun to the Earth within a few days, providing for a roughly 2-day advance warning if the CME is successfully seen leaving the Sun on a potential trajectory with Earth. A hit may occur with as little as 40 minutes of warning based only on definitive satellite confirmation. Their effects typically last for one to two days, although impacted equipment may need repair or replacement.

**Solar Radiation Storms** result in protons colliding with satellites and affected people. They can penetrate deeply and damage electronics or biologic DNA. Space missions may be delayed to ensure astronaut safety. Circuits may malfunction or see a complete loss of operation. Lesser events may cause temporary satellite jamming. Some estimate that 10% to 15% of all satellites could be rendered inoperative by a severe storm. Other impacts include the loss of some High Frequency (HF) radio communications and navigation position errors. They typically occur with roughly 20 minutes of warning and last for a few hours to several days.

**Radio Blackouts** are caused by bursts of X-ray and Extreme Ultraviolet radiation emitted from solar flares that ionize the sunlit side of the Earth. This increases the amount of energy lost as radio waves pass through the region, primarily affecting HF radio communications (impacts may spill over to VHF and higher frequencies). They are among the most common space weather events affecting the planet, occurring roughly 2,000 times each solar cycle. The X-rays arrive at the speed of light, taking eight minutes to reach the Earth. Blackouts typically last from a few minutes to several hours.

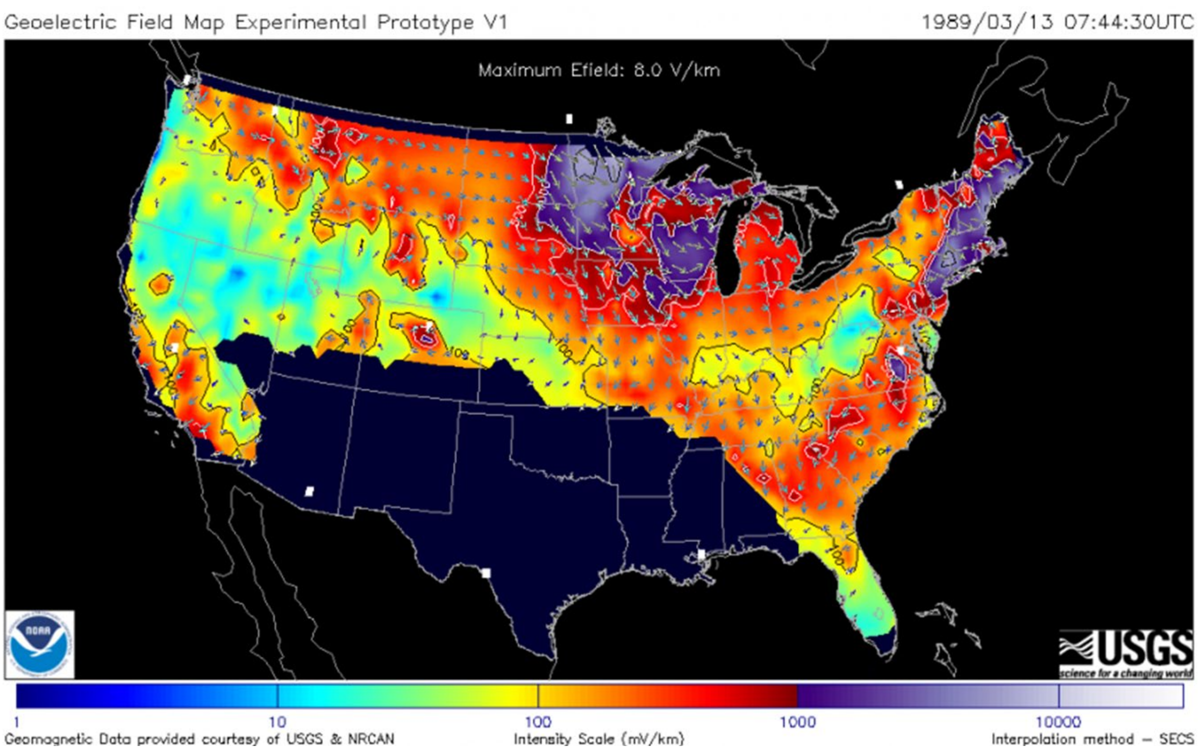
Terrestrial regions near the poles or with higher magnetic latitudes are more likely to experience some of these effects due to variations in our planet's magnetic sphere. Michigan's location puts it at an above-average risk. This is especially true for the Upper Peninsula, although higher populated areas such as those in southeast Michigan are still susceptible. Beyond geographic location, variations in the geologic composition of the planet's crust and mantle also play a role, with some ground not as good at naturally absorbing geomagnetic storm impacts (leading in turn to potentially being more absorbed by infrastructure). A 2020 paper entitled "A 100-year Geoelectric Hazard Analysis for the US High-Voltage Power Grid" considered these and other features in order to map which power lines would be likely to uptake more storm energy. The northeastern seaboard and Minnesota areas were the most impacted. The map from the study omits major portions of the south due to a lack of magnetotelluric survey data. It should also be noted that pipelines may be affected, especially those that are longer and, for Michigan, those that run north and south. Charges induced at the northern end will be stronger, and since the southern end will not be as charged, a current will flow through the pipeline that can increase corrosion. Piping that is already corroded could eventually be compromised.

**100-Year Storm-Induced Voltage on the National Electric Power Grid**




(source: USGS)

Experimental mapping from the USGS attempts to show what the country's increased geoelectric fields looked like on March 13, 1989. This date corresponds with the large space weather event that caused a major blackout in the Quebec, Canada region during this time (described below). Geoelectric fields in the Upper Peninsula were particularly high.




There remains difficulty in estimating how frequently large events such as this may impact the Earth. The Quebec incident has been traditionally referred to as a once in hundred-year type event. A 2021 study offers a different viewpoint, postulating that such an incident could occur somewhere on the planet more frequently, perhaps once every 45 years. Firm conclusions are beyond the scope of this publication. Experimental geoelectric field mapping is available that attempts to measure the current geomagnetic induction hazard being placed upon man-made conductors (such as electrical power lines).

### *Specific Impacts*

Impact on the Public, Property, Facilities, and Infrastructure
Space weather impacts can result in communications problems. Electrical and piping infrastructure may be affected. An extreme storm similar to the Carrington event (below) may cause permanent electronic damage and potentially take the grid years to fully recover. Personal property is not typically damaged during routine storms, although radio function and digital communications are often temporarily impaired. Transportation impacts could include air travel and any modality where computers manage transportation or navigation systems. Astronauts and passengers in high-altitude aircraft may see increased exposure to ionizing radiation/x-rays. Satellites may stop functioning or lose orbit.

Impact on the Economic Condition of the State
Although events like Quebec's1989 power outage (below) have led to newer best practices, the potential for extensive electronic system disruptions could be economically devastating during a worst-case scenario. Disruption to utility systems could halt manufacturing or create gaps in fuel supplies. Many sectors now rely upon satellites, including precision farming. The delivery of goods, including food, could be affected. The airline industry could be particularly hard hit. The US National Academy of Sciences estimates that a "Carrington-like" event happening today would cost the national economy roughly $2T during the first year.

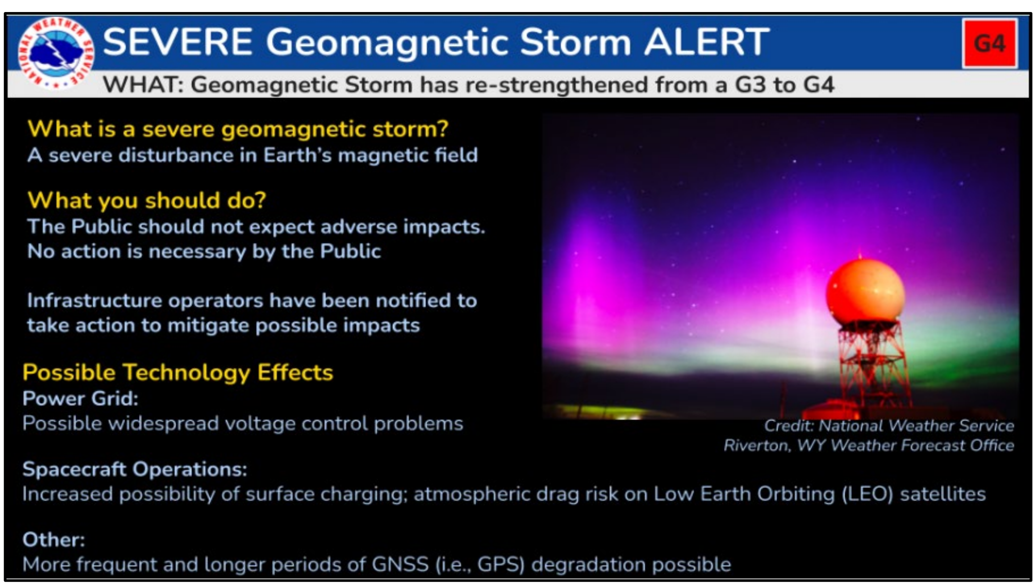
Impact on the Environment
While the relationship is nuanced, the Sun's irradiance is fundamental to our planet's climate and life as we know it. Other sources or space weather also impact our atmosphere and environment. Micro-level considerations attributable to acute solar events include wildfire risks (i.e., powerline sparking associated with extreme geomagnetic storms). Hazardous material facilities and transportation may be put more at risk during space weather events.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Interruptions may occur with radios, locational systems, and other electronics often used for emergency response. Activities that involve electronic navigation may need to use less capable older systems and techniques. It is unknown to what extent newer cars, including autonomous vehicles, would be affected during an extreme event, with speculation varying widely (some postulate highway gridlock).

### *Select Space Weather Occurrences*

Although many events had minimal impacts upon modern Michigan, other historical examples and "close calls" are included to illustrate risk. Rating scale (G3, G4, etc.) explanations for event severity appear at the end of this chapter.

March – April, 2023
This two-month period saw G3 and G4 geomagnetic storms that due to their primary areas of effect resulted in only nominal impacts for highly populated areas (including Michigan). The events are included for educational purposes and to serve as examples for associated alerts.



(source: NWS, April 24, 2023)

February 2022
The company SpaceX lost dozens of satellites after being hit by a geomagnetic storm a day after launch. Instruments suggested the severity of the storm increased atmospheric drag by up to 50%, causing them to fall from orbit and burn.

September 6, 2017- Caribbean
A solar flare created a geomagnetic storm, triggering a R3 radio blackout. The NOAA reported that high-frequency radio used by aviation, maritime, ham radio, and other emergency bands was unavailable for up to eight hours, notably on the same day Category 5 Hurricane Irma was passing through the Caribbean.

July 23, 2012
A solar observatory detected one of the largest solar storms ever recorded. If the solar eruption had taken place even one week earlier it may have resulted in the planet facing a potentially worst-case scenario event.

December 6, 2006 – International
A burst of solar radio wave energy disrupted GPS units across the entire Western hemisphere. Some navigation systems were disrupted for several minutes, including for military aircraft.

October 19 to November 7, 2003 – International, "Halloween Storms"
A series of geomagnetic storms took place in late October. The aviation sector was affected when navigation systems designed to keep traffic at safe distances were disabled. This lasted roughly 30 hours across most of the US. The storms interrupted GPS function, blocked high-frequency radio, and damaged power transformers in South Africa. Emergency procedures were implemented at nuclear plants in Canada and the northeastern US.

April-May, 1998
The failure of an altitude control system for a Galaxy IV satellite, typically valued at over $200M, led to the disruption of 45 million electronic paging devices. Several satellite problems were noted, with researchers eventually concluding that the disruptions were caused or exacerbated by a series of storm-related events leading up to the malfunctions.

January 11, 1997
A multi-million dollar satellite was incapacitated by the impact of a coronal mass ejection. It was officially decommissioned when the function could not be restored.

January 1994 – Canada
Inclement space weather caused electric charges to build up within two communications satellites before damaging discharges. One satellite was temporarily disabled for seven hours. The second went out of service entirely and took six months before its functions were fully restored. The disruptions prevented news information from being electronically delivered to 100 newspapers and 450 radio stations. Television and data services to more than 1,600 remote communities broke down with the second satellite failure. Telephone service in 40 communities was also interrupted. Total costs were estimated at $50-70M.

March 13, 1989 – Canada and Eastern United States, "Quebec Blackout"
Geomagnetic storms caused by a solar flare led to the widespread blackout of almost all of Quebec, affecting as many as six million people for a period of nine hours. Only five transmission lines were initially impacted, but the system was unable to withstand the loss of 21,350 megawatts of capacity. The blackout closed schools and businesses, shut down the Montreal Metro Airport, and delayed flights at other airports. Street traffic backups occurred as traffic signals malfunctioned. Workers in downtown Montreal were stranded in dark offices, stairwells, and elevators. The loss of power created $100M in economic damages, including stalled production processes, idled workers, and spoiled products. Effects were also felt elsewhere, with power surges leading to overloaded transformers in New Jersey. Major power substations experienced voltage swings, some generators went offline, and the USAF temporarily lost its ability to track satellites. It was reported that the broader power grid covering the Northeastern and Midwestern US had also been close to collapsing.

August 4, 1972 – Illinois, others
A solar flare caused the failure of long-distance telephone communications across Illinois (power systems for transatlantic cables were redesigned as a result of this event). Electric grid disturbances were reported in locations across North America. A scientific paper (Knipp, Fraser, Shea, and Smart, 2018) asserted that the storms impacted US military operations, including the unintended detonation of sea mines.

May 16, 1921 – International, “Great Storm”
An extremely strong geomagnetic storm occurred, that according to one study would have resulted in large-scale blackouts across the northwestern US (including Michigan) and the Pacific Northwest if it were to happen today. These figures were extrapolated from estimates based on regions susceptible to power grid collapse and the experiences of Quebec’s power failures from 1989. Extra-high-voltage transformers were considered to be particularly vulnerable, with places like New Hampshire, New Jersey, and Pennsylvania at high risk.

August 28 to September 2, 1859 – International, “Carrington Event”
A large solar flare was observed by astronomer Richard Carrington and independently recorded by Richard Hodgson. Telegraph disruptions occurred in diverse parts of the world during two days of visibly expanded auroras. Various damages and minor injuries resulted from equipment failures and sparks. Some telegraph systems could still transmit even after being disconnected from the system. Evidence taken from arctic ice estimates the storm was the most intense of the past 500 years (nearly twice as powerful as the next closest event, although certain individual intensities have since been individually but not simultaneously matched). Such an event happening today would create far-reaching and long-lasting consequences.

### *Select Agencies and Programs*

Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act
Sponsored by Michigan Senator Gary Peters, the 2020 PROSWIFT Act sets forth provisions for mitigating the effects of space weather and directs several agencies and organizations to improve forecasting capabilities.

National Oceanic and Atmospheric Administration Space Weather Prediction Center
Current space weather conditions are broken down by hazard type and severity (see the table at the end of this chapter). Forecasts and alerts are accompanied by several dashboards, including for aviation, electric power, and emergency management. Material is relayed in part from GOES-R satellites, which monitor both the Sun and Earth. Experimental geoelectric field mapping for the US began in 2023.

Other Solar Monitoring and Measurement Programs
Various spacecraft are used to gather space weather data, with a partial list including:

- The Solar and Heliospheric Observatory is a collaborative international project between NASA and the European Space Agency.

- The Hinode Spacecraft carries a space-borne telescope and other instruments as it follows a Sun-synchronous orbit around the planet. It is part of an international collaborative launched out of Japan.

- The Solar Terrestrial Relations Observatory uses combined views that cover most of the solar surface at all times, including the far side of the Sun.

- The Solar Dynamics Observatory program mission focuses on the Sun’s magnetic field, solar coronal activity, space weather, and irradiance underlying planetary ionospheres.

- The Advanced Composition Explorer (ACE) provides solar wind monitoring and measurement in near real-time. Located at a point of gravitational equilibrium between the Earth and the Sun, ACE provides one hour of advance notice about impending geomagnetic activity that can disrupt communications and/or overload power grids.

### *Supplementary Material*

Three space weather scales are used to summarize potential impacts, using a 5-category classification system for geomagnetic storms (G-scale), solar radiation storms (S-scale), and radio blackouts (R-scale). Impacts may occur together or separately but have been combined into one table on the following page in order to conserve space. The abbreviations of HF and LF refers to *high frequency* and *low frequency* radio waves, and O refers to an event’s relative likelihood of *occurrence*.

**Space Weather Scales (See Previous Page)**

| **Category Labels** | **Geomagnetic Storms** (G-scale effects and frequency) | **Solar Radiation Storms** (S-scale effects and frequency) | **Radio Blackouts** (R-scale effects and frequency) |
|---|---|---|---|
| Minor<br>G1<br>S1<br>R1 | G1 events can cause weak power grid fluctuations, minor impacts on satellite operations, effects on migratory animals, and widely visible auroras seen in Northern Michigan. O: about 900 days per solar cycle. | S1 events result in minor impacts on HF radio in polar regions. O: about 50 such events per solar cycle, each of which can last more than 1 day. | R1 events cause minor degradation of HF radio communication on the sunlit side of Earth, and occasional loss of radio contact. LF navigation signals used by maritime and general aviation systems may be degraded for brief intervals. O: about 950 days per solar cycle. |
| Moderate<br>G2<br>S2<br>R2 | G2 events can cause high-latitude power systems to experience voltage alarms. Long-duration storms may cause transformer damage. Corrections to satellite orientation and orbital drag prediction may be required. HF radio propagation can fade at higher latitudes. Auroras may be visible throughout Michigan. O: about 360 days per solar cycle. | S2 events may expose persons in high-flying aircraft to elevated radiation risks* in areas of high latitude. Infrequent single-event upsets of satellite operations are possible. Possible effects on HF propagation and navigation through polar regions. O: about 25 events per solar cycle, each which can last more than 1 day. | R2 events cause a limited blackout of HF radio communications on the sunlit side of Earth, and loss of radio contact for tens of minutes. LF navigation signals may also be degraded for tens of minutes. O: about 300 days per solar cycle. |
| Strong<br>G3<br>S3<br>R3 | G3 events may require voltage corrections at power systems or trigger false alarms on protective devices. Satellite orientation problems may need correction. Increased component surface charging and atmospheric drag may occur. Intermittent LF radio navigation problems may occur. O: 130 days per solar cycle. | S3 events can expose people in high-flying aircraft to radiation risks in areas of high latitude. Satellite operations may experience single-event upsets, imaging system noise, and slight solar panel inefficiencies. Degraded HF radio propagation in polar regions. Navigation position errors are likely. O: about 10 events per cycle (each can exceed 1 day). | R3 events cause a wide area blackout of HF radio communication and loss of radio contact for about an hour on the sunlit side of Earth. LF navigation signals may be degraded for about an hour.<br>O: about 140 days per solar cycle. |
| Severe<br>G4<br>S4<br>R4 | G4 events may cause widespread voltage control problems for power systems, and mistaken exclusion of grid key assets by some protective systems. Satellites may experience surface charging, tracking and orientation problems that may need correction. Pipelines may experience induced currents. HF radio propagation is sporadic. LF radio disrupted. Satellite-based navigation may be degraded for hours. O: about 60 days per solar cycle. | S4 events can expose persons in high-flying aircraft to radiation risks* in areas of high latitude. Satellites may experience memory device problems, imaging systems noise, orientation problems, and degraded solar panel efficiency. A blackout of HF radio communications is likely through the polar regions. Increased navigation errors over several days are likely. O: about 3 events per solar cycle (each can exceed 1 day). | R4 events cause an HF radio communication blackout on most of the sunlit side of Earth for 1 to 2 hours, with HF radio contact lost during this time. LF navigation signals cause increased errors in positioning for 1 to 2 hours. Minor disruptions of satellite navigation are possible on the sunlit side of Earth. O: about 8 days per solar cycle. |
| Extreme<br>G5<br>S5<br>R5 | G5 events may cause widespread voltage control and protective system problems in power systems, with some grid systems completely blacking out or collapsing, and possible damage to transformers. Satellites may see extensive surface charging, orientation, tracking, and linkage problems. Pipelines may receive induced currents reaching hundreds of amps. HF radio may be out for 1 to 2 days in many areas. LF may be out for hours. Satellite based navigation may be degraded for days. Bright auroral lights visible at night. O: about 4 days per solar cycle. | S5 events can expose persons in high-flying aircraft to radiation risks* in areas of high latitude. Satellites may be rendered useless, may receive permanent solar panel damage, or may experience memory problems, loss of control, serious imaging data noise, and navigation problems. Complete HF radio communications blackouts are possible throughout the polar regions. Navigation operations will be extremely difficult and error laden. O: less than 1 event per solar cycle should occur, although an event may exceed 1 day in duration. | R5 events cause a complete HF radio blackout on the entire sunlit side of Earth for a number of hours. No HF radio contact with mariners and aviators in this sector. LF navigation signals experience outages for many hours on the sunlit side of Earth, causing loss in positioning. Satellite navigation errors in positioning increase for several hours on the sunlit side and may spread into the night side of the Earth. O: fewer than 1 event per cycle. |

(source: NOAA; see previous page for abbreviation explanations)

**Space Weather Overview: Additional Materials**

Solar winds from the Sun continually bathe much of the solar system, emanating outwards until they are halted by the pressures of counterposing interstellar gases. The Earth is partially protected by its atmosphere and surrounding magnetosphere. There are however weak spots in the planet's magnetic field near our two poles, and some outbursts are simply too powerful to be fully mitigated. The planet is also surrounded by "belts" of charged particles (called Van Allen belts), which pose additional hazards to spacecraft and astronauts.

The Sun's emissions include most of the electromagnetic wave spectrum, from harmless radio frequencies to infrared (heat) and ultraviolet radiation, all colors of visible light, x-rays, and microwaves. Their intensity varies, with gamma waves normally emitted only during flare events. Powerful magnetic forces also come into play, affecting the distribution of heat energy and sometimes causing cooler areas known as sunspots. The relatively low temperatures of sunspot areas are coupled with a rise in energy potential above the Sun's surface. Research is progressing to associate sunspot grouping with the likelihood of solar storm activity. Larger groups that are more magnetically complex are likely to pose the highest threat, corresponding to higher "McIntosh classes" (a system for categorizing sunspot patterns).

Solar prominences are important features of the Sun that are comprised of plasma. They stay connected to the surface as they extend out into the solar corona, often taking the form of arch and loop patterns. A solar flare is generated when magnetic fields are unable to maintain these shapes and is typically seen as an intense flash of light. Some may break away from the sun completely, creating a CME. A CME may also occur as a spontaneous outward burst of gas, shooting large quantities of matter and electromagnetic radiation into space. While the two phenomena can occur at the same time (the strongest flares are almost always correlated with a CME), their differences as to the type of matter they emit, how they travel, and their effects on nearby planets can carry important distinctions.

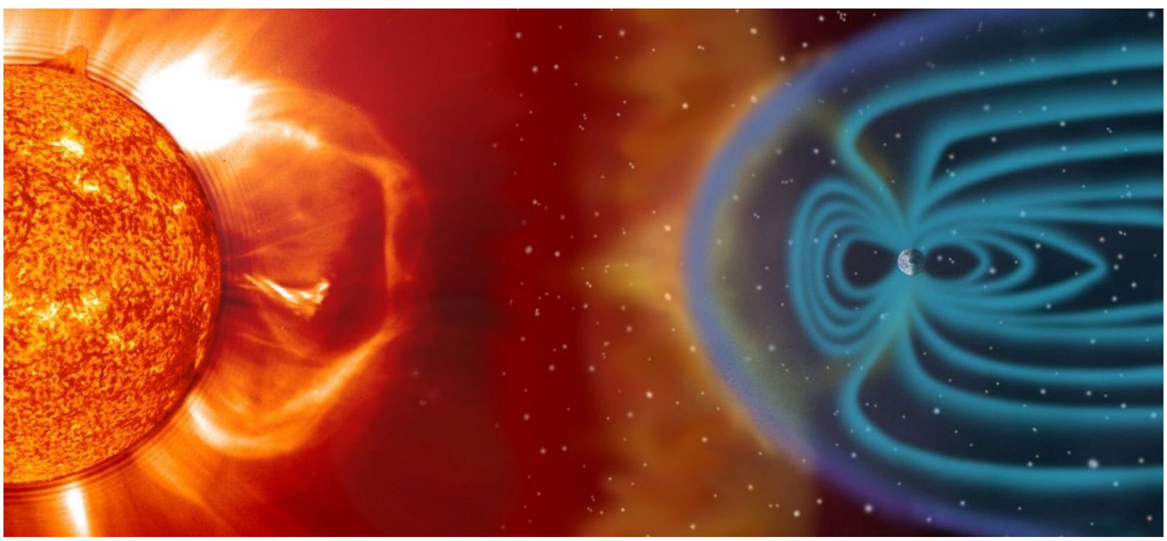


Illustration of a CME interacting with the Magnetosphere (not to scale). Courtesy of the European Space Agency.

As a CME hits the magnetosphere its storm effects are seen globally within a few minutes. The impact causes acceleration of electrons to the energies near and inside the Van Allen belts' orbit. These electrons pose a significant hazard to satellite systems, and the belts can remain in an activated state for days or weeks following a large storm. In the ionosphere, the strongest currents occur in the auroral regions (circular bands around the northern and southern magnetic poles). In the Michigan region this would typically occur above Canada, but the auroras can move dramatically south during strong events. These interactions represent the biggest threat to ground-based conductive systems (e.g., electric lines, natural gas pipelines, railroad tracks). These currents, generated by particles precipitating from the magnetosphere, also cause disturbances in the ionosphere that impact communication signals.

Scientists track traditional solar cycles, which include a period of time known as a solar maximum. It features higher levels of Sun activity and ultraviolet radiation. This increases the drag upon low orbiting satellites, which require boosting to stay aloft. For reasons still under study, CMEs are most prevalent during the declining phase that takes place after a solar maximum. Unanticipated large events (such as the 2020 M-20 class solar flare) may however still occur closer to times of a solar minimum. Ultimately a CME can occur anytime during a solar cycle

# AFTERWORD

Commentary on Catastrophic Incidents

This publication contemplates the most significant emergency management related risks our state and local communities may face. However, the MHA should not be considered all-encompassing. The document attempts to strike a balance between potential hazards and their ability to trigger requisite emergency response. Incidents are further seen through a lens of frequency and likely severity.

It can be challenging to determine how much effort should be spent analyzing hazards with a remote chance of occurring. Some infrequent hazards may still be briefly mentioned due to the sheer magnitude of their destructive potential. A solar storm that could create a prolonged nationwide blackout may still not happen in our lifetime but still allows for some level of mitigation. On the other hand, a supernova Sun would be so devastating it would simply destroy the Earth. The MHA focuses on Michigan hazards that through a combination of frequency and severity should be routinely considered as part of state and local emergency management processes.

Emergency managers should look for commonalities with more frequent risks when attempting to mitigate low frequency/high severity hazards. For example, not all "routine" blackout mitigation efforts would be helpful in the case of a severe solar storm, but many could be. Building shelters used for tornadoes could apply to other hazard if considerations are taken into account during the planning process. Such synergies can be extremely beneficial when dealing with scarce resources.

It is important to acknowledge that even relatively benign hazards may become catastrophic under the right conditions. This can be because of interconnected impacts with other hazards, or simply be a matter of scale for the incident. For example, a typical forest fire can be relatively well controlled in many circumstances, but looking at large forest fires in California shows great exceptions. While much of the material in the MHA is geared towards hazard levels that local communities are the most likely to face, this does not mean that outlier events won't occur. Indeed, in the aggregate and given enough time, its statistically probable that some such catastrophic events will happen.

Catastrophes also deserve mentioning because those that don't occur within our borders may still impact Michigan. As an example, even a devastating Atlantic hurricane may result in only heavy rains for the State, along with some moderate level of flooding that has already been contemplated. This may nevertheless occur during a time when Michigan is already facing different hazards, tying up resources or complicating planning efforts. Mutual aid agreements are also in place between states to assist one another in the case of major incidents. Such events would most likely call for the coordination of emergency personnel between Wisconsin, Indiana, Ohio, and Ontario, but could involve any state or nation. Large numbers of evacuees may need to be sheltered. While it is beyond the ability of local emergency managers to fully analyze all remote catastrophic events, putting complete blinders on towards such incidents is also undesirable. As parting food for thought, some events are listed below to remind us that even the unthinkable could still impact Michigan communities:

**A Supervolcano Event**

A so-called "supervolcano", estimated to have occurred only three times in the past 2.1 million years, would emit billions of tons of ash into the air with disastrous global effects. The largest eruption in recorded history was that of Mount Tambora (Indonesia) in 1816, which still led to a "year without a summer" and worldwide food shortages.

**Atlantic Ocean Tsunami Event**

Whether it originates from a seismic event or celestial impact, a large tsunami hitting the Eastern Seaboard would result in widespread damage. An event of sufficient size and velocity has the potential to be a catastrophic incident, resulting in the type of water displacement seen in the 2004 Indian Ocean tsunami or the 2011 Japanese Fukushima disaster. Michigan emergency resources would be diverted and used, and some portion of mass evacuees may need to be sheltered. Michigan's economy and that of the nation would be severely impacted depending on location.

**Invasion of the United States**

Despite our military strength, an invasion by foreign aggressors is not an impossibility. Technological advances have made even conventional warfare more deadly, and chemical, biological, or nuclear weapons may be used. World War III type scenarios could see mass relocations of people and massive changes to resource use and ways of life. Ethnically diverse populations within Michigan could be disproportionally affected depending on the identity of aggressors.

# Appendix A

**Base Maps**
The following maps profile Michigan's 83 counties and adjusted census urban boundary areas to aid in identifying the locations mentioned in this publication. The State's official travel map is another available resource.

The MHA places counties into loosely divided areas for purposes of analysis. While some counties could be differently assigned, the grouping's main purpose is to simply create four generally cohesive areas. Some hazard chapters include data (e.g., Storm Events Database) that gets grouped in this manner. Such divisions are not used for other purposes and don't mirror official MSP/EMHSD regions.

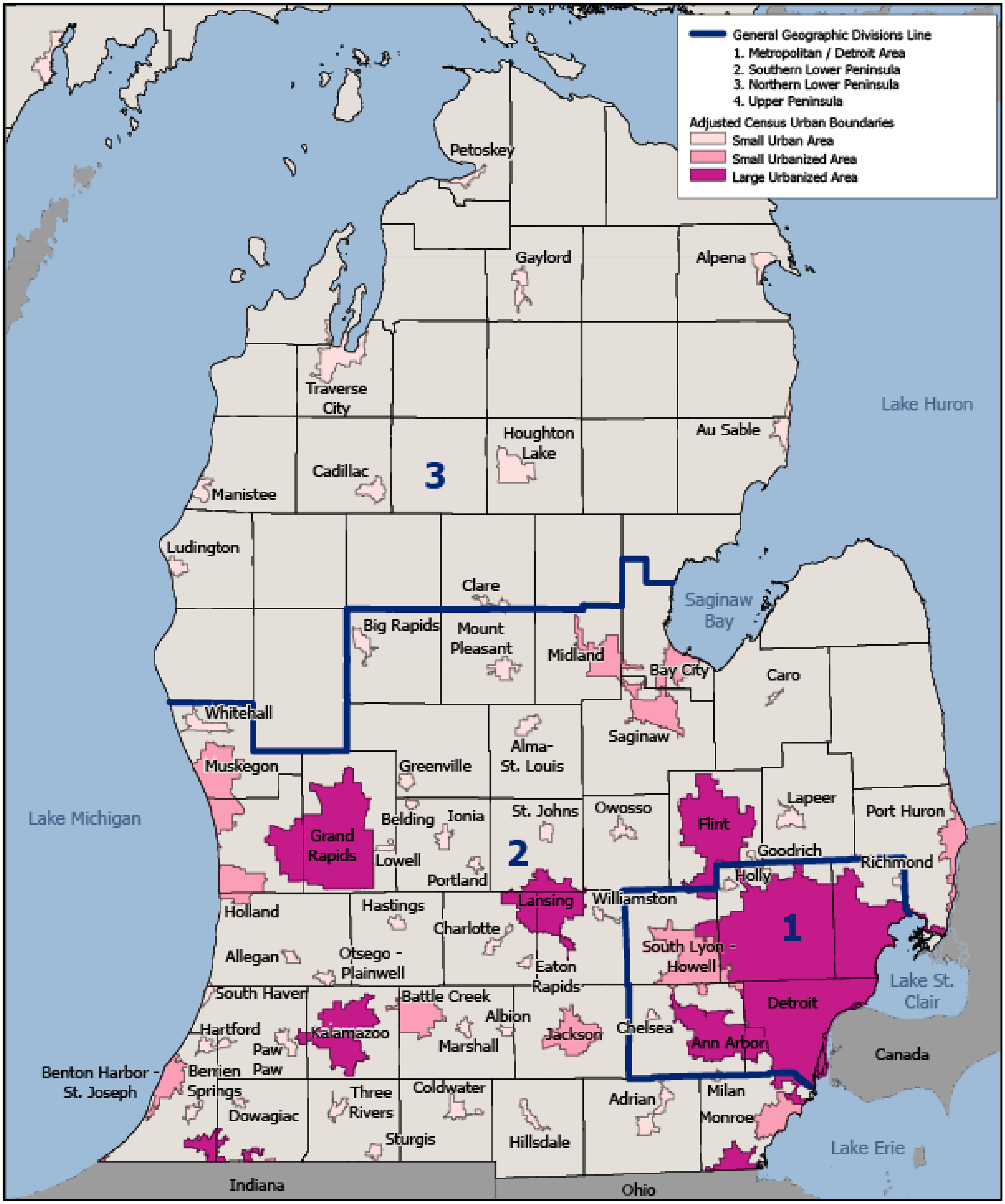
Division 1: Metropolitan / Detroit (5 counties)
Division 2: Southern Lower Peninsula (34 counties)
Division 3: Northern Lower Peninsula (29 counties)
Division 4: Upper Peninsula (15 counties)

Counties within a division are not listed alphabetically but instead follow a geographic orientation that generally begins with the most southwest county and then continues east, moving across in rows and eventually ending to the north and east. This somewhat mimics common wind directions during summer months but is far from a perfect representation. Currently this format is being retained only for consistency with past editions of this publication.

| Metropolitan/Detroit | Southern Lower Peninsula | Northern Lower Peninsula |
|---|---|---|
| Washtenaw | Berrien | Oceana |
| Wayne | Cass | Newaygo |
| Livingston | St. Joseph | Mason |
| Oakland | Branch | Lake |
| Macomb | Hillsdale | Osceola |
| | Lenawee | Clare |
| **Upper Peninsula** | Monroe | Gladwin |
| Gogebic | Van Buren | Arenac |
| Iron | Kalamazoo | Manistee |
| Ontonagon | Calhoun | Wexford |
| Houghton | Jackson | Missaukee |
| Keweenaw | Allegan | Roscommon |
| Baraga | Barry | Ogemaw |
| Marquette | Eaton | Iosco |
| Dickinson | Ingham | Benzie |
| Menominee | Ottawa | Grand Traverse |
| Delta | Kent | Kalkaska |
| Schoolcraft | Ionia | Crawford |
| Alger | Clinton | Oscoda |
| Luce | Shiawassee | Alcona |
| Mackinac | Genesee | Leelanau |
| Chippewa | Lapeer | Antrim |
| | St. Clair | Otsego |
| | Muskegon | Montmorency |
| | Montcalm | Alpena |
| | Gratiot | Charlevoix |
| | Saginaw | Emmet |
| | Tuscola | Cheboygan |
| | Sanilac | Presque Isle |
| | Mecosta | |
| | Isabella | |
| | Midland | |
| | Bay | |
| | Huron | |

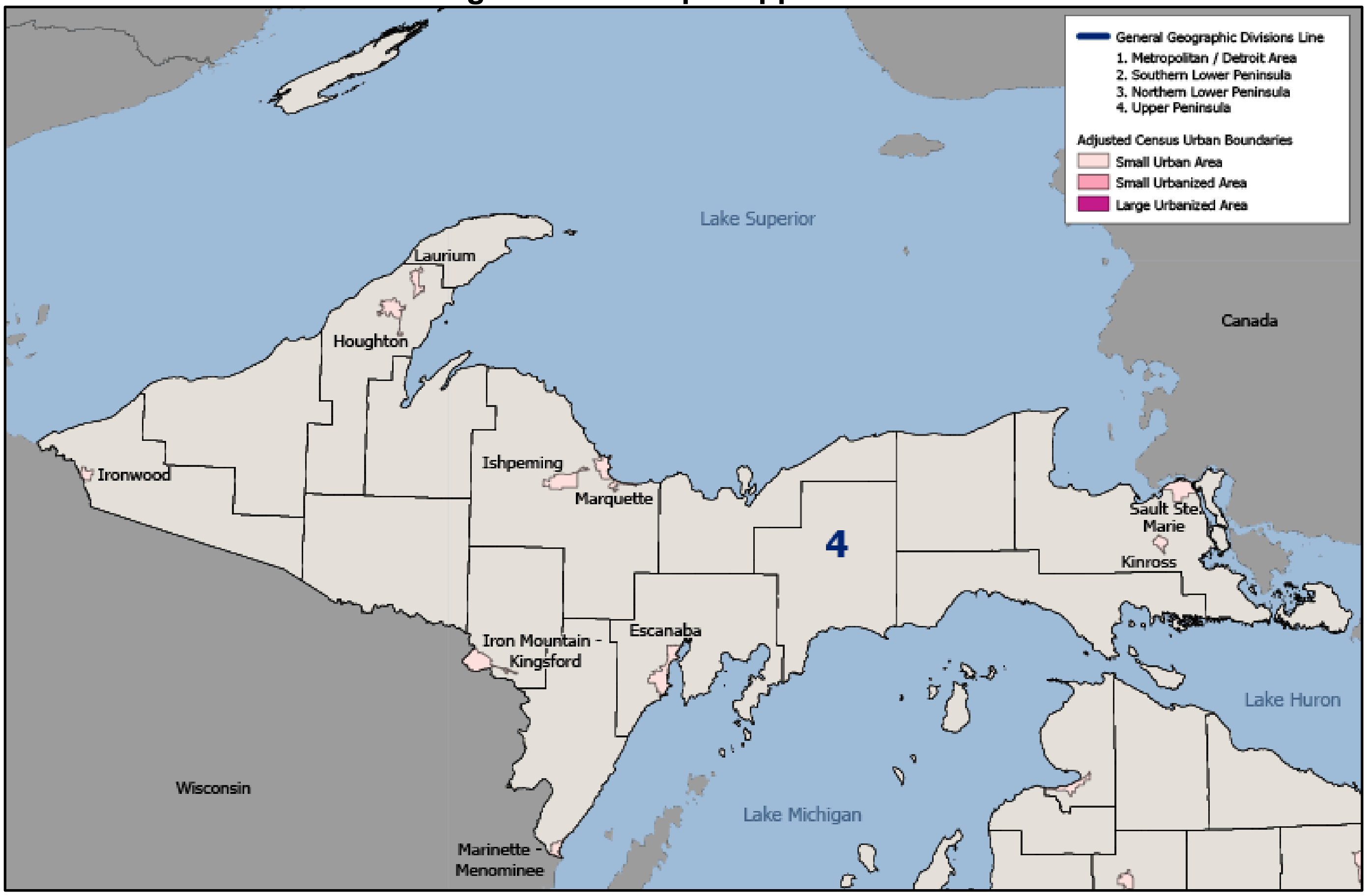
# Michigan Profile Map – Counties

## Michigan Profile Map – Lower Peninsula



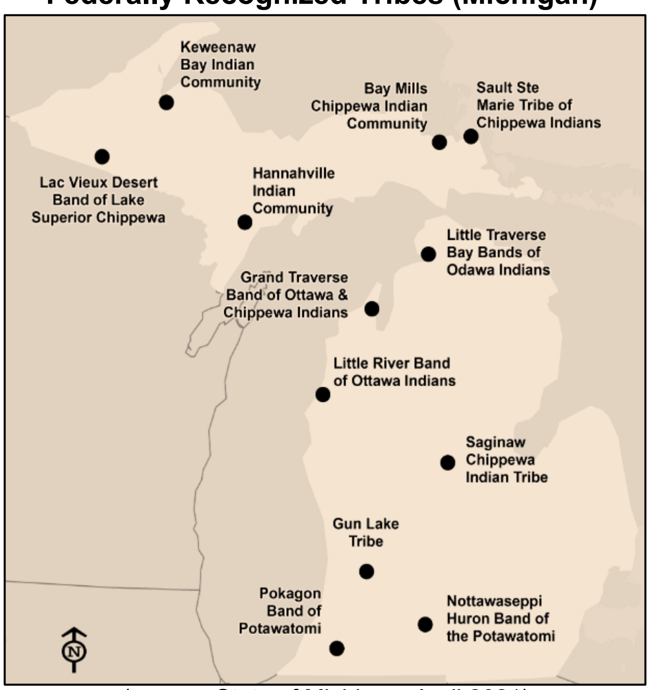

(source: MSP/EMHSD, June 2023; Adjusted Census Urban Boundaries include: urban cluster areas with minimum population of 5,000, or urbanized areas as designated by the US Census, or entire corporate limits of any incorporated city or village designated as partially urban by the Census, or adjacent areas which meet other agreed upon specified criteria.)

## Michigan Profile Map – Upper Peninsula




(source: MSP/EMHSD, June 2023)

## Federally Recognized Tribes (Michigan)




(source: State of Michigan, April 2021)

Michigan shares geography with twelve sovereign tribal nations that are federally recognized by the US government. A larger version of the accompanying map (left) can be found HERE. The map is intended only for general informational purposes, does not show all locations, and is subject to change.

The MSP/EMHSD maintains a more detailed map of tribal lands, best viewed online due to the small size of some parcels. Especially large sections of land exist on reservations located within the geography of Isabella and Baraga counties.

Other detailed maps can be viewed on EMHSD's Online Tools webpage. These include the NRI, RAPT, and MiEJScreen: Environmental Justice Screening Tool.

## Appendix B

**Database and Summations**

The MHA has traditionally relied on the analysis of natural hazards. Due to historical changes in data collection, there are different periods of record availability depending on the hazard, with 1996 beginning the most complete period of time. The website is maintained by NOAA/NWS.

The database has strengths and weaknesses, but in many cases represents the best available data despite its limitations. It is designed to include only *significant* weather phenomena, which often means an event that caused significant (and reported) property damage. Even then, some natural hazards, such as tornadoes, appear to be more robustly included than others, such as wildfires. Criteria for some datasets has changed over time. Comparing information taken from the same database can be advantageous, but data nuances and limitations should be taken into consideration before drawing broad conclusions. The role of outlier events should also be kept in mind when analyzing the following roughly 26 years of data (since 1996) and their effects on state totals.

One method of analysis is to rank estimated damages. The NCEI damage definition states: "*Property damage estimates should be entered as actual dollar amounts if a reasonably accurate estimate from an insurance company or other qualified individual is available. If this estimate is not available, then the preparer has two choices: either check the "no information available" box or make an estimate [an estimate for flooding must always be included]. Typically, damage refers to damage inflicted to private property (e.g., structures, objects, vegetation) as well as public infrastructure and facilities".* Crop damages, when reported, are tracked separately. Initial estimates do not generally see revision and are typically never adjusted for inflation. Some other NCEI products may account for inflation (Consumer Price Index (CPI)) where specifically stated.

As noted in the MHA's standalone chapters, the MHA aggregates many NCEI categories in order to provide a more straightforward analysis. For example, this publication combines the NCEI categories of "Ice Storm", "Sleet", and "Freezing Fog" for the MHA category of "Freezing Rain" (while still placing generic snowstorms and blizzards together in a different category).

**Reported Damaging Events, Select NCEI Categories (Michigan, 1/1/1996 through 4/30/2023)**

| Corresponding MHA Category | Reported Damaging Events | Total Property Damage Estimates | Deaths | Injuries |
|---|---:|---:|:---:|:---:|
| Floods | 1,413 | $3,140,642,000 | 12 | 8 |
| High Winds | 10,415 | $1,163,454,097 | 42 | 282 |
| Tornadoes | 458 | $445,697,030 | 9 | 210 |
| Hail | 4,508 | $394,128,300 | 0 | 5 |
| Freezing Rain | 432 | $316,774,000 | 2 | 5 |
| Snow | 9,549 | $62,306,500 | 2 | 10 |
| Wildfire | 28 | $19,686,000 | 0 | 4 |
| Lightning | 318 | $18,343,000 | 18 | 117 |

(source: NCEI and MHA Chapters; See relevant MHA hazard chapters for category aggregation)

Flooding is the highest-ranked hazard category based on property damages, with high winds (non-tornadic) coming in second. On a per-incident basis, tornadoes are more damaging than wind events but happen much less frequently. Hail comes close to meeting tornado damage totals, but an outlier hail event accounts for much of its damages over this time period (outlier events are not unique to hail). Data from such outlier events may give the impression that a hazard typically causes more damage than it actually does. Outliers also serve as a reminder that significant events of an infrequent nature can and do happen (and may be quite costly despite their relatively rare occurrence).

It may sometimes be helpful to combine data for snow and freezing rain as "winter weather", as certain mixed precipitation events can be difficult to discreetly categorize when being put into the NCEI database. Freezing rain is parsed out here however as it can be particularly damaging. Due to the nature of NCEI reporting, wildfires are underrepresented in this table (see the Wildfires Chapter). The number of events reported for lightning may appear low, but it should be kept in mind that routine, non-damaging lightning is not being considered. Lightning's death totals are still higher than for floods, however.

Hazard analysis based on injury ranking appears on the following page (including for Extreme Heat and Extreme Cold, whose property damage totals are not reliably reflected in the NCEI database).

**Reported Damaging Events, Select NCEI Categories (Michigan, 1/1/1996 through 4/30/2023)**

| Hazards, Ranked by # of Injuries | Reported Events | Significant Injuries | Deaths | Injuries Per Event | Deaths Per Event |
|---|---|---|---|---|---|
| Extreme Heat | 318 | **882** | 8 | 2.7736 | 0.0252 |
| High Winds | 10,415 | **282** | 42 | 0.0271 | 0.0040 |
| Tornadoes | 458 | **210** | 9 | 0.4585 | 0.0197 |
| Extreme Cold | 915 | **200** | 29 | 0.2186 | 0.0317 |
| Lightning | 318 | **117** | 18 | 0.3679 | 0.0566 |
| Snow | 9,549 | **10** | 2 | 0.0010 | 0.0002 |
| Floods | 1,413 | **8** | 12 | 0.0057 | 0.0085 |
| Freezing rain | 432 | **5** | 2 | 0.0116 | 0.0046 |
| Hail | 4,508 | **5** | 0 | 0.0011 | 0.0000 |
| Wildfire | 28 | **4** | 0 | 0.1429 | 0.0000 |
| **Ranked by Injury Ratio** | | | | | |
| Extreme Heat | 318 | 882 | 8 | **2.7736** | 0.0252 |
| Tornadoes | 458 | 210 | 9 | **0.4585** | 0.0197 |
| Lightning | 318 | 117 | 18 | **0.3679** | 0.0566 |
| Extreme Cold | 915 | 200 | 29 | **0.2186** | 0.0317 |
| Wildfire | 28 | 4 | 0 | **0.1429** | 0.0000 |
| High Winds | 10,415 | 282 | 42 | **0.0271** | 0.0040 |
| Freezing rain | 432 | 5 | 2 | **0.0116** | 0.0046 |
| Floods | 1,413 | 8 | 12 | **0.0057** | 0.0085 |
| Hail | 4,508 | 5 | 0 | **0.0011** | 0.0000 |
| Snow | 9,549 | 10 | 2 | **0.0010** | 0.0002 |

(source: NCEI and MHA Chapters; See relevant MHA hazard chapters for category aggregation)

These stacked tables display the same data but are ranked by different criteria. They demonstrate the effects that both extreme heat and extreme cold can have on individuals, somewhat independently of associated hazards (e.g., snow may still trap people in vehicles, and high winds contribute to wind chill). Looking at injuries and no deaths, extreme heat ranks the highest in both tables, with wind-related events coming in second and third for the overall numbers of injuries. Tornadoes in particular were ranked notably high on both lists.

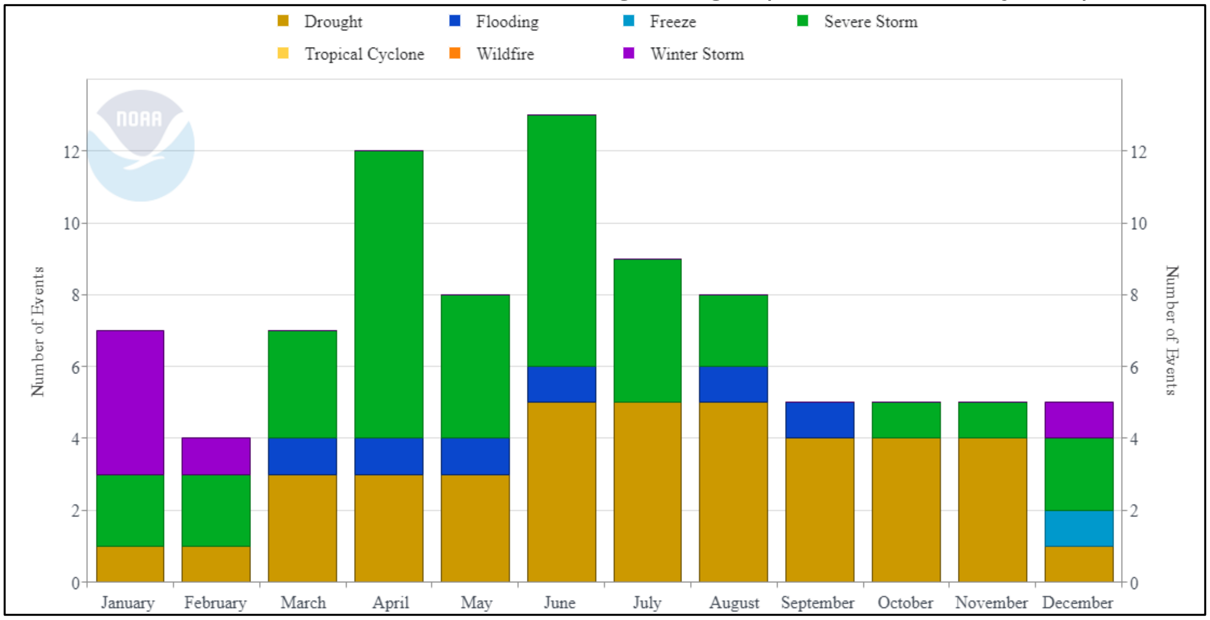
Extreme heat events were the only hazard that, on average, resulted in more than one injury per event. Tornadoes approached “half” an injury on average, per event, followed by lightning. Reported lightning events involved a death at the highest rate, not surprising given that a reported death may have been the only reason the incident was included in the database.

While past data can be helpful for general educational purposes, changing climate conditions are expected to impact what might have otherwise been continued trends going forward. This is discussed in select hazard-specific chapters. Some changes (e.g., more days with a higher potential for extreme heat) seem obvious. Other changes, like the frequency of “offseason” tornadoes, or the future severity of thunderstorms in the state, require more nuanced considerations. See the associated section in the MHMP for more information.

Another method of study is to focus on the largest, most damaging of events. Such an analysis appears on the next page, reinforcing the sentiment that more damaging storm-related incidents (of both a “summer” and “winter” nature) have been occurring over the past decade.

**Billion Dollar Disasters (Impact on Michigan)**
Some of the nation’s biggest weather-related disasters have generated at least $1B in damages, 50 of which have at least partially impacted the State to some degree since 1980. All but one event affecting Michigan was associated with either severe storms (68% prevalence/43% total costs), flooding (8%/26%), drought (10%/26%), or winter storms (12%/5%). A widespread 1983 freeze event was the lone exception. Events are most common from the spring through mid-summer (April–August) followed by mid-winter through early spring (January-March).

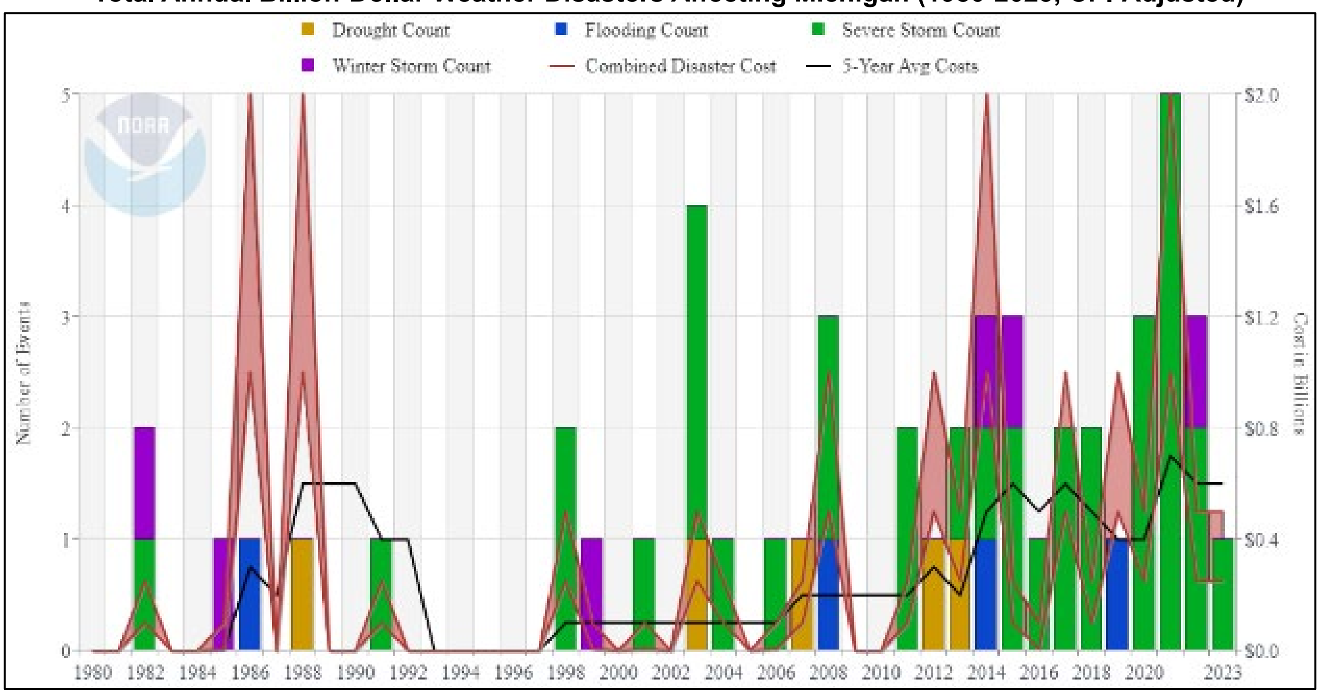
**Billion Dollar Weather Disasters Affecting Michigan (1980-2023, CPI-Adjusted)**




(source: NOAA Billion-Dollar Weather and Climate Disasters, accessed July 2023)

Looking at those top four hazards over time since 1980 (see chart below) there can be seen a trend towards increasing costs during the most recent 1-2 decades. This holds true despite two older and particularly devastating events (one of which was a 1988 drought).

**Total Annual Billion-Dollar Weather Disasters Affecting Michigan (1980-2023, CPI-Adjusted)**




(source: NOAA Billion-Dollar Weather and Climate Disasters, accessed July 2023)

# Appendix C

**State and Federal Disaster Declarations**
A historical table listing state and federal declarations for Michigan is provided, as well as descriptions of the different types of associated declarations. Agricultural-related disaster declarations issued through the US Department of Agriculture are not specifically covered, with information available HERE.

State declarations:

- State of Emergency: Declared by the Governor if they find that an emergency has occurred, or a threat of emergency exists. An emergency means any occasion or instance in which the Governor determines state assistance is necessary to supplement local capabilities to save lives, protect property, and public health and safety, or lessen or avert the threat of a catastrophe in any part of the state.

- State of Disaster: Declared by the Governor if they find that a disaster has occurred, or a threat of a disaster exists. A disaster means an occurrence of widespread or severe damage, injury, or loss of life or property due to a natural or human-made cause.

Both declarations have the same effects under the Michigan Emergency Management Act, 1976 PA 390, as amended, activating the response and recovery aspects of applicable state and local Emergency Operations Plans and authorizing the deployment and use of emergency forces and use or distribution of supplies, equipment, etc. to aid response and recovery efforts. Among other authorities, they also allow the Governor to enter reciprocal aid agreements with other states and to seek federal aid. Some state declarations are issued as Executive Orders.

Federal declarations

- Emergency: The President can declare an emergency for any instance where the President determines federal assistance is needed. Emergency declarations supplement State and local or Indian tribal government efforts in providing emergency services, such as the protection of lives, property, public health, and safety, or to lessen or avert the threat of a catastrophe in any part of the US. The total amount of assistance provided for in a single emergency may not exceed $5M. The President shall report to Congress if this amount is exceeded.

- Major Disaster: The President can declare a major disaster for any natural event, including any hurricane, tornado, storm, high water, wind-driven water, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought, or, regardless of cause, fire, flood, or explosion, that the President determines has caused damage of such severity that it is beyond the combined capabilities of state and local governments to respond. A major disaster declaration provides a wide range of federal assistance programs for individuals and public infrastructure, including funds for both emergency and permanent work.

Types of federal assistance vary depending on whether an Emergency or Major Declaration is made (as determined by the Robert T. Stafford Disaster Relief and Emergency Assistance Act). Assistance available under an emergency declaration is restricted to limited programs available to public entities (only rarely to individuals and households). A Major Disaster Declaration makes available a wider variety of assistance programs for governments, as well as for individual assistance.

**Declarations Table**
There have been 103 incidents involving state declarations from 1976 through July of 2023 in Michigan (some incidents may amend an existing declaration as they expand whereas others may involve multiple executive orders). Some state declarations were also accompanied by federal declarations. A table is provided on the following page.

Three federal declarations were made on Michigan's behalf for which no state declaration may have been issued. These include EM-3160-MI (Michigan Severe Winter Storm, declared January 10, 2001), FSA-2261-MI (Michigan Tower Lake Complex Fire, declared May 6, 1999), and EM-3035-MI (Michigan Drought, declared March 2, 1977). It should also be noted that one federal declaration may sometimes be associated with multiple state declarations, and multiple federal declarations may sometimes be associated with one state declaration.

## Michigan Declarations, 1976 – August 2023 (Including Federal Declarations, As Applicable)

| State Count (1976) | Date of Incident | Year | Type of Incident | Affected Area | Type of Declaration | Associated Federal Declaration | Federal Declaration Number |
|---|---|---|---|---|---|---|---|
| 103 | 8/24/2023 | 2023 | Thunderstorms (Tornadoes, High Winds, Flooding) | Eaton, Ingham, Ionia, Kent, Livingston, Monroe, and Wayne Counties; City of South Lyon (Oakland County), City of New Baltimore and Chesterfield Twp. (Macomb County) | Emergency | - | - |
| 102 | 4/11/2023 | 2023 | Flooding | Alger, Baraga, Dickinson, Gogebic, Houghton, Iron, Marquette, Ontonagon Counties | Emergency | - | - |
| 101 | 10/6/2022 | 2022 | Fire | Menominee County | Emergency | - | - |
| 100 | 8/13/2022 | 2022 | Water Main Break | Lapeer, Macomb, Oakland, and St. Clair Counties | Emergency | - | - |
| 99 | 5/12/2022 | 2022 | Flooding | Marquette County | Emergency | - | - |
| 98 | 5/11/2022 | 2022 | Flooding | Mecosta County | Emergency | - | - |
| 97 | 5/20/2022 | 2022 | Tornado | Otsego County | Emergency | - | - |
| 96 | 8/30/2021 | 2021 | Hazardous Materials Leak | Monroe and Wayne Counties | Emergency | - | - |
| 95 | 8/11/2021 | 2021 | Severe Weather | Branch, Hillsdale, and St. Joseph Co. | Emergency | - | - |
| 94 | 8/5/2021 | 2021 | Fire | Menominee County | Emergency | - | - |
| 93 | 7/24/2021 | 2021 | Thunderstorms | Armada Township (Macomb Co.), Village of Armada (Macomb Co.), White Lake Township (Oakland Co.) | Emergency | - | - |
| 92 | 7/7/2021 | 2021 | Thunderstorms | City of Farmington (Oakland Co.), City of Farmington Hills (Oakland Co.), City of Southfield (Oakland Co.) | Emergency | - | - |
| 91 | 6/25/2021 | 2021 | Flooding, Tornadoes | Huron, Ionia, Washtenaw, and Wayne Co. | Emergency | Major Disaster | 4607 |
| 90 | 2/20/2021 | 2021 | Extreme Cold | All 83 counties | Emergency | - | - |
| 89 | 5/19/2020 | 2020 | Flooding | Arenac, Gladwin, Iosco, Midland, and Saginaw Counties | Emergency | Emergency / Major Disaster | 3525 / 4547 |
| 88 | 3/10/2020 | 2020 | Pandemic | All 83 counties | Emergency | Emergency / Major Disaster | 3455 / 4494 |
| 87 | 7/20/2019 | 2019 | Flooding | Lake County | Emergency | - | - |
| 86 | 5/25/2019 | 2019 | Flooding | Tuscola County | Emergency | - | - |
| 85 | 4/30/2019 | 2019 | Flooding | Wayne County | Emergency | - | - |
| 84 | 3/14/2019 | 2019 | Flooding | Newaygo County | Emergency | - | - |
| 83 | 2/7/2019 | 2019 | Severe Winter Weather | Ionia County | Emergency | - | - |
| 82 | 2/7/2019 | 2019 | Severe Winter Weather | City of Grand Rapids | Emergency | - | - |
| 81 | 1/29/2019 | 2019 | Extreme Cold | All 83 counties | Emergency | - | - |
| 80 | 7/26/2018 | 2018 | Drinking Water Contamination | Kalamazoo County | Disaster | - | - |
| 79 | 7/11/2018 | 2018 | Flooding | Houghton County | Disaster | - | - |
| 78 | 6/18/2018 | 2018 | Flooding | Gogebic, Houghton, and Menominee Counties | Disaster | Major Disaster | 4381 |
| 77 | 2/19/2018 | 2018 | Flooding | City of Grand Rapids and City of Lansing; Allegan, Arenac, Barry, Berrien, Cass, Clare, Eaton, Ingham, Ionia, Kalamazoo, Kent, Newaygo, Mecosta, Ogemaw, Oscoda, Ottawa, and St. Joseph Co. | Disaster | - | - |
| 76 | 6/22/2017 | 2017 | Flooding | Bay, Gladwin, Isabella, and Midland Counties | Disaster | Major Disaster | 4326 |
| 75 | 12/24/2016 | 2016 | Sewer Collapse/ Sinkhole | City of Fraser; Macomb County | Emergency | - | - |
| 74 | 10/16/2016 | 2016 | Flooding | Chocolay, Skandia, and West Branch Townships (Marquette Co.) | Disaster | - | - |

| State Count (1976) | Date of Incident | Year | Type of Incident | Affected Area | Type of Declaration | Associated Federal Declaration | Federal Declaration Number |
|---|---|---|---|---|---|---|---|
| 73 | 7/12/2016 | 2016 | Severe weather | City of Wakefield (Gogebic Co.), Township of Bessemer (Gogebic Co.), Township of Erwin (Gogebic Co.); Gogebic Co. | Disaster | - | - |
| 72 | 8/2/2015 | 2015 | Thunderstorms | City of Traverse City (Grand Traverse Co.), Township of Acme (Grand Traverse Co.), Township of East Bay (Grand Traverse Co.), Township of Garfield (Grand Traverse Co.), Township of Long Lake (Grand Traverse Co.), Township of Peninsula (Grand Traverse Co.), and Township of Whitewater (Grand Traverse Co.); Grand Traverse, and Leelanau Co. | Disaster | - | - |
| 71 | 6/22/2015 | 2015 | Tornado | City of Portland, Orange Township, and Portland Township (Ionia Co.) | Disaster | - | - |
| 70 | 9/26/2014 | 2014 | Bridge collapse | City of Detroit (Wayne Co.) | Emergency | - | - |
| 69 | 8/11/2014 | 2014 | Urban flooding | Macomb, Oakland, and Wayne Co. | Disaster | Major Disaster | 4195 |
| 68 | 4/25/2014 | 2014 | Contaminated water | City of Flint (Genesee Co.) | Emergency | Emergency | 3375 |
| 67 | 4/12/2014 | 2014 | Flooding | Isabella, Mecosta, Missaukee, Muskegon, Newaygo, Osceola, Roscommon, and Wexford Co. | Disaster | - | - |
| 66 | 2/13/2014 | 2014 | Deep frost | Charlevoix, Cheboygan, Chippewa, Delta, Emmet, Gogebic, Luce, Mackinac, and Marquette Co. | Emergency | - | - |
| 65 | 4/16/2013 | 2013 | Flooding | Allegan, Baraga, Barry, Benzie, Genesee, Gogebic, Gratiot, Houghton, Ionia, Iron, Kent, Keweenaw, Marquette, Mecosta, Midland, Muskegon, Newaygo, Ontonagon, Osceola, Ottawa, and Saginaw Co.; City of Grand Rapids (Kent Co.); City of Ionia (Ionia Co.) | Disaster | Major Disaster | 4121 |
| 64 | 5/25/2012 | 2012 | Wildfire | Luce and Schoolcraft Co. | Disaster | - | - |
| 63 | 5/11/2012 | 2012 | Flooding | Genesee County | Emergency | - | - |
| 62 | 5/31/2011 | 2011 | Thunderstorms | City of Battle Creek (Calhoun Co.); Calhoun Co. | Emergency | - | - |
| 61 | 7/27/2010 | 2010 | Oil pipeline spill | Calhoun Co. | Disaster | - | - |
| 60 | 6/9/2010 | 2010 | Thunderstorms, tornadoes | Monroe Co. | Emergency | - | - |
| 59 | 7/21/2009 | 2009 | Tanker truck explosion, fire | Oakland Co. | Emergency | - | - |
| 58 | 6/19/2008 | 2008 | Flooding, Tornadoes | Manistee, Wexford, Lake, Ottawa, and Osceola Co. | Emergency | Major Disaster | 1777 |
| 57 | 6/13/2008 | 2008 | Flooding, Tornadoes | City of Saginaw (Saginaw Co.), Allegan Co., Eaton Co., City of Lansing (Ingham Co.), and Mason Co. | Emergency | Major Disaster | 1777 |
| 56 | 8/27/2007 | 2007 | Tornado | City of Fenton (Genesee Co.) | Emergency | - | - |
| 55 | 8/10/2007 | 2007 | Wildfire | Luce Co. | Emergency | - | - |
| 54 | 7/28/2006 | 2006 | Thunderstorms, heavy rain | Oscoda Co. | Emergency | - | - |
| 53 | 2/27/2006 | 2006 | Severe winds, ice storm | Montcalm Co. | Emergency | - | - |
| 52 | 9/4/2005 | 2005 | Hurricane evacuation | All 83 counties | Disaster | Emergency | 3225 |
| 51 | 6/3/2004 | 2004 | Thunderstorms, flooding | Arenac, Barry, Berrien, Cass, Genesee, Gladwin, Ingham, Ionia, Jackson, Kent, Livingston, Macomb, Mecosta, Newaygo, Oakland, Ottawa, Saginaw, St. Clair, St. Joseph, Sanilac, Shiawassee, Van Buren and Wayne Co. | Disaster | Major Disaster | 1527 |
| 50 | 4/30/2004 | 2004 | Insect infestation (Emerald Ash Borer) | Genesee, Ingham, Jackson, Lapeer, Livingston, Macomb, Monroe, Oakland, Washtenaw and Wayne Co.; City of Allen Park (Wayne Co.); City of Ann Arbor (Washtenaw Co.); City of Birmingham | Emergency | - | - |

| State Count (1976) | Date of Incident | Year | Type of Incident | Affected Area | Type of Declaration | Associated Federal Declaration | Federal Declaration Number |
|---|---|---|---|---|---|---|---|
| | | | | (Oakland Co.); City of Dearborn (Wayne Co.); City of Dearborn Heights (Wayne Co.); City of Detroit (Wayne Co.); City of Fraser (Macomb Co.); City of Livonia (Wayne Co.); City of River Rouge (Wayne Co.); City of Romulus (Wayne Co.); City of Southfield (Oakland Co.); City of Sterling Heights (Macomb Co.); City of Trenton (Wayne Co.); City of Warren (Macomb Co.); City of Wayne (Wayne Co.); Bloomfield Township (Oakland Co.); Canton Township (Wayne Co.); Charter Township of Plymouth (Wayne Co.); Lathrup Village (Oakland Co.) | | | |
| 49 | 8/15/2003 | 2003 | Electric power failure | Macomb, Monroe, Oakland, Washtenaw, and Wayne Co. | Emergency | Emergency | 3189 |
| 48 | 5/15/2003 | 2003 | Flooding | City of Marquette, Marquette Township, and Negaunee Township (Marquette Co.) | Emergency | - | - |
| 47 | 4/16/2002 | 2002 | Flooding | Baraga, Houghton, Iron, Marquette, and Ontonagon Co.; City of Ironwood (Gogebic Co.) | Disaster | Major Disaster | 1413 |
| 46 | 12/29/2001 | 2001 | Heavy snow | Emmet Co. | Emergency | - | - |
| 45 | 10/26/2001 | 2001 | Severe winds | Kalamazoo Co. | Disaster | - | - |
| 44 | 3/9/2001 | 2001 | Flooding | Genesee Co. | Disaster | - | - |
| 43 | 9/20/2000 | 2000 | Urban flooding | Wayne Co. | Disaster | Major Disaster | 1346 |
| 42 | 6/7/2000 | 2000 | Gasoline pipeline rupture | Blackman Twp. (Jackson Co.) | Emergency | - | - |
| 41 | 8/5/1999 | 1999 | Mine Shaft Cave-in | Dickinson Co. | Emergency | - | - |
| 40 | 7/5/1999 | 1999 | Tornado | Oscoda Co. | Disaster | - | - |
| 39 | 1/15/1999 | 1999 | Blizzard, snowstorm | City of Detroit (Wayne Co.) | Emergency | Emergency | 3137 |
| 38 | 9/27/1998 | 1998 | Severe winds | Otsego Co. | Emergency | - | - |
| 37 | 9/1/1998 | 1998 | Thunderstorms, severe winds | City of Niles (Berrien Co.) | Emergency | - | - |
| 36 | 7/23/1998 | 1998 | Thunderstorms, severe winds | Wayne Co.; City of Dearborn (Wayne Co.); City of Warren (Macomb Co.) | Disaster | Major Disaster | 1237 |
| 35 | 5/29/1998 | 1998 | Thunderstorms, severe winds | Bay, Clinton, Gratiot, Ionia, Kent, Mason, Mecosta, Montcalm, Muskegon, Newaygo, Oceana, Ottawa, Saginaw, and Shiawassee Co.; Village of Armada (Macomb Co.) | Disaster | Major Disaster | 1226 |
| 34 | 4/1/1998 | 1998 | Flooding | Alpena Co. | Emergency | - | - |
| 33 | 7/3/1997 | 1997 | Tornadoes, flooding | Genesee, Macomb, Oakland and Wayne Co.; City of Detroit (Wayne Co.); Village of Chesaning (Saginaw Co.) | Disaster | Major Disaster | 1181 |
| 32 | 6/27/1997 | 1997 | Rainstorms, flooding | Allegan and Ottawa Co. | Disaster | - | - |
| 31 | 6/21/1996 | 1996 | Rainstorms, flooding, tornado | Bay, Lapeer, Saginaw, Sanilac, St. Clair, and Tuscola Co.; City of Midland (Midland Co.) | Disaster | Major Disaster | 1128 |
| 30 | 5/22/1996 | 1996 | Flooding | Berrien Co. | Disaster | - | - |
| 29 | 12/13/1995 | 1995 | Snowstorm | City of Sault St. Marie (Chippewa Co.) | Emergency | - | - |
| 28 | 7/8/1994 | 1994 | Flooding | Lapeer, Tuscola and Sanilac Co. | Disaster | - | - |
| 27 | 2/23/1994 | 1994 | Underground freeze | Charlevoix, Cheboygan, Chippewa, Delta, Gogebic, Houghton, Mackinac, Marquette, Ontonagon, Schoolcraft Co. | Emergency | Major Disaster | 1028 |
| 26 | 4/20/1993 | 1993 | Flash flood | Shiawassee Co. | Disaster | - | - |
| 25 | 7/16/1992 | 1992 | Heavy rain | Gogebic Co. | Disaster | - | - |

| State Count (1976) | Date of Incident | Year | Type of Incident | Affected Area | Type of Declaration | Associated Federal Declaration | Federal Declaration Number |
|---|---|---|---|---|---|---|---|
| 24 | 7/14/1992 | 1992 | Tornado | Cass Co. | Disaster | - | - |
| 23 | 10/6/1990 | 1990 | Tornado | Genesee Co. | Disaster | - | - |
| 22 | 9/16/1990 | 1990 | Ship explosion, fire | Bay Co. | Emergency | - | - |
| 21 | 5/9/1990 | 1990 | Wildfire | Crawford Co. | Emergency | - | - |
| 20 | 6/8/1989 | 1989 | Flooding, severe winds | Branch, Kalamazoo, and St. Joseph Co.; Village of Manchester (Washtenaw Co.) | Disaster | - | - |
| 19 | 6/9/1988 | 1988 | Fire | City of Corunna (Shiawassee Co.) | Disaster | - | - |
| 18 | 8/18/1987 | 1987 | Airline crash | City of Romulus (Wayne Co.) | Disaster | - | - |
| 17 | 9/12/1986 | 1986 | Flooding, heavy rain | Allegan, Arenac, Bay, Clare, Clinton, Genesee, Gladwin, Gratiot, Huron, Ionia, Isabella, Kent, Lake, Lapeer, Macomb, Manistee, Mason, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, Shiawassee, Tuscola, and Van Buren Co. | Disaster | Major Disaster | 774 |
| 16 | 2/21/1986 | 1986 | Great Lakes flooding, wave action | Allegan, Arenac, Bay, Berrien, Grand Traverse, Iosco, Macomb, Marquette, Menominee, Monroe, Muskegon, Ottawa, Saginaw, St. Clair, Tuscola, Van Buren, and Wayne Co. | Disaster | - | - |
| 15 | 9/13/1985 | 1985 | Heavy rain, flash flood | Alcona Co. | Disaster | Major Disaster | 744 |
| 14 | 9/10/1985 | 1985 | Heavy rain, flooding | Genesee, Lapeer, and Saginaw Co. | Disaster | Major Disaster | 744 |
| 13 | 4/13/1985 | 1985 | Great Lakes flooding, wave action | Arenac, Bay, Macomb, Monroe, Saginaw, St. Clair, Tuscola, and Wayne Co. | Disaster | - | - |
| 12 | 1/15/1985 | 1985 | Ice storm | Allegan, Barry, Berrien, Calhoun, Eaton, Genesee, Ingham, Jackson, Kalamazoo, Lapeer, Livingston, Oakland, and Van Buren Co.** | Disaster | - | - |
| 11 | 7/15/1983 | 1983 | Wildfire | Schoolcraft Co. | Disaster | - | - |
| 10 | 3/19/1982 | 1982 | Flooding | Berrien and Monroe Co. | Disaster | Major Disaster | 654 |
| 9 | 7/21/1980 | 1980 | Thunderstorms, severe winds | Allegan, Berrien, Calhoun, Cass, Jackson, St. Joseph, Van Buren, Washtenaw, and Wayne Co.; City of Grand Haven and Village of Spring Lake (Ottawa Co.) | Disaster | Major Disaster | 631 |
| 8 | 5/13/1980 | 1980 | Tornado | Kalamazoo and Van Buren Co. | Disaster | Major Disaster | 621 |
| 7 | 8/9/1978 | 1978 | Sewer main break | Macomb Co. | Disaster | - | - |
| 6 | 6/30/1978 | 1978 | Thunderstorms, severe winds, hail, rain | Berrien Co. | Disaster | - | - |
| 5 | 6/28/1978 | 1978 | Thunderstorms | Allegan Co. | Disaster | - | - |
| 4 | 1/26/1978 | 1978 | Blizzard, snowstorm | All 83 counties | Disaster | Emergency | 3057 |
| 3 | 12/10/1977 | 1977 | Snowstorm | City of Hamtramck (Wayne Co.) | Disaster | - | - |
| 2 | 4/6/1977 | 1977 | Tornado, severe winds | Clinton, Eaton, Kalamazoo, and Livingston Co. | Disaster | - | - |
| 1 | 1/28/1977 | 1977 | Blizzard | Allegan, Barry, Berrien, Chippewa, Cass, Eaton, Hillsdale, Ionia, Muskegon, Newaygo, Oceana, Ottawa, Sanilac, Shiawassee, and Van Buren Co. | Disaster | Emergency | 3030 |

# Appendix D

**Document Maintenance and Change Log**
The chapters within the MHA are fully revised at least once every five years, on a rotating basis through the publication of different editions. New editions are named using the year the publication was approved, which typically occurs before the end of the year in question. The full revision of this edition was approved by FEMA in April 2024. Subsequent partial updates to this edition will occur as necessary and will be noted in a change log below.

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**Current MHA Natural Hazards edition: 2024, Version 1**

Version 1: Noteworthy changes from the 2019 MHA for this 2024 edition include: fluvial and pluvial flooding being combined into one chapter, extreme temperatures being split into two chapters (extreme cold and extreme heat), fog information generally moving to go alongside transportation incidents (with freezing fog moved to freezing rain), and drought moved to the ecological hazards section alongside extreme heat, wildfires, and invasive species.

Several chapters saw revision based on emerging trends. More information on air particulates was added to the Wildfires Chapter due to the 2023 Canadian wildfires. The newly separated Extreme Heat Chapter was revised to include more information on cooling centers and heat related impacts to vulnerable populations. The Great Lakes Shoreline Chapter had content added related to reductions in seasonal ice cover. More data was included in the Dam and Levee Failures Chapter to ensure continued compliance with the HHPD Grant Program. Information on tribal nations was added to the map section in Appendix A. A new MSP/EMHSD Online Tools webpage was created.

The historical events/examples listed in each chapter had their ordering reversed, with newer events now listed first. As new events were added some older events were deleted if they were not associated with a declaration and deemed duplicative for educational purposes. Such events still reside in older archived versions of this document.

Chapter specific mitigation alternatives/opportunities, largely duplicated in the MHMP, now appear exclusively in the MHMP. Chapter specific impacts related to public confidence in state government, a requirement under EMAP, became a stand-alone appendix in the MHMP.