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EMERGENCY MANAGEMENT AND
HOMELAND SECURITY DIVISION
Michigan Department of State Police

Michigan Hazard Analysis

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INTRODUCTION

Michigan is vulnerable to a wide range of natural, technological and human-related hazards. Periodic disasters result from floods, tornadoes, winter storms, severe thunderstorms and other events, causing injuries and loss of life, disruption of services, economic impacts, and significant property damage. Such events often have negative impacts on the affected communities for long times afterward. Major disasters have heightened the awareness of Michigan's vulnerability to such events, such as the Flint water emergency, the metropolitan Detroit floods of 2000 and 2014, the 2010 Enbridge oil spill, the 2008 derecho, the "Great Blackout" of 2003, annual severe thunderstorms in various locations, the ice storm and power outages of 2013, the 1987 crash of Northwest Airlines Flight 225 near Detroit Metro Airport, and the 1953 Flint tornado that killed 115 persons.

Advancements in technology, the increased development and use of potentially hazardous chemicals, and known vulnerabilities in public and private utility infrastructure have resulted in a new range of technological risks. Major incidents have increased public awareness and concern about technological threats in Michigan. In addition, human-related threats can cause significant injuries, loss of life, and property destruction. Public health emergencies, terrorism and similar criminal incidents, the impacts of civil disturbances, and an ever-increasing reliance on computer networks, all provide examples of the wide array of problems that emergency managers must address in their hazard mitigation and emergency preparedness efforts.

Emergency managers must also consider how events in other States may affect Michigan communities. The terrorist events of September 11, 2001 (and subsequent anthrax threats) had a national effect. When New Orleans and nearby areas were struck by hurricanes in 2005, Michigan was active in providing assistance to the affected states, as well as receiving and housing evacuees from those areas. A major disaster or national-level emergency might occur in the form of a New Madrid earthquake, another act of major terrorism, cyber-attack, or some other event that is of national significance even if it doesn't directly harm Michigan's physical territory. The era of globalization means that distant events tend to affect prices, supplies of goods and energy, communication and information systems, and other services that are important to Michigan's residents, businesses, agencies, environment, economy, and quality of life.

Managing these varied threats to protect life and property is the primary challenge faced by emergency managers at all levels of government. In order to meet that challenge, emergency managers must first obtain a thorough understanding of the array of hazards that confront the state. The first step in the process of building an effective emergency management capability is the preparation of a hazard analysis that provides an understanding of that array of risks.

Through the process of conducting a detailed hazard analysis, emergency managers become aware of the nature, extent and magnitude, and destructive potential of the natural, technological, and human-related hazards that might impact their area. By pinpointing the locations where these hazards have occurred in the past, and by examining knowledge of new or emerging risks, it is possible to estimate the probability of such events occurring in a given area, as well as the vulnerability of people and property located there. Coupled with relevant land use and demographic information at the local level, a hazard analysis becomes a powerful planning tool that enables emergency managers to set priorities and goals for resource allocation, hazard mitigation, and emergency preparedness activities.

The Emergency Management and Homeland Security Division of the Michigan Department of State Police (EMHSD/MSP) is the coordinating agency for all emergency management and homeland security activities of state and local government in Michigan. In conjunction with other governmental agencies and private organizations, the EMHSD/MSP mitigates, prepares for, responds to, and assists in the recovery from disasters and emergencies in the state. The EMHSD/MSP regularly updates the Michigan Emergency Management Plan (MEMP), which outlines federal, state, and local emergency management responsibilities within Michigan (preparedness and response information), and the Michigan Hazard Mitigation Plan (MHMP), which identifies risks and vulnerabilities, and seeks ways to reduce them. The Michigan Hazard Analysis is coordinated with these other documents, and also serves as a foundation for the development of other state plans. It provides a large array of information for local communities to use in developing their own hazard analyses. Local emergency managers can also refer to EMHSD Publication 201 (Local Emergency Planning Workbook) and EMHSD Publication 207 (Local Hazard Mitigation Planning Workbook) to develop a hazard analysis for their community.

BRIEF PROFILE OF THE STATE OF MICHIGAN

Michigan has a land area of 58,216 square miles and a population of about 9.9 million persons. Its 83 counties include numerous urbanized areas, including Metropolitan Detroit. Most Michigan residents live within these urbanized areas, which are mostly located in the southern portion of the State. Michigan is completely covered by local, incorporated government entities—every inch of the State is part of a township, city, or village, and all residents of these minor civil divisions are also residents within one of Michigan's counties. This constitutes a general political and taxation structure for Michigan's many communities, although additional districts overlay these areas as well, such as school districts and congressional districts.

Located in the midst of four of the Great Lakes, Michigan's fundamental geographic feature is its division into Lower and Upper Peninsulas. The Lower Peninsula encompasses approximately 70% of Michigan's total land area, and the Upper Peninsula accounts for the other 30%. The two peninsulas are divided by the Straits of Mackinac, which allow Lake Michigan to drain into Lake Huron. The southern half of the Lower Peninsula has a level to gently rolling surface, with hills rising to elevations between 1,000 and 1,200 feet. (Lakes Michigan and Huron average about 577 feet above sea level.) The northern half of the Lower Peninsula has higher elevations, with hilly belts of glacial origin reaching elevations of 1,200 to 1,700 feet. The eastern half of the Upper Peninsula is relatively level and often swampy. The western half is higher and more rugged. Michigan has borders on four of the five Great Lakes and has the longest shoreline of any inland state—about 3,200 miles. Michigan also has over 10,000 inland lakes and 36,000 miles of streams.

Michigan has a diversified economy based on agriculture, manufacturing, tourism, services, and professional trades. More automobiles and trucks are produced in Michigan than in any other state. Michigan is the nation's top producer of office furniture, a major source of information technology and software, and a national leader in machine tools, chemicals, and plastics. Michigan is also one of the nation's leading agricultural producers, consistently ranking number one in several product categories.

Michigan has a well-developed, multi-modal transportation system that supports the state's diversified economic activities. The highway system consists of a network of interstate, federal, state, and local routes that connect Michigan communities to major metropolitan areas and economic markets around the country. Michigan has 19 airports that offer commercial passenger jet service to major domestic and international destinations. Freight railroad lines link Detroit and other metropolitan areas with Chicago and other major manufacturing and business centers in the United States and Canada. Michigan also offers 40 Great Lakes ports to facilitate waterborne commerce. Each year, Michigan's transportation system helps move 240 million tons of cargo by truck, rail, air, and ship.

Due to its geography and location, Michigan will always be threatened by natural hazards. The State of Michigan and local governments must always be prepared to manage those types of events when they occur. The principal natural hazard threats to Michigan are floods, thunderstorm winds and lightning, tornadoes, hail, ice/sleet storms, drought, severe winter weather, wildfires, invasive species, extreme temperatures, and geomagnetic storms.

Michigan's principal technological hazard threats include hazardous material incidents, petroleum and natural gas pipeline accidents, other infrastructure failures, structural fires, and major transportation accidents. (It should be noted that many of these threats are a direct or indirect result of the state's position as a major national and international manufacturing and business center. The technological threats present in Michigan are not unlike those present in other industrialized states of similar size and character.)

Michigan's principal human-related hazards include public health emergencies, cyber-attacks, weapons of mass destruction, civil disturbances, and terrorism (and similar criminal activities).

State of Michigan Profile Map

Michigan has a diverse population, a diversified economy, and a broad array of physical environments, community types, and living arrangements. A map of Michigan (see next page) specifically portrays some of this diversity for readers who need to quickly estimate the potential impacts of a disaster event within some area of the state.

Many maps of Michigan (or the United States as a whole) do not include relevant information about neighboring lands, so this brief profile of Michigan will first make mention of the fact that it is adjacent to the states of Ohio, Indiana, and Wisconsin, as well as the Canadian province of Ontario. Michigan's area includes substantial portions of four of the Great Lakes (Superior, Michigan, Huron, and Erie), as well as smaller Lake St. Clair (northeast of Detroit). Despite the prominence of Great Lake shorelines in Michigan's geographic situation, it is extensively connected with its three neighboring states, and with the Canadian province of Ontario. These connections include physical highways, marine ferries and shipping traffic, critical infrastructure (e.g. pipelines, power lines), and communication networks (phone lines, cellular towers, broadcast signals, the internet).

The Michigan Profile Map presents the State of Michigan in a manner that emphasizes its large number of local governments, and provides a general impression about how most of its people, industry, and resources are geographically distributed. The next few pages will provide an explanation of the information shown on this map, with overviews of general trends and risk patterns across the state.

The Michigan Profile Map is primarily intended for use from an emergency management perspective, as a broad background for this analysis of many types of hazards—natural, technological, and human-related. No single map can contain all the information that is relevant for these tasks, so the Michigan Profile Map should merely serve as a starting point, to be supplemented by the many other specialized maps included in the following pages (or that are available from other government departments and authoritative sources).

The Michigan Profile Map presents a selective overview of the general characteristics of Michigan's present settlement, land use, and production patterns. Since many of these patterns correspond with differences in climate and vegetation, it was deemed useful to designate four general geographic divisions within the state:

Geographic Division	Number of Counties	Population (2010 census)	Percent of State Total
1. The Upper Peninsula	15	311,361	3.2%
2. Northern Lower Peninsula	29	717,977	7.3%
3. Southern Lower Peninsula	34	4,464,620	45.2%
4. Metropolitan Detroit	5	4,389,682	44.4%
STATE TOTAL	83	9,883,640	

Geographic Divisions 1 and 2 are predominantly rural, with great quantities of designated forest lands and a fairly specialized scope for its agricultural production, tending to fall within the Köppen Dfb climate category (humid continental, with generally cooler and shorter summers). Geographic Divisions 3 and 4 tend to fall into a slightly warmer climate category (Köppen Dfa) and to contain a larger-scale array of less specialized agricultural production, in closer proximity to major cities than is possible within the less populated northern areas. Area 4 originally had a swampier nature than other parts of southern Michigan, but today is most distinctive because it is dominated by the Detroit Metropolitan Area, which is an order of magnitude larger than any other urban area in Michigan, and larger than any other Midwestern metropolitan area except for Chicago.

It must be emphasized that these divisions are not meant to correspond with existing planning regions, emergency management districts, Urban Area Security Initiative areas, or census economic areas. The "Community Classification" categories on the map need to be thoroughly explained, in order to fully understand how the map was designed (and how the general geographic divisions were defined). This explanation follows the map on the next page. It is worth noting at the outset that some communities may include areas that better resemble the description for a different category (e.g. a large park may have a rural character within a large central city), and this map doesn't attempt to provide such detail. These classifications are meant only to provide an overview of the State, rather than to precisely indicate local land use patterns.


State of Michigan
Profile Map
Lake Superior
Houghton
Marquette
Ironwood
Iron Mountain
Escanaba
Menominee
(Wisconsin)
SAULT STE. MARIE, ON-MI
(Ontario, Canada)
1
Traverse City
Gaylord
Alpena
2
Lake Huron
Cadillac
Harrison
Ludington
Midland
BAY CITY
Mt. Pleasant
Lake Michigan
SAGINAW
PORT HURON
MUSKEGON
FLINT
GRAND RAPIDS
3
LANSING
HOLLAND
4
DETROIT
KALAMAZOO
JACKSON
(Ontario, Canada)
BENTON HARBOR
BATTLE CREEK
MONROE
Lake Erie
Adrian
SOUTH BEND-ELKHART, IN
(Indiana)
(Ohio)
TOLEDO, OH
General Geographic Divisions line
1 Upper Peninsula
2 Northern Lower Peninsula
3 Southern Lower Peninsula
4 Detroit Metropolitan Area
Lakes
Forest Areas
Community Classifications
Urban Center
Surrounding Urban Area
Suburban
Exurban
Rural
Produced by:
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Emergency Management and Homeland Security Division
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Urban Centers

Michigan has many cities located across its lands, from the very small (Omer, population 313) to the very large (Detroit, 2010 population 713,777), and many of these date back to the 1800s as official corporate entities. These historical cities appear in black on the map, representing areas that tend to have the greatest densities in population, infrastructure, and the built environment. Only cities have been included in this classification (not villages or townships), but not all cities have been designated as urban centers. Because of the different forms that urban development had taken in the post-WWII period, in which automobile accommodations had become the norm, only cities that had incorporated before the end of World War II were included in this category.

Most of these cities contain a traditional downtown area that has long attracted people from outlying areas to engage in commercial or recreational activities, meet with government representatives, visit hospitals, or meet with others in social, civic, or religious activities. Some of the most historically significant structures in Michigan are located within these cities, and they also contain a vast amount of Michigan's vital government facilities, hospitals, police and military resources, large educational institutions, and major industrial firms. Some of these "urban center" cities contain relatively small downtowns, in cases where they function as "suburbs" near a larger central city, but they have still been classified here as urban centers because their initial formation conformed to a particular style of development that was predominant before World War II. For example, the streets tended to be laid out in the form of a grid, urban designs tended to focus upon regular access to a thriving central downtown district, and much less accommodation was made for the use of private automobiles by residents.

Dense development patterns and an emphasis upon efficiency characterized most urban center construction projects. Historically, it was to the advantage of most residents and businesses to locate as close as possible to shared transportation and utility resources, and these were designed to accommodate the needs of the persons using them at their time of construction. Many of these designs (for example, combined sewer systems that handle both sanitary and storm drainage functions) are still being changed even today, to accommodate the needs of a larger population that is more productive, enjoys a higher standard of living, and uses more energy to power its higher-technology devices, buildings, and industries. The systems present in these urban centers tend to be the most complex found in the state, and although the capacity to repair most breakdowns in these systems is usually readily available within the larger cities, the complexity and corollary impacts of such breakdowns are also likely to be greater. For example, if a power failure causes traffic signals to fail, this will have a smaller impact upon roadway congestion in a rural area than it would in a central city. Despite the great population density within large urban centers, these communities tend to have a large number of roadways available for use, and the traditional "grid" pattern of street design has long offered a huge number of alternative routes by which people could evacuate an area by car (at least for short distances).

Surrounding Urban Areas

Since World War II, most of the urban functions that had historically been contained within the urban centers quickly grew beyond the boundaries of those cities. It used to be that the costs of transportation, construction, and urban utilities had required most developments to take place within a city. After World War II, the widespread availability of affordable automobiles, and an increased capacity to affordably build and supply utilities in outlying areas, meant that new projects of all kinds could be built in many possible locations beyond the existing central cities. For many businesses and residents, it still made sense to be located near the central city, but many decided not to stay within the political boundaries of the existing cities. A great many new cities incorporated near the older central cities after World War II, typically by converting part or all of an existing township into a city, through a special voting process. Some recent geography texts refer to these areas as "the outer city" (with central cities termed as "the inner city").

Even though some of these new cities (e.g. Southfield) grew to include impressive high-rise office buildings and major expressway interchanges, they still tend to be distinguished from the older urban centers by having a lower average density of population, more widely spaced and modern buildings and infrastructure, and transportation arrangements that are focused upon the predominance of private automobiles. In these locations, it is harder for a resident to choose a residence that allows convenient access to public transit, places of work, hospitals, government offices, and shopping areas unless a car is used to access them. For some types of hazards, the less dense design of these cities is very helpful. For example, contagious illness is much easier to control when people do not need to use public transit systems, and do not live in very crowded residential patterns.

The function of these areas within a broader metropolitan area becomes clearer when looking at the overall land development patterns, as shown on the Michigan Profile Map, rather than focusing only upon the political boundaries between adjacent cities. Whereas large cities in the 19th Century tended to expand through the annexation of adjacent lands, and to contain numerous wards (districts) within them, the 20th Century tended to instead favor urban expansion across a contiguous array of politically (and fiscally) independent cities and townships. On the positive side, this development pattern provided a greater amount of political control by residents over their local governments. On the negative side, certain parts of each urban area tended to become increasingly worse off in fiscal terms, since local taxes were no longer shared throughout an entire urban area. Similarly, various types of infrastructure and services sometimes became increasingly difficult to coordinate across municipal boundaries, and the functions and services provided by urban centers were sometimes not adequately compensated for by users who lived outside of the providing city. Neighboring cities would often spend money on redundant services and facilities, rather than pooling their funds together into combined systems that could benefit from an economy of scale. From an emergency management perspective, though, these redundancies of services and infrastructure can actually increase local resilience—the seeming inefficiencies of duplicate systems and services can sometimes mean that an infrastructure breakdown in one city remains limited in scope, while infrastructure continues to function normally in adjacent areas.

Any city known to have incorporated after World War II has been included in the "surrounding urban area" category instead of being classified as part of an urban center. However, some heavily populated townships have also been classified in this category, as urban. (In many cases, there is little practical difference in the character of such townships based upon whether they stayed as townships or officially become cities.) Any Michigan township with a population density of at least 1400 persons per square mile of land area has been classified within this category, as "urban." These communities (whether townships or cities) often may not contain traditional downtown districts, but frequently do have specialized areas for shopping (shopping malls), conducting business (office complexes), and manufacturing products (industrial parks). Although these highly separated land uses may sometimes appear to be inconvenient from the perspective of transportation access, economic efficiency, and design regulations, there are often an economic logic underlying their design, which can resemble the outer, more specialized areas on the outskirts of a typical central city. There can also be emergency management benefits realized from this design, in that a disaster in one location (e.g. an industrial explosion or hazardous materials spill) might only affect one element of an urban production system, leaving other locations and activities intact because they were too far away to be impacted.

In terms of evacuation potential, most of these cities have very few local roads that were laid out in the traditional "grid" pattern, but there still tend to be a limited number of alternative routes available. Many neighborhoods might seem maze-like at first, but may allow traffic to eventually wind its way to the other side. When modern navigational systems are working correctly, these designs may not form great obstacles to evacuating drivers. Many of these cities (and urban townships) do have a moderate number of "collector" roads that can relieve traffic congestion.

Suburban Areas

In this classification system, a suburb indicates only a township of moderate development and population density, located near an urban center. No cities are included in this classification. Townships with a population density between 277 and 1399 persons per square mile of land area have generally been given this classification as "suburban."

Many of these suburban areas are charter townships, and the main distinctions between a charter township and a city involve a cap on the township's tax rate, a charter township's acceptance of a pre-defined charter, and a self-imposed set of restrictions upon the types and densities of land uses permitted in the township. Although some of these land use restrictions might seem at first to be artificial and arbitrary to an observer, in many cases the restrictions are roughly in accordance with the level of development that would normally occur in the newest and most outlying districts of a city. Thus, in either city or suburb, a skyscraper will not normally arise in the midst of a low-density residential neighborhood, and there are many cases in which new factories or warehousing operations are built on a city's fringe, especially along rivers or railroad tracks that may be vital to those facilities. Indeed, one of the main trends from the 20th Century, continuing to this day, is the increased economic feasibility of building many types of projects in outlying locations. Some suburban areas contain very important industrial, office, shopping, and recreational facilities.

For emergency management purposes, the main distinction between the previous "urban" classification and the "suburban" one is that newer and lower-density development will be typical in the suburban areas. A disaster in a suburban area will tend to affect fewer people than a comparable disaster within an urban area. However, due to the limited extent of the area's road infrastructure, these suburban areas can be more vulnerable to transportation back-ups, to the point of making some areas excessively difficult to evacuate quickly. Few, if any, suburban neighborhood streets are laid out in "grid" fashion, and many limited developments may not provide any new through-roads, with cul-de-sacs and small looping-back roads instead forming a predominant pattern. Expressway ramps and bridges over rivers might be far too few in number and capacity, leading to excessive traffic backups on area expressway routes (and the few main streets that connect with it), if one of those ramps or bridges becomes unusable. The community's main (arterial) roads are often just slightly revamped versions of the original "country roads" that existed before all the new suburban growth. Often, the addition of occasional turn lanes have been the only upgrades that have taken place during the community's recent decades of development, and these fundamentally two-lane roads can quickly become clogged with slow traffic when an accident occurs or an evacuation is attempted.

SPECIAL NOTE: All of Michigan's lands are located not merely within Michigan's 83 counties, but are also considered to be part of a "minor civil division" (a city, village, or township). The United States census tends to treat villages more like special taxation areas within townships, rather than as small cities, but Michigan also has a great number of small communities that are neither villages nor cities. In this document, these communities will be called "towns," with the understanding that this word has a distinctive meaning to refer to communities located within Michigan's townships. The Michigan Profile Map shows the boundaries of all of these many townships, but does not show all the small villages and "towns." Most rural areas include such "towns," and although some are mere hamlets, barely distinguished from the rural areas around them, others may be quite sizeable (e.g. Houghton Lake). Such "towns" tend to include either their own post office or school district, and thus may be called by a completely different name than the surrounding township (or may cross over the borders of adjacent townships).

<u>Exurban Areas</u>

The term "exurb" refers to a fairly low-density township with many residents who regularly commute to a larger area for many or most of their major needs. Suburbs tend to provide a moderate number of urban amenities, including employment, to their residents, but exurbs tend merely to provide residential housing areas and a selective few basic services and provisions. In many cases, standard groceries are obtained from a traditional village, "town," or small city that had existed before a commuter population had moved into the area. Exurbs do not contain enough employment opportunities for all the residents who live there, and so in addition to residents who choose to commute long distances to work (or who are able to "telecommute"), exurbs may also be home to a large proportion of retirees. Exurbs are generally low in population and development density (except for the central villages or small urban centers that tend to serve them). Various services (including health care) tend to be very limited in these areas.

Townships with a population density between 139 and 276 persons per square mile of land area have generally been classified here as exurbs. Some exceptions were granted, such as Breitung Township (near Iron Mountain), in which part of the very large township (67.7 square miles of land area) functioned as a suburb, while another part was quite rural. Another exception was made for the City of Mackinac Island, since its overall population density was rural (it has one of the smallest populations among Michigan cities) and it is generally only accessible by ferry or airplane. Although most suburbs exist on the farthest fringes of urban areas, a few additional types of areas also received this classification, such as communities that are not connected with cities, used for resorts, retirement living, or seasonal homes. An example is Houghton Lake, in Roscommon County, which has a "town" around the lake's shores, but is not actually a city. Some communities were designated as exurbs merely because its center was a "town" or village rather than a city. The United States census tends to treat villages as a special taxation zone within a township, and the Michigan Profile Map was predominantly based upon census data.

<u>Rural Areas</u>

Most of Michigan has been classified as "rural" on the Michigan Profile Map. This does not in any way indicate that these areas are unimportant! In addition, it must be noted that a great number of villages and "towns" exist throughout these rural areas, but are not marked on the map, due to their comparatively small sizes. (Thus, the SPECIAL NOTE provided above, explaining the meaning of "town" within this document.)

Some of Michigan's most productive, famous, and important industries are found throughout its rural areas. For example, extraction industries have been quite important to Michigan, whether the mining that had once caused the Western Upper Peninsula to thrive, or the petroleum and natural gas deposits that are increasingly in demand worldwide, or even just Michigan's abundant supplies of fresh water. Logging, farming, the cattle industry, and facilities for renewable energy (e.g. wind farms or hydroelectric dams) are other important facilities and infrastructure that exist throughout most of Michigan's rural areas. Due to the limitations inherent in the use of only a single statewide map, these types of production were not represented graphically. However, more information is presented later in this document, as well as in the remaining pages of this Michigan profile.

Statewide Hazards and Regional Hazards

The most damaging hazards in Michigan, in terms of property and crop damage, appear to be floods, fixed site hazardous materials incidents (including industrial accidents), oil/gas pipeline accidents, public health emergencies, and severe winds. The top three hazards included huge events within the past 20 years whose costs each topped $1 billion.

An initial ranking on the basis of estimated physical damages and known response/recovery costs during recent decades, resulted in the following initial list (which did not include cyber-attack and several other hazards whose assessment is less straightforward):

1. **Flooding**: statewide expected annual losses are now estimated at more than $100 million ($25.69 million had previously been estimated in the 2014 Michigan Hazard Mitigation Plan, but federal disaster 4195 confirmed a higher magnitude more in line with earlier MDEQ estimates, as that Metro-Detroit flood event was quite similar to federal disaster 1346 during the previous decade).
2. **Fixed site hazardous materials incidents and/or industrial accidents**: statewide expected annual losses of about $57 million.
3. **Oil/gas pipeline accidents**: statewide expected annual losses of about $57 million.
4. **Public health emergencies**: immense human costs from pandemic illness, PBB, Flint water emergency, etc. are estimated to average in the tens of millions each year.
5. **Severe winds**: statewide expected annual losses of about $25.4 million.
6. **Tornadoes**: statewide expected annual losses of about $19.6 million.
7. **Hail**: statewide expected annual losses of about $16.6 million.
8. **Ice/sleet storms**: statewide expected annual losses of about $11 million.
9. **Drought**: statewide expected annual losses of about $8.4 million.
10. **Snowstorms**: statewide expected annual losses of about $3.3 million.
11. **Hazardous materials transport**: statewide expected annual losses of about $3 million.
12. **Wildfires**: statewide expected annual losses of about $1.1 million.

13-16. **Invasive species, infrastructure failures, major structural fires, major transportation accidents**: statewide expected annual losses of at least $1 million (although these costs are difficult to estimate).

17. **Geomagnetic storms**: statewide expected annual losses of up to about $1 million.
18. **Lightning**: statewide expected annual losses of about $966,000.
19. **Extreme cold**: statewide expected annual losses of about $300,000.
20. **Land subsidence**: statewide expected annual losses of about $200,000 (but recent events have involved technological, urban infrastructure breakdowns as a cause, such as broken water mains that cause road collapses, which are expected to increase in frequency and severity).

The statewide expected annual loss from **earthquakes**, **shoreline hazards**, impacting **celestial objects**, and **scrap tire fires** are each estimated to be less than $100,000 (although extremely rare catastrophic asteroid strikes are a possibility that has here been downplayed in favor of smaller and likelier impacts expected within normal human time-frames). Hazards such as **extreme heat** and **fog** do not have direct property damage normally associated with them.

Michigan's position as a national and international manufacturing and business center means that the state will remain vulnerable to hazardous material incidents and other technological hazards.

Further considerations are included in the following Hazard Analysis Summary Table that has been updated from the one that first appeared in the 2014 Michigan Hazard Mitigation Plan.

Hazard Analysis Summary Table

	Average annual events	Average annual deaths	Average annual injuries	Average annual property and crop damage	Development trend effects	Risk rating: casualties	Risk rating: property	Risk Rating: economic costs	Risk rating: Infrastructure effects	Risk rating: Environment	Frequency as a top local hazard
Hail	**191**	**0**	**0.2**	**$18.2 million**	+	**1**	**2**	**2**	**1**	**1**	**Some**
Lightning	**14**	**0.8**	**5.3**	**$0.8 million**	=	**1**	**1**	**2**	**2**	**2**	**Some**
Ice and sleet storms	**16**	**0.2**	**0.5**	**$11.4 million**	+	**1**	**2**	**3**	**3**	**1**	**Some**
Snowstorms	**360**	**0.1**	**0.1**	**$1.9 million**	+	**1**	**1**	**2**	**2**	**1**	**Many**
Severe winds	**395**	**1.7**	**12.6**	**$51.3 million**	+	**1**	**2**	**3**	**3**	**1**	**Many**
Tornadoes	**18**	**3.6**	**49.6**	**$17.2 million**	+	**2**	**2**	**3**	**3**	**2**	**Many**
Extreme heat	**11**	**0.4**	**41.0**	**None reported**	=	**2**	**0**	**2**	**2**	**0**	**Some**
Extreme cold	**35**	**1.0**	**9.4**	**$6.4 million**	=	**2**	**2**	**3**	**3**	**1**	**Some**
Fog	**4**	**0.1**	**0.1**	**None reported**	+	**1**	**0**	**1**	**1**	**0**	**None**
Flooding	**48**	**0.4**	**0.3**	**$106.6 million**	+	**1**	**2**	**3**	**3**	**2**	**Some**
Shoreline hazards	**2**	**1.4**	**0.4**	**< $0.1 million**	+	**1**	**2**	**3**	**2**	**1**	**Some**
Dam failures	**> 1**	**> 0.1**	**> 0.1**	**$0.3 million**	+	**1**	**2**	**3**	**2**	**2**	**Some**
Drought	**3**	**0**	**0**	**$7.0 million**	?	**0**	**0**	**3**	**1**	**2**	**Few**
Wildfires	**1**	**> 0**	**0.2**	**$1.0 million**	+	**1**	**2**	**3**	**2**	**3**	**Some**
Invasive species	**< 1**	**< 1**	**> 1**	**> $1.0 million**	?	**1**	**2**	**3**	**1**	**3**	**None**
Earthquakes	**< 1**	**> 0**	**> 0**	**< $1 million**	+	**2**	**2**	**2**	**2**	**2**	**Few**
Subsidence	**> 1**	**< 0.1**	**< 1**	**$0.2 million**	+	**2**	**2**	**2**	**2**	**1**	**Few**
Celestial impacts (impacting object)	**< 1**	**0**	**> 0**	**< $0.1 million**	+	**1**	**1**	**1**	**1**	**1**	**None**
Celestial impacts (space weather)	**< 1**	**0**	**0**	**< $1.0 million**	+	**1**	**1**	**2**	**2**	**1**	**None**
Structural and industrial fires (major)	**> 1**	**> 1**	**> 1**	**$57.0 million**	-	**2**	**2**	**2**	**1**	**2**	**Few**
Scrap tire fires	**< 1**	**0**	**0**	**< $1.0 million**	=	**0**	**1**	**2**	**1**	**2**	**Few**
Hazardous materials incident (fixed site)	**> 1**	**> 1**	**> 7**	**$4.0 million**	+	**2**	**2**	**2**	**2**	**2**	**Some**
Nuclear power plant	**< 1**	**0**	**> 0**	**< $0.1 million**	+	**1**	**1**	**2**	**2**	**2**	**Few**
Hazardous materials (transportation)	**> 1**	**> 1**	**> 1**	**> $3.0 million**	+	**2**	**2**	**2**	**2**	**2**	**Some**
Oil & gas pipelines	**> 1**	**> 1**	**> 1**	**$57.0 million**	+	**1**	**2**	**2**	**2**	**2**	**Few**
Oil & gas wells	**< 1**	**< 1**	**< 1**	**< $1.0 million**	+	**1**	**1**	**1**	**1**	**1**	**Few**
Infrastructure failures	**> 1**	**< 1**	**< 1**	**> $1.0 million**	+	**2**	**1**	**3**	**3**	**2**	**Some**
Energy emergencies	**< 1**	**0**	**0**	**None reported**	+	**1**	**0**	**2**	**2**	**1**	**None**
Transportation accidents (major)	**> 1**	**> 3**	**> 18**	**> $1.0 million**	+	**2**	**1**	**2**	**1**	**1**	**Few**
Catastrophic incidents	**< 1**	**> 0**	**> 0**	**Outside of MI**	=	**1**	**1**	**2**	**2**	**2**	**Few**
Civil disturbances	**< 1**	**< 1**	**> 1**	**< $1.0 million**	=	**2**	**2**	**2**	**1**	**1**	**Few**
Nuclear attack	**< 1**	**> 1**	**> 1**	**> $1.0 million**	-	**2**	**2**	**2**	**2**	**2**	**Many**
Public health emergencies	**< 1**	**> 10**	**> 100**	**None reported**	-	**2**	**0**	**2**	**2**	**1**	**Few**
Terrorism and similar activities	**< 1**	**> 1**	**> 1**	**> $1.0 million**	=	**2**	**2**	**2**	**2**	**2**	**Some**
Cyber-attack	**Many**	**<1**	**<1**	**Undetermined**	?	**1**	**1**	**2**	**2**	**1**	**Some**

"**Average annual**" numbers are medium-term estimates only. Medium-term means that most estimates were based upon decades' worth of data, to predict future decades' risk. Some entries merely say less than (<) or greater than (>) some value.

Development trend effects use the following symbols to estimate the effects from Michigan's recent land use trends (which still mainly involve a net shift toward constructing suburban, exurban, and rural detached homes for persons moving out of denser areas).

"+" means increasing risks, "=" means few net effects, "-" means decreasing risks, "?"means trends are unclear

Risk Ratings are based upon the estimated severity of average annual impacts (medium-term), as follows:

"0" means negligible: The risks as currently known are not likely to cause any emergency-level event.

"1" means minor: There is a known although infrequent chance for impacts of moderate or purely local severity.

"2" means significant: A regular pattern of moderate effects, or an infrequent chance of severe impacts.

"3" means major: A regular pattern or high risk of major impacts, of statewide significance.

"**Frequency as a top local hazard**" refers to the number of local plans listing this as one of their top hazards. Categories include "Many," "Some," "Few," and "None." Note that because FEMA requires the analysis of natural hazards, but not technological and human-related hazards, local plans are inclined to favor the listing of natural hazards.

Some figures round down to zero (e.g. less than 1 death in the period of over 20 years), and have been expressed as ">0" to distinguish them from a true zero.

The preceding table is an effort to "compare apples with oranges" by presenting estimated annual impacts from each type of hazard (although some hazards are too new or unclear to have a precise set of impacts accurately estimated in such a clear-cut manner). This table is still limited by a need for additional information, since some hazards have little or no event history within Michigan, and could benefit from the insights, research, and analysis of additional subject-matter experts. The more detailed chapters that follow will present more thorough and nuanced information and explanations about each type of hazard, organized into overarching sections by general hazard type (natural, technological, human-related). However, since it is important to provide an overall summary of the findings of this analysis, the following table attempts to do so.

Summary of Michigan's Estimated Hazard Rankings

Note: Many hazard assessments are based upon a limited historical analysis and therefore their estimated rankings should be treated merely as rough estimates.

Type of Hazard	Priority	Reason
Floods	Top	Many damaging incidents: urban, riverine, and coastal; disruptive
Public health emergencies	Top	Major incidents involving water quality, PBB (1973), pandemic potential
Oil and gas pipeline incidents	Top	Billion-dollar Kalamazoo River event (2010), related concerns
Major fires or industrial incidents	Top	Dearborn plant explosion (1999), potential casualties and disruption
Invasive species	Top	Potential Asian Carp and agribusiness impacts, Emerald Ash Borer damage
Severe winds	Top	Regularly occurring incidents with serious damages, widespread impacts
Tornadoes	Top	Potential for extreme damage and massive casualties, though uncommon
Infrastructure failures	Top	Potential impacts and disruption from major blackouts, though uncommon
Extreme heat	Top	Potential for widespread human impacts, burden upon infrastructure
Cyber-attack	*	Potential economic, infrastructure, disruptive effects; global source of risk
Catastrophic incidents	*	Recent hurricane impacts and other potential national emergencies; supply risks
Nuclear attack	*	Potential for terrorist device; potential from geopolitical strife
Terrorism and similar incidents	*	Recent U.S. incidents, 2012 sniper, 2009 airline incident, 1927 Bath School event
Hazardous materials incident (site)	High	Many events of local concern occur frequently; potential for serious events
Hazardous materials transportation	High	Many events of local concern occur frequently; potential for serious events
Ice storms	High	Michigan's most damaging winter hazard; infrastructure/transportation breakdowns
Major transportation accidents	High	A pattern of major interstate crashes, 1987 plane crash near Detroit
Hail	High	Strong events, although uncommon, have been as costly as tornadoes
Wildfires	High	Long wildfire history; some large-scale emergency events, potential casualties
Extreme Cold	High	Causes human casualties, infrastructure failures, and some other disruptions
Drought	High	Huge historical impacts might again be felt; agriculture's importance in Michigan
Dam failures	High	Severe potential impacts upon selected locations; costly environmental risks
Great Lakes shoreline hazards	High	High lake levels, harmful algal blooms, casualties from dangerous currents
Lightning	High	More casualties than many hazards, but trickier to mitigate; needs awareness
Subsidence	*	Imminent need to assess Western U.P. risks; an increase in urban subsidence
Space weather	*	A strong geomagnetic storm could cause widespread infrastructure failures
Civil disturbances	*	Recent U.S. incidents, multiple historical events within Michigan
Energy emergencies	*	Currently an interagency priority, but closer to preparedness than mitigation
Snowstorms	Medium	Annual events in each part of Michigan, transportation risks; limited damages
Scrap tire fires	Medium	Multiple past events, but tire quantities have been greatly reduced in recent years
Earthquakes	Medium	Unclear risks in Western U.P. subsidence zones; potential infrastructure loss
Nuclear power plant accidents	Medium	Events are rare, most are not severe, few facility locations, extensive preparedness
Oil and gas well accidents	Medium	Disaster events are rare; usually limited to one site or small area
Celestial impacts	Medium	Catastrophic impacts are very rare; shorter-term risks tend to be limited
Fog	Medium	Problematic for transportation; the worst direct impacts involve freezing fog

* The hazards marked with an asterisk are especially difficult to assess, but have been placed to divide the sets of top-priority hazards from the high and medium-impact ones.

Every hazard in this list is considered significant, having the potential to result in at least a local emergency situation. These rankings are primarily based upon the state's actual history of property damage, crop losses, human casualties, economic and environmental impacts, and secondarily upon theoretical estimates of risks and vulnerabilities involving hazards that do not have a clear history of occurrences to extrapolate from. Some potentially catastrophic events are not ranked according to just their worst-case destructive potential. Instead, this table seeks to balance each hazard's short- and medium-term likelihood, as currently understood, with their corresponding level of expected impacts within these limited time-frames. Although **climate trends** have been described in an entirely new chapter in this document, the topic has not yet been ranked here. It can be conceived in terms of its influence upon the hazards that have been ranked. State rankings differ from national/global ones.

Profiles of Each Geographic Division

The following pages describe each geographic division's characteristics that are considered to be most relevant for an analysis of risks and hazard impacts. Where information is provided about population centers, the 2010 census has been the source of information used. The "urban areas" designated by the U.S. Census have tended to be presented here as the most relevant means of conveying information about most of Michigan's populated areas, since they are defined in terms of specific land use patterns rather than broad political boundaries. Some of the official urban areas are treated as part of a larger metropolitan area (e.g. Howell and Detroit), as noted in the descriptions that follow. The lists include all the urbanized areas, recognized "urban clusters," and comparable cities over 2,500. Since this is just an overview, it focuses upon distinct urban areas in order of population, by geographic division. Emphasis is placed upon regional social communities (urbanized areas, urban clusters) rather than each individual political jurisdiction. (Note: In cases where the city population is larger than the urban cluster population, the city's statistic is used here.) The following summaries also include lists of hazards that have been identified as significant within each geographic division. As explained in the rest of this document, hazards are still possible even not commonly prioritized as most significant, but the following references merely provide a rough overview of the different kinds of events that are typically identified as a major threat within local and regional hazard analyses across the State's different geographic areas.

<u>1. The Upper Peninsula</u> (15 counties)

As shown on the Michigan Profile Map, most of the Upper Peninsula is covered with forest lands, and most inhabitants live in small cities, villages, and towns in the midst of these forests. These communities are often very historic. The Upper Peninsula used to have a huge timber and mining industry, during the 19th Century, and had lost most of its population during the 20th Century after these industries had declined in size. (In 1910, Calumet-Laurium used to be one of Michigan's most populous communities—Houghton County had a population of 88,008 and Calumet Township's population of 32,845 was comparable to that of Jackson, Kalamazoo, or Lansing at the time, but today the township only has 6,489 residents.) The Upper Peninsula's historic mining industry makes certain portions of it more vulnerable than the rest of the State to large-scale ground subsidence risks (the "subsidence" chapter provides more detail). The western U.P. has large areas covered by the Ottawa National Forest, the eastern U.P. has two large areas that together compose the Hiawatha National Forest, and there are seven MDNR State Forest Districts covering the entire U.P. Isle Royale is Michigan's only National Park area.

The Upper Peninsula is predominantly rural, and every one of its counties has a population density that is well below the State's average. Because the area developed during the 1800s, most of its cities have areas that date from that time period. The Upper Peninsula is adjacent to Wisconsin and Ontario, Canada, and some cities are part of urban areas that cross over state (and national) borders. These cross-border urban areas include Sault Ste. Marie (Ontario and Michigan), Iron Mountain-Kingsford (Michigan and Wisconsin), and Marinette-Menominee (Wisconsin and Michigan).

Taking into account the broader metropolitan areas, then, the city of Sault Ste. Marie might be considered the most significant for the Upper Peninsula. Although the Michigan portion of this area has only about 14,000 people, the much larger Canadian city of Sault Ste. Marie dominates an urban area of nearly 100,000 total population. All marine traffic going from Lake Huron to Lake Superior passes through the Soo Locks, in this area. This includes marine traffic traveling to and from major ports such as Duluth (Minnesota) and Thunder Bay (Ontario, Canada). The only Interstate Highway in the Upper Peninsula (I-75) goes through this city and crosses the International Bridge into Canada. The Mackinac Bridge is another vital element of Michigan's infrastructure, providing a highway connection between Michigan's Upper Peninsula and its Lower Peninsula. Several high-quality surface highways cross the Upper Peninsula and provide the main routes for its truck traffic. Along with freight trains, these highways pass through large areas of State and National Forest Lands, which means that wildfires are one of the most significant threats in the area.

The following hazards are most frequently identified as significant within the Upper Peninsula's local and regional plans:

Natural Hazards: Thunderstorms, Severe Winter Weather, Severe Winds, Tornadoes, Extreme Temperatures, Flooding, Shoreline Hazards, Dam Failures, Drought, Wildfires, Invasive Species, Subsidence.
Technological Hazards: Structural fires, Infrastructure Failures.
Human-Related Hazards: Civil Disturbances, Nuclear Attack, Public Health Emergencies, Terrorism.

The Upper Peninsula's urban areas and clusters, ranked by population size according to the 2010 U.S. census, are:

(Sault Ste. Marie Ontario-MI)	92,303 (2016 Canadian census agglomeration plus 2010 U.S. city census)
Marquette	26,946 (in Marquette County)
Escanaba	20,850 (in Delta County)
(Marinette-**Menominee**, WI-MI)	19,431 (Michigan part has 8,570 in Menominee County)
Iron Mountain-Kingsford (MI-WI)	19,228 (Michigan part has 17,594 in Dickinson County)
Houghton	15,452 (in Houghton County)
Sault Ste. Marie (Michigan part only)	14,144 (total city population) (Michigan part in Chippewa County)
Ishpeming-Negaunee	12,301 (in Marquette County)
Laurium-Calumet-Lk. Linden-Hubbell	7,325 (in Houghton County)
Ironwood (MI-WI)	7,134 (Michigan part has 5,229 in Gogebic County)
Kinross-Kincheloe	6,555 (in Chippewa County)
Manistique	3,482 (in Manistique County)
Newberry	3,225 (in Luce County)
Iron River	3,208 (in Iron County)
Munising	2,972 (in Alger County)
K.I. Sawyer CDP	2,624 (in Marquette County)
St. Ignace	2,531 (in Mackinac County)

Compared to other areas of the state, the Upper Peninsula has a larger percentage of its workforce engaged in the following economic sectors: agriculture, forestry, fishing, and hunting; mining, quarrying, and oil/gas extraction; utilities, construction, health care and social assistance; arts, entertainment, and recreation; and accommodation and food services. The total market value of agricultural products in the Upper Peninsula is estimated to be 1.2% of Michigan's total agricultural production, based upon 2012 Census of Agriculture information. More specifically, the value of the Upper Peninsula's production of livestock, poultry, and their products constitutes about 2.0% of the state total, while its value-share of crops (including greenhouse and nursery products) is only about 0.7%. The Upper Peninsula has nearly 490,000 acres of farmland, or 4.9% of the state's total. These values are consistent with principles of economic geography, in which useful agricultural products that produce a lesser return per acre tend to be located farther from urban areas, where larger-sized farms are more affordable. The Upper Peninsula specializes in the following agricultural products, in terms of having a greater percentage of its farmland dedicated to their production: barley, oats, hay/grass/silage/greenchop, and sunflower seeds.

<u>2. The Northern Lower Peninsula</u> (29 counties)
This area is predominantly rural in nature, and (as shown on the Michigan Profile Map) is widely covered with forest lands, but includes significant resort and tourist areas, and profitable groves of fruit-growing trees. It is a popular area for hunters, and has a large proportion of its housing units dedicated to seasonal and recreational uses (e.g. hunting lodges, summer cabins). This part of the state includes the Huron National Forest in the east and the Manistee National Forest in the west, along with eight State Forest Districts of the MDNR. Many small cities, villages, and towns are located throughout the area's 29 counties. A generally good system of surface highways connects the area. Trains are limited to freight uses, rather than passenger travel. A few airports and passenger ferries are in operation within the area, and there are some excellent ports for handling marine traffic.

The following hazards are most frequently identified as significant within the Upper Peninsula's local and regional plans:

Natural Hazards: Thunderstorms, Severe Winter Weather, Severe Winds, Tornadoes, Extreme Temperatures, Flooding, Shoreline Hazards, Dam Failures, Drought, Wildfires, Invasive Species.
Technological Hazards: Structural fires, Scrap Tire Fires, Oil and Gas Well Accidents, Infrastructure Failures.
Human-Related Hazards: Nuclear Attack, Public Health Emergencies, Terrorism.

The urban areas in the Northern Lower Peninsula, ranked by population according to the 2010 U.S. census, are:

Traverse City	47,109 (in Grand Traverse County)
Alpena	14,258 (in Alpena County)
Cadillac	11,690 (in Wexford County)
Ludington	10,710 (in Mason County)
Manistee	9,606 (in Manistee County)
Houghton Lake-Prudenville	8,300 (in Roscommon County)
Gaylord	8,298 (in Otsego County)
Petoskey	8,210 (in Emmet County)
Au Sable-Oscoda	6,384 (in Iosco County)
Clare	5,597 (in Clare County)
Cheboygan	4,867 (total city population; in Cheboygan County)
Fremont	4,496 (in Newaygo County)
East Tawas	4,372 (in Iosco County)
Charlevoix	4,179 (in Charlevoix County)
Grayling	3,858 (in Crawford County)
Boyne City	3,785 (total city population; in Charlevoix County)
Harrison	3,589 (in Clare County)
Newaygo	3,335 (in Newaygo County)
Gladwin	2,934 (in Gladwin County)
Rogers City	2,827 (total city population; in Presque Isle County)
Kalkaska	2,668 (in Kalkaska County)
St. Helen CDP	2,668 (in Roscommon County)
Hart	2,556 (in Oceana County)

The Northern Lower Peninsula has a larger percentage of its workers in retail trade than other parts of the state do. The total market value of agricultural products in the Northern Lower Peninsula is estimated to be 9.2% of Michigan's total agricultural production, based upon 2012 Census of Agriculture information. More specifically, the value of the area's production of livestock, poultry, and their products constitutes about 12.8% of the state total, while its value-share of crops (including greenhouse and nursery products) is about 7.1%. The Northern Lower Peninsula contains nearly 1,600,000 acres of farmland, or 16.0% of the state's total. These values are consistent with principles of economic geography, in which useful agricultural products that produce a lesser return per acre tend to be located farther from urban areas, rather than intensely competing with non-agricultural economic sectors over land prices. The Northern Lower Peninsula specializes in the following agricultural products, in terms of having a greater percentage of its farmland dedicated to their production: orchards, sunflower seeds, hay/grass/silage/greenchop, oats, sorghum, barley, and vegetables.

3. The Southern Lower Peninsula (excluding Metro Detroit) (34 counties)
This area contains many medium-sized urban areas and most of Michigan's traditional farming and livestock grazing lands. It is adjacent to the States of Indiana and Ohio, and the Canadian province of Ontario. Some out-of-state metropolitan areas extend into this part of Michigan, such as South Bend, Elkhart, Michigan City, Toledo, and Sarnia. This part of the state is extremely well-served by the Interstate Highway System, and many colleges and State universities are found throughout the area. Many features of historic and scenic interest draw tourists from other parts of the state and country. University sports venues, the Michigan International Speedway, minor league baseball, many different museums, zoos, professional theaters, historic sites, and well-known manufacturing facilities (e.g. Kellogg breakfast cereals) are numbered among the area's many cultural attractions.

The following hazards are most frequently identified as significant within the Upper Peninsula's local and regional plans:

Natural Hazards: Thunderstorms, Severe Winter Weather, Severe Winds, Tornadoes, Ice/Sleet Storms, Extreme Temperatures, Flooding, Shoreline Hazards, Dam Failures, Drought, Invasive Species, Earthquakes.

Technological Hazards: Structural fires, Scrap Tire Fires, Hazardous Materials Incidents, Nuclear Power Plant Emergencies, Pipeline Accidents, Oil and Gas Well Accidents, Infrastructure Failures, Energy Emergencies, Transportation Accidents.

Human-Related Hazards: Civil Disturbances, Nuclear Attack, Public Health Emergencies, Terrorism.

The largest urban areas connected with the Southern Lower Peninsula (outside of Metropolitan Detroit) are:

Grand Rapids	589,060 (Grand Rapids UA plus exurban Lowell, Dorr, Sparta, Cedar Springs UCs)
(Toledo, OH-MI)	507,643 (Monroe County has 28,461 in suburban/exurban parts of the urbanized area.)
Flint	356,218 (in Genesee County)
Lansing	319,849 (Lansing's UA of 313,532 plus exurban Williamston's UC of 6,317)
(South Bend, IN-MI)	278,165 (Berrien and Cass counties have 36,295 in suburban/exurban parts of the area.)
Kalamazoo	221,443 (Kalamazoo's UA of 209,703 plus exurban Otsego-Plainwell pop. of 11,740)
(Sarnia-Port Huron, ON-MI)	183,257 (Port Huron UA of 87,106 plus 96,151 in Sarnia 2016 census agglomeration)
Muskegon	171,848 (161,280 Muskegon UA, plus exurban Whitehall-Montague UA of 10,568)
(Elkhart, IN-MI)	143,592 (Berrien and Cass Counties have 900 in a small outlying part of the area.)
Saginaw	126,265 (in Saginaw County)
Holland	99,941 (in Allegan and Ottawa Counties)
Jackson	90,057 (in Jackson County)
Port Huron	87,106 (Michigan UA only, not including Canada's Sarnia area: St. Clair County)
Battle Creek	78,393 (in Calhoun County)
Bay City	70,585 (in Bay County)
(Michigan City-LaPorte, IN-MI)	66,025 (the southwest corner of Berrien County has 595 at the urban area's fringe)
Benton Harbor-St. Joseph	61,022 (in Berrien County; includes the Fair Plain area)
Midland	59,014 (in Midland County)
Monroe	51,240 (in Monroe County)
Adrian	44,823 (in Lenawee County)
Mt. Pleasant	37,447 (in Isabella County)
Owosso	22,426 (in Shiawassee County)
Alma-St. Louis	16,924 (in Gratiot County)
Coldwater	16,876 (in Branch County)
Ionia	14,409 (in Ionia County)
Big Rapids	14,241 (in Mecosta County)
Lapeer	13,424 (in Lapeer County)
Sturgis	13,040 (in St. Joseph County)
Charlotte	12,682 (in Eaton County)
Hillsdale	11,646 (in Hillsdale County)
Paw Paw Lake-Hartford	11,589 (in Berrien and Van Buren Counties; includes Coloma and Watervliet)
Three Rivers	10,820 (in St. Joseph County)
Greenville	9,743 (in Montcalm County)
Albion	9,219 (in Calhoun County)
Paw Paw	8,684 (in Van Buren County)
St. Johns	8,425 (in Clinton County)
Hastings	7,713 (in Barry County)
Marshall	7,683 (in Calhoun County)
Berrien Springs	7,358 (in Berrien County)
Allegan	6,322 (in Allegan County)
Dowagiac	6,082 (in Cass County)
Goodrich-Ortonville	5,860 (in Genesee and Oakland Counties)
South Haven	5,791 (in Van Buren County)
Belding	5,789 (in Ionia County)
Eaton Rapids	5,408 (in Eaton County)
Caro	5,113 (in Tuscola County)
Portland	5,020 (in Ionia County)
Frankenmuth	4,972 (in Saginaw County)
Durand	4,854 (in Shiawassee County)
Wayland	4,518 (in Allegan County)
Perry-Morrice	4,290 (in Shiawassee County)
Coopersville	4,275 (total city population; in Ottawa County)
Constantine-White Pigeon	4,074 (in St. Joseph County)
Dundee	3,957 (total village population; in Monroe County)
Imlay City	3,792 (in Lapeer County)
Vassar	3,714 (in Tuscola County)
Bad Axe	3,490 (in Huron County)

Blissfield	3,340 (total village population; in Lenawee County)
Middleville	3,319 (total village population; in Barry County)
Somerset	2,910 (in Hillsdale County)
Ithaca	2,910 (in Gratiot County)
Sandusky	2,775 (in Sanilac County)
Brooklyn	2,773 (in Jackson County)
Canadian Lakes CDP	2,756 (in Mecosta County)
Almont	2,719 (in Lapeer County)
Gun Lake	2,660 (in Barry County)
Potterville	2,617 (in Eaton County)
Douglas-Saugatuck	2,570 (in Allegan County)

The Southern Lower Peninsula (outside of Metro Detroit) has a larger proportion of its workers in the manufacturing sector than other parts of the state. Its percentages employed in educational and other services are significantly larger than for Michigan as a whole. It has many colleges and universities. Lansing is the state capital and contains many government agencies. Among the many recreational and cultural attractions are large stadiums and performance venues, which tend to require special preparation and management when it comes to protecting attendees from threats and hazards. Various convention centers and downtown areas tend to regularly attract large numbers of persons, who similarly may require special planning to protect them from threats and hazards.

The total market value of agricultural products in the Southern Lower Peninsula (outside of Metro Detroit) constitutes 86.6% of Michigan's total agricultural production, based upon information within the 2012 Census of Agriculture. More specifically, the value of the Southern Lower Peninsula's production of livestock, poultry, and their products constitutes 83.6% of the state total, while its value-share of crops (including greenhouse and nursery products) is 88.3%. The Southern Lower Peninsula (outside of Metro Detroit) has nearly 7,500,000 acres of farmland, or 75.3% of the state's total. These values are consistent with principles of economic geography. Contrary to popular belief, the most intense areas of high-value agricultural production in Michigan tend to be located within ready driving distance of large urban markets and transportation hubs. This location allows more perishable commodities to quickly reach high-population markets before spoilage can occur. In addition, agricultural products that produce a higher return per acre are able to be located closer to urban areas, even if competing forms of land use have driven up land prices a bit. The Southern Lower Peninsula (outside of Metro Detroit) specializes in the following agricultural products, in terms of having a greater percentage of its farmland dedicated to their production: sugar beets for sugar, dry edible beans, soybeans, wheat, and corn. This is the only one of the 4 main geographic areas whose share of Michigan's agricultural market value is greater than its share of the state's farmland, indicating a higher average agricultural productivity.

4. Metropolitan Detroit (5 counties)
This area contained the first large Michigan settlements, which developed into the expanding City of Detroit throughout the industrial revolution and then became world-famous as "The Motor City." The largest American automobile companies tended to develop in this area of Michigan, and eventually became "the big three"—Ford, General Motors, and Chrysler, with their world headquarters located in Dearborn, Detroit, and Auburn Hills, respectively. Although the area's population increased by the greatest amount during the first half of the 20th Century (Detroit's peak census population was in 1950, at 1,849,568 persons), the metro area continued to increase slowly for 50 years thereafter—until the most recent census revealed the effects of various economic challenges, which registered an overall decline of modest proportions (while most of the metropolitan counties continued to grow at a decent rate).

The following hazards are most frequently identified as significant within the Upper Peninsula's local and regional plans:

Natural Hazards: Thunderstorms, Severe Winter Weather, Severe Winds, Tornadoes, Ice/Sleet Storms, Extreme Temperatures, Flooding, Shoreline Hazards, Dam Failures, Drought, Invasive Species.
Technological Hazards: Structural fires, Scrap Tire Fires, Hazardous Materials Incidents, Nuclear Power Plant Emergencies, Pipeline Accidents, Infrastructure Failures, Energy Emergencies, Transportation Accidents.
Human-Related Hazards: Civil Disturbances, Nuclear Attack, Public Health Emergencies, Terrorism.

The largest urban areas in the Detroit Metropolitan region, according to the 2010 U.S. census, are:

Detroit 3,863,533 (or 4,182,779, including 319,246 in the Windsor area in Ontario)

(NOTE: 3,734,090 are in Metro Detroit, plus 119,509 in the South Lyon-Howell urbanized area and the exurbs of Richmond and Fowlerville, 6,140 and 3,794 respectively; in Wayne, Oakland, Macomb, and Livingston Counties.)

Ann Arbor-Ypsilanti-Saline 313,536 (306,022 Ann Arbor UA plus 7,514 in Milan exurb; Washtenaw County)

(NOTE: Detroit and Ann Arbor might be considered to be one giant Metro area of 4,177,069; or 4,496,315 with Windsor.)

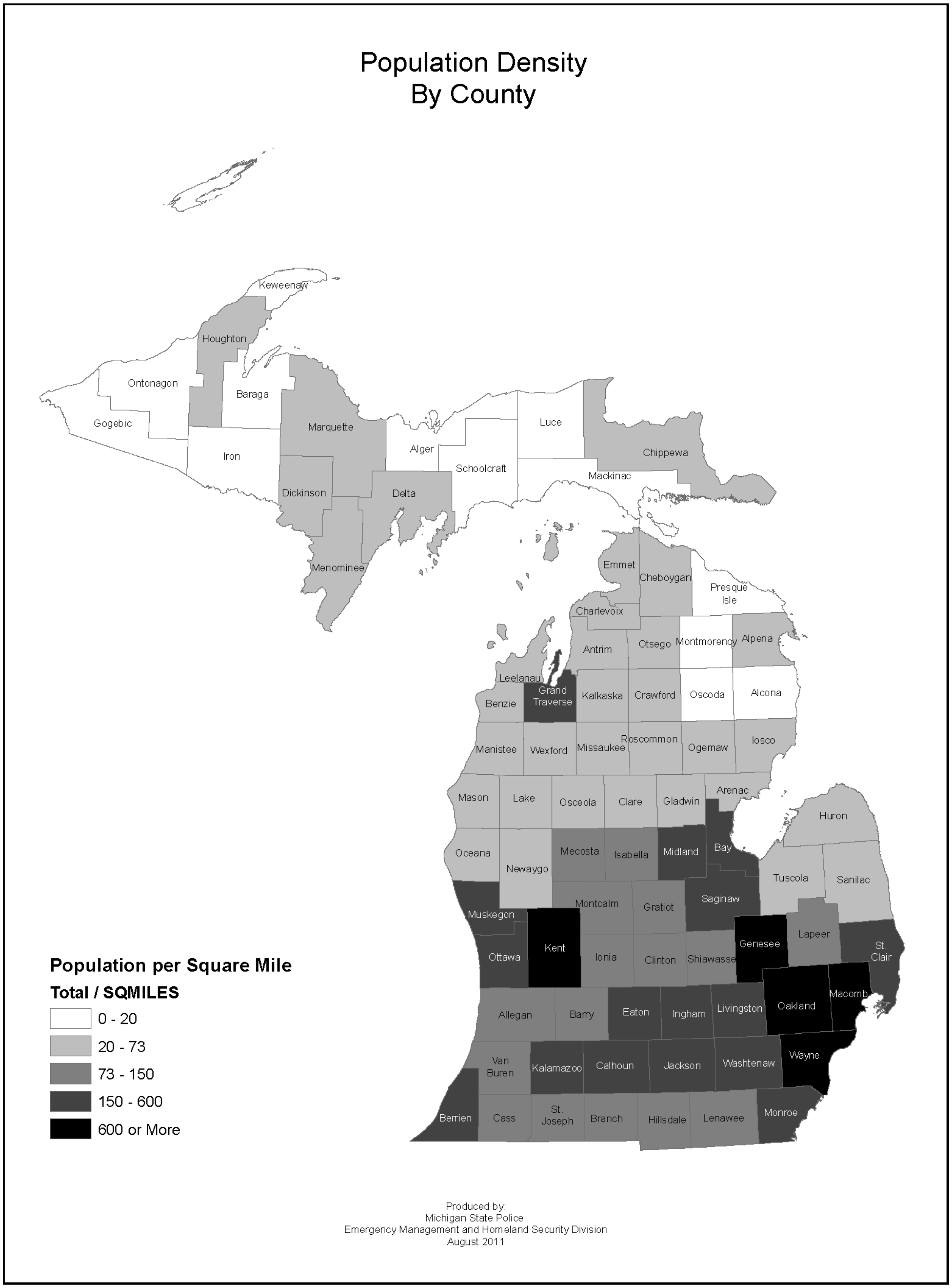
Holly 8,229 (in Oakland County)

Chelsea 5,329 (in Washtenaw County)

The area employs a larger percentage of its workforce in certain economic sectors than other parts of Michigan do. These sectors include wholesale trade, transportation and warehousing, information, finance and insurance, real estate and rental and leasing; professional, scientific, and technical services; management of companies and enterprises, and administrative support and waste management and remediation services. The total market value of agricultural products in Metropolitan Detroit is 3.1% of Michigan's total agricultural production, based upon 2012 Census of Agriculture information. More specifically, the value of Metro Detroit's production of livestock, poultry, and their products constitutes 1.6% of the state total, while its value-share of crops (including greenhouse and nursery products) is 3.9%. Metro Detroit has about 370,000 acres of farmland, or 3.7% of the state's total. These values are consistent with principles of economic geography, in which more perishable agricultural products need to be located closer to urban areas, for quick access to markets and transportation hubs. The Detroit metropolitan area specializes in the following agricultural products, in terms of having a greater percentage of its farmland dedicated to their production: sunflower seeds, soybeans, wheat, and vegetables.

Michigan's hazards can also be thought of in **seasonal** terms. Although light snow sometimes falls during warmer months and other unusual events do sometimes occur, many hazards are strongly associated with particular times of year, and should encourage patterns of preparedness to occur on an annual cycle. The current annual pattern for Michigan's seasonal hazards appears to be the following:

March:	Final month for the highest-risk period involving influenza epidemics
April:	<u>Winter risk season</u> (involving significant risk of extreme cold, snowstorms, blizzards, and ice/sleet storms) ends in the Lower Peninsula
May:	Winter risk season ends in the Upper Peninsula, non-winter risk season begins in the Lower Peninsula
Late **May**:	Non-winter risk season begins in the Upper Peninsula (involving significant risk of extreme heat events, severe thunderstorms, lightning, hail, tornadoes, and wildfires)
Early **September**:	End of the <u>non-winter risk season</u> in the Upper Peninsula
Late **September**:	Winter risk season begins in the Upper Peninsula, end of non-winter risk season in most of the Lower Peninsula
Early **October**:	End of non-winter risk season in the southernmost counties of the Lower Peninsula
October:	Start of the highest-risk period for influenza epidemics or pandemics
Early **November**:	Winter risk season begins in the Northern Lower Peninsula
Late **November**:	Winter risk season begins in the Southern Lower Peninsula


Population Density
By County
Keweenaw
Houghton
Ontonagon
Baraga
Gogebic
Iron
Marquette
Alger
Luce
Schoolcraft
Chippewa
Mackinac
Dickinson
Delta
Menominee
Emmet
Cheboygan
Presque Isle
Charlevoix
Otsego
Montmorency
Alpena
Antrim
Leelanau
Grand Traverse
Benzie
Kalkaska
Crawford
Oscoda
Alcona
Manistee
Wexford
Missaukee
Roscommon
Ogemaw
Iosco
Mason
Lake
Osceola
Clare
Gladwin
Arenac
Huron
Oceana
Newaygo
Mecosta
Isabella
Midland
Bay
Tuscola
Sanilac
Muskegon
Montcalm
Gratiot
Saginaw
Lapeer
Ottawa
Kent
Ionia
Clinton
Shiawassee
Genesee
St. Clair
Macomb
Allegan
Barry
Eaton
Ingham
Livingston
Oakland
Van Buren
Kalamazoo
Calhoun
Jackson
Washtenaw
Wayne
Berrien
Cass
St. Joseph
Branch
Hillsdale
Lenawee
Monroe
Population per Square Mile
Total / SQMILES
0 - 20
20 - 73
73 - 150
150 - 600
600 or More
Produced by:
Michigan State Police
Emergency Management and Homeland Security Division
August 2011

The following table presents selected economic information for Michigan and its four geographic divisions (as defined in this document). Various economic sectors have been listed, along with their shares of annual employment within each region or the state (using 2015 County Business Patterns information). It has been possible to improve this table from that within the 2014 plan by including reasonable estimates for data that had been removed to preserve confidentiality at the local level. The result is to have all columns (regions) now neatly total 100% and to allow a direct comparison of regional production specializations across Michigan.

2015 County Business Patterns		**MICHIGAN**	**U.P.**	**N.L.P.**	**S.L.P.**	**Metro**
NAICS code	**2015 NAICS code description**	**% of MI workers**	**% of UP workers**	**% of NLP workers**	**% of SLP workers**	**% of Metro workers**
------	Total for all sectors	100.0%	100.0%	100.0%	100.0%	100.0%
11----	Agriculture, forestry, fishing and hunting	0.1%	1.1%	0.5%	0.1%	0.0%
21----	Mining, quarrying, and oil and gas extraction	0.1%	1.7%	1.0%	0.1%	0.0%
22----	Utilities	0.6%	0.8%	0.7%	0.7%	0.5%
23----	Construction	3.7%	5.2%	5.0%	3.7%	3.4%
31-33	Manufacturing	15.7%	13.0%	16.5%	19.4%	12.6%
42----	Wholesale trade	4.8%	2.7%	3.2%	4.8%	5.0%
44-45	Retail trade	12.9%	17.5%	17.8%	13.3%	11.8%
48----	Transportation and warehousing	3.1%	2.7%	2.4%	3.1%	3.2%
51----	Information	1.9%	1.6%	1.2%	1.4%	2.4%
52----	Finance and insurance	4.1%	4.0%	3.3%	3.8%	4.4%
53----	Real estate and rental and leasing	1.4%	1.2%	1.5%	1.2%	1.6%
54----	Professional, scientific, and technical services	6.9%	3.1%	2.9%	3.8%	10.2%
55----	Management of companies and enterprises	3.3%	0.5%	1.2%	2.8%	4.2%
56----	Administrative & Support & Waste Management & Remediation Services	6.8%	2.9%	3.8%	6.4%	7.6%
61----	Educational services	2.0%	1.2%	1.0%	2.7%	1.6%
62----	Health care and social assistance	16.6%	20.6%	18.5%	16.5%	16.3%
71----	Arts, entertainment, and recreation	1.3%	1.5%	1.3%	1.2%	1.4%
72----	Accommodation and food services	10.3%	14.2%	13.8%	10.3%	9.7%
81----	Other services (except public administration)	4.4%	4.7%	4.4%	4.7%	4.0%
99----	Industries not classified	0.0%	0.1%	0.1%	0.0%	0.0%

The percentages that are shaded within this table show which geographic division has the highest percentage of its workers involved in each particular economic sector. For example, the Upper Peninsula has the highest proportion of workers involved in the agriculture, forestry, fishing, and hunting sector (NAICS code 11).

Although employing only a small percentage of Michigan workers, its agricultural production sector is large and very important to the state's economy. Michigan's total land area encompasses about 37 million acres, and about 26.7% of that was reported as farmland within the 2012 Census of Agriculture. Of this farmland, over a quarter involves corn production. Michigan's other dominant crops include soybeans (about 20% of farmland), hay, grass, silage, and greenchop feed (about 10.7% of farmland), and wheat (about 5.4% of farmland). Regional specializations had already been described within the section on Michigan's general geographic areas. Overall, 63.5% of Michigan's agricultural market value is from crops and nursery/greenhouse products, while 36.5% is from livestock, poultry, and their associated products.

Michigan's position as a national and international manufacturing and business center means that the state is susceptible to hazardous material incidents and other technological hazards. Extensive planning and preparation has been done to aid in responding to these types of events, and that work must continue and perhaps even be expanded as the number and potential impacts of technological hazards continues to grow.

Michigan, which contains three operating commercial nuclear power plants, has continued to develop and expand its capabilities to respond to a nuclear accident. Although stringent steps are taken at each plant to ensure safe and trouble-free power generation, accidents can occur. To combat that possibility, Michigan must continue to be a leader in nuclear safety to ensure that the state's residents are adequately protected from the potentially harmful effects of an accidental radioactive material release.

Unfortunately, Michigan has experienced major acts of terrorist-like criminal action. On May 18, 1927, a disgruntled taxpayer set off a bomb in a schoolhouse in Bath, killing 45 persons (mostly children) and injuring 58 others. In 1992 and 1999, eco-terrorists committed arson attacks against Michigan State University research facilities. In 2009, Michigan narrowly avoided having a major terrorist act occur, as an attempt to bomb a passenger airline over Detroit did not succeed. As evidenced by the mounting history of criminal and terrorist events and plots—the bomb blasts at the World Trade Center in 1993, Oklahoma City in 1995, the Summer Olympics in 1996, the Boston Marathon in 2013, and the New York Metro Area in 2016; the September 2001 terrorist strikes in New York City and Washington D.C.; lethal shooting events at the University of Texas (1966), in a McDonald's restaurant in San Diego (1984), at a restaurant in Killeen, TX (1991), at Columbine High School (1999), along Washington D.C. highways in 2002, at Fort Hood in Texas (2009), in the Century 16 cinema in Aurora, CO (2012), at Sandy Hook Elementary in Newtown, CT (2012), in San Bernardino, CA (2015), a nightclub in Orlando, FL (2015), at a Congressional recreational baseball game in Arlington, VA (2017), in the First Baptist Church in Sutherland Springs, Texas (2017), and at the Country Music Festival in Las Vegas (2017); and attacks involving motor vehicles in Columbus, OH (2016), Charlottesville, VA (2017), and New York City (2017)—constant vigilance is needed by all citizens to prevent and deter future events of these types.

Finally, substantial actions must be taken to mitigate the hazards outlined in this report. Hazard mitigation is defined as "any action taken before, during or after a disaster or emergency situation to permanently eliminate or reduce the long-term risk to human life and property from natural, technological and human-related hazards." Hazard mitigation actions, especially if implemented in a coordinated, inter-governmental, inter-disciplinary manner, can effectively reduce the damage, suffering, injury, and loss of life and property associated with these hazards. That, in turn, helps reduce disaster response and recovery costs, saving untold millions of dollars in public and private disaster relief assistance. In addition, hazard mitigation can greatly reduce the social, economic and political disruptions that disasters bring to bear on Michigan communities. The old adage "an ounce of prevention is worth a pound of cure" is certainly true when it comes to disasters.

It is for those reasons that this Hazard Analysis is coordinated with the Michigan Hazard Mitigation Plan, the Michigan Emergency Management Plan, the Michigan Citizen-Community Emergency Response and Coordinating Council, the Emergency Management Accreditation Program (EMAP), FEMA's Threat and Hazard Identification and Risk Assessment process (THIRA), and other plans, groups, agencies, and processes. Continuing to promote and advance the art and science of hazard mitigation will help ensure that Michigan's citizens are protected, to the maximum extent possible, from the harmful impacts of future disasters.

Introduction to the Hazard Analysis

This hazard analysis had previously been updated as a component within the 2014 Michigan Hazard Mitigation Plan (MHMP). The previous publication of a separate Michigan Hazard Analysis was in 2012. This follows an approximately 5-year cycle in which an updated Michigan Hazard Analysis gets updated between updates of the full hazard mitigation plan, and its updated content is then included within the next edition of that plan.

This introduction provides an overview of how this document is organized, and the kinds of assessment it provides for approximately three dozen identified hazards relevant to Michigan. Some sections now include additional detail about topics which had been treated less systematically in previous Michigan analyses. The same overall layout of the document has been retained. In some cases, topics that had been presented within the same chapter have been separated into multiple distinct chapters.

The format of this document is designed to meet the standards of the Federal Emergency Management Agency (FEMA) and of the Emergency Management Accreditation Program (EMAP). Multiple hazards are also addressed from the perspective of emergency response, within the Michigan Emergency Management Plan (MEMP—MSP/EMHSD Publication 101). This document is designed to support and facilitate the production and update of local hazard analyses by emergency management programs (or their partners/consultants) at the level of municipalities, counties, tribal entities, and planning regions throughout the state. Full consideration is given to all types of hazards—natural, technological, and human-related.

This hazard analysis may serve as one component within a broad network of other concepts, activities, and phases of emergency management (aka mission areas). Although the Michigan Hazard Mitigation Plan will need to focus more specifically upon hazard mitigation activities, this hazard analysis document is designed with a somewhat broader scope. Its descriptions of historical events, by itself, can be very useful for those who are preparing for, responding to, or recovering from similar events. Several approaches have been used to analyze different types of hazards, but each specific hazard chapter now shares a fundamental format which better allows for a comparison and prioritization of these hazards.

The many hazards analyzed here are made more comprehensible by organizing their chapters into broad sections and themes. Many of the most closely-related hazards are therefore located near each other in the same general section of this analysis. There is extensive overlap between natural hazards. Similarly, several technological hazards and human-related hazards also tend to share a great deal in common with each other. The three major divisions within this document correspond to these three major hazard classifications: natural hazards, technological hazards, and human-related hazards. Within these three major sections, several themes have been identified to further bundle information about hazards that are closely related to each other. Persons who need information about weather hazards, for example, do not need to jump between sections separated by hundreds of pages, but instead can refer specifically to a single section of this plan.

However, it must not be overlooked that there are potential flaws in any possible way to linearly organize this document. Many of Michigan's weather hazards frequently cause electrical power failures to occur, and although the weather hazards are all located within the first section of this document (natural hazards), a full understanding of the impacts of these weather events will require a reader to also check into the chapter on infrastructure failures (within the technological hazards section of this document).

Even though numerous hazards are presented separately in different chapters of this document, in order to make these topics as easy as possible to learn about and study, it should also be useful to consider how Michigan's hazards can relate to each other. A major disaster can include "cascading effects" in which one form of hazard causes another. For example, among its other damages, a tornado could cause a power failure to occur, and an extensive power failure can result in a public health emergency. Although this document presents separate chapters for tornadoes, power failures, and public health emergencies, Michigan citizens should be aware of the extent to which these problems may occur together. Various passages of text explain how initial hazards can lead to additional hazards, such as a severe windstorm that leads to an electrical power failure.

This document begins with a section on **natural hazards**. It makes sense to list these hazards first, because they so commonly affect Michigan. There is not a single part of Michigan that isn't susceptible to severe weather, for example. Within the natural hazards section, weather hazards have been listed first. Most of the weather hazards subsection deals with violent warm-weather events such as thunderstorms and tornadoes, but there is also an entire component that addresses hazardous winter weather. One of the weather-related hazards, extreme temperatures, addresses both summer and winter weather issues in one section.

Many weather hazards affect the hydrological conditions in Michigan and its local communities, and therefore the weather hazards section is immediately followed by a section dealing with hydrological hazards—flooding and drought. The flood hazard section includes three major components—inland (riverine) flooding, Great Lakes shoreline hazards, and dam failures. The shoreline hazards component not only includes information about flooding, but topics relevant to coastline areas along the Great Lakes—storm surges (seiches), rip currents, Great Lakes water recession, and shoreline erosion.

The first two natural hazard subsections flow well into a consideration of Michigan's two main ecological hazards—wildfires and invasive species (whose chapter has been substantially rewritten). Both weather and hydrological conditions affect Michigan's ecological conditions, and its vulnerability to wildfires and invasive species. The natural hazards section wraps up with a subsection on Michigan's geological hazards, including one chapter on space weather and another on meteorites and other impacting objects, which considers the impact or threatened impact of physical bodies upon the Earth's land, sea, or atmosphere—rare as a hazard but having the potential for effects that are truly catastrophic. Space weather, mainly solar storms, have the potential to disrupt and destroy important infrastructure. These issues are given a realistic assessment here that may contrast with some of the alarmist media presentations that have appeared in recent years. "Climate trends" is the major new chapter added to this document since its previous edition, designed to satisfy FEMA planning requirements as well as to provide reliable information to readers who may vary widely in their scientific backgrounds.

The **technological hazards** section includes two major subsections—one dealing with industrial hazards and the other with infrastructure problems. Within the industrial hazards subsection are components dealing with fires, hazardous materials incidents of various kinds, nuclear power plant issues, and accidents involving Michigan's oil and gas pipelines and wells. Although some of these chapters have already dealt with infrastructure failures of certain kinds, the full subsection on infrastructure problems involves major infrastructure system failures, energy emergencies, and major transportation accidents.

The final major section of the hazard analysis, **human-related hazards**, contains six components, including an overview of the general topic of catastrophic incidents (national emergencies). In recent decades, major national incidents involving terrorism and hurricanes have made it clearer than ever how interconnected we all are. We as a state experience both direct and indirect effects from events that take place elsewhere in the nation and the world. The catastrophic incidents section provides an overview of events, such as 9/11 and Hurricanes Katrina and Rita, whose scale may necessitate extensive activities within Michigan even though the direct impacts of the event primarily occurred outside of our state. There is also an updated chapter on civil disturbances and on nuclear attack, followed by an updated section on public health emergencies. The final section on terrorism and similar criminal activities now includes a separate section dealing specifically with cyber-attacks.

The result is meant to be a document that is comprehensive, up-to-date, valid, interesting, and useful. Many of the sources used in the earliest editions of this document had not been cited in a manner that allowed them to remain readily updated as the text needed revisions. Although this document's information was all reviewed and, in many cases, double-checked, the sources specifically cited here are often just ones used new material that was added to this edition, or for specific images or maps. Citations for text adapted from earlier documents (e.g. the 2006 and 2012 editions of the Michigan Hazard Analysis) might be tracked down through those earlier documents, but government document formats have tended to differ over time, especially compared with academic documents, in the precision and consistency of citation use. In order to more readily update and present a huge amount of information within this single document, the decision was made not to provide detailed citations. Importantly, some of the sources used to describe Michigan's hazards are not ones that allow verification by most readers (such as LEIN messages, Flash Reports, local hazard mitigation plans, internal disaster documentation, the personal experiences of those in response and recovery agencies, and emergency management correspondence). If there is a question about any of the information in this document, inquiries can be directed to Mike

Sobocinski at (517) 284-3947 (or sobocinskim@michigan.gov) and the information can then be double-checked or its basis explained.

One final note may also be helpful regarding the sometimes-lengthy lists of historical incidents included in this plan. Some of the rarer types of incidents may use examples from outside of Michigan, when it was felt that an insufficient number or variety of Michigan examples was available, or because they involved scenarios that in some manner were deemed to be noteworthy for an analysis of that hazard. On the other hand, lengthy lists of Michigan examples have been provided for other hazards—often with a reduced font size. These lists usually contain specific local information, and are intended to help provide links between this state level plan and plans at the local level. **This document has been designed to allow its information to be searchable by county** (when an electronic search function is used with its digital edition). The inclusion of specific local information in this document has been widely agreed to be helpful for those who develop and update local hazard mitigation plans, just as the review and consideration of local plans has been helpful for this update of the latest State plan. Therefore, an impressive level of detail has been retained within this document, even though this results in a gradual increase in the document's length. Readers may scrutinize or skim over these more detailed sections as they like, but this plan has been revised from the perspective that the best means of analyzing hazards is to maintain the solid and detailed historical grounding that had evolved through its earlier editions.

An increasing number of users are no longer using a printed copy of this document, and therefore can easily make use of digital search functions while ignoring the document's overall length. For example, this document may easily be opened from the internet or downloaded onto a device, and a search function such as "Ctrl F" or "Find in page…" will allow users to type the name of their Michigan county into a small search window. This will result in dozens of "hits" (county references identified in this document by the digital search), for any county whose name is searched for. Such county references usually involve material that can easily be copied and pasted into local hazard analyses and plans, as a convenient way to help develop or update them.

With an introductory overview now provided to readers, an outline of the full hazard analysis is hereby presented, as a quick guide to the hundreds of pages that follow. A list follows, summarizing their estimated rankings at the state level. (**Please note that many hazard assessments are based upon a limited historical analysis and therefore should be treated merely as rough estimates.**) A general graph is included, showing how the various hazards can cause one another (as a complex system), or worsen their impacts.

Outline of the Michigan Hazard Analysis

I. Natural Hazards
- A. Weather Hazards
  - 1. Thunderstorms
    - a. Hail
    - b. Lightning
  - 2. Tornadoes
  - 3. Severe winds
  - 4. Extreme temperatures
  - 5. Winter storms
    - a. Ice and sleet storms
    - b. Snowstorms and blizzards
  - 6. Fog
- B. Hydrologic Hazards
  - 1. Floods
    - a. Riverine floods (and erosion)
    - b. Pluvial and urban floods (and landslides)
    - c. Great Lakes shoreline hazards (seiches, ice surges, erosion, algal blooms, currents)
    - d. Dam and levee failures
  - 2. Drought
- C. Ecological Hazards
  - 1. Wildfires
  - 2. Invasive species (aquatic and terrestrial)
- D. Geologic Hazards
  - 1. Climate Trends
  - 2. Ground Movement
    - a. Earthquakes
    - b. Subsidence
  - 3. Celestial Impacts
    - a. Space Weather
    - b. Meteorites and other impacting objects

II. Technological Hazards
- A. Industrial Hazards
  - 1. Structural and Industrial Fires (including scrap tire fires and industrial explosions)
  - 2. Hazardous Material Incidents
    - a. Fixed site incidents (including oil and gas wells)
    - b. Nuclear power plant emergencies
    - c. Transportation incidents
    - d. Petroleum and natural gas pipeline accidents
- B. Infrastructure Problems
  - 1. Infrastructure failures (electric, water, sewer, communication, transportation)
  - 2. Energy emergencies
  - 3. Transportation accidents (air, rail, highway, marine)

III. Human-Related Hazards
- A. Catastrophic incidents (national emergencies)
- B. Civil disturbances (including protests, hooliganism, riots, and insurrection)
- C. Nuclear attack
- D. Public health emergencies (including contagion and air, water, or food contamination)
- E. Terrorism and similar criminal activities
- F. Cyber-attacks

Summary of Michigan's Estimated Top Hazards

Note: Many hazard assessments are based upon a limited historical analysis and therefore their estimated rankings should be treated merely as rough estimates.

Type of Hazard	Ranked Priority	Reason for ranking
Floods	Top	Many damaging incidents: urban, riverine, and coastal; disruptive
Public health emergencies	Top	Major incidents involving water quality, PBB (1973), pandemic potential
Oil and gas pipeline incidents	Top	Billion-dollar Kalamazoo River event (2010), related concerns
Major fires or industrial incidents	Top	Dearborn plant explosion (1999), potential casualties and disruption
Invasive species	Top	Potential Asian carp and agribusiness impacts, Emerald Ash Borer damage
Severe winds	Top	Regularly occurring incidents with serious damages, widespread impacts
Tornadoes	Top	Potential for extreme damage and massive casualties, though uncommon
Infrastructure failures	Top	Potential impacts and disruption from major blackouts, though uncommon
Extreme heat	Top	Potential for widespread human impacts, burden upon infrastructure
Cyber-attack	*	Potential economic, infrastructure, disruptive effects; global source of risk
Catastrophic incidents	*	Recent hurricane impacts and other potential national emergencies
Nuclear attack	*	Potential for terrorist device; potential from geopolitical strife
Terrorism and similar incidents	*	Recent U.S. incidents, 2012 sniper, 2009 airline incident, 1927 Bath event
Hazardous materials incident (site)	High	Many events of local concern occur frequently; potential for serious events
Hazardous materials transportation	High	Many events of local concern occur frequently; potential for serious events
Ice storms	High	Michigan's most damaging winter hazard; infrastructure/transport breakdown
Major transportation accidents	High	A pattern of major interstate crashes, 1987 plane crash near Detroit
Hail	High	Strong events, although uncommon, have been as costly as tornadoes
Wildfires	High	Long wildfire history; some large-scale emergency events, potential casualties
Extreme Cold	High	Causes human casualties, infrastructure failures, and some other disruptions
Drought	High	Huge historical impacts might again be felt; agriculture's importance in Michigan
Dam failures	High	Severe potential impacts upon selected locations; costly environmental risks
Great Lakes shoreline hazards	High	High lake levels, harmful algal blooms, casualties from dangerous currents
Lightning	High	More casualties than many hazards, but trickier to mitigate; needs awareness
Subsidence	*	Imminent need to assess Western U.P. risks; an increase in urban subsidence
Space weather	*	A strong geomagnetic storm could cause widespread infrastructure failures
Civil disturbances	*	Recent U.S. incidents, multiple historical events within Michigan
Energy emergencies	*	Currently an interagency priority, but closer to preparedness than mitigation
Snowstorms	Medium	Annual events in each part of Michigan, transportation risks; limited damages
Scrap tire fires	Medium	Multiple events, but tire quantities have been greatly reduced in recent years
Earthquakes	Medium	Unclear risks in Western U.P. subsidence zones; potential infrastructure loss
Nuclear power plant accidents	Medium	Events are rare, most are not severe, few locations, extensive preparedness
Oil and gas wells	Medium	Disaster events are rare; usually limited to one site or small area
Celestial impacts	Medium	Catastrophic impacts are very rare; shorter-term risks tend to be limited
Fog	Medium	Problematic for transportation; the worst direct impacts involve freezing fog

* The hazards marked with an asterisk are especially difficult to assess, but have been placed to divide the sets of highest-priority hazards from the medium and lower-impact ones.

<u>Every hazard in this list is considered significant</u>, having the potential to result in at least a local emergency situation. These rankings are primarily based upon the state's actual history of property damage, crop losses, human casualties, economic and environmental impacts, and secondarily upon theoretical estimates of risks and vulnerabilities involving hazards that do not have a clear history of occurrences to extrapolate from. Some potentially catastrophic events are not ranked according to just their worst-case destructive potential. Instead, this table seeks to balance each hazard's short- and medium-term likelihood, as currently understood, with their corresponding level of expected impacts within these limited time-frames. Although **climate trends** have been described in an entirely new chapter in this document, the topic has not yet been ranked here. It can be conceived in terms of its influence upon the hazards that have been ranked. State rankings differ from national/global ones.

In addition, some attention has been given to the way in which vulnerabilities and priorities can vary throughout different parts of the state. A subsection within most chapters lists (where appropriate) the counties whose local hazard mitigation plans had identified that chapter's hazard as one of their most significant local concerns. Moreover, the situations within different geographic areas of the state has been given more attention. Many chapters include tables and maps showing how each hazard has affected each county. The following table summarizes some of this data (for natural hazards) at the level of the four general geographic divisions defined and described in this document's Introduction.

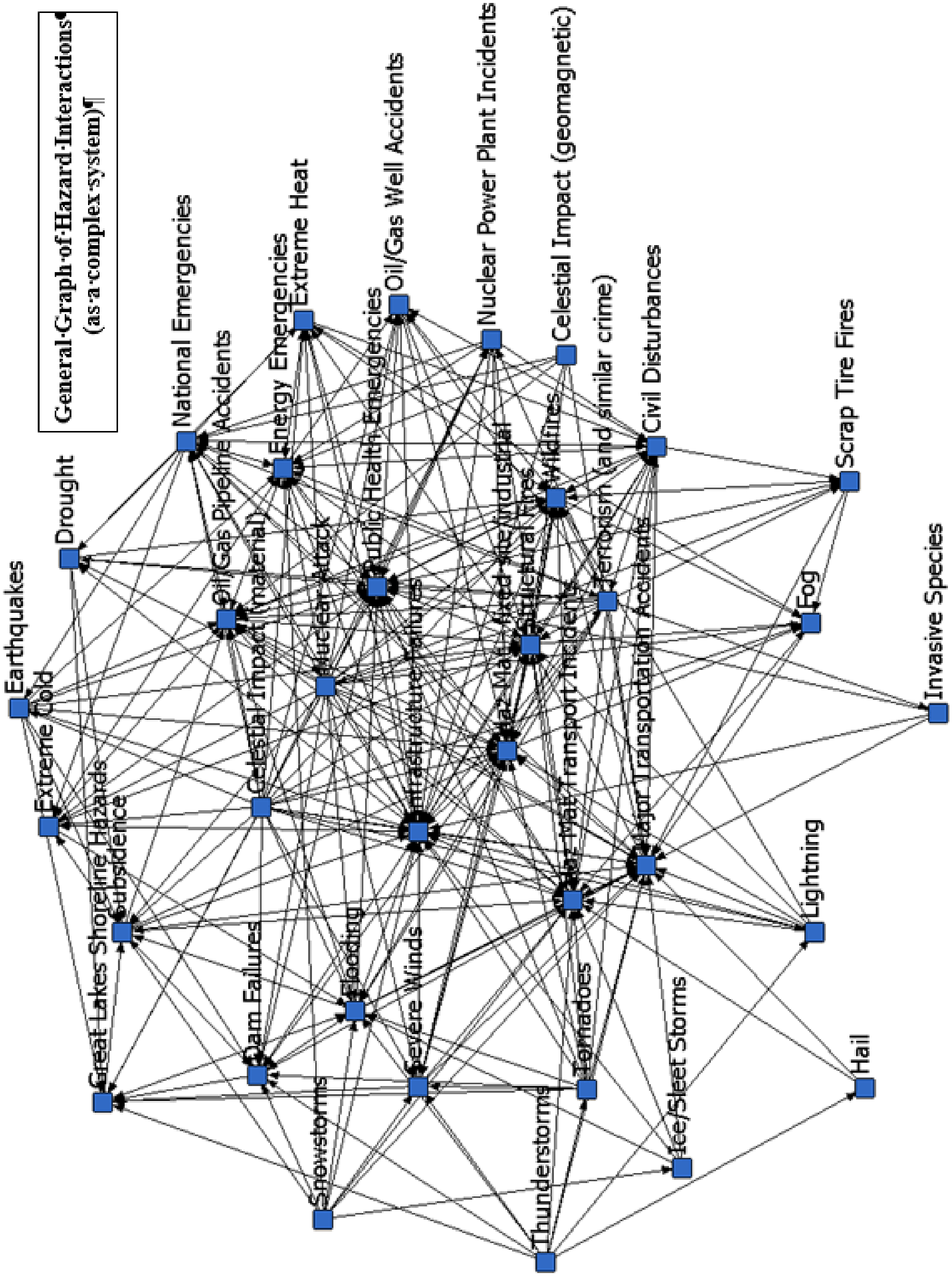
Quantitative Summary by Region

Source: NCEI Storm Events online database* (1996-2017)

	Average annual events	Average annual deaths	Average annual injuries	Average annual property and crop damage	Average annual events	Average annual deaths	Average annual injuries	Average annual property and crop damage
Geographic Division→	**Upper Peninsula**				**Northern Lower Peninsula**			
Hail	**2.2**	**0**	**0**	**$3,302,677**	**1.3**	**0**	**>0**	**$2,012,844**
Lightning	**0.1**	**0.1**	**0.2**	**$24,600**	**0.1**	**0.3**	**1.3**	**$49,337**
Ice and sleet storms	**0.2**	**0**	**0**	**$14,063**	**0.1**	**0**	**0**	**$83,205**
Snowstorms	**8.8**	**0.1**	**0.1**	**$70,900**	**3.7**	**0**	**0**	**$1,243,754**
Severe winds	**3.0**	**0.1**	**0.1**	**$1,064,335**	**1.9**	**0.2**	**2.6**	**$4,647,190**
Tornadoes	**0.1**	**0**	**0**	**$351,568**	**0.1**	**>0**	**0.2**	**$348,474**
Extreme heat	**>0**	**0**	**0**	**$0**	**>0**	**0**	**0**	**$0**
Extreme cold	**1.4**	**>0**	**0**	**$0**	**0.1**	**0**	**0**	**$3,492,242**
Fog	**0.2**	**0**	**0**	**$0**	**>0**	**0**	**0**	**$0**
Flooding	**0.8**	**>0**	**0**	**$2,374,256**	**0.3**	**0**	**0**	**$2,591,244**
Shoreline hazards	**1.1**	**0.5**	**0**	**$9,469**	**>0**	**0.2**	**>0**	**$0**
Drought*	**>0**	**0**	**0**	**$0**	**>0**	**0**	**0**	**$0**
Wildfires	**>0**	**0**	**0.2**	**$849,201**	**>0**	**0**	**0**	**$109,689**
***NOTE: This source is not comprehensive for drought impacts. Please refer to the Drought chapter, appearing later.**								
Geographic Division→	**Southern Lower Peninsula**				**Metropolitan Detroit**			
Hail	**2.6**	**0**	**0.2**	**$11,752,581**	**6.5**	**0**	**0**	**$1,173,300**
Lightning	**0.2**	**0.2**	**2.1**	**$293,770**	**1.1**	**0.3**	**1.6**	**$457,788**
Ice and sleet storms	**0.2**	**0**	**>0**	**$2,948,718**	**0.2**	**>0**	**0.2**	**$8,366,709**
Snowstorms	**3.2**	**0**	**>0**	**$535,555**	**2.3**	**0**	**0.3**	**$88,314**
Severe winds	**6.3**	**0.8**	**7.7**	**$3,145,786**	**15.8**	**0.5**	**2.2**	**$14,230,488**
Tornadoes	**0.3**	**0.2**	**2.6**	**$9,332,874**	**0.3**	**>0**	**4.6**	**$7,101,064**
Extreme heat	**0.2**	**0**	**3.1**	**$0**	**0.6**	**0.4**	**38.3**	**$0**
Extreme cold	**0.2**	**0.1**	**5.7**	**$1,389,866**	**0.7**	**0.8**	**3.7**	**$283,598**
Fog	**>0**	**>0**	**>0**	**$0**	**0.1**	**0**	**0**	**$0**
Flooding	**0.7**	**0.3**	**0.4**	**$11,782,215**	**1.7**	**>0**	**0**	**$90,584,306**
Shoreline hazards	**0.8**	**0.8**	**0.4**	**$938**	**0**	**0**	**0**	**$0**
Drought*	**>0**	**0**	**0**	**$0**	**0.1**	**0**	**0**	**$7,031,360**
Wildfires	**>0**	**0**	**0**	**$0**	**>0**	**0**	**0**	**$938**

"Average annual" numbers are medium-term estimates only. Medium-term means that most estimates were based upon decades' worth of data, to predict future decades' risk. Some figures round down to zero (e.g. less than 1 death in the period of over 20 years), and have been expressed as ">0" to distinguish them from a true zero.

The next page presents a graph that roughly illustrates the many causal interconnections between Michigan's hazards. Each labeled box represents a hazard. Arrows pointing to it show other hazards that could cause or worsen its severity of impacts. Arrows pointing from a box lead to other boxes, showing the hazards that it can cause to occur (or worsen the impacts of).



General Graph of Hazard Interactions
(as a complex system)

I. Natural Hazards
A. Weather Hazards

The following outline summarizes the significant weather hazards covered in this section:

1. Thunderstorms
   a. hail
   b. lightning
2. Tornadoes
3. Severe Winds
4. Extreme Temperatures
5. Winter storms
   a. ice and sleet storms
   b. snowstorms and blizzards
6. Fog

These weather hazards can be thought of in general terms, according to whether they involve winter weather conditions or not. The winter storms section and half of the extreme temperatures section should be referred to for a good overview of Michigan's winter weather hazards (along with the hydrological hazards section appearing later). The other sections focus upon weather conditions that predominate in the non-winter months. However, it must be noted that fog and strong winds may be present during any season (although the strongest winds in Michigan are usually associated with severe thunderstorms). Strong winter winds may occur in conjunction with sleet and ice, and are a specific part of blizzard events, all described in the winter weather section. When ice and sleet have already weakened an area's tree limbs, power lines, and infrastructure, winter winds are often the final straw that causes tree limbs (or entire trees) to topple across roads or utility lines, causing life-threatening infrastructure breakdowns during periods of extreme cold. Because many types of events overlap or occur simultaneously, it makes sense to study these weather topics together, to consider these areas of overlap and similarity.

The non-winter months usually see the other types of severe weather hazards—thunderstorms and tornadoes, lightning and hail, and extreme heat. Thus, most of this section of the hazard analysis describes hazards that regularly occur during the non-winter months. The seasons in Michigan do not completely match those seen on the standard calendar, and they vary a little bit depending upon the area of the State being considered. As will be described further in the material on each hazard, Michigan's weather is affected by its location in the middle of the Great Lakes. Locations next to, or distant from, a Great Lakes shoreline, will often have different weather patterns and hazard risks. There is also a general trend relating to how far to the north the area under consideration is located. Michigan may be thought of in terms of three broad geographic divisions: the Upper Peninsula, the Northern Lower Peninsula, and the Southern Lower Peninsula. The Upper Peninsula, in addition to containing the northernmost locations and the areas of highest elevation (e.g Mount Arvon in Baraga County, at 603m), also has areas that are more exposed to weather patterns blowing in from the west, without the extent of moderating Lake Michigan influence enjoyed by the Lower Peninsula. This exposes the Upper Peninsula to colder average temperatures and longer winters. The Lower Peninsula contains a northern region that contains large areas of forest, hilly landscape, and higher elevations (e.g. Grove Hill, in northern Osceola County, at 522m), and a southern region that is much flatter, less forested, and has predominantly agricultural and urban land uses.

Although three general Michigan regions each have different degrees of risk and vulnerability from weather hazards, it is important to note that all of them are at-risk from each of the hazards in this section. The risks merely vary by the probability of the worst impacts, and the degree and severity of the "typical" impact. Every one of Michigan's 83 counties has experienced severe thunderstorms and at least one confirmed tornado. Every county is also susceptible to strong winds, extreme temperatures, and severe winter weather. The variation across Michigan is primarily one of likelihood and the range of intensity.

Therefore, for the weather hazards, it may make sense to think in terms of two parts of the year: winter and non-winter. Although mild snowfall and cold temperatures may occur a little bit outside of the main period of wintry weather, such events tend not to be serious ones, and therefore a general distinction can be made between the "winter weather risk season" and the "non-winter weather risk season." The winter weather risk season is defined in terms of historically documented events involving extreme cold and significant snowstorms. Seasons of winter weather risk include months during which record low temperatures are near enough to zero to make it likely that wind chill advisories would be issued, and when record snowfall levels have amounted to at least several inches. Even if these events are less likely on the "edges" of the season, they have occurred and therefore risk periods can be generally defined in terms of the two "seasons" below. Conversely, all non-winter months are susceptible to extreme heat (in which record high temperatures go above 90 degrees Fahrenheit and thus make it likely that a heat advisory might need to be issued).

On the basis of this historical analysis, it was determined that the main risk periods for weather events can be assigned to the following months, for Michigan's three general regions. (**NOTE: Do <u>not</u> use these seasons to define wind and tornado risks.** For example, strong tornadoes have occurred in months such as October and April. Also, **freezing rain and ice/sleet storms may occur** whenever the temperatures can reach the freezing point of 32°F, which is a longer time period than the winter risk season described below.)

1. Southern Lower Peninsula:	Winter risk season from late November to early April Non-winter risk season from early May to late September

(extend that last risk season to early October for the southernmost tiers of counties, such as Berrien and Wayne)

2. Northern Lower Peninsula:	Winter risk season from early November to April Non-winter risk season from late May to late September
3. Upper Peninsula	Winter risk season from Late September to May Non-winter risk season from late May to early September

Some variation may be expected between counties, especially shoreline counties that observe the tempering effect of the Great Lakes, but the "seasons" proposed here may be good "rules of thumb" for the times of the year when different types of weather risks will occur in different parts of Michigan. The extreme heat hazard, for example, will affect the Upper Peninsula for a somewhat shorter time period each year than it does the Southern Lower Peninsula. However, this difference does not change the fact that once the risk season has arrived, both areas are at risk. In July, for example, the City of Ironwood had a record high temperature of 103 degrees, and although the record high temperatures in the Southern Lower Peninsula have reached 108 degrees, the highest recorded temperature in Michigan was actually felt in the Northern Lower Peninsula, when Oscoda County hit 112 degrees (although Mecosta County also reached that temperature, and major weather stations across those regions reported temperature records of just 106 degrees). Thus, although there are differences and trends between regions and within them, the fact that <u>all</u> have experienced extreme heat waves must be recognized. In other words, the commonalities shared by Michigan's regions are often more important than the differences, when it comes to weather-hazard preparedness and mitigation.

Historic Precipitation and Snowfall Records at Various Michigan Locations

The counties listed below start with the northernmost tier in Michigan, and proceed generally southward, tier by tier.

Upper Peninsula	**Record Precipitation**	**Record Snowfall**
Hancock (Houghton County)	3.58” (May 17 & Sept. 4)	26.5” (Jan. 18)
Ironwood (Gogebic County)	6.72” (July 21)	24.0” (Dec. 16)
Munising (Alger County)	3.51” (May 31)	20.0” (March 15)
Sault Ste. Marie (Chippewa Co.)	5.92” (Aug. 3)	26.6” (Dec. 10)
Northern Lower Peninsula	**Record Precipitation**	**Record Snowfall**
Alpena (Alpena County)	5.14” (Sept. 3)	18.2” (Feb. 22)
Gaylord (Otsego County)	5.00” (Aug. 17)	20.0” (Nov. 23)
Traverse City	4.30” (Aug. 23)	16.0” (Jan. 25 & Nov. 29)
Gladwin (Gladwin County)	5.00” (May 20)	15.0” (Dec. 11)
East Tawas (Iosco County)	3.72” (Aug. 16)	20.0” (Feb. 14)
Southern Lower Peninsula	**Record Precipitation**	**Record Snowfall**
Harbor Beach (Huron County)	6.04” (Sept. 10)	18.0” (Feb. 21)
Big Rapids (Mecosta County)	7.64” (Sept. 11)	16.0” (Jan. 30)
Flint (Genesee County)	6.04” (Sept. 10)	14.5” (Jan. 26)
Grand Rapids (Kent County)	4.22” (June 5 & Aug. 19)	16.1” (Jan. 26)
Port Huron (St. Clair County)	3.97” (Sept. 7)	14.3” (March 27)
Pontiac (Oakland County)	4.75” (Oct. 1)	18.0” (Dec. 2)
Detroit (Wayne County)	4.74” (July 31)	24.5” (April 6)
Bloomingdale (Van Buren Co.)	9.78” (Sept. 1)	20.0” (Dec. 10)
Ann Arbor (Washtenaw County)	4.54” (Aug. 6)	15.8” (Dec.1)
Jackson (Jackson County)	5.31” (June 21)	16.0” (March 17)
Benton Harbor (Berrien County)	6.60” (May 30)	25.0” (Dec. 6)
Coldwater (Branch County)	5.37” (June 26)	17.0” (Jan. 26)
Adrian (Lenawee County)	4.74” (Sept. 3)	15.0” (Jan. 26)

Source: Extreme Michigan Weather, by Paul Gross (2010, University of Michigan Press, Ann Arbor)

For more information about the assessment of rainfall events (which can cause flash flooding), please refer to the precipitation-related information contained in the Thunderstorm Hazards section.

NOTE: In addition to numerous sources already referenced* in previous editions of this plan, the updated and newly added text for this 2018 Michigan Hazard Analysis has benefited greatly from the following printed books:

Meteorology Today, 10th ed, by C. Donald Ahrens. Brooks/Cole, Belmont CA et al., 2013.

Handbook of Applied Hydrology, 2nd ed. by Vijay P. Singh. McGraw-Hill, New York et al., 2017.

* Note: A huge array of newspaper articles, web sites, government documents, official records, and books of all types have formed the basis of the information in this document. However, since previous editions did not connect each source with its corresponding text, there has not been a clear way to amend this document’s bibliography to correspond with the extensive changes that have been made over the years. Some sources used in earlier documents are expected to be out of date, and some of them were never listed when the 2006 update of the Michigan Hazard Analysis was published. Therefore, although the authors are confident in the quality of the information here, much of this edition does not attempt specific citations.

Overlap Between Weather Hazards and Other Sections of the Hazard Analysis

Extreme summer heat can increase the chances of wildfires (which has its own chapter in the "Ecological Hazards" section of this plan). Weather events involving precipitation have effects upon local hydrology. Heavy precipitation, and/or melting snow, can cause flooding. Ice jams and log jams (a source of which may include woody debris toppled into drains and streams by strong winds) can also cause flooding. For more information about flooding, please refer to the flood chapters within the "Hydrological Hazards" section. That section also includes a chapter on droughts, which also have their origin in weather, but stem from a pattern involving too little precipitation rather than too much.

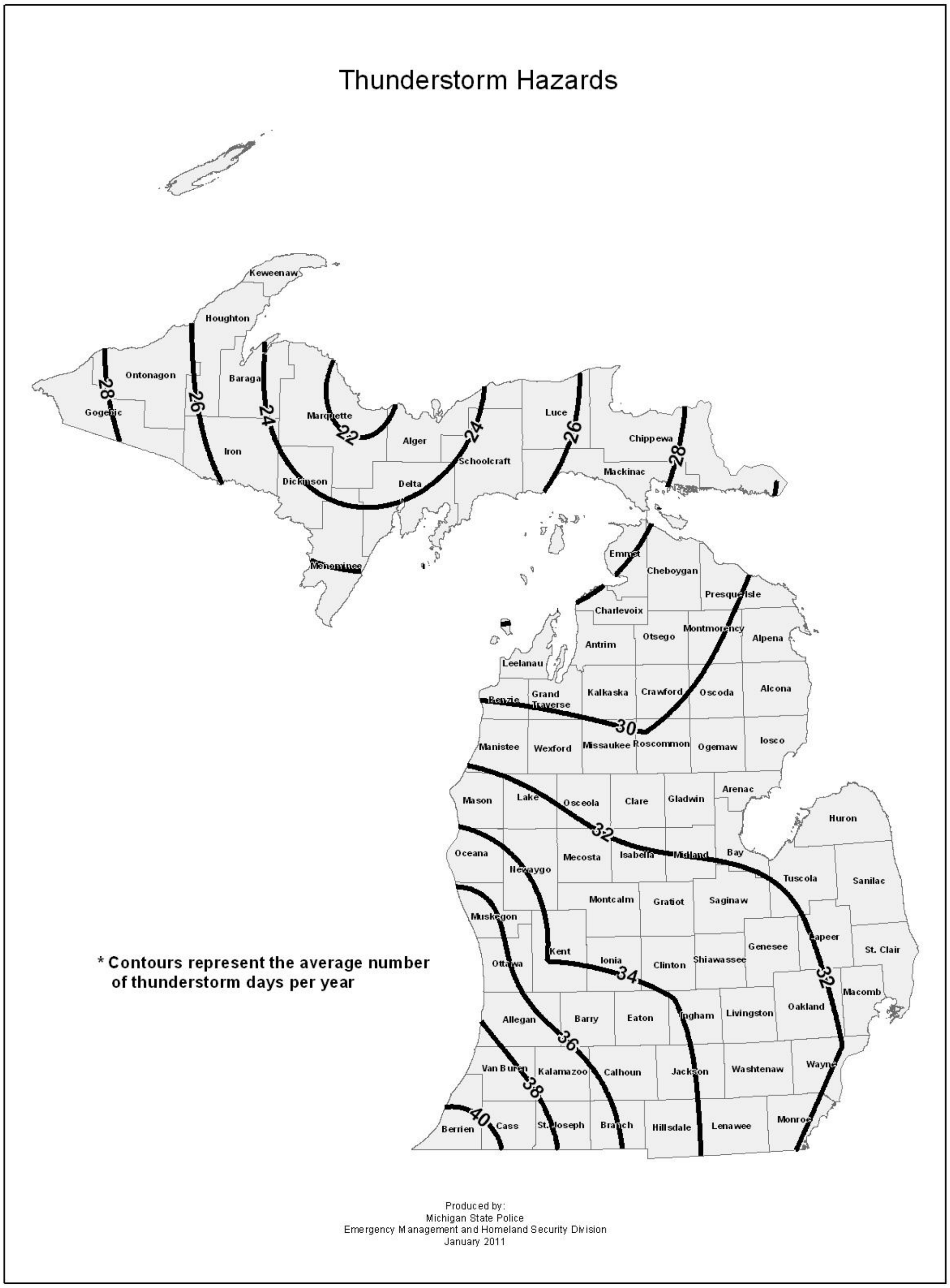
There is a strong connection between all of these extreme weather events and the "technological hazard" of infrastructure failure, which has its own chapter in the "Technological Hazards" section of this plan. Severe weather has also been a factor in major transportation accidents, which also has a chapter of its own in the Technological Hazards section.

Selection of Hazard Mitigation Strategies

Previous MSP/EMHSD documents have tended to consider a wide array of activities that could in some manner help to protect lives, property, the environment, etc., without clearly distinguishing which of these activities are hazard mitigation and which ones deal with other phases of emergency management (preparedness, response, or recovery). This document emphasizes, where possible, the types of activities that are most properly considered to be hazard mitigation, especially those that are (or should be) eligible for federal funding. It must be admitted that not all of the hazards faced by Michigan are ones that have very clear-cut hazard mitigation activities, although many ideas have indeed been included here. **Input is requested from all readers to help identify effective hazard mitigation activities for inclusion in this (as well as future and local-level) hazard mitigation document(s).**

Thunderstorm Hazards

Severe thunderstorms are weather systems accompanied by strong winds (at least 56mph), lightning, heavy rain (that could cause flash flooding), hail (at least ¾" diameter), or tornadoes. Severe thunderstorms can occur at any time in Michigan, although they are most frequent during the warm spring and summer months from May through September. The potential thunderstorm threat is often measured by the number of "thunderstorm days" – defined as days in which thunderstorms are observed. As the map below indicates, various areas in Michigan are subject to an average of at least 20 thunderstorm days per year, and up to just over 40 days per year in the state's southwestern corner. The Lower Peninsula, in general, is subject to approximately 28-40 thunderstorm days per year, while the Upper Peninsula average is closer to 20-30 thunderstorm days per year. This map is based upon data from various National Weather Service (NWS) stations within (and near) Michigan.



Thunderstorms form when warm, humid air rises and moisture condenses into expanding cloud formations when reaching a higher layer of cool, dry air. Cumulus and then cumulonimbus clouds (frequently called "thunderheads") are formed through these processes. These clouds often become enormous (stacking as much as 40,000 feet high) and build up tremendous amounts of water and energy, which are eventually released in the form of high winds, heavy rain, lightning, and possibly hail and tornadoes.

Thunderstorms are typically short-lived (often lasting no more than 30-40 minutes) and fast moving (30-50 miles per hour). Strong frontal systems, however, may spawn one squall line after another, composed of many individual thunderstorm cells. Severe thunderstorms may also cause severe flood problems because of the torrential rains that they may bring to an area. Thunderstorms sometimes move very slowly, and can thus dump a tremendous amount of precipitation onto a location. Flooding can result, including pluvial (flash floods and "urban flooding") and fluvial (riverine) flooding. Please refer to the hydrological hazard section for more information about flood hazards. Large complexes of thunderstorms, called mesoscale convection systems (MCSs), may operate as a larger-scale weather system and persist for several hours or more. Even larger mesoscale convection complexes (MCCs) can be up to 1,000 times larger than an ordinary individual "cell thunderstorm." Another problem caused by excessive rainfall involves the release of untreated sewage in order to allow old, combined sewer systems (CSSs) to more quickly drain storm waters away from an urban area. These combined sewer overflow (CSO) releases tend to lower water quality within receiving streams and water bodies. These specific thunderstorm hazards are addressed further in the following sections on hail, lightning, tornadoes, and severe winds; and in later sections on flooding, infrastructure failures, and public health emergencies. (although all of these hazards can also occur when no thunderstorm activity is evident).

Thunderstorm hazards have some degree of predictability and are closely monitored by the National Weather Service. In addition to daily forecasts, which predict the probability of rainy or stormy weather, the NWS system of Watches and Warnings helps communities understand when there is a potential risk of severe thunderstorms, or if severe thunderstorms are imminent. When the NWS issues a "Severe Thunderstorm Watch," it means that thunderstorms with large hail and damaging winds are possible in your area. When the NWS issues a "Severe Thunderstorm Warning," it signifies that severe thunderstorms (with the damaging winds and hail) are in your area or are imminent.

The NWS has five offices that serve Michigan and are responsible for monitoring and providing predictions and bulletins for the entire state. The five offices are in Gaylord, Grand Rapids, Marquette, Pontiac, and Syracuse (Indiana). These stations provide information on severe weather watches and warnings, but also provide useful Doppler Radar images that track the movement of thunderstorms in your area. The Syracuse office covers portions of southwest Michigan (www.weather.gov/iwx); the Grand Rapids station covers the remainder of southwest Michigan (www.weather.gov/grr); the Detroit station covers Southeast Michigan (www.weather.gov/dtx); the Gaylord station covers the north central portion of the Lower Peninsula and the eastern edge of the Upper Peninsula (www.weather.gov/apx); and the Marquette station examines the majority of the Upper Peninsula (www.weather.gov/mqt).

Since thunderstorms bring the potential for dangerous hail, lightning, straight-line winds, and tornadoes, it is necessary to further examine each of those hazards in the following sections of this plan. **Useful historical information on hail, severe winds, lightning, and tornadoes for your county can be found through the National Centers for Environmental Information (NCEI) website at** https://www.ncdc.noaa.gov/stormevents/. Data for each county in the state are listed there, and there are historical records of significant events for dozens of natural hazards. This is one of the most convenient information sources for the analysis of hazards, and was used extensively for this document.

Hazard Mitigation Activities for General Thunderstorm Hazards

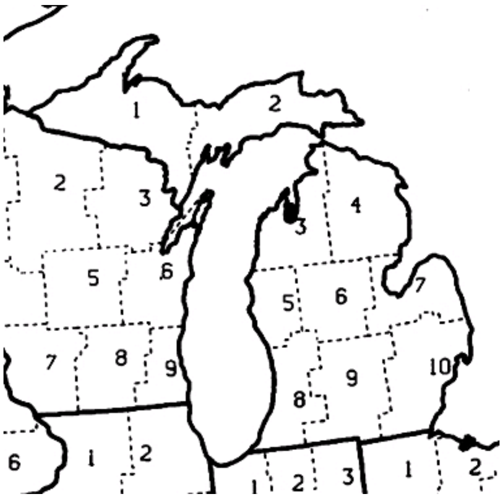
- Increased coverage and use of NOAA Weather Radio, and public early warning systems and networks.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines (where appropriate).

Emphasis in Local Hazard Mitigation Plans

Thunderstorms were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Alger, Allegan, Antrim, Arenac, Benzie, Calhoun, Cass, Charlevoix, Clare, Delta, Dickinson, Emmet, Genesee, Grand Traverse, Gratiot, Huron, Ionia, Iosco, Isabella, Kalamazoo, Kalkaska, Lapeer, Leelanau, Luce, Mackinac, Manistee, Menominee, Missaukee, Monroe, Newaygo, Ogemaw, Osceola, Saginaw, St. Clair, Schoolcraft, Tuscola, Washtenaw, Wayne, and Wexford (37 counties, a slight increase since 2014).

Michigan's 10 climate divisions (for the monitoring and analysis of precipitation)

Source: Rainfall Frequency Atlas of the Midwest, by Floyd A Huff and James R. Angel. Midwestern Climate Center and Illinois State Water Survey, 1992



Instructions for the Use of This Section

This section is useful for the assessment of rain and thunderstorm events, with implications also for flash flooding. It allows various levels of rainfall precipitation events to be interpreted in terms of their severity, based upon the historical frequency with which such events had occurred in the past.

The map at left shows Michigan's ten climate divisions, each of which is matched with data in the multi-page table below. The table contains sections listing numbers for each of Michigan's ten divisions. For a given precipitation event, find the row that most closely matches the duration of the rainfall event. Move across the row to find the number that is closest to the number of inches of rainfall for that event. The column in which that number appears tells the "recurrence interval" for that level of precipitation. A recurrence interval is the average amount of time that elapses between precipitation events of that particular severity level. Longer recurrence intervals indicate a more severe event. The most extreme events listed in the table are those with a 100-year recurrence interval. Such events are so severe that they are expected (on average) to occur only about one time per century. Precipitation-based flooding is more likely to result from events with a longer recurrence interval. Any Michigan rainfall amounts that exceed the values listed in the table are very rare and severe indeed!

As an example of the procedure described above, if we assess a Baraga County event that was 6 hours long and had involved 3 inches of rain, the Division 1 section of the table contains a row labeled "6-hr" and the column that most closely matches the 3" rainfall amount contains a value of 3.13", matching up with a 25-year recurrence interval (definitely a major rainfall event).

Table: Mean Frequency Distributions for Storm Periods of 5 Minutes to 10 Days, by Climate Division, and Recurrence Intervals of 2 Months to 100 Years in Michigan (for use with thunderstorm and flood hazards)

		Rainfall (inches) for each given recurrence interval											
Division	*Duration*	*2-month*	*3-month*	*4-month*	*6-month*	*9-month*	*1-year*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*
Division 1: Baraga, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Marquette, Menominee, Ontonagon Counties													
01	10-day	1.69	2.04	2.35	2.76	3.17	3.45	4.28	5.34	6.17	7.27	8.11	8.99
01	5-day	1.41	1.69	1.91	2.22	2.55	2.77	3.38	4.23	4.91	5.86	6.65	7.50
01	72-hr	1.24	1.46	1.65	1.91	2.20	2.39	2.96	3.69	4.29	5.11	5.79	6.49
01	48-hr	1.14	1.33	1.48	1.72	1.98	2.15	2.64	3.31	3.84	4.59	5.20	5.86
01	24-hr	1.07	1.25	1.37	1.58	1.79	1.95	2.39	3.00	3.48	4.17	4.73	5.32
01	18-hr	1.01	1.17	1.28	1.48	1.68	1.83	2.25	2.82	3.27	3.92	4.45	5.00
01	12-hr	0.94	1.09	1.19	1.38	1.56	1.70	2.08	2.61	3.03	3.63	4.12	4.63
01	6-hr	0.80	0.93	1.02	1.18	1.34	1.46	1.79	2.25	2.61	3.13	3.55	3.99
01	3-hr	0.69	0.80	0.88	1.01	1.15	1.25	1.53	1.92	2.23	2.67	3.03	3.40
01	2-hr	0.62	0.72	0.79	0.92	1.04	1.13	1.39	1.74	2.02	2.42	2.74	3.09
01	1-hr	0.51	0.59	0.64	0.75	0.85	0.92	1.12	1.41	1.64	1.96	2.22	2.50
01	30-min	0.40	0.46	0.50	0.58	0.66	0.72	0.88	1.11	1.29	1.54	1.75	1.97
01	15-min	0.29	0.34	0.37	0.43	0.49	0.53	0.65	0.81	0.94	1.13	1.28	1.44
01	10-min	0.23	0.26	0.29	0.33	0.38	0.41	0.50	0.63	0.73	0.88	0.99	1.12
01	5-min	0.13	0.15	0.16	0.19	0.21	0.23	0.29	0.36	0.42	0.50	0.57	0.64
Division 2: Alger, Chippewa, Delta, Luce, Mackinac, Schoolcraft Counties													
02	10-day	1.61	1.94	2.23	2.62	3.02	3.28	3.93	4.78	5.44	6.43	7.22	7.98
02	5-day	1.25	1.50	1.70	1.97	2.26	2.46	3.00	3.71	4.25	5.11	5.81	6.55
02	72-hr	1.15	1.35	1.52	1.77	2.03	2.21	2.62	3.27	3.78	4.57	5.23	5.94
02	48-hr	0.97	1.13	1.26	1.46	1.68	1.83	2.31	2.98	3.49	4.24	4.88	5.55
02	24-hr	0.91	1.06	1.16	1.34	1.53	1.66	2.09	2.71	3.19	3.87	4.44	5.03
02	18-hr	0.86	1.00	1.09	1.26	1.44	1.56	1.96	2.55	3.00	3.64	4.17	4.73
02	12-hr	0.79	0.92	1.01	1.17	1.32	1.44	1.82	2.36	2.78	3.37	3.86	4.38
02	6-hr	0.69	0.80	0.88	1.01	1.15	1.25	1.57	2.03	2.39	2.90	3.33	3.77
02	3-hr	0.58	0.68	0.74	0.86	0.98	1.06	1.34	1.73	2.04	2.48	2.84	3.22
02	2-hr	0.53	0.61	0.67	0.78	0.88	0.96	1.21	1.57	1.85	2.24	2.58	2.92
02	1-hr	0.43	0.50	0.55	0.63	0.72	0.78	0.98	1.27	1.50	1.82	2.09	2.36
02	30-min	0.34	0.39	0.43	0.49	0.56	0.61	0.77	1.00	1.18	1.43	1.64	1.86
02	15-min	0.25	0.29	0.31	0.36	0.41	0.45	0.56	0.73	0.86	1.04	1.20	1.36
02	10-min	0.19	0.22	0.24	0.28	0.32	0.35	0.44	0.57	0.67	0.81	0.93	1.06
02	5-min	0.11	0.13	0.14	0.16	0.18	0.20	0.25	0.33	0.38	0.46	0.53	0.60

Page 2 of Table: Mean Frequency Distributions for Storm Periods of 5 Minutes to 10 Days, by Climate Division, and Recurrence Intervals of 2 Months to 100 Years in Michigan (for use with thunderstorm and flood hazards)

		Rainfall (inches) for each given recurrence interval											
Division	*Duration*	*2-month*	*3-month*	*4-month*	*6-month*	*9-month*	*1-year*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*
Division 3: Antrim, Benzie, Charlevoix, Emmet, Grand Traverse, Kalkaska, Leelanau, Manistee, Missaukee, Wexford Counties													
03	10-day	1.63	1.96	2.26	2.66	3.06	3.33	3.99	4.92	5.65	6.66	7.50	8.35
03	5-day	1.29	1.54	1.75	2.02	2.33	2.53	3.10	3.91	4.57	5.46	6.23	7.04
03	72-hr	1.09	1.27	1.44	1.67	1.92	2.09	2.62	3.36	3.96	4.86	5.56	6.35
03	48-hr	0.97	1.13	1.26	1.46	1.68	1.83	2.34	3.02	3.55	4.31	4.94	5.60
03	24-hr	0.89	1.04	1.13	1.31	1.49	1.62	2.09	2.70	3.21	3.89	4.47	5.08
03	18-hr	0.84	0.97	1.06	1.23	1.40	1.52	1.96	2.54	3.02	3.66	4.20	4.78
03	12-hr	0.78	0.90	0.99	1.14	1.30	1.41	1.82	2.35	2.79	3.38	3.89	4.42
03	6-hr	0.67	0.78	0.85	0.99	1.12	1.22	1.57	2.03	2.41	2.92	3.35	3.81
03	3-hr	0.57	0.67	0.73	0.84	0.96	1.04	1.34	1.73	2.05	2.49	2.86	3.25
03	2-hr	0.52	0.60	0.66	0.76	0.86	0.94	1.21	1.57	1.86	2.26	2.59	2.95
03	1-hr	0.42	0.49	0.53	0.62	0.70	0.76	0.98	1.27	1.51	1.83	2.10	2.39
03	30-min	0.33	0.38	0.42	0.49	0.55	0.60	0.77	1.00	1.19	1.44	1.65	1.88
03	15-min	0.24	0.28	0.31	0.36	0.40	0.44	0.56	0.73	0.87	1.05	1.21	1.37
03	10-min	0.19	0.22	0.24	0.28	0.31	0.34	0.44	0.57	0.67	0.82	0.94	1.07
03	5-min	0.10	0.12	0.13	0.15	0.17	0.19	0.25	0.32	0.39	0.47	0.54	0.61
Division 4: Alcona, Alpena, Cheboygan, Crawford, Iosco, Montmorency, Ogemaw, Oscoda, Otsego, Presque Isle, Roscommon Counties													
04	10-day	1.56	1.88	2.17	2.55	2.93	3.19	3.77	4.56	5.22	6.10	6.85	7.60
04	5-day	1.26	1.51	1.70	1.98	2.27	2.47	2.99	3.68	4.23	4.97	5.58	6.23
04	72-hr	1.12	1.31	1.48	1.72	1.98	2.15	2.63	3.27	3.75	4.45	5.00	5.60
04	48-hr	1.00	1.17	1.30	1.51	1.74	1.89	2.32	2.88	3.33	3.93	4.43	4.95
04	24-hr	0.94	1.09	1.20	1.39	1.57	1.71	2.11	2.62	3.04	3.60	4.06	4.53
04	18-hr	0.89	1.03	1.13	1.30	1.48	1.61	1.98	2.46	2.86	3.38	3.82	4.26
04	12-hr	0.82	0.95	1.04	1.21	1.37	1.49	1.84	2.28	2.64	3.13	3.53	3.94
04	6-hr	0.70	0.82	0.90	1.04	1.18	1.28	1.58	1.96	2.28	2.70	3.05	3.40
04	3-hr	0.60	0.70	0.76	0.88	1.00	1.09	1.35	1.68	1.95	2.30	2.60	2.90
04	2-hr	0.54	0.63	0.69	0.80	0.91	0.99	1.22	1.52	1.76	2.09	2.35	2.63
04	1-hr	0.44	0.51	0.56	0.65	0.74	0.80	0.99	1.23	1.43	1.69	1.91	2.13
04	30-min	0.35	0.40	0.44	0.51	0.58	0.63	0.78	0.97	1.12	1.33	1.50	1.68
04	15-min	0.25	0.29	0.32	0.37	0.42	0.46	0.57	0.71	0.82	0.97	1.10	1.22
04	10-min	0.20	0.23	0.25	0.29	0.33	0.36	0.44	0.55	0.64	0.76	0.85	0.95
04	5-min	0.12	0.13	0.15	0.17	0.19	0.21	0.25	0.31	0.36	0.43	0.49	0.54
Division 5: Lake, Mason, Muskegon, Newaygo, Oceana Counties													
05	10-day	1.64	1.97	2.27	2.67	3.07	3.34	4.14	5.28	6.21	7.59	8.75	10.02
05	5-day	1.38	1.65	1.86	2.16	2.48	2.70	3.36	4.30	5.07	6.25	7.26	8.36
05	72-hr	1.18	1.38	1.56	1.81	2.08	2.26	2.88	3.74	4.46	5.45	6.31	7.26
05	48-hr	1.04	1.22	1.36	1.58	1.81	1.97	2.53	3.34	4.01	4.97	5.81	6.73
05	24-hr	0.97	1.13	1.24	1.43	1.63	1.77	2.28	3.00	3.60	4.48	5.24	6.07
05	18-hr	0.91	1.06	1.16	1.34	1.53	1.66	2.14	2.82	3.38	4.21	4.93	5.71
05	12-hr	0.85	0.99	1.08	1.25	1.42	1.54	1.98	2.61	3.13	3.90	4.56	5.28
05	6-hr	0.73	0.85	0.93	1.08	1.22	1.33	1.71	2.25	2.70	3.36	3.93	4.55
05	3-hr	0.62	0.72	0.79	0.92	1.04	1.13	1.46	1.92	2.30	2.87	3.35	3.88
05	2-hr	0.57	0.66	0.72	0.83	0.95	1.03	1.32	1.74	2.09	2.60	3.04	3.52
05	1-hr	0.46	0.53	0.58	0.67	0.76	0.83	1.07	1.41	1.69	2.11	2.46	2.85
05	30-min	0.36	0.42	0.45	0.53	0.60	0.65	0.84	1.11	1.33	1.66	1.94	2.25
05	15-min	0.26	0.31	0.34	0.39	0.44	0.48	0.62	0.81	0.97	1.21	1.41	1.64
05	10-min	0.20	0.24	0.26	0.30	0.34	0.37	0.48	0.63	0.76	0.94	1.10	1.27
05	5-min	0.12	0.13	0.15	0.17	0.19	0.21	0.27	0.36	0.43	0.54	0.63	0.73
Division 6: Clare, Gladwin, Gratiot, Isabella, Mecosta, Midland, Montcalm, Osceola Counties													
06	10-day	1.76	2.12	2.44	2.87	3.30	3.59	4.31	5.36	6.21	7.46	8.51	9.54
06	5-day	1.44	1.72	1.95	2.26	2.59	2.82	3.40	4.22	4.89	6.11	7.17	8.31
06	72-hr	1.23	1.45	1.64	1.90	2.18	2.37	2.88	3.62	4.24	5.27	6.17	7.18
06	48-hr	1.09	1.28	1.42	1.65	1.90	2.06	2.51	3.17	3.71	4.59	5.35	6.20
06	24-hr	1.02	1.19	1.30	1.51	1.71	1.86	2.27	2.85	3.34	4.15	4.84	5.62
06	18-hr	0.96	1.12	1.23	1.42	1.61	1.75	2.13	2.68	3.14	3.90	4.55	5.28
06	12-hr	0.89	1.04	1.13	1.31	1.49	1.62	1.97	2.48	2.91	3.61	4.21	4.89
06	6-hr	0.76	0.89	0.97	1.13	1.28	1.39	1.70	2.14	2.50	3.11	3.63	4.22
06	3-hr	0.65	0.76	0.83	0.96	1.09	1.19	1.45	1.82	2.14	2.66	3.10	3.60
06	2-hr	0.59	0.69	0.76	0.87	0.99	1.08	1.32	1.65	1.94	2.41	2.81	3.26
06	1-hr	0.48	0.56	0.61	0.70	0.80	0.87	1.07	1.34	1.57	1.95	2.27	2.64
06	30-min	0.38	0.44	0.48	0.56	0.63	0.69	0.84	1.05	1.24	1.54	1.79	2.08
06	15-min	0.28	0.32	0.35	0.41	0.46	0.50	0.61	0.77	0.90	1.12	1.31	1.52
06	10-min	0.21	0.25	0.27	0.32	0.36	0.39	0.48	0.60	0.70	0.87	1.02	1.18
06	5-min	0.12	0.14	0.15	0.18	0.20	0.22	0.27	0.34	0.40	0.50	0.58	0.67

Page 3 of Table: Mean Frequency Distributions for Storm Periods of 5 Minutes to 10 Days, by Climate Division, and Recurrence Intervals of 2 Months to 100 Years in Michigan (for use with thunderstorm and flood hazards)

		Rainfall (inches) for given recurrence interval											
Division	*Duration*	*2-month*	*3-month*	*4-month*	*6-month*	*9-month*	*1-year*	*2-year*	*5-year*	*10-year*	*25-year*	*50-year*	*100-year*
Division 7: Arenac, Bay, Huron, Saginaw, Sanilac, Tuscola Counties													
07	10-day	1.57	1.89	2.18	2.56	2.94	3.20	3.88	4.75	5.39	6.21	6.83	7.48
07	5-day	1.22	1.46	1.66	1.92	2.21	2.40	2.96	3.68	4.23	4.99	5.61	6.26
07	72-hr	1.11	1.30	1.47	1.70	1.96	2.13	2.62	3.28	3.78	4.49	5.05	5.66
07	48-hr	1.02	1.20	1.33	1.54	1.78	1.93	2.37	2.97	3.41	4.03	4.52	5.04
07	24-hr	0.96	1.12	1.23	1.42	1.61	1.75	2.14	2.65	3.05	3.56	3.97	4.40
07	18-hr	0.90	1.05	1.15	1.33	1.51	1.64	2.01	2.49	2.87	3.35	3.73	4.14
07	12-hr	0.84	0.97	1.06	1.23	1.40	1.52	1.86	2.31	2.65	3.10	3.45	3.83
07	6-hr	0.72	0.84	0.92	1.06	1.21	1.31	1.61	1.99	2.29	2.67	2.98	3.30
07	3-hr	0.62	0.72	0.78	0.91	1.03	1.12	1.37	1.70	1.95	2.28	2.54	2.82
07	2-hr	0.56	0.65	0.71	0.82	0.93	1.01	1.24	1.54	1.77	2.06	2.30	2.55
07	1-hr	0.45	0.52	0.57	0.66	0.75	0.82	1.01	1.25	1.43	1.67	1.87	2.07
07	30-min	0.36	0.42	0.45	0.53	0.60	0.65	0.79	0.98	1.13	1.32	1.47	1.63
07	15-min	0.26	0.30	0.33	0.38	0.43	0.47	0.58	0.72	0.82	0.96	1.07	1.19
07	10-min	0.20	0.24	0.26	0.30	0.34	0.37	0.45	0.56	0.64	0.75	0.83	0.92
07	5-min	0.12	0.13	0.15	0.17	0.19	0.21	0.26	0.32	0.37	0.43	0.48	0.53
Division 8: Allegan, Berrien, Cass, Kalamazoo, Kent, Ottawa, Van Buren Counties													
08	10-day	1.81	2.18	2.51	2.95	3.39	3.69	4.33	5.23	5.96	7.39	8.63	10.03
08	5-day	1.48	1.77	2.00	2.32	2.67	2.90	3.45	4.27	4.95	6.16	7.28	8.46
08	72-hr	1.29	1.52	1.72	1.99	2.29	2.49	3.00	3.75	4.41	5.50	6.45	7.51
08	48-hr	1.14	1.33	1.48	1.72	1.98	2.15	2.63	3.32	3.91	4.93	5.83	6.82
08	24-hr	1.07	1.25	1.37	1.58	1.79	1.95	2.37	3.00	3.52	4.45	5.27	6.15
08	18-hr	1.01	1.17	1.28	1.48	1.68	1.83	2.23	2.82	3.31	4.18	4.95	5.78
08	12-hr	0.94	1.09	1.19	1.38	1.56	1.70	2.06	2.61	3.06	3.87	4.58	5.35
08	6-hr	0.80	0.93	1.02	1.18	1.34	1.46	1.78	2.25	2.64	3.34	3.95	4.61
08	3-hr	0.69	0.80	0.88	1.01	1.15	1.25	1.52	1.92	2.25	2.85	3.37	3.94
08	2-hr	0.62	0.72	0.79	0.92	1.04	1.13	1.37	1.74	2.04	2.58	3.06	3.57
08	1-hr	0.51	0.59	0.64	0.75	0.85	0.92	1.11	1.41	1.65	2.09	2.48	2.89
08	30-min	0.40	0.46	0.50	0.58	0.66	0.72	0.88	1.11	1.30	1.65	1.95	2.28
08	15-min	0.29	0.34	0.37	0.43	0.49	0.53	0.64	0.81	0.95	1.20	1.42	1.66
08	10-min	0.23	0.26	0.29	0.33	0.38	0.41	0.50	0.63	0.74	0.93	1.11	1.29
08	5-min	0.13	0.15	0.16	0.19	0.21	0.23	0.28	0.36	0.42	0.53	0.63	0.74
Division 9: Barry, Branch, Calhoun, Clinton, Eaton, Hillsdale, Ingham, Ionia, Jackson, Shiawassee, St. Joseph Counties													
09	10-day	1.77	2.13	2.45	2.89	3.32	3.61	4.26	5.15	5.83	6.81	7.60	8.40
09	5-day	1.43	1.71	1.93	2.24	2.58	2.80	3.36	4.10	4.71	5.57	6.27	6.99
09	72-hr	1.27	1.49	1.68	1.95	2.24	2.44	2.93	3.59	4.16	4.95	5.59	6.28
09	48-hr	1.17	1.37	1.52	1.77	2.03	2.21	2.66	3.28	3.79	4.50	5.10	5.73
09	24-hr	1.12	1.30	1.42	1.64	1.87	2.03	2.42	2.98	3.43	4.09	4.63	5.20
09	18-hr	1.05	1.22	1.34	1.55	1.76	1.91	2.27	2.80	3.22	3.84	4.35	4.89
09	12-hr	0.97	1.13	1.24	1.43	1.63	1.77	2.11	2.59	2.98	3.56	4.03	4.52
09	6-hr	0.84	0.97	1.06	1.23	1.40	1.52	1.82	2.24	2.57	3.07	3.47	3.90
09	3-hr	0.71	0.83	0.91	1.05	1.20	1.30	1.55	1.91	2.20	2.62	2.96	3.33
09	2-hr	0.65	0.76	0.83	0.96	1.09	1.18	1.40	1.73	1.99	2.37	2.69	3.02
09	1-hr	0.52	0.61	0.66	0.77	0.87	0.95	1.14	1.40	1.61	1.92	2.18	2.44
09	30-min	0.41	0.48	0.52	0.61	0.69	0.75	0.90	1.10	1.27	1.51	1.71	1.92
09	15-min	0.30	0.35	0.38	0.45	0.51	0.55	0.65	0.80	0.93	1.10	1.25	1.40
09	10-min	0.24	0.28	0.30	0.35	0.40	0.43	0.51	0.63	0.72	0.86	0.97	1.09
09	5-min	0.13	0.15	0.17	0.19	0.22	0.24	0.29	0.36	0.41	0.49	0.56	0.62
Division 10: Genesee, Lapeer, Lenawee, Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, Wayne Counties													
10	10-day	1.56	1.88	2.17	2.55	2.93	3.19	3.82	4.64	5.27	6.11	6.79	7.51
10	5-day	1.28	1.53	1.73	2.01	2.31	2.51	3.05	3.68	4.16	4.78	5.26	5.74
10	72-hr	1.18	1.38	1.56	1.81	2.08	2.26	2.74	3.34	3.76	4.31	4.74	5.16
10	48-hr	1.08	1.26	1.41	1.63	1.88	2.04	2.48	3.04	3.44	3.96	4.36	4.78
10	24-hr	1.03	1.20	1.31	1.51	1.72	1.87	2.26	2.75	3.13	3.60	3.98	4.36
10	18-hr	0.97	1.13	1.23	1.43	1.62	1.76	2.12	2.59	2.94	3.38	3.74	4.10
10	12-hr	0.90	1.04	1.14	1.32	1.50	1.63	1.97	2.39	2.72	3.13	3.46	3.79
10	6-hr	0.77	0.90	0.98	1.13	1.29	1.40	1.69	2.06	2.35	2.70	2.99	3.27
10	3-hr	0.66	0.77	0.84	0.97	1.10	1.20	1.45	1.76	2.00	2.30	2.55	2.79
10	2-hr	0.59	0.69	0.76	0.87	0.99	1.08	1.31	1.59	1.82	2.09	2.31	2.53
10	1-hr	0.48	0.56	0.62	0.71	0.81	0.88	1.06	1.29	1.47	1.69	1.87	2.05
10	30-min	0.38	0.44	0.48	0.56	0.63	0.69	0.84	1.02	1.16	1.33	1.47	1.61
10	15-min	0.28	0.32	0.35	0.41	0.46	0.50	0.61	0.74	0.85	0.97	1.07	1.18
10	10-min	0.21	0.25	0.27	0.32	0.36	0.39	0.47	0.58	0.66	0.76	0.84	0.92
10	5-min	0.12	0.14	0.15	0.18	0.20	0.22	0.27	0.33	0.38	0.43	0.48	0.52

Hail

Lumps of ice that form in weather systems such as thunderstorms, and then fall to earth as solid precipitation.

Hazard Description

Hail is produced by thunderstorms when strong updrafts among the clouds carry water droplets above the freezing level and cause the formation of ice pellets around some nucleus (such as a water crystal or speck of dust). These can remain suspended in the winds and can continue to grow larger until their weight is no longer supportable and they fall to earth, possibly accompanied by heavy rains. Large falling hailstones can batter crops, dent autos, and injure wildlife and people. Large hail is a characteristic of severe thunderstorms, and it may precede the occurrence of a tornado.

Hail can be especially damaging to crops, home roofs, and automobiles. More than $1 billion in hail damages occurs annually across the United States. Most Michigan counties see an average of 2 hail events per year, and statewide, there is usually at least one intense hailstorm per year that causes significant damages. Unfortunately, for many hailstorms, the total damages to property go unreported. However, the frequency of various sizes of hail has been well-documented (see below), and each county in Michigan should plan to experience between 1 and 3 events per year.

As a product of the strong thunderstorms that frequently move across the state, the size of hail is usually proportional to the intensity of the storm cell that generates it. As a thunderstorm passes over, hail usually falls near the center of the storm, along with the heaviest rain. Sometimes, a thunderstorm's strong winds can occur at high altitudes and blow the hailstones away from the storm's center, causing an unexpected hazard at places that otherwise might not appear threatened.

Hazard Analysis

Most hailstones reported in Michigan range in size from a pea (¼" diameter) to a golf ball (1¾" diameter), but hailstones larger than baseballs (2¾" diameter) have occurred with the most severe thunderstorms. In 2009, the official threshold that denotes severe hail events was increased from 0.75" to 1.00". The following table provides the official classifications of hail magnitude, as often used in weather reporting and event records. Some statistics cover multiple categories of hail magnitude (by combining table cells together).

Descriptive size of hail	Diameter	Number of MI events (1996-2017)	Impacts:	Areas of occurrence
Pea	¼" (6mm)	Too many to include	Minimal structural impacts, but crop damages can be severe.	Every county in Michigan
Marble or mothball	½" (13mm)			
Penny or dime	¾" (19mm)	Too many to include	Old threshold for severe hail, raised to 1" in 2009.	Every county in Michigan
Nickel	0.9" (22mm)			
Quarter	1" (25mm)	} 1213	$70.1M property damage, $3.55M in crop damage	Every county in Michigan
Half-dollar	1¼" (32mm)	}		
Walnut or ping-pong ball	1½" (38mm)	} 501	$229M property damage, $3.71M crop damage, 3 inj.	Almost all counties throughout the state
Golf ball	1¾" (44mm)	}		
Hen's egg	2" (51mm)	68	$28.846 million in property damage, $730,000 in crop damages, 1 injury	More than half of MI counties located across the entire state
Tennis ball	2½" (64mm)	12		
Baseball	2¾" (70mm)	14		
Tea cup	3" (76mm)	12	Dmgs: $12M prop., $2.8M crop	Marquette, Midland…
Grapefruit	4" (102mm)	2	$800K in property damage	Gogebic, Jackson
Softball	4½" (114mm)	1	$32.6M in property damage	Ogemaw County
	TOTAL:	4,069	$376M property, $13M crop	All MI counties

Sources: Two left columns—Coenraads 2006:224, the rest—NCEI Storm Events database (to 4-30-2017), with edits.

The likelihood of severe hailstorms in specific Michigan counties is expected to be proportional to the frequency of thunderstorms in that county, but as the tables in this chapter show, the impacts of hail are much harder to characterize than the mere frequency of occurrence (of which the map of Michigan thunderstorm days in the preceding section might provide a general indication). Severe hail damage patterns bear some similarity to tornadoes—they rarely damage a specific location, but can cause widespread damage when they do occur. Unlike tornadoes, most persons have seen plenty of small and harmless hail, and therefore may be totally unaware of the hazardous nature of large hail.

Hail History for Michigan Counties – arranged by geography – Jan. 1, 1996 to April 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Hail Events	Days with Hail	Tot. property damage	Tot. crop damage	Injuries
Washtenaw	184	75	$10,000		
Wayne	155	69	$7,000		
.Livingston	55	30			
Oakland	166	71	$25,011,000		
Macomb	135	67	$2,000		
5 Co Metro region	139 avg.	62 avg.	Total $25,030,000	-	0
Berrien	54	31	$8,000	$1,300,000	
Cass	28	22	$12,000		
St. Joseph	47	29			
Branch	55	30	$1,000,000		
Hillsdale	38	26	$2,000,000		
Lenawee	99	52	$2,150,000		1
Monroe	80	44			
.Van Buren	32	25	$50,415,000	$305,000	
Kalamazoo	58	42	$129,705,000	$370,000	
Calhoun	37	31	$325,000	$285,000	
Jackson	38	34	$380,000	$225,000	
.Allegan	52	33	$712,000	$392,000	
Barry	41	34	$360,000	$205,000	
Eaton	42	34	$440,000	$325,000	
Ingham	40	26	$400,000	$235,000	
.Ottawa	59	43	$497,000	$297,000	
Kent	77	53	$15,002,000	$370,000	
Ionia	16	15	$4,175,000	$100,000	
Clinton	29	22	$170,000	$125,000	
Shiawassee	37	29	$2,800,000	$2,000,000	
Genesee	160	67			
Lapeer	61	35			
St. Clair	72	38	$125,000		
.Muskegon	43	29	$440,000	$260,000	
Montcalm	32	26	$1,170,000	$145,000	1
Gratiot	28	22	$155,000	$130,000	
Saginaw	97	41	$300		
Tuscola	71	47			
Sanilac	50	34	$155,000	$10,000	
.Mecosta	25	21	$325,000	$170,000	
Isabella	37	24	$170,000	$195,000	
Midland	87	39	$10,127,000		
Bay	89	32	$20,050,000		2
Huron	60	39	$5,500		
34 Co S Lower Pen	55 avg.	34 avg.	Total $243,273,800	Total $7,444,000	4

Continued on next page…

Part 2 of Hail History for Michigan Counties – arranged by geographic division

.Oceana	30	24	$260,000	$175,000	
Newaygo	33	22	$295,000	$200,000	
.Mason	17	13	$95,000	$40,000	
Lake	15	12	$110,000	$65,000	
Osceola	15	12	$80,000	$70,000	
Clare	30	26	$465,000	$110,000	
Gladwin	29	24			
Arenac	36	25	$10,000		
.Manistee	20	13		$35,000	
Wexford	23	19			
Missaukee	24	19			
Roscommon	34	28			
Ogemaw	40	24	$32,600,000		
Iosco	50	31			
.Benzie	12	10			
Grand Traverse	27	21			
Kalkaska	13	11			
Crawford	25	19			
Oscoda	38	23			
Alcona	44	31			
.Leelanau	34	22	$85,000	$3,055,000	
Antrim	29	18	$65,000	$1,030,000	
Otsego	37	19			
Montmorency	29	21		$50,000	
Alpena	31	22		$100,000	
.Charlevoix	30	22	$45,000		
Emmet	15	12	$100,000		
Cheboygan	16	13			
Presque Isle	26	18	$3,500,000	$300,000	1
29 Co N Lower Pen	28 avg.	20 avg.	Total $37,710,000	Total $5,230,000	1
Gogebic	48	28	$750,000		
Iron	49	31	$4,100,000		
Ontonagon	46	32			
Houghton	50	28	$10,000		
Keweenaw	4	4			
Baraga	34	26			
.Marquette	131	57	$64,647,000		
Dickinson	67	42	$225,000		
Menominee	66	39	$600,000		
Delta	70	37	$19,000		
Schoolcraft	36	28	$100,000		
Alger	45	26	$5,000		
.Luce	16	15			
Mackinac	15	13			
Chippewa	24	17			
15 Co Upper Pen	47 avg.	28 avg.	Total $70,456,000	-	0
MICHIGAN TOTAL	4,069	655	$376,470,300	$12,674,000	5
Annual average	191	31	$17,649,310	$594,170	0.2

Although damaging hail is much less frequent than thunderstorms, since only a fraction of all thunderstorms produce damaging hail, there is still an unusual aspect to the types of events that cause damages to occur. Hail is most likely for severe thunderstorms that also produce great amounts of precipitation, but although damaging hail has occurred in every part of Michigan, the events producing the largest-sized hail are not always reported to be damaging, and much smaller-sized hail often causes far greater negative impacts. The vast majority of reported property damage in Michigan stems from just a few events. This unusual pattern is also reflected in the geographic variation in damage reports by county. As shown in the 2-page table on the previous pages, most of the property damage caused by hail in the past 22 years had been reported within just a few counties: Kalamazoo, Marquette, and Van Buren. Although the pattern seen in this data might suggest a geographic component to damaging hail risks, there is no clear reason why the Detroit Metro area would be more damage-resistant than the Kalamazoo or Grand Rapids areas. Therefore, the severe hail damages in the latter areas are probably the result of pure chance, given that the data only cover a couple of decades. The important thing to note is that both the Upper Peninsula and the Lower Peninsula have endured extensive damage from rare but large hail events.

Even if most of Michigan's citizens experience hail only as a curiosity that seems infrequent and harmless, those who are involved in agricultural production are aware of the harm that hail can cause to their crops. Many kinds of produce are vulnerable to damage, whether fruit or vegetable: potatoes, beans, tomatoes, corn, soybeans, apples, peaches, grapes, plums, cherries and raspberries have all been damaged or destroyed by hailstorms in Michigan.

Property damage often involves hail impacts upon motor vehicles, but widespread damage to the roofs and siding of homes can also occur. Even though automobiles can be protected in garages, some hail is large enough to cause damage to built structures themselves. Thus, in addition to the other types of thunderstorm hazards (lightning, winds and tornadoes, and excessive precipitation), serious damage can come from severe hail.

A major damaging hail event can be expected in Michigan multiple times per year, although the typical county will see such impacts only over the course of several years. Statistics since that time 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 growing season of May through August. As a result, the damage to crops from hail can be extensive.

There have been 5 injuries in Michigan due to hail events since the beginning of 1996. These involved persons who were outdoors and directly exposed to the impact of hailstones. Two of the injuries occurred in a sailboat during a hailstorm in 1999. Another was a motorcyclist who received a minor injury when struck on the mouth. The other injury documented on NCDC involved a person who was attempting to move a vehicle into a shelter, and was thus exposed.

The National Weather Service forecasts of severe thunderstorms usually give sufficient warning time to allow residents to take appropriate action to reduce the effects of hail damage on vehicles and some property. However, it is harder to prevent damage to crops. More details about specific Michigan events, and resulting damages, is provided in the subsection, below, about significant Michigan hailstorms. At least $300 million in property and crop damage has occurred from hail events in Michigan since 1996.

Impact on the Public, Property, Facilities, and Infrastructure

Hail generally causes minor property damage within its area of impact, but large hail also discourages the public from outdoor activities and events, due to concerns involving safety and comfort. Some kinds of crops might be severely enough hit to cause their prices to increase. Most damage involves automobiles, fragile materials such as glass, and the outer layers of structures, such as the siding and roof materials on houses. Some facilities, such as greenhouses, may be especially vulnerable, unless they had been designed to resist hail impacts. Some utilities wires and components might be damaged and temporarily inoperable.

Impact on the Economic Condition of the State

Severe hail is as rare as tornadoes but can therefore be underestimated, as most persons only have experience with small-sized hail that does little or no damage. Although a severe hail event can do a great deal of damage to property and crops, this tends to occur within a limited area of the state and only for a short time. Economic hardship tends to be limited to the area within and near the hail damage, such as agricultural areas that had suffered extensive crop damage, damaged businesses that had to close at least temporarily, or recreational events that had to be cancelled. The type of impacts expected from hail do not normally exceed these limited areas, and although state assistance may be required during a disaster event, hail is not considered unusually costly compared to other disasters that cause similar amounts of damage. The effects upon some recreational events might cause them to be cancelled and therefore to have an effect upon a local area's economy and annual budget unless some sort of compensating insurance policy had been in place.

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. Although special training and safety precautions have usually been taken (e.g. for line-repair workers), responders are still more exposed to and at-risk from the impacts of hail. Fortunately, most episodes of hail are brief and it is usually easy to take cover to avoid being injured.

Impact on the Environment

The primary effects of hail on the natural environment are its impacts upon vegetation and its physical harm to wildlife. Plants with well-established root systems will seldom die, but some younger or smaller forms of vegetation may not survive a severe hail storm. Hail can damage some fruit and vegetable plants and render them unfit for sale in markets. 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 can exacerbate flooding, and an accumulation of ice can potentially clog or reduce the effectiveness of drainage paths, culverts, and grates.

Impact on Public Confidence in State Governance

If hail causes infrastructure failures, a question may be raised about the adequacy of that infrastructure, its maintenance, and its design and regulation. In events that require mass sheltering, such as schools or large gatherings (e.g. a county fair or community-sponsored event), the ability of local and state government to adequately plan for severe weather is often vital to the success of such events, which themselves are often important for various sectors of the local and state economy. Citizen discontent and media-exacerbated controversies have arisen from situations in which inadequate planning was evident, or provisions for public sheltering were inadequate.

Significant Hailstorms in Michigan since 1985

May 1985 - Lower Peninsula (western and eastern counties)

In May 1985, severe thunderstorms accompanied by hail struck the western and eastern counties of the Lower Peninsula, causing great damage. Two-inch hail was reported in Cass County and $2 million in damages to fruit crops were reported in Kent County.

March 27, 1991 - Lower Peninsula (central and southern counties)

On March 27, 1991, severe thunderstorms and accompanying high winds and hail caused considerable damage across a large portion of central and southern Lower Michigan, damaging homes, businesses, farms and some public facilities. A total of three deaths and 27 injuries were attributed to the storms. Egg to baseball-sized hail, some exceeding 2.5" in diameter, was reported in the vicinity of Buchanan in Berrien County. In Kalamazoo and Portage in Kalamazoo County, softball size hail, up to 4.5" in diameter, did extensive damage to automobiles, windows and trees.

April 12, 1996 - Lower Peninsula (southern counties)

Up to golf ball sized hail fell across southern Michigan along the path of severe thunderstorms. Tree limbs, power lines, windows, aluminum and vinyl siding on houses were damaged. Numerous recreational vehicles parked at a dealership were badly damaged. The event resulted in $5 million in property damage, predominantly in the counties of Hillsdale ($2m), Lenawee ($2m), and Branch ($1m). One injury was reported in Clayton (Lenawee County).

July 2, 1997 - Lower Peninsula (Berrien County)

A severe thunderstorm during the early morning hours of July 2, 1997 pounded Berrien County with 1" to 2.25" diameter hail that caused agricultural losses of nearly $1 million. The hail destroyed 280 acres of fruits and 100 acres of vegetables in a two-mile wide swath from Stevensville southeast to the county line. Damaging hail was reported in numerous other locations across the Lower Peninsula on July 2—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. (Refer to the Tornadoes section for additional information.)

June 24, 1998 - Lower Peninsula (central and southern counties)

On June 24, 1998 two tracts of severe thunderstorms crossed the state moving east to west—one tract stretched across central Lower Michigan, while the other moved into the southern portion of the state. The more northerly thunderstorms produced large amounts of hail in several counties, ranging from dime to quarter sized hail up to baseball size (2.75" in diameter) hail. Damage was widespread, but not overly severe. However, in Petoskey, hail (2.5" in diameter) caused $100,000 in damage to cars on two lots west of town. In Ingham County, near Onondaga, baseball-sized hail damaged auto glass and roofs, but specific damage figures were not available.

Sept. 26, 1998 - Lower Peninsula (northern counties)

A line of severe thunderstorms ravaged northern Lower Michigan during the weekend of September 26-27, 1998, producing hail up to 2" in diameter in Manistee County and destroying an estimated 30,000-35,000 bushels of apples at area farms. The same storm system produced tennis ball-sized hail north of Gladwin, which damaged several homes and vehicles. In Arenac County, near Sterling, 3.5" diameter hail damaged crops and injured some livestock at area farms, and damaged several homes, satellite dishes, and vehicles.

June 9, 2000 - Iron River (Iron County); Randville-Grand Bluff (Dickinson County)
In the early morning hours of June 9, 2000 a line of thunderstorms moved through Iron County, producing 1.75" 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 $2.3 million in roof and siding damage. Ping-pong ball sized hail in the Randville-Grand Bluff area in Dickinson County caused an additional $225,000 in damage to 20 homes and 20 vehicles. Total hail damage in Iron County was estimated at $4.1 million.

July 14, 2000 - Algonac (St. Clair County)
On the afternoon of July 14, 2000 severe thunderstorms produced large hail in St. Clair County. Hailstones as large as baseballs (2.75" in diameter) fell in Algonac, causing $125,000 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 five feet into the air.

July 13, 2004 - Posen (Presque Isle County)
On July 13, 2004 a devastating hailstorm caused extensive damage in the small town of Posen in Presque Isle County. The hail (2.75" in diameter) was driven at times by wind gusts around 60 miles per hour. Most buildings and vehicles in the community suffered some sort of damage. Holes were punched in roofs and siding, cars were dented and windows were broken. A local church had to patch 300 holes in its roof. Damage to a school roof was estimated at nearly $200,000, and a local greenhouse lost over a thousand two-foot by two-foot window panes. One individual suffered a badly bruised back as he tried to move his vehicle to shelter. Substantial damage was done to crops (largely potatoes, along with some beans, tomatoes and corn) in nearby fields.

July 28, 2006 – Western Upper Peninsula
An approaching cold front interacting with an extremely unstable airmass triggered a widespread outbreak of severe weather across western and central Upper Michigan from the late afternoon on the 28th until just after sunrise on the 29th. Hail of up to 4 inches in diameter resulted in significant damage to roofs, siding, and automobiles. Revised damage estimates from this hail are currently listed in the NCEI storm events database as specifically totaling $750,000 in Wakefield (Gogebic County), $50,000 at Covington (Baraga County), $10,000 at Kenton (Houghton County), $4000 at Ewen (Ontonagon County), and $3000 at Garden (Delta County). Damages had formerly been estimated at $60 million, and later greatly revised downward.

June 20, 2007 – Marquette (Marquette County)
One of the most significant hailstorms in memory pummeled downtown Marquette and Harvey during the afternoon of June 20, 2007. While most of the hail was less than golf ball size, there were a few reports of hail that was three inches in diameter. The hail accumulated to several inches deep in downtown Marquette, and storm drains clogged from shredded leaves caused melting hail to result in street flooding. Hundreds of houses sustained significant damage to roofs and sidings. In addition, thousands of cars were damaged. Damage estimates from the storm for Marquette and surrounding areas were reported to total over $64 million.

July 26, 2007 – Southern Lower Peninsula (especially Shiawassee and Lenawee Counties)
Large hail hammered areas in a 3-mile radius around Durand for 50 minutes. The hail, at times, was as big as golf balls. A local newspaper reported $1.8 million in hail damages to homes alone. Hundreds of homes and vehicles were significantly damaged, with the latter averaging $4,000 per vehicle. This resulted in an estimate of $1 million in total vehicle damages. Many crops in the area were also destroyed. One farmer estimated $400,000 in losses to soybeans alone. Total crop damages were estimated at $2 million in Shiawassee County, bringing the total cost of the hailstorm to over $5 million. A local newspaper reported $75,000 in total damages to patrol cars and other vehicles at the Lenawee County Fair. This event will be remembered for the extreme intensity of large hail that it generated.

April 5, 2010 – Southwestern Michigan
Severe thunderstorms produced large hail and winds greater than 80 mph. The most significant damage occurred in the southern portions of Kalamazoo County, with damages estimated at $125 million, but Van Buren County was also struck heavily, with damages estimated at $50 million. To the west-southwest of Schoolcraft (Kalamazoo County), the siding of many homes was destroyed on their west-facing sides, where they were battered by large hail of about 1.75 inches in diameter. The estimated damages from this storm event include strong wind effects, not just hail impacts.

April 26, 2011 – Southern Lower Peninsula (especially Ionia, Kalamazoo, Kent, and Montcalm Counties)
Several thunderstorm supercells produced large hail reported as up to 2" in diameter. An EF-0 tornado near Burnips (Allegan County) and an injurious lightning strike in Portage (Kalamazoo County) also occurred during this weather event. Hail damages included areas northeast of Belding (Ionia County, $4 million), south of Stanton (Montcalm County, $1 million), across northern Kalamazoo County ($4 million), and in Kent County ($2 million).

July 27, 2014 – Bay, Midland, Oakland Counties
A powerful set of thunderstorms swept across the Lower Peninsula, initially pelting Bay and Midland Counties with hail up to 3 inches in diameter (larger than a baseball). A couple hours later, Oakland County felt the most severe weather impacts, with hail reported up to 2.5" in diameter (the size of a tennis ball). Wind damages also occurred during these storms, with total damages estimated at $100 million, but the damages specifically from hail amounted to about $20,075,000 in Bay County, $10,126,000 in Midland County, and $25,015,000 in Oakland County. Smaller, less damaging hail also fell in various other counties during that day.

August 2, 2015 – Ogemaw County
Multiple waves of severe thunderstorms crossed over the Lower Peninsula, producing widespread straight-line winds and the largest-sized hail ever recorded in Northern Michigan. The largest hail reached a diameter of about 4.5 inches, slightly larger than a softball! The results added up to about $32.6 million in property damage in Ogemaw County, according to a NOAA database. About 350 structures were damaged by the hail, along with a very large number of vehicles, some of which were considered destroyed.

July 8, 2016 – Northern Lower Peninsula
Powerful thunderstorms produced very large hail and some damaging winds as they swept across ortherm Michigan. Some locations in Antrim, Charlevoix, and Leelanau Counties experienced hail as large as 3" 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 percent of the cherry crop in the northwest Lower Peninsula was damaged in this event. Total crop damages were estimated at $4.15 million, of which $3 million occurred in Leelanau County and $1 million was in Antrim County. Property damage amounted to about $261,000 (of which $66,000 was due to strong winds), and was especially noted in the following locations: McGinn (Alcona County), Kerston and Alpena (Alpena County), Central Lake (Antrim County), Standish (Arenac County), East Jordan (Charlevoix County), Bates (Grand Traverse County), Empire (Leelanau County), and Houghton Lake (Roscommon County).

Programs and Initiatives
Note: Many of the programs and initiatives in place to mitigate, prepare for, respond to, and recover from other severe thunderstorms hazards (straight-line winds, lightning and tornadoes) have the dual purpose of also protecting against hail. As a result, there is some overlap in these "programs and initiatives" descriptions for each respective hazard. This redundancy helps each hazard section to stand alone, although it is still useful to refer to other hazard sections for additional, often-relevant information.

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including storms that are likely to produce damaging hail. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches/Warnings

The National Weather Service issues a **watch** for an area when the meteorological conditions are conducive to the development of severe weather there. People in the watch area are instructed to stay tuned to National Oceanic and Atmospheric Administration (NOAA) weather radio and other media for weather updates, and to watch for developing storms.

Once radar or a trained Skywarn spotter detects the existence of severe weather, the National Weather Service will issue a specific **warning**, such as a "severe thunderstorm warning," that identifies where the weather system was observed, the direction in which it is moving, and the time frame during which the storm is expected to affect an area. Persons in the warning area are instructed to seek shelter immediately, postpone outdoor events, or to take other actions.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

Severe Weather Awareness Week

Each spring, the Emergency Management and Homeland Security Division of the Michigan Department of State Police, in conjunction with the Michigan Committee for Severe Weather Awareness, sponsors Severe Weather Awareness Week. This annual public information and education campaign focuses on such severe weather events as tornadoes, thunderstorms, lightning, high winds, flooding and hail. Informational materials on hail and other thunderstorm hazards are disseminated to schools, hospitals, nursing homes, other interested community groups and facilities, and the general public.

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Hazard Mitigation Activities for Hail

- Increased coverage and use of NOAA Weather Radio.
- Public early warning systems and networks.
- Tree trimming and maintenance to prevent limb breakage and to safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)

- Buried/protected power and utility lines. (NOTE: Where appropriate: Burial may sometimes cause additional problems and costs in cases where eventual cable breakages are harder to locate and more expensive to repair.)
- Moving vehicles into garages or other covered areas.
- Purchase of insurance that includes coverage for hail damage.
- Using structural bracing, window shutters, laminated glass in window panes, and impact-resistant roof shingles to minimize damage to public and private structures.

Emphasis in Local Hazard Mitigation Plans

Hail was identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Arenac, Calhoun, Charlevoix, Clinton, Eaton, Gratiot, Huron, Ingham, Luce, Mackinac, Oakland, Washtenaw (12 counties, a slight decrease since 2014). These counties are located within all of Michigan's general geographic divisions, confirming that hail is a widespread risk within the state.

Lightning

The discharge of electricity from within a thunderstorm.

Hazard Description

Lightning is a random and unpredictable product of a thunderstorm's tremendous energy. The energy in the storm produces an intense electrical field like a giant battery, with the positive charge concentrated at one end and the opposite charge concentrated at the other. Lightning strikes when the difference between positive and negative charges becomes great enough to overcome the resistance of the surrounding air and allow electricity to be abruptly transferred. To reduce the charge differences that have built up, lightning can jump from cloud to cloud, cloud to ground, ground to cloud, or even from the cloud to the air surrounding the thunderstorm. Most lightning stays within the clouds, but about 20% of it involves contact with the ground. Lightning strikes can generate current levels of 30,000 to 40,000 amperes, with air temperatures often superheated to higher than 50,000 degrees Fahrenheit (hotter than the surface of the sun) and speeds approaching one-third the speed of light.

Hazard Analysis

Globally, there are about 2,000 thunderstorms occurring at any given time, and those thunderstorms cause approximately 100 lightning strikes upon the ground each second. In the United States, approximately 100,000 thunderstorms occur each year, and every one of those storms generates lightning. A single thunderstorm can produce hundreds or even thousands of lightning strikes. However, many persons in the general public still perceive lightning as a minor hazard. That perception lingers even though lightning damages many structures and even causes more deaths per year, on average, than tornadoes or hurricanes. Many lightning deaths and injuries could be avoided if people would have more respect for the threat lightning presents to their safety.

Lightning deaths are usually caused by the electrical force shocking the heart into cardiac arrest or throwing the heartbeat out of its usual rhythm. Lightning can also cut off breathing by paralyzing the chest muscles or damaging the respiratory center in the brain stem. It takes only about one-fiftieth of an ampere of electric current to contract chest muscles and stop breathing, and one-hundredth of an amp can disrupt a human heartbeat. Lightning can also cause severe skin burns that can lead to death if complications from infection set in.

Most (73% of) damaging lightning strikes occur during the heavy thunderstorm-risk months of June (21%), July (30%), and August (22%), according to National Oceanic and Atmospheric Administration (NOAA) and the National Lightning Safety Institute (NLSI) from 35 years of data in the period from 1959-1994. They also found that the most likely time of day when damaging strikes are reported is during the late afternoon hours between 2pm and 6pm. Although 91% of incidents involved only a single victim suffering injury or death, the remaining 9% of incidents involved multiple simultaneous victims. There is no safety in numbers, when it comes to lightning.

The NLSI has estimated that 85% of lightning victims are children and young men (ages 10-35) engaged in recreation or work-related activities. Approximately 10% of lightning strike victims die, and 25% of survivors suffer serious long-term after-effects such as memory and attention deficits, sleep disturbance, fatigue, dizziness, hearing loss, and numbness.

Electricity flows from areas with a negative electrical charge (a surplus of electrons) to areas with a positive electrical charge (a deficit of electrons). Objects or substances that have opposite charges are electrically attracted to each other, and on the surface of the Earth, positive charges tend to be the greatest in protruding objects such as trees, poles, and buildings. Dry air tends to act as an insulator, while humid and moist air is increasingly useful as a medium of electric conduction, helping lightning to flow and reduce the different electrical charges that had built up.

Lightning can be especially damaging for electrical infrastructure, causing localized power outages and damage to phone lines and communication systems. Computers are also especially vulnerable to lightning strikes. In terms of property losses from lightning, statistics vary widely according to source. The Insurance Information Institute (a national clearinghouse of insurance industry information) estimated that lightning damage amounted to nearly 5% of all paid insurance claims. The NLSI estimated that annual lightning damage to property exceeds $4-5 billion across the U.S. Electric utility companies across the country estimated as much as $1 billion per year in damaged equipment and lost revenue from lightning. The Federal Aviation Administration (FAA) reports approximately $2 billion per year in airline industry operating costs and passenger delays from lightning. Because lightning-related damage information is compiled by so many different sources, using widely varying collection methods and criteria, it is difficult to determine a collective damage figure for the U.S. from lightning. However, annual lightning-related property damages are conservatively estimated at several billion dollars per year, and those losses are expected to continue to grow as the use of computers and other lightning-sensitive electronic components becomes more prevalent.

Lightning-Related Impacts on Michigan

Lightning death rates have lessened in recent decades, and an increase in danger awareness and protective policies may be partly responsible. According to National Weather Service records through the mid-2000s, Michigan had incurred 101 lightning deaths, 711 lightning injuries, and 810 lightning casualties (deaths and injuries combined) – consistently ranking the state near the top of the nation in all three categories. During the period 1959-1995, Michigan was ranked 2nd nationally (behind Florida) in lightning injuries, and 12th nationally in lightning deaths. As the following tables indicate, Michigan's lightning deaths and injuries were fairly consistent with the national trends in terms of the location of deadly or injury-causing strikes. More recent data indicates notable improvement in Michigan's statistics, ranking it #13 in number of lightning deaths (11) between the years 1998 and 2008. The newest NCDC/NCEI data, however, show that in the past 20 years, Michigan still saw 113 lightning injuries and 18 deaths.

Lightning-Related Deaths in Michigan: 1959-July 2005

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: Storm Data, National Climatic Data Center

Lightning-Related Injuries in Michigan: 1959-July 2005

LIGHTNING INJURIES: 711		
Number of Injuries	**Location**	**Percent of Total**
243	Open fields, ball fields	34%
104	Under trees (not golf)	15%
35	Golf course	5%
26	Boats / water-related	4%
19	At telephone	3%
20	Near tractors / heavy equipment	3%
264	Other location / unknown	37%

Source: Storm Data, National Climatic Data Center

Because it is virtually impossible to provide complete protection to individuals and structures from lightning, this hazard will continue to be a problem for Michigan's residents and communities. However, lightning deaths, injuries, and property damage can continue to be reduced through a combination of public education, human vigilance, technology, and building safety enhancements.

Lightning History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Lightning Events	Days with Event	Total property damage	Injuries	Deaths
Washtenaw	21	19	$1,820,000	4	2
Wayne	21	17	$857,000	18	3
.Livingston	12	12	$1,844,000	1	
Oakland	39	33	$2,318,000	5	1
Macomb	25	19	$2,927,000	7	
5 County Metro region	24 avg.	20 avg.	$9,766,000	35	6
Berrien	3	3	$840,000	1	
Cass					
St. Joseph	6	6	$30,000	2	1
Branch					
Hillsdale	1	1			1
Lenawee	18	14	$880,000		1
Monroe	9	8	$168,000	2	
.Van Buren	2	2	$200,000	2	
Kalamazoo	3	3	$20,000	10	
Calhoun	1	1	$11,000		
Jackson					
.Allegan	1	1	$5,000		
Barry	1	1		1	
Eaton					
Ingham					
.Ottawa	3	3	$60,000	1	
Kent	3	3	$1,000,000		
Ionia	1	1		1	
Clinton					
Shiawassee	6	6	$225,000	1	
Genesee	15	15	$222,500	11	1
Lapeer	9	6	$1,327,000	4	
St. Clair	6	6	$28,000	1	
.Muskegon	1	1	$40,000		
Montcalm	1	1		4	
Gratiot					
Saginaw	7	6	$202,500		
Tuscola	1	1	$100,000		
Sanilac	5	4	$145,000		
.Mecosta	2	2	$50,000	4	
Isabella	1	1	$10,000		
Midland	6	6	$70,000		
Bay	5	4	$63,000		
Huron	5	4	$570,000		
34 County S Lower Peninsula	4 avg.	3 avg.	$6,267,000	45	4

Continued on next page…

Part 2 of Lightning History for Michigan Counties – arranged by geographic division

.Oceana					
Newaygo	1	1	$100,000		
.Mason					
Lake					
Osceola					
Clare	1	1	$5,000		
Gladwin	1	1		6	1
Arenac	1	1	$500		
.Manistee	2	2			1
Wexford	1	1			
Missaukee	3	3	$1,000	2	
Roscommon	2	2	$55,000		
Ogemaw	2	2		6	
Iosco	3	3	$15,000	6	
.Benzie	1	1			
Grand Traverse	6	4	$170,000	1	1
Kalkaska	2	2		1	
Crawford	1	1		1	
Oscoda	2	2		1	2
Alcona					
.Leelanau	2	2	$40,000		
Antrim	2	2	$80,000		
Otsego	4	4	$503,000		
Montmorency					
Alpena	1	1		1	
.Charlevoix	1	1			
Emmet	1	1	$4,000		
Cheboygan	3	3	$75,000	3	
Presque Isle	3	3	$4,000		1
29 Co N Lower Peninsula	1.6 avg.	1.5 avg.	$1,052,500	28	6
Gogebic	2	2		1	1
Iron	1	1	$50,000		
Ontonagon					
Houghton	2	2	$25,000		
Keweenaw					
Baraga					
.Marquette	5	5	$56,000		
Dickinson	3	3	$171,000		
Menominee	1	1		1	
Delta					
Schoolcraft					
Alger	2	2		3	1
.Luce	1	1	$70,000		
Mackinac	1	1	$150,000		
Chippewa	1	1	$2,800		
15 Co Upp. Pen	1.3 avg.	1.3 avg.	$524,800	5	2
MICHIGAN TOTAL	305	189	$17,611,300	113	18
Annual average	14	9	$825,636	5.3	0.8

Although Michigan's counties experience from about 20 to 40 thunderstorm days per year, there are a smaller number of known damaging lightning events per year (about 14 such events per year, on average). Michigan's average deaths from lightning are approximately 1 per year, and injuries average about 5 per year. Property damage from major events totals over $17 million since 1996 – averaging nearly $1 million per year. (Data from the National Climatic Data Center have been used to calculate these statistics.) The Southeastern part of Michigan has a noticeably greater rate of damaging lightning events than other areas, as shown in the NCDC summary tables on the previous pages. Southeast Michigan counties average at least 1 damaging event per year, but the rest of the state averages about one-tenth of this rate. The data reveals some correlation between urbanized land uses and lightning vulnerability, which makes sense from the perspective that a location that is hit in an urban area is more likely to have humans and property in or near that location, to be harmed. But there is also a greater incidence of lightning damage specifically within the southeastern counties, as a result of weather patterns and not just the level of development present there.

Large outdoor gatherings (e.g., sporting events, concerts, campgrounds, fairs, festivals, etc.) are particularly vulnerable to lightning strikes that could result in many deaths and injuries. This vulnerability underscores the importance of developing site-specific emergency procedures for these types of events, with particular emphasis on adequate early detection, monitoring, and warning of approaching thunderstorms. Early detection, monitoring, and warning of lightning hazards, combined with prudent protective actions, can greatly reduce the likelihood of lightning injuries and deaths. In addition, close coordination between event organizers, local emergency management officials, and response agencies (i.e., police, fire, emergency medical care) can help prevent unnecessary (and often tragic) delays and mistakes in rendering care should a lightning incident occur. As shown in Ann Arbor, during a 2011 college football match, even an entire stadium of 100,000 persons can be successfully evacuated in order to protect people's lives and safety.

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, and has ignited structural fires and wildfires, which in turn present serious additional risks and harm to the public and its property. Electrical and communications infrastructure can be affected by lightning strikes, causing widespread inconvenience and, in some cases, life-threatening impairment of needed medical equipment and emergency response. Since physical methods of lightning protection do not provide absolute protection most facilities in Michigan have at least a limited possibility of being struck by lightning. Similarly, infrastructure can be directly damaged or, if it involves electrical components and conductors, can have its function interrupted and its capacity destroyed by electrical forces that completely overwhelm its design.

Impact on the Economic Condition of the State

Lightning has historically affected only specific locations. Although it is possible for impacts upon an important production facility or infrastructure component to cause notable impacts in a particular economic sector or geographic area of the state, no such impacts are expected. The largest-scale production facilities and utility providers typically take lightning risks and effects into account when their facilities are designed.

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. Although special training and safety precautions have usually been taken (e.g. for line-repair workers), nevertheless, responders are more exposed to and at-risk from lightning. This makes the use of various equipment more difficult and inhibits the ability of responders to work safely outdoors. Support staff who do not have special equipment and training cannot be placed at risk during severe weather, and usually have to delay activities such as damage assessments, until the weather clears. Search and rescue operations can be severely hampered and critically delayed, in some circumstances. Delivery of specialized services may be affected if a central facility is damaged or destroyed by a lightning strike, or if lightning impairs the providing power grid to a large enough extent.

Impact on the Environment

Trees can be blown apart completely if struck by lightning, or have branches and bark broken off that can scar and kill them. Lightning can cause trees and natural vegetation to catch fire, and large wildfires (q.v.) can be devastating upon an area's short-term ecological condition. Dry lightning is lightning that occurs with no precipitation at ground level, and this type of lightning is the most common natural cause of wildfires. Humans and wildlife can both be killed or injured when struck by lightning, and smoke from wildfires is unhealthy to breathe.

Impact on Public Confidence in State Governance

When lightning causes infrastructure failure, a question may be raised about the adequacy of that infrastructure, its maintenance, and its design and regulation. In events that require mass sheltering, such as schools or large gatherings (e.g. a county fair or community-sponsored event), the ability of local and state government to adequately plan for severe weather is often vital to the success of such events, which themselves are often important for various sectors of the local and state economy. Citizen discontent and media-exacerbated controversies have arisen from situations in which inadequate planning was evident, or provisions for public sheltering were inadequate.

Significant Lightning Incidents

As one might expect in a state with a high number of lightning deaths and injuries, lightning incidents involving one individual are fairly common in Michigan. However, lightning incidents involving groups of individuals also take place. Over the past 35 years, numerous lightning incidents in Michigan have resulted in multiple injuries:

Significant Lightning Incidents in Michigan

August 23, 1975 – Leslie (Ingham County)

Ninety people were injured, one seriously, when lightning struck a campground during a severe thunderstorm.

June 20, 1979 – Camp Grayling (Crawford County)

Forty-five National Guardsmen were injured and three of them hospitalized when lightning struck a mess tent during a training mission.

July 7, 1994 – Potterville (Eaton County)

Lightning struck a swimming lake at Fox Memorial Park near Potterville, injuring 22 people (one critically). This strike seemingly came from “out of the blue.” That is, there was not a storm actually overhead when it occurred. This is why waters need to be evacuated when there is any indication of lightning nearby.

June 21, 1995 – Ishpeming (Marquette County)

Although no one was injured in this event, a lightning strike caused a fire that destroyed a 100-year old church in downtown Ishpeming, with damages estimated at over a million dollars. Lightning also destroyed the chimney of a downtown house there, during the same storm event.

July 18, 1996 – Gladwin (Gladwin County)

A single bolt of lightning from a distant thunderstorm struck and killed the pitcher in a men’s league softball game. Several in the infield were knocked to the ground by the lightning and three were taken to the hospital that day. Three additional persons had been injured.

June 21, 1997 – Otisville (Genesee County)

After lightning struck a building that was housing a children’s event, eight children were taken to the hospital with complaints of numbness and tingling. Fortunately, none of the injuries appeared to be serious.

July 26, 1997 – Farmington Hills (Oakland County)

$750,000 in damage was caused when lightning started a fire in a two-story apartment building.

September 19, 1997 – Southern Lower Peninsula (Midland, Van Buren, Barry, and Kalamazoo Counties)

Lightning struck a farm near Coleman (Midland County), killing 4 horses and doing $10,000 in damage. Lightning also damaged 2 houses in Waterford Township (Oakland County) and an apartment building in Westland (Wayne County). The South Haven Community Hospital (Van Buren County) received a direct lightning strike on its radio tower, disabling communications there ($200,000 damage). A young boy received minor injuries at Hastings (Barry County) when lightning struck near him. Lightning started a house fire in Climax Township (Kalamazoo County), resulting in $20,000 of damage.

June 16, 1998 – Southern Lower Peninsula (Wayne, Washtenaw, and Kent Counties)

A severe thunderstorm developed and a great amount of lighting was produced. A man was killed by lightning 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 (Wayne County). A transmitting antenna for a radio station in the Hudson Mills area (Washtenaw County) was struck and had to be replaced (about $100,000 damage). A Livonia residence suffered significant damage from a lightning strike (about $2,000 in damage). In Alto (Kent County), lightning started a fire that destroyed a new educational building at a church.

July 21, 1998 – Southern Lower Peninsula (Muskegon, Kent, Macomb, and Wayne Counties)

Severe thunderstorms brought severe winds and frequent lightning to both the east and west parts of the southern Lower Peninsula. In the west, the counties of Muskegon, Kent, and Ottawa suffered more than a half-million dollars of damage from lightning strikes, which caused several major fires. In Muskegon County, lightning caused an attic fire in a house ($40,000 damage) in Muskegon Township, a fire in a storage building in Egelston Township, and power outages that affected 7,500 persons. In Kent County, more than $500,000 in damage resulted from a lightning-caused fire that heavily damaged an apartment building in Grand Rapids, destroying six apartments on the top floor and damaging at least 10 additional apartments when the roof caved in. 15,000 homes lost electricity throughout the Grand Rapids metro area, mostly caused by lightning strikes. The southeastern part of the state was even more heavily impacted by these thunderstorms, resulting in state and federal disaster declarations in Wayne and Macomb County. 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 $275,000 in damage in Sterling Heights (Macomb County). In Waterford Township (Oakland County), a woman was hospitalized after being struck by lightning in a park.

August 10, 1998 – Brighton (Livingston County)

Thunderstorm-produced lightning struck a store northwest of Brighton. The resulting fire destroyed the building ($1.5 million in damage).

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. Later that evening, lightning struck a tree in Dearborn Heights, and a man working nearby was struck by a limb from the tree, causing injuries which hospitalized him.

May 18, 2000 – Detroit Metro Airport (Wayne County)

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

July 27-28, 2000 – Southeast Michigan (Macomb, Lapeer, Sanilac Counties)

Near Romeo (Macomb County), a lightning strike started a fire that destroyed an auto mall on July 28 ($1 million damage). The previous day, lightning caused a fire that destroyed a manufacturing building and damaged a nearby company structure in Dryden (Lapeer County, $650,000 damage). In the Sandusky area (Sanilac County), a lightning-produced fire partially destroyed a barn ($15,000 damage).

December 11, 2000 – Ann Arbor (Washtenaw County)

Northwest of Ann Arbor, $1.1 million in property damage resulted when lightning caused a large home to be destroyed in the middle of a winter storm emergency.

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 $800,000.

September 19, 2002 – Ann Arbor (Washtenaw County)

One roofer was killed and two others were badly injured in Ann Arbor when they were hit by lightning during a thunderstorm.

July 4, 2003 – Oscoda (Iosco County)

During thunderstorms, lightning destroyed a large business sign whose fragments damaged nearby vehicles. One car had four occupants injured by shattering glass, and damages were estimated at $10,000.

July 16, 2005 – Macomb Township (Macomb County)

One house was completely destroyed by fire as the result of a lightning strike. Five additional house fires started in the areas of 22 and 23 Mile Roads, due to other lightning strikes from the same storm event. Total damages amounted to about a million dollars.

July 17, 2006 – Southeastern Michigan (Saginaw and Wayne Counties)

Intense thunderstorms produced lightning that seriously damaged a Church bell tower in Saginaw ($106,000 damage), and caused one injury and one death in the central-city area of Wayne County, when a couple sought refuge outdoors by going under a tree, which was then struck during the storm.

July 22, 2009 – Big Rapids (Mecosta County) and Gaylord (Otsego County)

At 8:45 am, a non-severe thunderstorm caused lightning to strike pine trees at Ferris State University, as four construction workers were standing nearby. All four workers were injured. That same afternoon, a lightning strike 1 mile north of Gaylord ignited a fire that rapidly spread through the Alpine Haus apartment complex, destroying it and leaving 52 persons without housing. Fortunately, no one was hurt in the apartment fire, but damages were estimated at $500,000.

July 15, 2010 – Vestaburg (Montcalm County)

Lightning struck four young persons between 9 and 18 years of age at a baseball diamond near Vestaburg. Fortunately, all survived the incident, but their injuries required special emergency care, including emergency medical flights to the appropriate care facilities.

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 $500,000.

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 (Portage). One man went into cardiac arrest but was able to be treated at a nearby hospital and released. The ages of the victims ranged from 12 to 41.

September 3, 2011 – Ann Arbor (Washtenaw County)

Michigan Stadium (with a capacity of over 100,000 people) was evacuated during a football game, due to a thunderstorm. The game was eventually called off in the third quarter, due to the strong winds, heavy downpours of rain, and several lightning strikes.

June 18, 2012 – Ellsworth (Antrim County)

Lightning struck a home in Banks Township, and the resulting fire destroyed the home (causing about $80,000 in damage).

July 18, 2013 – Luce County

Lightning started a house fire that caused $70,000 in damages and caused the death of an elderly man.

June 28, 2014 – Ogemaw County

Six persons were injured by a lightning strike at the Rifle River State Recreation Area, south of Lupton. After being transported to a hospital in West Branch, all were treated and released.

July 18, 2015 – Jackson County

During the "Faster Horses Festival" at the Michigan International Speedway (Brooklyn, Jackson County), severe weather caused a concert to be evacuated around 8:20pm, with tens of thousands of persons in attendance. The main stage was dismantled after visible lightning appeared in the sky, and weather sirens were sounded. The performance by headline act Brad Paisley was delayed by as much as three hours.

August 3, 2015 – Wayne County

An upscale Canton-area home was struck by lightning, and the resultant house fire caused extensive damage, estimated at $300,000. No one was injured in this incident (although just one day earlier, lightning had injured two persons at a campground in Cheboygan County).

May 16, 2017 – Lapeer County

In the southwestern part of Lapeer County, lightning struck a house at 4 o'clock in the morning, blowing out windows and causing extensive damage to the home's interior. A back deck was also damaged, along with some of the siding, adding up to about $40,000 in damage.

July 25, 2017 – Menominee County

The Seventh Day Adventist Church near Wilson was struck by lightning, and the subsequent fire resulted in about $500,000 in damage, destroying the building.

Programs and Initiatives

Although absolute protection from lightning is not possible in most locations, the consequences of lightning strikes can be diminished (both in terms of deaths and injuries and property damage) through the implementation of the following programs and initiatives:

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including storms that are likely to produce damaging lightning. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service

(NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches and Warnings

The National Weather Service issues a **watch** for an area when the meteorological conditions are conducive to the development of severe weather there. People in the watch area are instructed to stay tuned to National Oceanic and Atmospheric Administration (NOAA) weather radio and other media for weather updates, and to watch for developing storms.

Once radar or a trained Skywarn spotter detects the existence of severe weather, the National Weather Service will issue a specific **warning**, such as a "severe thunderstorm warning," that identifies where the weather system was observed, the direction in which it is moving, and the time frame during which the storm is expected to affect an area. Persons in the warning area are instructed to seek shelter immediately, postpone outdoor events, or to take other actions.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

National Weather Service Education

The National Weather Service issues severe thunderstorm watches and warnings when there is a threat of severe thunderstorms. However, lightning, by itself, is not sufficient criteria for the issuance of a watch or warning (every storm would require a watch or warning). The National Weather Service has an extensive public information program aimed at educating citizens about the dangers of lightning and ways to prevent lightning-related deaths and injuries.

Severe Weather Awareness Week

Each spring, the Emergency Management and Homeland Security Division, Michigan Department of State Police, in conjunction with the Michigan Committee for Severe Weather Awareness, sponsors Severe Weather Awareness Week. This annual public information and education campaign focuses on such severe weather events as tornadoes, thunderstorms, hail, high winds, flooding and lightning. Informational materials on lightning hazards are disseminated to schools, hospitals, nursing homes, other interested community groups and facilities, and the general public.

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

Lightning Protection for Structures

The National Lightning Safety Institute (NLSI: www.lightningsafety.com) has a mission to promote lightning safety education. They have extensive expertise in the lightning hazard and lightning mitigation, especially for structures. Although strategies to reduce lightning vulnerability are available, there is currently no strategy for total lightning protection, due to the unpredictable nature of that hazard.

NLSI has identified a systematic lightning hazard mitigation approach that can be followed to protect structures from lightning damage. That approach attempts to mitigate both the direct and indirect effects of lightning strikes through the application of appropriate structural safety improvements, as identified in a comprehensive lightning safety analysis. Full details of this mitigation approach can be obtained at NLSI's web page. **Please note that this concept might be able to reduce lightning vulnerability, but lightning is not perfectly predictable, controllable, or preventable. Recommendations and projects of this nature cannot guarantee absolute safety during an event.**

Lightning risk calculators for buildings are available for free, online, through a web search of "Lightning Risk Calculators for Buildings." These calculators can help identify lightning vulnerabilities and can offer suggestions for reducing lightning risk. This more detailed information might be sought for some of the most important buildings in a community.

<u>All Hazards Resources for Rural Communities</u>
The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

<u>National Lightning Detection Network</u>
The National Lightning Detection Network (NLDN) is a commercial lightning detection network operated by a private company. NLDN data is available through a number of free web and mobile applications, with more advanced functions available through paid subscriptions. Past lightning data is available from 1989 to the present. Data from the NLDN can be used to improve the safety of participants at outdoor large gatherings such as sporting events, fairs, festivals, and concerts.

<u>Lightning Detection Systems</u>
A network for lightning detection exists in addition to local detection systems that had been installed at golf courses, parks, pools, sports venues, and other outdoor locations. These networks detect and monitor electrical activity in the atmosphere and give warning when lightning risks exist by activating a warning light, horn, or digital message. Early warning can provide the time needed to safely clear outdoor areas before actual lightning strikes occur. Real-time maps of lightning activity now exist online, at sites such as http://en.blitzortung.org/live_lightning_maps.php. Lightning strikes emit pulses of radio waves (**sferics**, formerly called "atmospherics") that can be quickly pinpointed through the triangulation of a network of detectors.

<u>Personal Protective Actions:</u>
Head to a sturdy enclosed building <u>before</u> a thunderstorm arrives. If caught outdoors when thunder is audible or lightning is visible, with no structure to shelter in, some level of protection can be provided by staying in a car with closed windows while not using its electronics or touching its outside doors/frame. Tents, storage sheds, and open rain covers (awnings or overhangs without surrounding walls) <u>do not</u> count as secure shelters from lightning. Being safe from lightning is much more difficult than merely finding cover from rainfall—an awning or tree may keep you dry but provides <u>no protection</u> against lightning (and may instead increase your vulnerability to a lightning strike).

If stuck outdoors with no secure shelter available at all, your best hope to try to reduce your risks from lightning strikes involve the following strategies:

1. Avoid water bodies, metal fences, heights, open fields, and lone trees or other tall objects. Instead, seek low-lying areas that aren't accumulating water, such as the side of a depression or ravine, or an area of smaller trees surrounded by tall ones. Then:
2. Adopt a defensive, self-shielding bodily posture until the bad weather has ended—crouching down with heels touched together and head between knees, with ears covered. The ideal posture involves only the forward part of one's feet actually touching the ground – not the heels. This posture will make you a smaller target, while also minimizing your contact with the wet ground, which may carry harmful electrical currents if lightning strikes nearby. A covered head and ears can help protect you from the effects of nearby forces and noise if lightning strikes nearby in rainy and misty, humid air. Small metal objects such as coins and pocket keys tend not to be worth the bother and cost to dispose

of, but larger metal backpack contents or carried items (such as an antenna or tent-poles) should be dropped away from where you are crouching. Although these may not be large enough to attract lightning, they will readily conduct electricity from a nearby strike that can harm you. If possible, members of a group should crouch at least 20 feet apart, to decrease the risk of having the whole group being struck. Such actions and crouching should occur immediately if anyone shows signs of an accumulating electric charge, such as hair that starts standing on end, feeling a tingling sensation, or hearing clicking sounds. Do not breathe as lightning is striking, as the nearby air may be so hot that it will cause further injury when inhaled. Finally:

3. Wait or rest within the safest position you could find, until 30 minutes after the last lightning and thunder has been observed, before resuming normal outdoor activities.

While indoors during weather with lightning, lower your risk of injury by avoiding contact with water, metal, electrical wires, and things that connect with the outdoors, including doors, windows, electrical appliances, and corded phon**es. Please note that these recommendations are merely able to reduce your lightning vulnerability, but lightning is not perfectly predictable, controllable, or preventable. These recommendations cannot guarantee safety during an event.**

Hazard Mitigation Activities for Lightning

- Increased coverage and use of NOAA Weather Radio.
- Public early warning systems and networks.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines. (NOTE: Where appropriate. Burial may sometimes cause additional problems and costs in case of breakage, due to the increased difficulty in locating and repairing any such problems.)
- Using surge protectors on critical electronic equipment.
- Installing lightning protection devices on the community's communications infrastructure and critical structures. More widespread use of lightning protection devices might also occur.

Emphasis in Local Hazard Mitigation Plans

Lightning was identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Branch, Delta, Huron, Luce, Mackinac, Menominee, Presque Isle, Schoolcraft, Van Buren, Washtenaw (10 counties, a decrease since 2014). This covers a diverse area across the state, including counties in each of Michigan’s general geographic divisions.

Tornadoes

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

Hazard Description

Tornadoes are rapidly rotating columns of air that impact the ground after forming from some of the severe thunderstorms that occur during Michigan's warm months. Tornadoes can cause catastrophic damage to either a limited or an extensive area. A tornado can have winds exceeding 200 miles per hour and can have widths over one mile. The deaths and injuries associated with tornadoes have declined since the 1950s, thanks to advances in severe weather forecasting and public and institutional awareness, but tornadoes can still be deadly killers. Although tornado deaths have decreased, tornado damages have increased in recent years, since a larger part of the country's land area contains developments with each passing year.

There can be wide sections of a community completely destroyed by one or more tornadoes. Neighborhoods can be reduced to piles of splintered trees and homes, and a junkyard of twisted metal objects. A strong tornado can level everything in its path. Communities need to be prepared for the possibility of having many residents without homes, areas with no electricity or phone service, a series of burst pipes, and a gigantic amount of wooden and metallic debris to clean up (in patterns that are both scattered and concentrated).

It should be kept in mind that winds are invisible until they pick up a sufficient amount of material that can allows their patterns to be seen, and it is this carried material (including dust) that provides a tornado with a visible form that is easy to recognize as a hazard. Funnel clouds can be invisible except for the liquid, dust, and debris that they carry. Therefore, a tornado can be present but not yet discernable as such to nearby persons. This is one reason why tornado warnings need to be taken seriously. A tornado's initial presence might only be directly observed by its effects upon things at ground level, with the main funnel cloud visibly forming only after enough material has been swept up from the ground. Many persons have placed themselves at risk by not realizing that tornadoes do not always appear in their classic, fully visible funnel form. That classic darkly visible form is merely the one that is most easily discernable in photographs, and is therefore the form that is most widely recognized from such photographs and video. Moreover, tornadic winds often reach well beyond existing visible funnels, and multiple tornadoes can form simultaneously. Some of the largest tornadoes merely appear like an entire thunderstorm cloud has sunk down to touch the ground—the funnel itself may not be discernable as such.

Hazard Analysis

Tornadoes in Michigan are most frequent in the spring and early summer when warm, moist air from the Gulf of Mexico collides with cold air from the polar air mass to generate severe thunderstorms. These thunderstorms often produce the violently rotating columns of wind known as funnel clouds. Winds that converge from different directions, heights, and speeds are the source of the spinning pattern that gets concentrated as distinct funnels of wind. Michigan lies at the northeastern edge of the nation's primary tornado belt, which extends from Texas and Oklahoma through Missouri, Illinois, Indiana, and Ohio. Most of a tornado's destructive force is exerted by the powerful winds that knock down walls and lift roofs from buildings in or near the storm's path. The violently rotating winds then carry debris aloft that can be blown through the air as dangerous missiles, which provides another mechanism by which tornadoes cause such severe destruction.

A tornado may have winds of over 200 miles per hour, and this is the source of their destructive power. Although a tornado may have an interior air pressure that is 10-20% below that of the surrounding atmosphere, the effect of this difference is insignificant compared with the force directly applied by the winds. The old belief that opening windows would equalize air pressure was a misguided and harmful one—closer analysis of filmed images and damage patterns has since revealed that it is the force of winds that lift eaves and break down walls and then causes some structures to appear to implode or explode under a direct tornado strike. In fact, opening any windows may provide additional means by which tornado winds can cause stress on interior walls, and make a structure more vulnerable to collapse.

The typical length of a tornado path is approximately 16 miles, but tracks much longer than that—even up to 200 miles—have been reported. Tornado path widths are generally less than one-quarter mile wide. Even though an average tornado might spend only a few minutes on the ground, those few minutes can result in devastating damages.

Historically, tornadoes have caused a great number of casualties, with the mean national annual average still amounting to some 60+ deaths. Property damage from tornadoes is in the hundreds of millions of dollars every year.

Tornado intensity is measured on the Enhanced Fujita Scale, which examines the damage caused by a tornado on homes, commercial buildings, and other man-made structures. The Enhanced Fujita Scale rates the intensity of a tornado based upon measured damages, rather than by its size. It is important to know that the size of a tornado is not necessarily an indication of its intensity. Large tornadoes can be weak, and small tornadoes can be extremely strong, and vice versa. It is very difficult to judge the intensity and power of a tornado while it is occurring. Generally, that can only be done after the tornado has passed, using the Enhanced Fujita Scale as the measuring stick. The Enhanced Fujita Scale is presented in the following table.

Although tornadoes are most commonly reported between 3pm and 9pm, they can occur at any time. Although they generally exist at the trailing edge of a thunderstorm, it is possible for them to be present in other locations and less readily recognized weather patterns.

The Enhanced Fujita Scale of Tornado Intensity

EF-Scale Number	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.

NOTE: When describing tornadoes, meteorologists often classify the storms as follows:
EF0 and EF1 = weak tornado; EF2 and EF3 = strong tornado; EF4 and EF5 = violent tornado
(Source: The Tornado Project; National Climatic Data Center)

The National Weather Service (NWS) had estimated that, since 1950, about 74% of tornadoes in the United States were classified as weak tornadoes (EF0 or EF1 intensity). Approximately 24% were classified as strong tornadoes (EF2 or EF3 intensity), and only about 3% were classified as violent tornadoes (EF4 or EF5 intensity). Those few violent tornadoes caused about 65% of all tornado-related deaths. Strong tornadoes accounted for another 33% of tornado-related deaths, while weak tornadoes caused only 1% of tornado-related deaths. If the data prior to 1950 is examined, the percentage of deaths attributable to violent tornadoes climbs drastically. That is largely due to the fact that tornado forecasting, awareness, and protection programs were not yet established. As a result, it was much more likely for death tolls from a single tornado to reach several hundred.

Maps and tables at the end of this section show the breakdown of tornadoes by geographic areas, since 1950, and also for the more recent period since 1996. An examination of the map and tables indicates that tornadoes occur more frequently in the southern-half of the Lower Peninsula than any other area of the state. This area could be referred to as Michigan's "tornado alley." Most tornadoes in Michigan come from the southwest and travel northeast, with many passing through the most densely populated areas of the state.

Records indicate that tornadoes in Michigan have been deadlier than in many other tornado-prone states. That is influenced by the high death toll associated with the June 8, 1953 and April 11, 1965 tornadoes. Several Michigan tornadoes have hit relatively densely populated areas, increasing their fatalities. Seasonally, the table below provides a good indicator of when deaths had occurred, based upon about 55 years of events. During that period, about 96% of the state's tornado-related deaths had occurred in the months of April, May and June. June has been Michigan's most deadly tornado month, with 54% of all deaths. If the June 8, 1953 tornado death toll of 115 people is excluded, April becomes the deadliest tornado month, with 77 deaths (32% of the total). Note that a tornado can sometimes appear during colder months.

Tornado-Related Deaths in Michigan, by Month: 1950-May 2005

JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
0	**0**	**3**	**77**	**23**	**130**	**3**	**1**	**1**	**0**	**1**	**0**	**239**

Source: National Climatic Data Center

Clearly, Michigan tornadoes present a serious threat, with over a thousand occurrences since 1950. Although deaths had mostly occurred before 1980, property damages have remained very heavy, though not consistently predictable in their pattern. As recent tornado events in Joplin, MO (2011) and Norman, OK (2013) showed, it is still possible today to have destructive tornadoes directly strike urban areas, as had occurred during Michigan's worst historical events.

The geographic risk for tornadoes in Michigan is far greater in the southern third of the state than in the northern two-thirds. 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 seen 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 extreme northern portion of the Lower Peninsula and the Upper Peninsula overall have a lower risk of tornadoes, but every county has had at least one, and a tornado impact can be disastrous for any county. For example, Oscoda County, which has a relatively low frequency of tornadoes, suffered devastating damage from a tornado at the town of Comins, in 1999.

Although tornadoes technically cannot be prevented, contained, or completely predicted, their potential impacts on Michigan's citizens and communities can be reduced. In general, improved surveillance and warning systems implemented by the National Weather Service and emergency management agencies, coupled with extensive public education campaigns, have been very effective in keeping the death toll down in recent years. Although serious casualties could not occur again if a strong tornado strikes a highly populated area, progress appears to have been made in allowing most persons to reach shelters in time. Other initiatives to reduce wind vulnerabilities, such as structural bracing, urban forestry practices, manufactured home anchoring, and strengthening electrical system components, can further help to reduce public and private property damage. When a hazard cannot be prevented, we can still achieve effective mitigate its impacts by identifying and reducing our vulnerabilities.

Tornado disasters require that communities plan and arrange for the mass care of residents left without electrical power, and for the clearance and disposal of tree and construction debris from roadways and facilities. Those are two of the primary challenges facing Michigan communities. Planning and preparedness efforts should include the identification of necessary mass care facilities and supplies, as well as debris removal equipment and services. In addition, communities should develop debris management procedures (to include the identification of multiple debris storage, processing and disposal sites) so that the debris stream can be handled in the most expedient, efficient, and environmentally safe manner possible.

National Weather Service data since 1950 indicated that Michigan has experienced an average of 15 tornadoes and 4 tornado-related deaths per year. The greatest number of tornadoes in one year was in 1974, with 39 tornadoes (8 of which occurred on April 3). The least number occurred in 1959, with only 2 tornadoes. In terms of "tornado days" (defined as days in which one or more tornadoes occur), Michigan experiences an average of 9 tornado days per year.

The maps and tables at the end of this section list the number of tornadoes experienced in each Michigan county for various timeframes, and from multiple sources. (Note: the numbers from different sources do differ, since many tornado events get classified or reclassified only after the event has ended, as a result of follow-up studies.)

In terms of intensity, Michigan's tornado records since 1950 almost match the national ones. Approximately 67% of all Michigan tornadoes have been weak tornadoes (EF0 or EF1 intensity), while 29% have been strong tornadoes (EF2 or EF3 intensity) and 4% have been classified as violent tornadoes (EF4 or EF5 intensity). However, those few violent tornadoes have been responsible for 88% of Michigan's tornado-related deaths. Strong tornadoes (EF2 or EF3 intensity) have accounted for approximately 11% of the deaths, while weak tornadoes (EF0 or EF1 intensity) have caused only 1% of all tornado-related deaths. Michigan has actually had a higher proportion of strong and violent tornadoes (approximately 33% in Michigan vs. 27% nationally), and its historical death toll from violent tornadoes is slightly higher than the national average (67% in Michigan vs. 65% nationally). Michigan's higher death toll is largely due to the tragic storm events that occurred in Flint in 1953 and across southern Michigan in 1965 (see the Significant Tornadoes section for more details). The Flint tornado is still within the national top ten ranking, and Michigan as a whole is ranked even higher in two national tornado statistical categories: (1) tornado deaths per 10,000 square miles, and (2) killer tornadoes as a percent of all tornadoes.

Killer Tornadoes: Selected 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, F?	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

Source: NOAA http://www.spc.noaa.gov/faq/tornado/killers.html ; http://www.tornadoproject.com/alltorns/topten2.htm

Please refer to the tables and descriptions on the following pages for more information on these and other significant tornadoes in Michigan. Fortunately, the trend over time has generally been toward a lesser number of tornado deaths. During the 1950s, 153 deaths occurred, when the total number of tornadoes recorded was 109. In the 1960s, the number of deaths dropped to 66 although the number of tornadoes went up a bit, to 123. In the 1970s, despite a whopping 251 tornadoes, only 8 deaths resulted, and the trend has stayed quite low ever since. The 1980s saw 10 tornado deaths and 212 tornado events, but the 1990s saw only 2 deaths among 173 events. During the 2000s, a total of 3 deaths occurred, and the total number of events numbered 160. Only 1 Michigan death has been reported so far during the current decade. The number of Michigan tornado injuries since 1950 has amounted to more than 3,100.

A list of tornadoes, by county, for the years 1950 to 2012, can be found here: http://www.tornadoproject.com/alltorns/mitorn.htm, while a list of tornado events from 1996 to present can be obtained from this online NOAA/NWS database (the source of a table at the end of this section): https://www.ncdc.noaa.gov/stormevents/

Since 1996, Michigan has averaged about 18 tornadoes per year, including some funnel clouds and dust devils that many definitions and sources would exclude. The longer-term annual average of about 4 tornado deaths and 60 injuries, since 1950, has gone down to less than 8 injuries and one death. Annual property damage averages more than $17 million per year, based upon events from 1996-2017. Higher-risk regions of Michigan are noted in the maps and tables at the end of this section. Personal and site vulnerabilities tend to vary according to the fitness and engineering involved in each particular case or type of structure. For example, some older structures may be more structurally vulnerable, as may lower-income areas in which insufficient maintenance has not been kept up. Persons with access and functional needs may face excessive challenges finding and reaching adequate shelter, in time.

Impact on the Public, Property, Facilities, and Infrastructure

Tornadoes are rightfully dreaded as the most severe windstorms to which most of Michigan is vulnerable. Ordinary public activities must be curtailed or rescheduled in order to avoid injury and death either from the force of the tornadic winds themselves (which have the capacity to lift persons, heavy objects, or even structures and throw them great distances), or from the impact of objects that are being thrown forcefully around by the storm. Sheltering needs are compounded by the danger of broken and flying glass—to best ensure residents' safety, it is necessary to find the most secure area possible within a structure or affected area. An underground or specially reinforced, window-free room is usually required to guarantee personal safety (sometimes at considerable economic expense). The effects of a strong tornado may disrupt normal community functions for some time, or even cause a small community to be practically destroyed. Tornadoes cause more annual injuries, on average, than any other Michigan hazard except for structural fires.

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. There is the possibility that a tornado might destroy a critical supply-chain component within a major industry, and thus cause a broad economic impact, but the odds of this occurring in the near future are very low, since most of Michigan's land area does not contain critical facilities and most tornadoes are limited to local impacts.

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. Although special training and safety precautions have usually been taken (e.g. for line-repair workers), nevertheless, responders are more exposed to and at-risk from the impact of winds. Fortunately, tornado events tend to be rather brief, but their unpredictability, and their difficulty of detection and avoidance, exacerbates the existing challenges involved in emergency response. Impeded traffic, power failures, debris, and road closures often make response activities and the use of equipment much more difficult.

Impact on the Environment

Tornadoes are dangerous violent rotating columns of winds that can produce wind speeds from 65 to more than 200 miles per hour, and can cause severe environmental damage. Damage to the environment includes debris, fires, and chemicals from damaged and destroyed structures, vehicles, and infrastructure, which can be scattered for miles. Building materials, chemicals, smoke, sewage, and machinery can land in and cause harm to human environments, natural environments, air, water, and wildlife. Animals (including domesticated livestock) and other organisms can be killed or injured in the event of a tornado. Trees can easily be uprooted, branches broken off, and woodlands can be destroyed by tornado impacts. Rural settings can be damaged and plant seeds can be carried to areas where they otherwise would not have been. There is also an increased threat of fire in areas where dead trees are not removed in a timely manner.

The most dangerous type of environmental impact would be when a tornado strikes a facility that contains hazardous or toxic materials, farm chemicals, trash in a local landfill, medical waste awaiting disposal, or radioactive materials. Not only can material be spread around the immediate site where the tornado strikes, a portion can be carried aloft and transported a great distance down streams or rivers. There is also a possibility that tornadoes can cause the spread of diseases, or fungi found in certain soils. Ruptured gas lines can harm local air quality and cause environmental damage by seeping into the soil, rivers, lakes, and streams.

Impact on Public Confidence in State Governance

When infrastructure failures occur, as from the impact of tornadic winds, a question may be raised about the adequacy of that infrastructure, its maintenance, and its design and regulation. For example, an assumption might be made by some that the burying of power lines should be undertaken (or required by legislation), even if it involves considerable expense, whereas a full consideration of the tradeoffs involved in such burial (e.g. greater difficulty in locating and repairing a broken line) may not have been considered. In events that require mass sheltering, such as schools or large gatherings (e.g. a county fair or community-sponsored event), the ability of local and state government to adequately plan for severe weather is often vital to the success of such events, which themselves are often important for various sectors of the local and state economy. Citizen discontent and media-exacerbated controversies have arisen from situations in which inadequate planning was evident, or provisions for public sheltering were inadequate.

Climate Change Considerations

According to the National Oceanic and Atmospheric Administration, there is no known way to predict whether or how climate change is affecting thunderstorm and tornado frequency or severity. These types of weather events involve a different scale of phenomenon than climate change, and models of the latter have not yet been able to predict local trends in the former (http://www.spc.noaa.gov/faq/tornado/).

Significant Tornadoes in Michigan

NOTE: Much additional information from 1950 to date can be found in the NCEI storm events database, online.

May 25, 1896 – Oakland and Lapeer Counties

One of the mere handful of F5 intensity tornado events to be recorded in Michigan's state history, this event resulted in 47 deaths and 100 injuries, as the communities of Ortonville, Oakwood, and North Oxford suffered from the touchdown of this monstrous storm.

June 5, 1905 – Sanilac and Tuscola Counties

This was the second of Michigan's few recorded tornadoes that were measured as a full F5 intensity level. Five persons were killed and 40 were injured.

June 6, 1917 – Kalamazoo County

A deadly tornado struck the Climax and Cass Lake areas very hard, resulting in 4 deaths and 50 injuries.

March 28, 1920 – Genesee County

Another deadly tornado event, this time impacting Fenton and Flint most heavily, caused 14 deaths.

May 21, 1953 – St. Clair County

Two persons were killed, and 68 injured, as an F4 tornado left a path 10 miles long and 1 mile wide. The total damage was estimated at $2.5 million.

June 8, 1953 – Flint (and Southeastern Michigan)

The June 8, 1953 Flint tornado, Michigan's worst storm to date (and classified as F5), is ranked 10th on the top ten list of single killer tornadoes that have occurred in the United States. It was also the last single tornado, until the May 2011 Joplin, MO EF5 tornado, to cause over 100 deaths in the U.S. The storm began its destructive path approximately two miles north of Flushing, moved east and devastated the north part of Flint before ending two miles north of Lapeer. The tornado obliterated homes on both sides of Coldwater Road for about one mile. It was there that most of the deaths occurred and the damage swath was over one-half mile wide. There were multiple deaths in at least 20 families. The final death toll stood at 115 in Flint alone, along with 785 injuries and total damage estimated at $19 million. Several tornadoes touched down in other locations in Michigan on that day as well, resulting in an additional nine deaths and 129 injuries statewide. 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).

April 3, 1956 – Hudsonville to Walker (Ottawa, Kent, and other Western Michigan Counties)

In 1956, a category F5 tornado struck first at Hudsonville, then traveled northeast and plowed through both Ottawa and Kent Counties, killing 14 and injuring 200. (Some sources cite 17 deaths and 300 injuries.) Over 700 homes were destroyed. Numerous other tornadoes classified as F4 took their toll on other counties such as Manistee (2 killed, 24 injured), Grand Traverse, Benzie, and Allegan. The community of Standale, damaged by this tornado, is now part of the City of Walker. Other impacts were reported in the counties of Barry, Montcalm, and Van Buren, all of which had F3 tornadoes on this same day.

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 at 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.

July 4, 1957 – Emmet, Livingston, Oakland, and Presque Isle Counties

Six persons were injured in Livingston County, when an F4 tornado occurred around the dinner hour. Oakland County was also impacted. Emmet County saw damages from an F1 tornado, and Presque Isle County saw similar impacts from an F2 event.

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 $2.5 million in property damage was caused. Two additional injuries occurred in nearby Monroe and Oakland Counties.

April 11, 1965 - Southern and Central Michigan

The April 11, 1965 Palm Sunday tornado outbreak, which affected many other states in the Midwest, had a particularly devastating impact on Michigan. As the following table indicates, a total of 25 tornadoes touched down in 15 southern and central Michigan counties, resulting in 53 fatalities, 800 injuries, and $310 million in damage to public and private property. Many of the tornadoes were rated F3 and F4 in intensity (strong and violent tornadoes), which undoubtedly contributed to the high death and injury tolls. Across the Midwest, this storm system spawned 47 confirmed tornadoes that collectively killed 271 and injured 3400. In addition to Michigan, the other states that were affected by the storms included Indiana, Illinois, Ohio and Wisconsin. One of the tragic Michigan impacts was at Manitou Beach (Hillsdale-Lenawee County), where storms stuck a church with many persons inside.

April 21, 1967 – Southwestern and South-Central Lower Peninsula

Numerous twisters caused many injuries and extensive property damage across the counties of Allegan, Barry, Berrien, Clinton, Eaton, Ionia, and Kent. Fortunately, there were no known fatalities, but NCDC records indicate a total of 51 persons injured and more than $28 million in property damage. A touchdown in Clinton County was of F4 intensity.

July 4, 1969 – Southeastern Michigan

Numerous tornado events marred the 1969 Independence Day holiday in Michigan. Although no fatalities were reported, 65 persons were injured across Jackson, Washtenaw, and Wayne Counties. Damages also occurred in Hillsdale County, and total estimates for the four counties exceeded $5 million, although predominantly noted in Washtenaw and Wayne.

April 3, 1974 – Southeastern Michigan

After several years without any Michigan fatalities from tornadoes, disaster struck with full force in 1974. Two persons were killed and 44 injured when numerous tornadoes touched down in the counties of Monroe, Hillsdale, Jackson, Lenawee, and Monroe. Damages totaled nearly $3 million, and mobile homes were especially vulnerable. Although a downward trend in fatalities and injuries had been observed in each decade since the 1950s, Michigan residents were again reminded about the deadly severity of its tornado hazard, and about the dangers from multiple tornadoes and touchdowns. This date was also nationally notable for its severe tornadoes. National Weather Service data reports a total of 239 tornadoes across the United States on this day—8 of which were in Michigan, 16 in Ohio, and 54 in Indiana! Nationally, 308 persons were killed by tornado impacts on this single day, 5,416 were injured, and property damages amounted to $1.5 billion. This "super outbreak" broke records as being the largest number of tornadoes to strike the United States in a single day.

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 TOTALS:	**25**	**53**	**800**	

Source: The Tornado Project / NCEI Storm Events Online Database

March 20, 1976 – Southeastern Michigan

Most of the Lower Peninsula's residents were threatened by severe weather on this day, but as the dinner hour arrived in Oakland and Macomb Counties, a pair of tornadoes of F4 and F3 severity caused the weather impacts to turn deadly. Two persons were killed (one in each county) and 58 were injured (mostly in Oakland County). Nearly $26 million in property damage was also tabulated. Impacts were reported for the counties of Calhoun, Eaton, Ingham, Ionia, Macomb, and Oakland.

April 2, 1977 – Southern Lower Peninsula

On this day, ten persons were injured in Kalamazoo, and then one person was killed and 44 injured in Eaton County. The tornado intensity in those counties was categorized as F4. Additional impacts were reported from F1 and F2 tornadoes in the counties of Clinton, Ingham, Livingston, and Shiawassee.

May 13, 1980 - Kalamazoo and Van Buren Counties

On May 13, 1980 two tornadoes occurred in southwest Michigan – one in Van Buren County and one in Kalamazoo. The Van Buren County tornado damaged over 500 structures and injured 15 persons. The Kalamazoo tornado damaged over 1,200 homes and caused five fatalities and 79 injuries. This was the greatest number of persons killed by a single tornado in Michigan since the April 11, 1965 occurrence. Damage in the two counties was so severe that a Presidential Major Disaster Declaration was granted to provide supplemental federal disaster assistance to those communities and individuals significantly affected by the storms.

July 4, 1986 – Menominee County

Another disastrous tornado event injured 12 and caused an estimated $2.5 million in property damage during the early evening on the Independence Day Holiday.

June 21, 1987 – Novi (Oakland County)

An F2 tornado caused 1 death, 6 injuries, and $250,000 in property damage.

October 4, 1990 – Genesee County

On October 4, 1990, an F2 intensity tornado touched down in Flint, Burton, and Davison Township (Genesee County), leaving a trail of destruction approximately 200 yards wide and four and one-half miles long. Over 30 homes and 20 businesses were severely damaged, and numerous roads and streets were blocked due to fallen trees and debris. One person was injured when his tractor-trailer was overturned by the strong winds while traveling on Interstate 69 in Burton. Total damage was estimated at $2.5 million. A Governor's Disaster Declaration was granted to provide supplemental state financial assistance to help pay for the cleanup costs associated with the storm.

March 27, 1991 – Lower Peninsula

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

April 16, 1992 – Plymouth (Wayne County)

On April 16, 1992, an F2 intensity tornado touched down in a mobile home park near Plymouth. The tornado destroyed 6 homes and damaged 14 others. Four residents of the mobile home park were injured. Total property damage was estimated at $2.5 million.

July 13, 1992 – Cass County

On July 13, 1992, an F2 intensity tornado touched down in northwest Cass County, leaving a trail of destruction one-half to one mile wide and six miles long. The tornado damaged or destroyed 40 homes, several agribusinesses, and one migrant labor camp. 25 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 $2.7 million in agricultural impacts. A Governor's Disaster Declaration was granted to provide supplemental state assistance with security, sheltering and mass care.

July 2, 1997 – Lower Peninsula

On July 2, 1997, a series of intense thunderstorms went through south-central and southeast Michigan. These storms spawned a total of 16 tornadoes, 13 of which occurred in the southeastern Michigan counties of Genesee, Lapeer, Livingston, Macomb, Oakland, Saginaw and Wayne. The total for southeast Michigan is the highest number for a single day since records have been kept from 1950. The tornadoes damaged or destroyed over 2,900 homes and nearly 200 businesses, and caused over $25 million in public damage and nearly $30 million in private damage. A total of 16 deaths were attributed to this storm front, but only 2 of those deaths were caused by the tornadoes. Another 120 persons were injured in the storm event (98 from tornadoes). The tornadoes and straight-line winds downed thousands of trees and power lines, which knocked out power to 350,000 electrical customers and caused significant public health and safety threats. Subsequent analysis by the National Weather Service indicated that the Wayne County tornado was F2 in intensity, while in Genesee County there were two F3 tornadoes and two F1 tornadoes. The remaining tornadoes were either F0 or F1 in intensity. A Presidential Major Disaster Declaration was granted for the five counties most severely impacted by the tornadoes and severe thunderstorms. Additional tornado impacts occurred in the northern counties of Arenac, Crawford, and Oscoda.

October 6, 1998 – Central-West Michigan

On October 6, 1998, a series of strong thunderstorms traveled through several counties in central Lower Michigan. The City of Big Rapids (Mecosta County) was hardest hit by the storms. The National Weather Service determined that an “F-1 mini tornado,” with winds reaching 80-90 miles per hour, had struck the Ferris State University campus, damaging several buildings and numerous surrounding residences and vehicles. The storm also downed trees and power lines in the area, and injured a dozen persons. The storm track was approximately 150 feet wide and one mile long. The storm dumped nearly 3 inches of rain in the Big Rapids area, flooding many streets and parking areas. In nearby Clare County, the storm destroyed one home, damaged ten others, and injured three persons. More limited damages occurred in the Vernon City area (Isabella County).

July 3, 1999 – Northeastern Lower Peninsula

On July 3, 1999, a tornado touched down near Lewiston in Montmorency County and traveled southeast for twenty-one miles through Oscoda and Alcona Counties, causing damage to homes and businesses and injuring two persons. The hardest hit areas included the Village of Comins and Clinton Township in Oscoda County. The destruction was devastating – 80 percent of the Village of Comins was damaged or destroyed by the storm. 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. Only three buildings in town – a bar, a party store, and a senior center – were left standing intact. After striking Comins, the storm continued on its path and damaged another 20 residences at nearby Crooked Lake in Alcona County. A Governor’s Disaster Declaration was granted to Oscoda County to provide supplemental state assistance with debris removal, clean up, and traffic control. Damage estimates approached $2 million.

May 21, 2001 – Southern and Central Michigan

On the afternoon of May 21, a line of severe thunderstorms moved across Michigan, spawning 21 tornadoes in 16 counties and causing damage in all but one of those counties. The hardest hit counties were Kalamazoo, Kent, Livingston and Oakland. Fortunately, no deaths or serious injuries occurred as a result of these storms. In total, the tornadoes caused about $5.5 million in property damage and $400,000 in agricultural crop damage. The largest share of the property damage—approximately $3 million—was caused by an F2 intensity tornado that struck Hartland and Tyrone Townships in Livingston County. The tornado tore through a golf course, destroying 12 vehicles and damaging 58 others, destroying 35 golf carts and a portion of the clubhouse, and injuring one person. The tornado also destroyed three nearby homes and two businesses, damaged another business, and downed hundreds of trees in the area. Several cars and semi-trailers were flipped and damaged when the tornado crossed U.S. 23. Additional damages were reported in the counties of Allegan, Barry, Clinton, Clare, Eaton, Genesee, Gratiot, Ionia, Isabella, Lapeer, Ottawa, and Shiawassee.

September 9, 2001 – Eaton and Ingham Counties

In the late afternoon hours of September 9, 2001, an F1 intensity tornado carved an 8-mile long by 900-yard wide swath of destruction through Delta Township in Eaton County. The tornado—packing winds of up to 110 miles per hour—destroyed the cooling towers at a Lansing Board of Water and Light power plant, causing $4 million in damage and forcing the plant to shut down its operations. The tornado also destroyed a business and damaged several others in an industrial park, damaged dozens of homes and barns, and downed numerous trees and power lines. Even though the tornado crossed three Interstate Highways and passed several housing subdivisions along its path, it did not cause any deaths or serious injuries. Damage totaled $15 million, mostly in Eaton County.

September 30, 2002 – Dickinson County

On September 30, 2002, a supercell produced three tornadoes and extensive downburst wind damage in southern Dickinson County. The majority of damage to the Iron Mountain, Kingsford and Quinnesec areas was caused by downburst winds, which knocked trees into homes, downed power lines, etc. The most significant damage was produced by the tornado that moved through Kingsford and Iron Mountain. An F1 intensity tornado developed in Florence County, Wisconsin and crossed the Menominee River just south of the Iron Mountain-Kingsford airport. 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 $7 million.

July 20, 2003 – Battle Creek (Calhoun County)

An F1 intensity tornado struck Calhoun County during the afternoon of July 20th, 2003. The tornado first touched down on the southeast side of Battle Creek. It lifted for several miles but eventually touched down again. It stayed on the ground for approximately three miles and intensified, causing a garage to be torn from a house and an older farm house to be rotated and pushed off its foundation. Three outbuildings and a barn were also destroyed. Roof shingle damage was also noted to other houses in the area. Hundreds of trees were uprooted or broken off. The tornado path was eight miles long and its width was nearly one-half mile wide in the area where the most severe damage occurred. The tornado caused nearly $1 million in property damage along with $200,000 in crop damage.

August 21, 2003 – Ingham County

On August 21, 2003, a tornado struck eastern Ingham County. The tornado’s path length was 4.5 miles long and it was up to ½-mile wide. It was on the ground for 15 minutes and was rated as a lower F2 on the original Fujita scale. A severe thunderstorm warning was initially issued for Ingham County and was soon upgraded to a tornado warning. Two homes were destroyed. A collapsed house trapped two persons inside, injuring both. Another house was damaged, a barn was leveled, and a pickup truck was blown off the road. Tornado-related property damage was $500,000, and crop damage was estimated at an additional $200,000.

August 24, 2007 – Southern Lower Peninsula

An EF3 tornado with wind speeds estimated at 140 mph produced its most severe damage along a path from M-50 just north of Kinsel Highway to just west of M-100 and Vermontville Highway near Potterville. A NWS storm survey indicated a tornado path which was 200 to 300 yards wide and 6.5 miles long. Fifteen homes were either destroyed or severely damaged. A roof was blown off a single-story home and windward-facing walls were blown in. The majority of the roof and garage from this home were not found. A roof was blown off a two-story home and its upper story front walls were blown in. Additional damage included the partial collapse of the upper story of a home, and another house blown off its foundation. Two barns were destroyed and another incurred heavy damage just west of Potterville. Six persons were injured, and property damages totaled more than $25 million. Tornado impacts were reported for the counties of Eaton, Genesee, Ingham, Lapeer, Livingston, Oakland, Shiawassee, and Washtenaw.

October 18-19, 2007 – Lower Peninsula

A tornado occurred at night, and based on extensive damage to buildings and trees, it was classified EF2, with top winds estimated between 120 and 130 mph. The tornado began just northeast of Mason around 10:28 pm EDT and moved northeast at 40 to 45 mph through the City of Williamston between 10:40 and 10:45 pm. Approximately 100 structures were damaged in a subdivision on the south side of Williamston. Two fatalities occurred about 4 miles northeast of Williamston, where a modular home and its two occupants were flipped into a pond. The tornado then moved into Shiawassee County, where 1 person was injured. Additional tornado impacts were felt after midnight in Genesee, Tuscola, and Huron Counties. Total property damages were more than $15 million. A tornado outbreak also rocked the Northern Lower Peninsula from dinnertime into the early evening of October 18, 2007. Six tornadoes on one day marked a new record for the Northern Lower Peninsula. A tornado fatality occurred in Kalkaska—the first in the Northern Lower Peninsula since March 30 1976, when a single death had occurred in Ogemaw County. The impacted northern counties were Alcona, Alpena, Cheboygan, Kalkaska, and Oscoda.

June 5-6, 2010 – Southern Lower Peninsula

Late in the evening on June 5, Berrien, Cass, Calhoun, and St. Joseph Counties experienced more than $2.6 million in tornado damages from events classified as EF1 and EF2. Then after midnight, two similarly classified tornadoes struck Monroe County. The stronger tornado was up to 800 yards wide and tracked 13 miles across Monroe County, including movement through the Village of Dundee, which was the hardest-hit location (after which the tornado weakened to EF0 levels in its east-southeastern course). The weaker tornado was up to 500 yards wide and tracked 5 miles from the Woodland Beach area to the northeast, reaching Estral Beach and proceeding out into Lake Erie. The weaker tornado was especially significant for two reasons—it caused some damage at the Fermi nuclear power facility, and it also impacted an area that was a project site for flood mitigation activities (at Estral Beach). The tornado damaged more than 125 homes and 23 vehicles, and set back a significant amount of flood mitigation project work in the area. Estimated damages from the weaker tornado amounted to $10 million. Estimated damages from the stronger tornado were $50 million. A total of 311 buildings were damaged in Monroe County, and 5 houses were destroyed. A weaker F1 tornado also caused $500,000 in damage to property in adjacent Lenawee County.

June 27, 2010 – St. Clair County

Among the tornado damages this day was a disastrous strike at a campground just north of I-69 and west of Wadhams Road in Clyde Township. One person was killed and four were injured. The tornado was classified as EF1, with winds up to 95 mph. About 10 campers were damaged or destroyed, including being blown into the water of a large pond nearby. Total damages at that location were estimated at $700,000. Total tornado damages that day amounted to more than $1.25 million.

April 26, 2011 – Allegan County

An EF-0 tornado (with winds peaking near 85 mph) damaged buildings from the Deboer Turkey Farm to trailers near Burnips (Allegan County). The tornado tore a small section of roof off a warehouse building, knocked over several trailers, and blew the windows out of several cars, then uplifted and collapsed an approximately 100-foot section of pole-barn. The roof was torn off about a 50-foot section of another barn. To the northeast, several small outbuildings were destroyed and trees were uprooted. Several houses received minor roof, soffit, and garage door damaged. The tornado lifted after partially destroying a 75 year-old barn. The property damage totaled approximately $1M.

March 15, 2012 – Southeast Michigan (Washtenaw, Lapeer, Monroe)

Three tornadoes resulted in more than $12 million in property damage. An EF-3 tornado touched down near Dexter (Washtenaw County), with maximum wind speeds of 135-140 mph. The tornado damaged at least 200 homes (20 severely), and destroyed two more. An EF2 tornado (with maximum wind speeds of around 125mph) struck approximately 5 miles northwest of Lapeer, leaving a damage path roughly 4.6 miles long with a maximum width of 400 yards. Damage included a destroyed garage, a house shifted off its foundation, uprooted trees and other minor structural damage. An EF0 tornado with maximum wind speeds of 85mph was confirmed in central Monroe County, near Yargerville. The estimated path length of this tornado was 0.5, miles with a maximum width of 50 yards. The damage consisted of siding and shingles blown off a house, a tipped car, a shed destroyed, and trees blown down.

July 6, 2014 – Kent and Ionia Counties

Late night tornadoes injured six persons south of Grand Rapids and caused more than $4.5 million in property damage. Winds reached 110 mph and the event was classified as an EF1 tornado, plus three additional EF0 tornadoes later on. The strongest tornado was on the ground for about 10 minutes, damaging and pushing down numerous trees, structures, and power lines. The trail of destruction began in the Byron Center area and tracked northeast into Wyoming and Kentwood.

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 $4.6 million in property damage was caused across the counties of Ionia, Saginaw, Tuscola, Sanilac, St. Clair, and Washtenaw Counties that evening and into the next morning.

August 20, 2016 – Southern Lower Peninsula

More than $5 million in property damage was caused by tornadoes that raged across the counties of Allegan, Ottawa, Kent, and Ionia. These twisters were all classified as EF0 or EF1, and fortunately no injuries or deaths were reported as a result of the event. The entire city of Bangor lost electric power that afternoon.

Programs and Initiatives

Note: Many of the programs and initiatives designed to mitigate, prepare for, respond to, and recover from severe straight-line winds have the dual purpose of also protecting against tornadoes. As a result, there is some overlap in the narrative programs and initiatives descriptions for each respective hazard. This redundancy allows each hazard section to stand alone, eliminating the need to refer to other hazard sections for basic information.

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including storms that are likely to produce tornadoes. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches/Warnings

The National Weather Service issues tornado watches for areas when the meteorological conditions are conducive to the development of a tornado. People in the watch area are instructed to stay tuned to NOAA weather radio and local radio or television stations for weather updates, and watch for developing storms. Once a tornado has been sighted and its existence is confirmed and reported, or Doppler Radar shows strong probability of the development or occurrence of a tornado, the National Weather Service will issue a tornado warning. The warning will identify where the tornado was sighted, the direction in which it is moving, and the time frame during which the tornado is expected to be in the area. Persons in the warning area are instructed to seek shelter immediately.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

Public Warning Systems

Numerous communities in Michigan have outdoor warning siren systems in place to warn the public about impending tornadoes and other hazards. Most of these systems were originally purchased to warn residents of a nuclear attack, but that purpose was expanded to include severe weather hazards as well. These systems can be very effective at saving lives in densely populated areas where the siren warning tone is most audible. In more sparsely populated areas where warning sirens are not as effective, communities are turning to NOAA weather alert warning systems to supplement or supplant outdoor warning siren systems. Unfortunately, a large number of communities across the state do not have adequate public warning systems in place to warn their residents of severe weather or other hazards. Federal funding specifically allocated to assist communities in the purchase of public warning systems has effectively disappeared, leaving many communities unable to purchase adequate systems to warn their residents of impending danger.

Attempting to fill some of that funding void, the State of Michigan has used federal Hazard Mitigation Assistance (HMA) funds to assist local communities in purchasing public warning systems. To date, HMA funds have been used to support 73 completed early warning system projects totaling $3.4 million (of which $2.4 million were provided by federal funds). Along with outdoor warning sirens, these projects included weather radios, transmitter equipment, and stream gauge project types. Many communities supplement these systems with education programs to ensure that residents know what to do once they receive warning of an impending hazardous event. Because HMA funds must be used to fund a wide variety of hazard mitigation projects, the amount of funds available to fund warning systems is limited to a small percentage of the overall available grant funds allocated to the state. The HMA funds are usually provided on a 75% federal, 25% local cost share. A Presidential major disaster declaration is required to activate some forms of this funding (HMGP). However, the HMA has provided substantial assistance to enhance many communities' local public warning capabilities.

Severe Weather Awareness Week

Each spring, the Emergency Management and Homeland Security Division, Department of State Police, in conjunction with the Michigan Committee for Severe Weather Awareness, sponsors Severe Weather Awareness Week. This annual public information and education campaign focuses on severe weather events such as tornadoes, thunderstorms, lightning, hail, high winds and flooding. The purpose of the tornado portion of this campaign is to inform the public about what tornadoes are and when they usually occur, what they should do if a tornado occurs, what community warning systems exist, and to provide other pertinent tornado-related information as appropriate. Informational materials are disseminated to schools, hospitals, nursing homes, other interested community groups and facilities, and the general public. Special educational programs are often conducted during this week.

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

Manufactured Home Anchoring

Manufactured homes are vulnerable to tornado damage if they are not properly anchored down. As a result, a major national effort has been initiated to encourage structural anchoring or "tie down" of manufactured homes. The Michigan Manufactured Housing Commission Administrative Rules (R 125.1602, Subsection 5) require new manufactured home installations in floodplains to be structurally anchored to a foundation. Through this requirement, the possibility of damage from wind is minimized. Although this will not protect a manufactured home from a direct hit by a tornado, it certainly will help prevent rollovers in most high-wind situations. Unfortunately, structures outside designated floodplains do not have to comply with the anchoring provision, although many owners choose to comply voluntarily. It should also be noted that local communities have the option of adopting an ordinance that requires anchoring of manufactured home installations located outside a designated floodplain. State anchoring system standards are outlined in Administrative Rules R 125.1605 through R 125.1608.

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

FEMA Safe Room Benefit-Cost Calculator

An advanced way for a community to analyze the tornado risk for various structures in its part of the state would be to make use of FEMA's 2000 computer model, "Benefit Cost Analysis of Hazard Mitigation Projects: Tornado and Hurricane Shelter Model." This program takes into consideration building information such as area, length, width, and location in the state, to determine whether or not a mitigation project involving reinforced "safe rooms" will provide adequate protection during a tornado for building occupants. Although this program does not specify exact risk of tornado damage for each community, it does provide an approximating regional model to follow for communities considering building tornado "safe rooms" to mitigate tornado deaths and injuries. If your community wants to know more about the feasibility of the "safe rooms," the model is available through the MSP/EMHSD office. Important Note: Only counties with greater tornado risks should inquire about the FEMA computer model, as the model does not work well for counties with very few tornado occurrences. Additionally, FEMA provides a disclaimer on the model that states that the results from the benefit-cost analysis are not conclusive or positively cost-effective—and that modeled projects are NOT guaranteed for potential government grants. For more information about safe rooms, refer to http://www.fema.gov/safe-rooms.

Electrical Infrastructure Reliability

One of the major problems associated with the severe winds from tornadoes and thunderstorms is the loss of electric power caused by trees falling on power lines. Michigan has had numerous widespread and severe electrical power outages caused by severe wind and other weather events. Several of those outages have resulted in upwards of 500,000 electrical customers (more than 5% of the State's population) being without power for several hours to several days at a time. Wind-related damage to electric power facilities and systems is a concern that is being actively addressed by utility companies across the state. Detroit Edison, Consumers Energy and other major electric utility companies have active, ongoing programs to improve system reliability and protect facilities from damage by tornadoes, severe straight-line winds, and other hazards. Typically, these programs focus on trimming trees to prevent encroachment of overhead lines, strengthening vulnerable system components, protecting equipment from lightning strikes, and placing new distribution lines underground. The Michigan Public Service Commission (MPSC) monitors power system reliability to help minimize the scope and duration of power outages.

Structural Bracing and Wind Engineering

One of the best ways to protect buildings from damage from severe winds associated with thunderstorms, tornadoes, or other high wind events is to install structural bracing and metal connectors (commonly called hurricane clips) at critical points of connection in the frame of the structure. Typically, this involves adding extra gable end bracing at each end of the structure, anchoring the roof rafters to the walls with metal connector straps, and properly anchoring the walls and sill plate to the foundation. This extra bracing helps ensure that the roof stays on the structure, and the structure stays anchored on its foundation. Experience in tornadoes and other high wind events has shown that once the roof begins to peel away from the walls, or the building begins to move off its foundation due to extreme lateral wind forces, major structural damage occurs. If the damage continues unabated, the building can end up being a total loss.

Urban Forestry and Tree Maintenance Programs

Urban forestry programs can be very effective in minimizing storm damage caused by falling trees or tree branches. In almost every tornado or other severe wind event, falling trees and branches cause power outages and clog public roadways with debris. However, a properly designed, managed and implemented urban forestry program can help keep tree-related damage and impact to a minimum. To be most effective, an urban forestry program should address tree maintenance in a comprehensive manner, from proper tree selection, to proper placement, to proper tree trimming and long-term care.

Every power company in Michigan has a tree trimming program, and numerous local communities have some type of tree maintenance program. The electrical utility tree trimming programs are aimed at preventing encroachment of trees and tree limbs within power line rights-of-way. Typically, professional tree management companies and utility work crews perform the trimming operations. At the local government level, an increasing number of Michigan communities have actual urban forestry departments or agencies. The following municipalities are known to have such programs in place, according to the MDNR’s Urban and Community Forestry Program: Adrian, Alma, Ann Arbor, Auburn Hills, Battle Creek, Bloomfield Township, Cadillac, Dearborn, Detroit, Grand Rapids, Grosse Pointe Park, Holland, Kalamazoo, Lansing, Livonia, Marquette, Milford, Monroe, Muskegon, Norway, Novi, Oak Park, Rochester Hills, Royal Oak, Southfield, Southgate, Traverse City, and Troy.

When proper pruning methods are employed, and when the work is done on a regular basis with the aim of reducing potential storm-related damage, these programs can be quite effective. Often, however, tree trimming work is deferred when budgets get tight or other work is deemed a higher priority. When that occurs, the problem usually manifests itself in greater storm-related tree debris management problems down the line. Although nothing will prevent tree damage from a direct tornado strike, a well-planned, well-managed urban forestry program can certainly reduce the scope and magnitude of the post-tornado tree debris problem.

Hazard Mitigation Activities for Tornadoes

- Increased coverage and use of NOAA Weather Radio, or comparable device-based notifications.
- Public early warning systems and networks.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines. (NOTE: Where appropriate. Burial may cause additional problems and costs when breakage or malfunction occurs, due to the increased difficulty in locating and repairing the problem.)
- Using appropriate wind engineering measures and construction techniques (e.g. structural bracing, straps and clips, anchor bolts, laminated or impact-resistant glass, reinforced entry and garage doors, window shutters, waterproof adhesive sealing strips, and interlocking roof shingles) to strengthen public and private structures against severe wind damage.
- Proper anchoring of manufactured homes and exterior structures such as carports and porches.
- Securing loose materials, yard, and patio items indoors, or where winds cannot blow them about.
- Construction of concrete safe rooms in homes and shelter areas in mobile home parks, fairgrounds, shopping malls, or other vulnerable public areas.

Assessments in Local Hazard Mitigation Plans

Tornadoes were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Allegan, Antrim, Arenac, Benzie, Berrien, Calhoun, Clinton, Dickinson, Eaton, Emmet, Genesee, Gratiot, Grand Traverse, Hillsdale, Huron, Ingham, Jackson, Kalkaska, Kent, Leelanau, Livingston, Luce, Macomb, Manistee, Mecosta, Menominee, Midland, Missaukee, Monroe, Montcalm, Newaygo, Osceola, Ottawa, Roscommon, Saginaw, Shiawassee, Washtenaw, Wayne, and Wexford (38 counties, an increase from 2014). These counties are located throughout the Lower Peninsula.

Tornado History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Tornado Events	Days with Funnel Clouds	Tot. property damage	Tot. crop damage	Injuries	Deaths
Washtenaw	6	6	$12,895,000			
Wayne	4	4	$91,250,000		90	
.Livingston	8	7	$10,220,000		3	
Oakland	7	7	$7,317,000			1
Macomb	5	4	$30,805,000		6	
5 Co Metro region	**6.0 avg.**	**5.6 avg.**	**$151,487,000**		**99**	**1**
Berrien	8	7	$2,110,000			
Cass	9	7	$6,000,000			
St. Joseph	7	5	$822,200		1	
Branch	2	2	$50,000			
Hillsdale	4	4	$351,000			
Lenawee	4	4	$580,000			
Monroe	8	7	$60,203,000		11	
.Van Buren	7	5	$110,000	$10,000		
Kalamazoo	8	7	$690,500	$142,000		
Calhoun	4	4	$3,200,000	$275,000		
Jackson	3	3	$700,000	$50,000		
.Allegan	10	9	$5,177,000			
Barry	3	3	$300,000			
Eaton	11	11	$50,357,000	$225,000	6	1
Ingham	9	9	$20,850,000	$200,000	2	2
.Ottawa	4	4	$750,000	$10,000		
Kent	13	9	$5,845,000	$30,000	6	
Ionia	7	6	$4,420,000	$55,000	5	
Clinton	4	4	$500,000	$150,000		
Shiawassee	10	8	$665,000		1	
Genesee	18	10	$18,510,000		2	1
Lapeer	9	9	$1,880,000			
St. Clair	9	9	$930,000		4	1
.Muskegon	3	3	$50,000			
Montcalm	4	4	$152,000	$25,000		
Gratiot	5	3	$675,000	$29,000	1	
Saginaw	15	11	$6,608,000	$5,500	2	
Tuscola	10	8	$1,611,000		1	
Sanilac	7	7	$985,000			
.Mecosta	2	2	$1,200,000		12	
Isabella	8	8	$715,000	$10,000	1	
Midland	3	3	$225,000			
Bay	6	6	$180,000			
Huron	7	7	$480,000		1	
34 Co S Lower Pen	**7.1 avg.**	**6.1 avg.**	**$197,881,700**	**$1,216,500**	**56**	**5**

Continued on next page…

Part 2 of Tornado History for Michigan Counties – arranged by geographic division

.Oceana						
Newaygo	4	4	$62,000	$10,000		
.Mason	1	1				
Lake	1	1	$150,000	$50,000		
Osceola	5	5	$512,000	$100,000	1	
Clare	3	3	$210,000	$10,000		
Gladwin	2	2	$90,000			
Arenac	4	4	$15,000	$1,000	1	
.Manistee	1	1	$15,000			
Wexford	2	2	$268,000			
Missaukee	1	1				
Roscommon	1	1				
Ogemaw	4	4	$115,030			
Iosco	2	2	$215,000			
.Benzie						
Grand Traverse						
Kalkaska	4	4	$1,260,000		1	1
Crawford	5	5	$145,000			
Oscoda	4	3	$2,890,000		2	
Alcona	3	3	$315,000			
.Leelanau	1	1	$20,000			
Antrim	2	2	$4,000			
Otsego	2	2	$226,000			
Montmorency	3	3	$210,000			
Alpena	4	3	$491,000			
.Charlevoix	1	1				
Emmet	1	1				
Cheboygan	3	3	$50,000			
Presque Isle	2	2				
29 Co N Lower Pen.	**2.3 avg.**	**2.2 avg.**	**$7,263,000**	**$171,000**	**5**	**1**
Gogebic	3	2	$175,000			
Iron	2	2	$17,000			
Ontonagon	1	1	$20,000			
Houghton	1	1				
Keweenaw	1	1				
Baraga						
.Marquette	9	8	$72,000	$5,000		
Dickinson	8	5	$7,013,000	$120,000		
Menominee	4	4	$35,000			
Delta	11	10	$38,000			
Schoolcraft						
Alger	2	2				
.Luce	2	2	$5,000			
Mackinac	1	1				
Chippewa						
15 Co Upp. Pen.	**3 avg.**	**2.6 avg.**	**$7,375,000**	**$125,000**		
MICHIGAN TOTAL	**382**	**296**	**$365,007,030**	**$1,512,000**	**160**	**7**
Annual average	**17.9**	**13.9**	**$17,111,901**	**$70,884**	**7.5**	**0.3**

NOTE: Includes the NCDC categories of "Dust Devil," "Funnel Cloud," and "Tornado." Different sources of information do provide different numbers.

Number of Tornadoes in Michigan, by County: 1950-2012

Parentheses: (range of Fujita intensities), then **d = deaths, i = injuries**

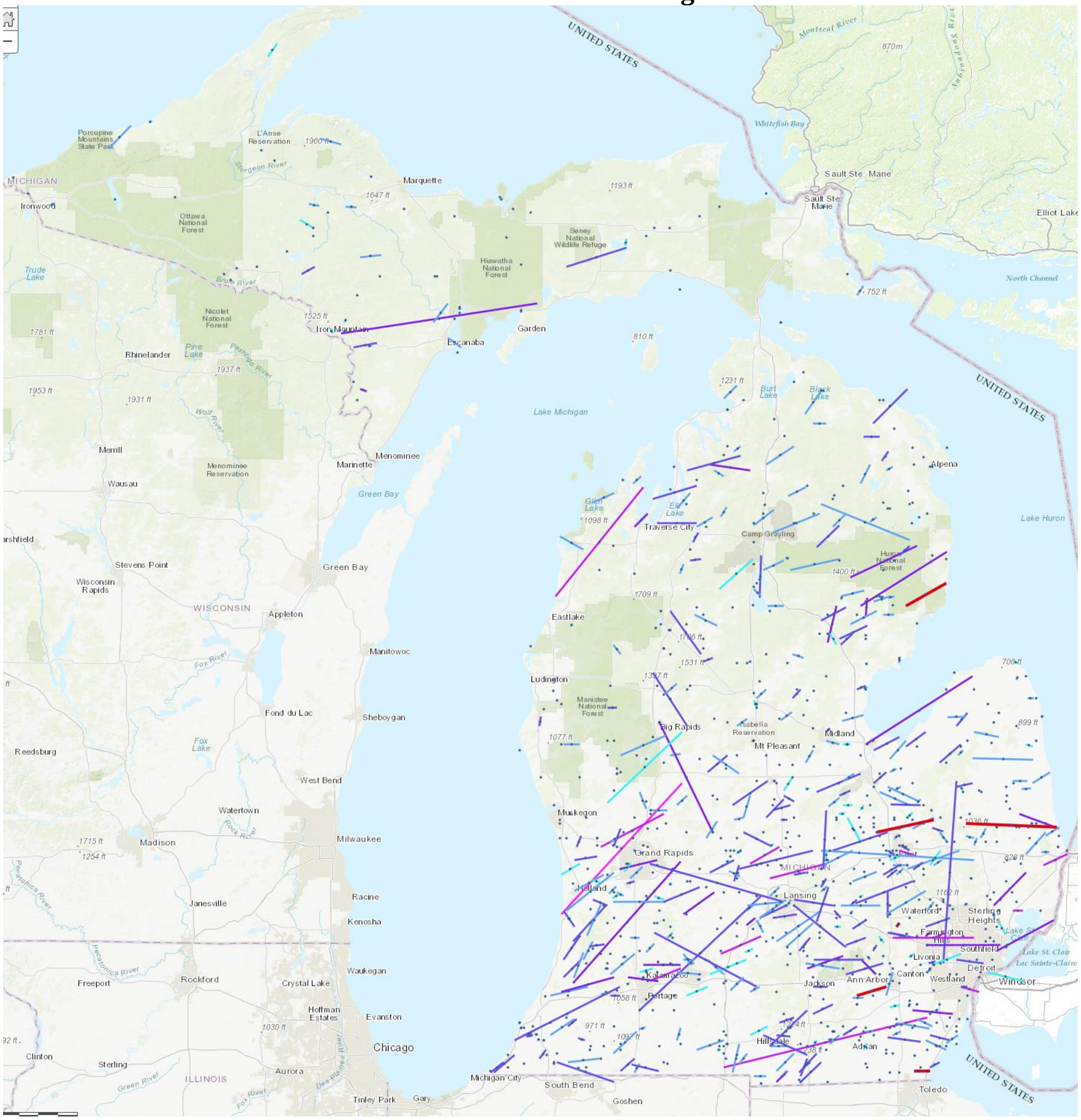
County (A-K)	Tornadoes: 1950-2012	County (L-Z)	Tornadoes: 1950-2012
Alcona (F0-F3) 0d, 0i	8	**Lake (F0-F1) 0d, 0i**	2
Alger (F0-F2) 0d, 0i	6	**Lapeer (F0-F4) 0d, 23i**	16
Allegan (F0-F5) 19d, 313i	25	**Leelanau (F0-F1) 0d, 0i**	3
Alpena (F0-F2) 0d, 0i	13	**Lenawee (F0-F3) 0d, 3i**	27
Antrim (F0-F3) 0d, 2i	8	**Livingston (F0-F4) 1d, 34i**	20
Arenac (F0-F2) 0d, 6i	6	**Luce (F0-F1) 0d, 0i**	3
Baraga (F0-F2) 0d, 0i	2	**Mackinac (F1-F1) 0d, 1i**	3
Barry (F0-F3) 0d, 7i	15	**Macomb (F0-F4) 12d, 243i**	20
Bay (F0-F3) 0d, 4i	13	**Manistee (F0-F4) 1d, 25i**	2
Benzie (F1-F1) 0d, 0i	3	**Marquette (F0-F1) 0d, 0i**	7
Berrien (F0-F2) 0d, 15i	31	**Mason (F0-F2) 0d, 8i**	5
Branch (F0-F4) 45d, 588i	16	**Mecosta (F0-F3) 0d, 25i**	7
Calhoun (F0-F3) 0d, 21i	13	**Menominee (F0-F3) 1d, 12i**	7
Cass (F0-F2) 0d, 25i	10	**Midland (F0-F2) 0d, 1i**	10
Charlevoix (F0-F1) 0d, 0i	3	**Missaukee (F0-F2) 0d, 0i**	7
Cheboygan (F0-F1) 0d, 0i	5	**Monroe (F0-F4) 6d, 65i**	31
Chippewa (F0-F1) 0d, 0i	6	**Montcalm (F0-F2) 0d, 7i**	8
Clare (F0-F1) 0d, 0i	7	**Montmorency (F0-F1) 0d, 2i**	6
Clinton (F0-F4) 1d, 26i	16	**Muskegon (F0-F2) 0d, 0i**	7
Crawford (F0-F2) 0d, 14i	9	**Newaygo (F0-F2) 2d, 3i**	12
Delta (F0-F2) 0d, 3i	10	**Oakland (F0-F4) 3d, 72i**	25
Dickinson (F0-F3) 0d, 0i	8	**Oceana (F0-F2) 0d, 4i**	5
Eaton (F0-F4) 1d, 52i	23	**Ogemaw (F0-F3) 1d, 9i**	12
Emmet (F0-F1) 0d, 0i	5	**Ontonagon (F0-F1) 0d, 0i**	3
Genesee (F0-F5) 120d, 970i	37	**Osceola (F0-F2) 0d, 1i**	12
Gladwin (F0-F3) 0d, 10i	9	**Oscoda (F0-F2) 0d, 0i**	4
Gogebic (F0-F1) 0d, 0i	3	**Otsego (F0-F1) 0d, 0i**	2
Gd. Traverse (F2-F3) 0d, 0i	3	**Ottawa (F0-F4) 5d, 144i**	18
Gratiot (F0-F2) 2d, 7i	13	**Presque Isle (F0-F2) 0d, 1i**	7
Hillsdale (F0-F3) 2d, 45i	21	**Roscommon (F0-F2) 0d, 0i**	8
Houghton (F0-F0) 0d, 0i	1	**Saginaw (F0-F3) 0d, 3i**	21
Huron (F0-F2) 0d, 1i	12	**Sanilac (F0-F3) 0d, 1i**	15
Ingham (F0-F2) 3d, 5i	22	**Schoolcraft (F0-F2) 0d, 2i**	2
Ionia (F0-F2) 0d, 7i	16	**Shiawassee (F0-F2) 0d, 15i**	21
Iosco (F0-F2) 4d, 13i	9	**St. Clair (F0-F4) 3d, 73i**	18
Iron (F0-F2) 0d, 2i	6	**St. Joseph (F0-F2) 0d, 1i**	11
Isabella (F0-F2) 0d, 7i	12	**Tuscola (F0-F2) 0d, 2i**	13
Jackson (F0-F3) 1d, 15i	15	**Van Buren (F0-F3) 0d, 29i**	16
Kalamazoo (F0-F4) 5d, 109i	25	**Washtenaw (F0-F3) 1d, 60i**	25
Kalkaska (F0-F2) 1d, 6i	6	**Wayne (F0-F4) 1d, 136i**	28
Kent (F0-F3) 0d, 38i	24	**Wexford (F0-F2) 0d, 1i**	8
Keweenaw (F0-F0) 0d, 0i	2	**STATEWIDE: (F0-F5) 241d, 3316i**	

(Parentheses provide the range of tornado classifications in each county, using the old Fujita F-scale)

NOTE: Different sources of information do provide different numbers.

Source: http://www.tornadoproject.com/alltorns/mitorn.htm

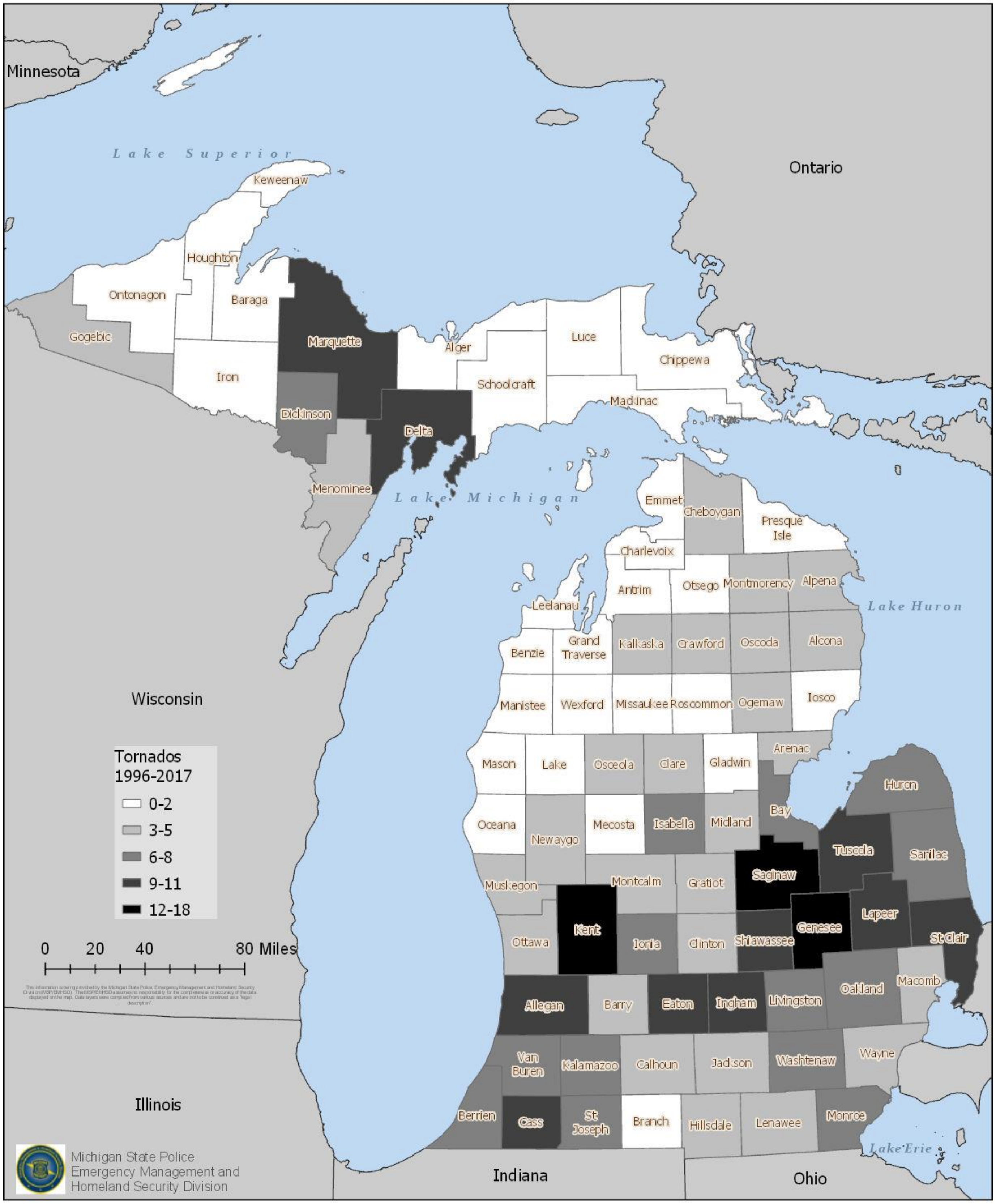
Michigan Tornado Track Map
Tornado locations and tracks in Michigan: 1950-2016



MSP Map produced with ESRI ArcGIS viewer

NOTE: Different sources of information do provide different numbers.

HISTORIC TORNADOES PER COUNTY



Number of Tornadoes per County, 1996-2017 (Source: NCEI)

Tornado Frequency (1996-2017), by land area (per 1,000 square miles)

Severe Winds

Non-tornadic winds of 58 miles per hour or greater.

Hazard Description

Severe winds, or straight-line winds, sometimes occur during severe thunderstorms and other weather systems, and can be very damaging to communities. Often, when straight-line winds occur, the presence of the forceful winds, with velocities over 58 mph, may be confused with a tornado occurrence. Severe winds have the potential to cause loss of life from breaking and falling trees, property damage, and flying debris, but tend not to cause as many deaths as tornadoes do. However, the property damage from straight line winds can be more widespread than a tornado, usually affecting multiple counties at a time. In addition to property damage to buildings (especially less sturdy structures such as storage sheds, outbuildings, etc.), there is a risk of infrastructure damage from downed power lines due to falling limbs and trees. Large scale power failures, with hundreds of thousands of customers affected, are common during straight-line wind events.

Hazard Analysis

Another dangerous aspect of straight line winds is that they occur more frequently beyond the April to September time frame than is seen with the other thunderstorm hazards. It is not rare to see severe winds ravage parts of the state in October and November—some winter storm events in Michigan have produced wind-speeds of 60 and 70 miles per hour. Stark temperature contrasts seen in colliding air masses along swift-moving cold fronts can occur during practically any month.

Figures from the National Weather Service indicate that severe winds occur more frequently in the southern-half of the Lower Peninsula than any other area of the state. On average, severe wind events can be expected 2-3 times per year in the Upper Peninsula, 3-4 times per year in the northern Lower Peninsula, and 5-7 times per year in the southern Lower Peninsula. It must be emphasized that this refers to winds from thunderstorms and other forms of severe weather, but **not** tornadoes.

Severe winds spawned by thunderstorms or other storm events have had devastating effects on Michigan, resulting in 36 deaths, about 270 injuries, and nearly $1.5 billion in damage to public and private property and agricultural crops since 1996. Severe wind events are characterized by wind velocities of 58 miles per hour or greater, with gusts sometimes exceeding 74 miles per hour (hurricane velocity), but do not include tornadoes. (Please refer to the Tornadoes section which follows, for more information on that hazard.)

National Weather Service forecasts of severe winds usually give sufficient warning time to allow residents to take appropriate action to reduce, at least to some degree, the effects of wind on structures and property. Damage from flying objects may be most difficult to prevent. However, proper structural bracing techniques can help minimize or even eliminate major damage due to the loss of a roof or movement of a building or housing unit off its foundation.

In terms of response to a severe wind event, the primary challenges facing Michigan communities are to provide for the mass care and sheltering of residents left without heat or electricity, and to mobilize sufficient resources to clear and dispose of downed tree limbs and other debris from roadways. In addition, downed power lines present a public safety threat that requires close coordination of response efforts between local agencies and utility companies. Thunderstorms and severe winds can affect every Michigan community. Therefore, every community should adequately plan and prepare for this type of emergency. That planning and preparedness effort should include the identification of necessary resources such as cots, blankets, food supplies, generators, and debris removal equipment and services. In addition, each community should develop debris management procedures (to include the identification of multiple debris storage, processing and disposal sites) so that the stream of tree and construction debris can be handled in the most expedient, efficient, and environmentally safe manner possible.

To mitigate the effects of severe winds, communities can: 1) institute a comprehensive urban forestry program, 2) properly brace and strengthen vulnerable public facilities, 3) ensure compliance with manufactured home anchoring regulations, 4) coordinate with utility companies on local restoration priorities and procedures, 5) improve local warning systems, and 6) encourage the use of structural bracing or, where appropriate, amend local codes to require its use in residential and commercial structures.

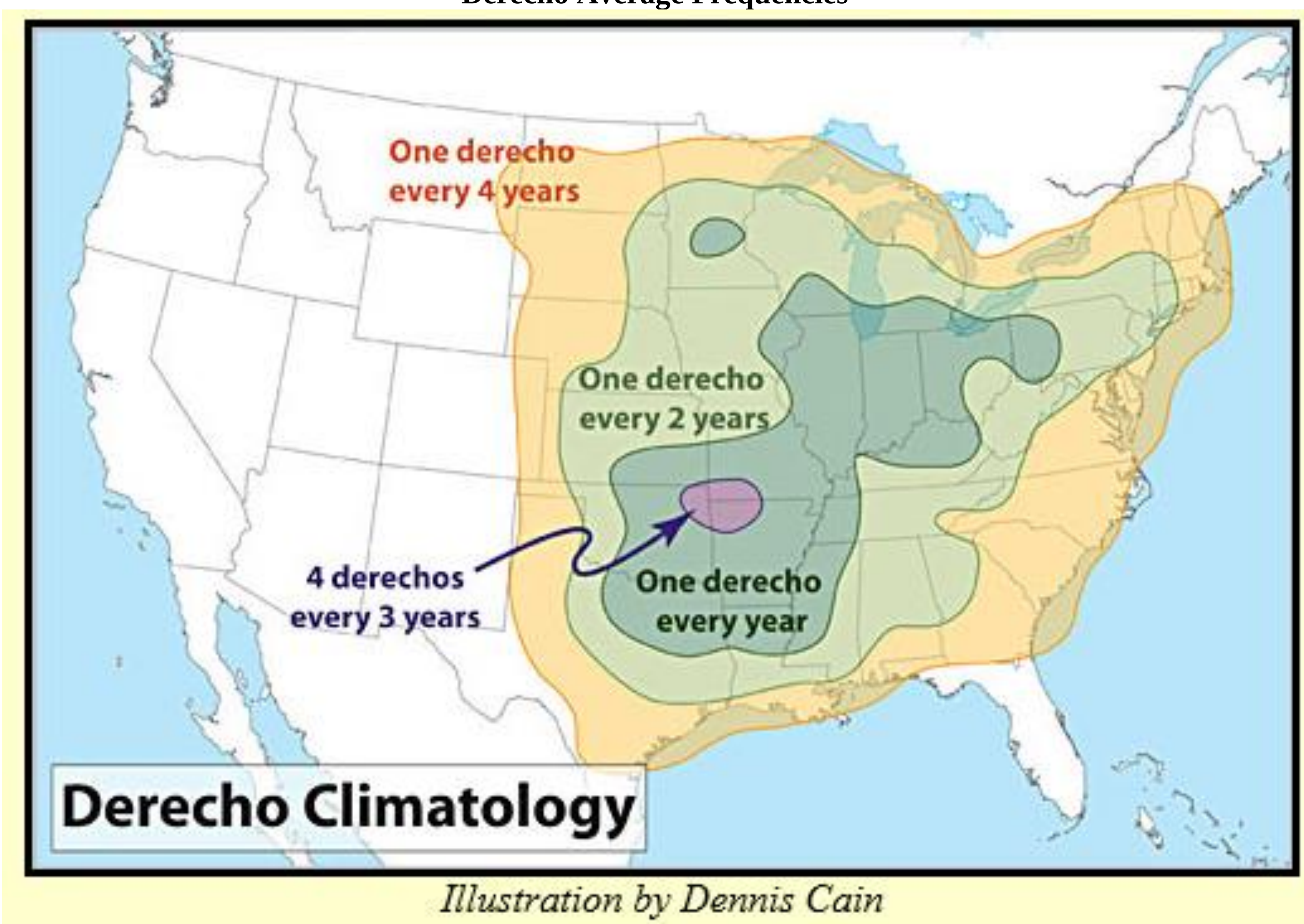
Microbursts

A microburst is a localized but powerful wind gust that typically occurs from a single storm. Microbursts result in what are often referred to as straight-line wind damage, and usually result in damage that is comparable to a brief, weak tornado. Typical damage from microburst winds involves widespread downed trees and power lines, trees falling on property, and minor structural damage.

Derecho

Derechos are usually large-scale storm systems that travel hundreds of miles and are many counties wide. The damage path of a derecho often exceeds 250 miles in length, with damage reports typically stretching across many states. Derechos can happen any time of the year, but are most common in Michigan during the warmer half of the year. Wind speeds in derechos can exceed 100 mph at times and often result in damage that is more widespread than most other storms and tornadoes in Michigan. The following map gives an indication of the pattern of Derecho frequency across the United States.

Derecho Average Frequencies



Source: http://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm#climatechange

As the following table shows, all forms of non-tornadic severe wind events average about 3 events per year in Upper Peninsula counties, 2 per year in northern Lower Peninsula counties, and 10 to 17 times per year in southern Lower Peninsula counties.

Severe Wind History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Severe Wind Events	Days with Severe Winds	Tot. property damage	Tot. crop damage	Injuries	Deaths
Washtenaw	334	161	$44,586,000		2	1
Wayne	351	163	$99,770,000		33	8
.Livingston	222	119	$32,303,000		1	
Oakland	473	173	$64,666,000		8	2
Macomb	304	142	$62,254,000		2	
5 Co Metro region	**337 avg.**	**152 avg.**	**$303,579,000**		**46**	**11**
Berrien	175	110	$812,500	$120,000	8	2
Cass	129	95	$1,169,000		6	
St. Joseph	152	93	$595,250			2
Branch	159	90	$369,000			
Hillsdale	148	89	$584,000		2	
Lenawee	225	119	$23,342,000		5	
Monroe	202	129	$22,151,000		8	
.Van Buren	102	77	$11,657,000	$40,000		1
Kalamazoo	117	94	$21,165,000	$145,000	1	
Calhoun	145	105	$41,438,000	$235,000	10	1
Jackson	125	91	$11,400,000	$30,000		
.Allegan	142	102	$13,988,000	$95,000	3	
Barry	96	74	$11,595,000	$55,000		
Eaton	90	69	$14,732,000	$180,000		
Ingham	109	77	$15,130,000	$55,000		
.Ottawa	104	77	$52,984,000	$10,060,000	21	4
Kent	133	93	$79,318,000	$20,085,000	60	3
Ionia	84	66	$11,514,000	$45,000	2	
Clinton	94	66	$12,198,000	$70,000		2
Shiawassee	132	96	$12,402,000			
Genesee	315	144	$35,912,000		3	
Lapeer	186	123	$15,401,000		1	
St. Clair	214	136	$31,706,000			
.Muskegon	91	64	$44,603,250	$5,030,000	5	1
Montcalm	76	63	$25,330,000	$70,000	23	
Gratiot	55	48	$11,464,000	$15,000		
Saginaw	208	115	$31,858,000		5	
Tuscola	162	100	$11,303,950			
Sanilac	120	78	$10,760,500	$4,000	1	
.Mecosta	44	37	$11,211,000	$10,000		
Isabella	64	55	$11,610,000	$25,000		
Midland	103	81	$10,828,000			
Bay	119	81	$13,011,000			1
Huron	145	86	$11,179,000			1
34 Co S Lower Pen	**134 avg.**	**89 avg.**	**$634,721,450**	**$36,369,000**	**164**	**18**

Continued on next page…

Part 2 of Wind History for Michigan Counties – arranged by geographic divisions

.Oceana	42	36	$14,692,000	$50,000	37	
Newaygo	59	47	$12,495,000	$50,000		2
.Mason	57	47	$7,382,000	$35,000	5	
Lake	36	35	$7,243,000			
Osceola	39	37	$5,682,500	$35,000	1	
Clare	47	40	$5,638,510	$15,000	1	2
Gladwin	37	30	$362,500			
Arenac	32	27	$274,500		4	
.Manistee	50	40	$612,500			
Wexford	45	37	$314,000			
Missaukee	22	19	$325,000			
Roscommon	60	49	$282,500		1	
Ogemaw	52	42	$456,500		1	
Iosco	38	29	$163,000			
.Benzie	28	23	$189,000			
Grand Traverse	45	35	$13,328,000	$1,000		
Kalkaska	30	24	$606,000			
Crawford	33	26	$1,509,000			
Oscoda	28	25	$173,000		1	
Alcona	46	39	$124,000		1	
.Leelanau	37	28	$24,141,000	$8,000		
Antrim	59	45	$847,000		1	
Otsego	43	40	$548,500			
Montmorency	40	33	$244,000	$5,000	1	
Alpena	46	38	$242,000			
.Charlevoix	37	32	$297,000			
Emmet	40	36	$388,000		1	
Cheboygan	33	30	$279,500			
Presque Isle	28	24	$100,000			
29 Co Northrn Lower Pen	**41 avg.**	**34 avg.**	**$98,939,510**	**$199,000**	**55**	**4**
Gogebic	98	65	$1,262,000	$1,000,000		1
Iron	59	43	$135,500	$2,000,000		
Ontonagon	63	44	$173,000	$1,060,000		
Houghton	105	66	$302,000	$1,000,000		
Keweenaw	41	38	$371,000			
Baraga	59	39	$484,000			
.Marquette	142	83	$3,249,250			2
Dickinson	70	49	$959,500			
Menominee	73	53	$136,500			
Delta	72	43	$1,112,700	$4,250,000	2	
Schoolcraft	42	36	$689,000	$2,613,000		
Alger	50	42	$259,500	$1,001,000	1	
.Luce	42	29	$187,000	$1,000		
Mackinac	27	24	$131,000			
Chippewa	34	29	$328,500			
15 Co Upp.Pen	**65 avg.**	**46 avg.**	**$9,780,450**	**$12,925,000**	**3**	**3**
MI. TOTAL	**8,415**	**909**	**$1,406,022,000**	**$49,393,000**	**268**	**36**
Annual avg.	**395**	**43**	**$49,038,575**	**$2,320,282**	**12.6**	**1.7**

NOTE: Combines the NCDC source's entries for "High Wind," "Strong Wind," and "Thunderstorm Wind."

Impact on the Public, Property, Facilities, and Infrastructure

Severe winds tend to impede transportation, causing slowed traffic and impaired control on roadways, and delays in the flight schedules for airlines. In addition, their physical impact can be comparable to that of a weak tornado, judged in terms of the severity of the resulting property damage, but often with a more widespread area of effect. Structural collapse, and damages caused by falling trees/limbs, can cause injury and impairment of the residential and commercial use of the affected properties. It is very common for winds to cause trees and their limbs to break, blocking roads and pulling down communication and power lines (with impacts similar to those described in the sections on lightning and infrastructure failures).

Impact on the Economic Condition of the State

The most common economic impact of severe winds involves the loss of electrical power, which can have economic repercussions for those businesses that do not have sufficient back-up systems to allow their operations to continue in an uninterrupted manner. Most power failures are of limited duration—interruptions might happen only for a moment, or may last for days. In any given Michigan location, it is fairly rare for longer power losses to occur as a result of severe winds. Most wind-caused damage is able to be located and repaired by utility companies within a reasonable time-frame, thus helping to keep economic impacts limited.

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. Although special training and safety precautions have usually been taken (e.g. for line-repair workers), nevertheless, responders are more exposed to and at-risk from the impacts of severe winds. Some winds, such as the most extreme gusts from severe straight-line winds (microbursts), can be brief, but can still be surprising and harmful to those caught in them. Strong winds can also persist for many hours and exacerbate the existing difficulties and challenges involved in emergency response—impeding traffic, causing power loss and road closures, and making the use of equipment more difficult.

Impact on the Environment

Non-tornadic winds of at least 58 mph are classified as severe winds and/or derechos. Some of the harmful effects of wind on the environment include full-grown trees being completely uprooted and knocked down, or large acreage of forest land being destroyed. Large amounts of debris, elements from collapsed structures, and destroyed natural vegetation can result from severe winds. Wildlife species can be harmed. Collapsed structures can contain combustible building materials, debris, chemicals, machinery, smoke, sewage, or other elements that can damage the environment. Lakeshore beach erosion can occur, along with rip currents in the water, as a result of severe winds. Winds can stir up sediments in waterways and thus disrupt the local ecosystem.

Impact on Public Confidence in State Governance

When winds cause infrastructure failures, a question may be raised about the adequacy of that infrastructure, its maintenance, and its design and regulation. In events that require mass sheltering, such as schools or large gatherings (e.g. a county fair or community-sponsored event), the ability of local and state government to adequately plan for severe weather is often vital to the success of such events, which themselves are often important for various sectors of the local and state economy. Citizen discontent and media-exacerbated controversies have arisen from situations in which inadequate planning was evident, or provisions for public sheltering were inadequate.

Recent Significant Severe Wind Events in Michigan

Various Dates – Lake Michigan (Oceana and Mason Counties)

The twenty-mile span of Lake Michigan between Little Point Sable, at Silver Lake, and Big Point Sable, north of Ludington, has earned a reputation as the "Graveyard of Ships." Beginning with the loss of the Neptune in 1839, through the Armistice (now Veterans') Day Storm of 1940, nearly seventy vessels have gone down in these treacherous waters. Gales and November snow storms have made navigation of this part of the lake a sailor's nightmare. Significant among the losses near Pentwater Harbor were the schooner Wright in 1854, the Minnie Corlett and the Souvenior in 1875, the Lamont in 1879, and the tug Two Brothers in 1912. The freighters William B. Davock, Anna C. Minch and Novadoc were all lost on November 11, 1940.

November 18, 1958 – Lake Michigan

The November 18, 1958 sinking of the 615-foot Carl D. Bradley limestone carrier in Lake Michigan, 60 miles west of the Mackinac Bridge, was due to excessive waves caused by winds up to 100 miles per hour. Mariners theorized that the “working” of the steel hull by 20-foot waves popped the rivets that held the ship’s plates together, causing the large vessel to split in two and sink. Thirty-three of the 35 crewmen onboard died in the accident.

November 10, 1975 – Lake Superior

The November 10, 1975 sinking of the freighter Edmund Fitzgerald in Lake Superior was due to excessive waves caused by severe winds exceeding 60 miles per hour. A total of 29 crewmen died in the accident.

July 15-20, 1980 – Southern Lower Michigan

Wind-related damages were so severe in the southern Lower Peninsula from July 15-20, 1980 that a Presidential Major Disaster Declaration was granted for 10 counties. Over 300,000 electrical customers were left without power, some for several days. During the recovery process, almost $6.8 million in public and private assistance was made available to affected local jurisdictions and to residents in the affected areas. Four million dollars in low-interest disaster loans were made available through the Small Business Administration.

April 30, 1984 – Lower Michigan

On April 30, 1984, a windstorm struck the entire Lower Peninsula, resulting in widely scattered damage, 1 death, and several injuries. Wind gusts measured up to 91 miles per hour in some areas. Damage was widely scattered, but extensive, with 6,500 buildings, 300 mobile homes, and 5,000 vehicles being damaged. Over 500,000 electrical customers lost power. In addition, 10 to 16=foot waves on Lake Michigan caused severe shore erosion, collapsing some cottages and driving many boats aground.

March 27, 1991 – Central and Southern Lower Michigan

On March 27, 1991, severe thunderstorms and accompanying high winds caused considerable damage across a large portion of central and southern Lower Michigan, damaging homes, businesses, farms, and some public facilities. In addition to numerous tornado impacts (q.v.), three deaths and 21 injuries were attributable to straight-line winds, and power was lost to 450,000 electrical customers (many for up to one week). The storms also caused hail in some areas. Eighteen of the wind injuries occurred in Branch County, where several houses and mobile homes were destroyed, business windows were blown out, and a truck and car were blown off of the I-69 expressway. In Berville (St. Clair County), a man died of a heart attack while trapped inside a mobile home blown off its foundation.

July 7, 1991 – Southern Lower Michigan

On July 7, 1991, a line of severe thunderstorms with very high winds crossed the southern Lower Peninsula. The National Weather Service recorded wind speeds of 60-70 miles per hour, with gusts in several locations exceeding 80 miles per hour. Several million dollars in damage occurred, and over one million electrical customers (more than 10% of the State's population) were left without power, some for several days. In addition, thousands of downed power lines caused significant public safety concerns and burdened an already difficult restoration process. Property damages were tallied in the counties of Ingham, Kent, and Oakland. In Lapeer County, a mobile home was tipped over, windows were blown out of several homes, and numerous trees and power lines were blown down.

July 13-15, 1995 – Statewide

From July 13-15, 1995, severe thunderstorms damaged numerous areas of Michigan. These storms, which produced winds up to 100 miles per hour with damaging golf-ball-sized hail and severe lightning, damaged hundreds of structures, and downed thousands of trees and power lines statewide. Damage was widespread, but the impacts were not severe or extensive enough in any one location to require supplemental disaster assistance. The strong winds produced widespread power outages. More than 400,000 electrical customers in southeast Michigan lost power due to the storms. In Roscommon County, over 100,000 trees were toppled by the winds. Wind gusts in that area were estimated in the 85-100 miles per hour range. A girl was killed when her pontoon boat flipped over while she attempted to return it to its dock. A stranded ORV-rider died of a heart attack before rescuers could cut a path through debris-blocked trails. One person was killed in Huron County when a barn collapsed between Bad Axe and Harbor Beach. Damages were reported in the following counties: Antrim, Clare, Crawford, Genesee, Gladwin, Gratiot, Huron, Ionia, Isabella, Kalkaska, Leelanau, Lenawee, Livingston, Mackinac, Mecosta, Midland, Monroe, Montcalm, Newaygo, Oceana, Ogemaw, Otsego, Roscommon, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, Washtenaw, and Wexford.

April 6-7, 1997 – West Michigan

On April 6-7, 1997, an intense early-spring low-pressure system moving across the Great Lakes brought gale force winds to much of Lower Michigan. Wind gusts of 50-70 miles per hour created 10-to-15-foot waves on the Lake Michigan shoreline, causing widespread wind damage and lakeshore beach erosion. Private damage was estimated at $5 million, 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 across the region, caused roof and structural damage to many buildings, and resulted in power outages for nearly 200,000 Consumers Energy electrical customers. The U.S. Army Corps of Engineers estimated that the severe beach erosion involved as much as 20 feet of beach loss in some areas. The beach erosion was due in part to the unusually high Great Lakes water levels, which were nearly 38 inches above average. One injury was later reported in this severe wind event.

July 2, 1997 – South-Central and Southeast Michigan

On July 2, 1997, a series of intense thunderstorms went through south-central and southeast Michigan, spawning severe straight-line winds, several tornadoes, and heavy rainfall. In some areas, the straight-line winds reached speeds of 70-100 miles per hour, causing significant structural damage and massive amounts of debris. Severe storms, tornadoes, and associated impacts caused a total of 7 deaths and 106 injuries. The tornadoes and straight-line winds downed thousands of trees and power lines, which knocked out power to 350,000 electrical customers. A Presidential Major Disaster Declaration was granted for the five-county area most severely impacted by the storm event. Straight-line wind damage was severe within the counties of Berrien, Calhoun, Cass, Clinton, Eaton, Gratiot, Ingham, Macomb, Midland, Saginaw, Washtenaw, and Wayne. (See the Tornadoes section for additional details on the tornadoes associated with these severe thunderstorms.)

October 5, 1997 – Delta and Schoolcraft Counties

Severe thunderstorms out of Canada pushed their way through the Upper Peninsula on October 5, 1997, creating numerous microbursts that caused significant damage in Delta and Schoolcraft counties. Winds estimated in excess of 100 miles per hour cut a 12-mile-wide swath of destruction in the two counties, downing thousands of trees and damaging 600 buildings and numerous vehicles. Total property, tree and agricultural losses were estimated at $3 million. The U.S. Forest Service reported damage to 9,000 acres of forest. The Michigan Department of Natural Resources suffered 500 acres of tree loss, and 200 acres of corporate forest were also heavily damaged. Fortunately, these microbursts occurred in lightly populated areas, or the impact on life and property might have been much greater.

May 31, 1998 – Southern Lower Peninsula

On May 31, 1998, a derecho raced across the Lower Peninsula around 4:30am, producing widespread 60 to 90 mph wind gusts that caused extensive tree and structural damage and left over 861,000 homes and businesses without electricity. Consumers Energy reported the derecho as the most destructive weather event in its history, leaving over 600,000 of its customers without power. There were four storm-related fatalities and 145 injuries (mostly minor) reported in the state. Statewide, approximately 250 homes and 34 businesses were destroyed and 12,250 homes and 829 businesses were damaged. Damage estimates totaled over $166 million. The highest wind gusts reached 120 to 130 mph in Spring Lake (Ottawa County) and Walker (Kent County), 100 mph in portions of Montcalm County (including Cody Lake and Stanton), and 90 mph in Rockford (Kent County) and Zeeland (Ottawa County). It took up to 10 days to fully restore power to certain areas, including the City of Walker and portions of Montcalm and Gratiot Counties. A Presidential Disaster Declaration was declared for 13 counties. Significant damages were reported in the counties of 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.

September 26-27, 1998 – Northern Lower Michigan

During the weekend of September 26-27, 1998, severe thunderstorms ravaged northern Lower Michigan, producing strong winds that damaged or destroyed homes, businesses and public facilities, and downed trees and power lines. Otsego County, specifically the city of Gaylord, was hardest hit, although damage was also reported in Crawford and Charlevoix counties as well. The storm front, which ran along and north of the M-32 corridor from East Jordan to Alpena, was approximately 12 miles wide and 15 miles long. When the front slammed into Gaylord, wind speeds had reached hurricane force of 80-100 miles per hour. The wind was accompanied by brief heavy rainfall and golf-ball-sized hail. The storm lasted only a few minutes in Gaylord, but the damage was tremendous. 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 – including the Otsego County Courthouse, which lost half of its roof. Approximately 818 homes were damaged throughout Otsego County, including 47 that were destroyed and 92 that incurred major damage. In addition, the storm injured 11 persons – none seriously. Region-wide, about 12,000 electrical customers lost power. A Governor's Disaster Declaration was granted to the county, to provide state assistance in the debris cleanup effort.

November 10-11, 1998 – Statewide

One of the strongest storms ever recorded in the Great Lakes moved across Michigan on the 10th and 11th of November, 1998, producing strong, persistent winds that damaged buildings, downed trees and power lines, killed one person, and left over 500,000 electrical customers in the Lower Peninsula without power. Wind gusts of 50-80 miles per hour were common, and a peak gust of 95 miles per hour was reported on Mackinac Island. Damage was widespread but relatively minor for a storm of that intensity. However, there were several pockets of significant damage across the state. In Troy, the walls of a church under construction were destroyed. In Flint, a warehouse lost its roof to the wind, and another had its roof damaged. In Mt. Clemens (Macomb Co.), a boat storage rack collapsed, causing about $500,000 in damage to 20 boats. In Frankfort (Benzie Co.), on the Lake Michigan shoreline, 80-90 mile per hour wind gusts destroyed a hangar at the City-County Airport ($500,000 in damage) and damaged six private planes. In Lake City (Missaukee Co.), the roof was blown off a hardware store. The U.S. Forest Service reported that at least $10 million worth of timber was lost in the Ottawa and Hiawatha National Forests. The strong winds generated 15 to 20-foot waves on Lake Michigan, while 8 to 15-foot waves were reported along the western Lake Superior shoreline. The waves caused considerable beach erosion in both locations. The extended period of strong winds even affected the water level in Saginaw Bay. By the morning of November 11, the winds had pushed so much water out into Lake Huron that the water level on Saginaw Bay bottomed out 50" below chart datum – over 5 feet below the recent average. The temporary loss of over 5 feet of water in the shallow bay exposed up to one-half of the bay bed, which briefly became dry land during the storm. As the wind died down later in the day, the water level rose again to its more normal level. Coincidentally, this storm system occurred on the anniversary of the storm system that had sunk the freighter Edmund Fitzgerald in Lake Superior in 1975.

May 17, 1999 – Central and Southern Lower Michigan

On May 17, 1999, a strong storm system raced through central and southern Lower Michigan, bringing with it severe winds, heavy rain, and large hail. Wind gusts of 60-70 miles per hour downed numerous trees and power lines, leaving 150,000 homes and businesses without power. Peak wind gusts of 115 miles per hour were recorded in Calhoun, Ingham, and Kent Counties. A wind gust caused a home under construction to collapse in Wyoming, killing one person and injuring another. In Lansing, utility poles snapped along I-496, although built to withstand 100 mile per hour winds, closing parts of the freeway for 26 hours and causing rush-hour traffic tie-ups. Response and recovery costs for Lansing city agencies (including the municipal power company) were pegged at $1.5 million.

July 4-5, 1999 – Several Northern States

The Boundary Waters-Canadian Derecho, also commonly called the Boundary Waters Blowdown, was an international Derecho that occurred during the afternoon and evening hours of July 4 and the early morning hours of July 5, 1999. It traveled over 1300 miles in 22 hours through Minnesota, Wisconsin, Michigan, Ontario, Quebec and Maine. There was a tremendous amount of lightning associated with this Derecho—around 6,000 lightning strikes per hour. The event caused $100 million in damage, killed 2 people and injured 70. Over 700,000 homes and businesses lost power.

July 24-25 and 31, 1999 – Southern Lower Michigan

During the last two weekends of July 1999, a series of severe thunderstorms, fueled by high temperatures and extreme humidity, moved across southern Lower Michigan. The storms produced strong wind gusts (estimated at 60-70 miles per hour), heavy rainfall, and hail in some areas. Most of the damage caused by the wind involved downed trees and power lines. A total of 430,000 electrical customers were left without power after the two weekend storms, many for more than 24 hours. Unfortunately, the outages occurred at a time when temperatures were soaring past 90 degrees and humidity was very high. Many electrical customers lost large amounts of perishable food to spoilage. After the July 24 storms, utility crews' restoration efforts were temporarily halted by another series of storms on the 25th. Damage to homes, businesses, vehicles, and boats was reported in southeast Michigan and the Saginaw Bay area. In Detroit, heavy rainfall flooded freeway underpasses with up to two feet of water, while golf-ball-sized hail was reported in Kawkawlin, Bay City, Zilwaukee, Goodrich, and Southfield.

May 9, 2000 – Southeast Michigan

During the afternoon and evening hours of May 9, 2000, an outbreak of severe thunderstorms (with winds gusting to 70 miles per hour) struck southeast Michigan, causing considerable damage across the region. The storm front produced a combination of straight-line winds and tornadoes, accompanied by large, damaging hail in many locations. In Lenawee County, strong winds destroyed several barns, flipped over a mobile home and recreational vehicle, caused numerous trees to fall on homes, destroyed grain bins, destroyed one airport hangar, and damaged two others. In Monroe County, dozens of trees were downed and a railroad depot was destroyed. In Washtenaw County, hundreds of trees were downed and a church and a grocery store were damaged. In Wayne County, a hangar at Detroit Metropolitan Airport collapsed, damaging the plane inside. Numerous other localities within Wayne County suffered damage to homes and businesses. The storms left more than 200,000 electrical customers without power, injured at least six persons, and caused several million dollars in property damage.

October 24, 2001 – Southern Lower Michigan

On October 24, 2001, much of Michigan began experiencing severe weather as the result of a strong cold front colliding with warm, moist air. The result was widespread strong winds (in excess of 50 miles per hour) and severe weather throughout the state, but particularly so in southern Lower Michigan where severe thunderstorm warnings were issued for 13 counties, and tornado warnings were issued for seven counties. Although numerous funnel clouds were sighted across the region, only two actually touched down—one affecting Livingston and Oakland Counties along a 15-mile path, and the other affecting Saginaw County. The vast majority of the damage produced by this storm system was from straight-line winds, which in Lansing were estimated to peak at 120 miles per hour. Region-wide, the storms killed two persons and injured at least 20 others, caused extensive flooding of roads and streets, downed thousands of trees and power lines (leaving 195,000 electrical customers without power), closed schools and businesses, and damaged hundreds of cars, homes, businesses, and public buildings. The areas most heavily impacted by this storm system were in the counties of Berrien, Cass, Ingham, and Kalamazoo. A Governor's Disaster Declaration was issued for Kalamazoo County, to provide supplemental state assistance for debris removal and cleanup.

July 31-August 2, 2002 – Central Michigan and Upper Peninsula

During the last day in July, severe weather hit central Michigan and the Upper Peninsula. The National Weather Service issued tornado warnings for seven counties in central Michigan. Funnel clouds were reported along a 120-mile stretch extending from Howard City to Onaway. Golf ball-size hail fell in Escanaba and thunderstorms soaked Houghton with 1.25" of rain in a two-hour period. About 14,000 Upper Peninsula Power Company customers lost electricity for several days due to 70 mile per hour winds that toppled trees and power lines in the western Upper Peninsula. Some Houghton customers were blacked out when high winds tore the metal roof off a Frito-Lay warehouse and it sliced through nearby power lines. From Tuesday night through mid-day Thursday, the National Weather Service issued 44 severe weather warnings for various parts of the Upper Peninsula. Property damage from straight-line winds was noted in the counties of Allegan, Barry, Calhoun, Clare, Ingham, Ionia, Kalamazoo, Kent, Mecosta, Montcalm, Newaygo, Ottawa, and Van Buren.

May 11, 2003 – Southeast Michigan

A strong cold front moved through the Great Lakes region during the morning of the May 11, 2003. Wind gusts of 55 to 60 mph were estimated across much of Wayne and Washtenaw counties. The rest of Southeastern Michigan generally had estimated wind gusts of 45 to 50 mph. The winds caused several trees to blow down across the area and several thousand homes and businesses across the area to lose power. The strong winds were also blamed for a hydrochloric acid leak from a plant in Ypsilanti. Investigators concluded that the high winds ripped a chunk of the plant's roof loose, smashing it into a distribution pipe, which caused roughly 100 gallons of acid to leak out.

July 4-6, 2003 – Southern Lower Michigan

A line of thunderstorms that developed over Wisconsin made its way across Lake Michigan over the Independence Day weekend, bringing wind gusts of more than 60 miles per hour, knocking down trees and leaving more than 200,000 customers without electricity. Power went out during one of the warmest weeks of the summer, causing many citizens to lose large amounts of perishable foods. In Brighton Township, residents of a subdivision were without running water for several days because they relied on electricity to operate wells. A small stretch of beaches in southwest Michigan turned deadly over the weekend, as 10 swimmers drowned from the storm-powered undercurrents. On July 4, more swimmers drowned in one day than the average for an entire summer in southwest Michigan. Nine fatal car accidents also 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.

August 1, 2003 – Southern Lower Michigan

Severe thunderstorms and winds up to 77 miles per hour swept through southern Lower Michigan on August 1, 2003, killing two persons. One man was killed while walking, when a wind-snapped tree limb hit his head. A woman was pronounced dead at a local hospital after being struck by lightning. A young boy survived a lightning strike the same day. The high winds caused about 127,000 electrical customers to lose power—most of whom regained it within a couple of days. Wind damages were reported in the counties of Calhoun, Jackson, Kalamazoo, Oceana, Shiawassee, and Van Buren.

November 12, 2003 – Southeast Lower Michigan

Wind gusts up to 74 miles per hour knocked down trees and power lines, causing a loss of power for more than 370,000 electrical customers in southeast Michigan. The harsh weather conditions forced many school districts to cancel classes. A live power line fell across eastbound Interstate 94, forcing the closure of the highway and causing a major traffic jam near Detroit Metropolitan Airport. Detroit's Department of Public Works received 73 telephone calls reporting trees down and other damage. 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.

November 6, 2005 – Southeast Michigan

On November 6, 2005, a deep and rapidly intensifying storm system moved through Southeast Lower Michigan during the morning. High winds along the associated cold front knocked down trees, leading to approximately 200,000 power outages. Winds were sustained out of the southwest at 30 to 40 mph, with gusts as high as 60 mph from mid to late morning. Street signs were toppled, traffic lights were sent spinning, and power lines were split. Many streets and roads had to be temporarily closed until trees blocking the way could be cleared. Property damage was estimated at $4.2 million in Wayne County, and $20,000 in Branch County.

May 15, 2007 – Southern Lower Michigan

Severe thunderstorm winds affected many counties and measured as high as 83 knots (at the Three Rivers Airport in St. Joseph County). Significant damages were caused at locations as diverse as Centreville, Schoolcraft, North Aurelius, and Howell. One mile north of Essexville (Bay County), a power plant's coal stacker was reported as having been destroyed when it was toppled over by strong winds, with damages estimated at $1.5 million. Other 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.

June 6 to 8, 2008 – much of the Lower Peninsula

Numerous thunderstorms produced damaging winds of up to 65 knots. The strongest winds were reported at Howell and Saginaw. The greatest damages occurred in the Saginaw area, where 12,000 residents lost electricity. Two miles north of Carrollton, dozens of trees were blown down, some knocking down power lines, some falling onto houses, some blocking roads, and one falling onto a car and injuring its two occupants. An entire roof was blown off a commercial building near the intersection of Stevens and Hamilton. 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 74 knots (at Marine City). There were also tornadoes and hail associated with this system. Damages were estimated at $17 million (both property and crops), and the storm systems were associated with 7 deaths and 3 injuries. More than 10,000 persons were without power for a week or more. This was the worst such wind event of the decade. Thousands of trees were lost, and great property damage was caused as they toppled onto houses and cars. Three casualties were caused by straight-line winds. One mile west of Spring Lake, a car was struck by a tree while it was being driven, killing the driver and injuring the passenger. A pedestrian was also killed by a falling tree, a mile southeast of Harrisburg. Numerous power lines were down, and boats were overturned in the water. 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.

August 9, 2009 – Statewide

On August 9, 2009, severe thunderstorms developed across west-central Lower Michigan, resulting in hundreds of trees, numerous utility poles, and utility line taken down by 60 to 80 mph winds. Fruitport took the brunt of the storm, with wind gusts of 70 to 80 mph lasting for about 10 minutes. Numerous homes were heavily damaged by falling trees. Significant damage to apple orchards occurred west of Sparta. The storm complex also produced an EF-0 tornado with a path 35 miles long and up to 9 miles wide. Wind damages were reported in the counties of Kent, Lapeer, Livingston, Macomb, Marquette, Muskegon, and St. Clair. A man in a vehicle was killed near Grand Haven as a result of this severe weather.

July 18, 2010 – Lower Peninsula

On July 18, 2010, a NWS storm survey team concluded that a series of wet micro bursts across southwestern Kent County had produced wind gusts ranging from 60 up to 80 mph, brought down several trees and power lines in the Wyoming and Cutlerville areas, and flipped over and destroyed 8 wood and metal sheds at a store near Cutlerville. A tornado damaged a home and broke or uprooted several trees just northeast of Wayland. A roof was lifted off of a garage in Wyoming, a shed was destroyed, and some structural damage occurred on a home, due to wind gusts. Straight-line wind damages were reported in the counties of Berrien, Kent, Lenawee, and Roscommon.

May 29, 2011 – Southern Lower Peninsula

Severe thunderstorms resulted in straight-line winds up to 100 mph, causing extensive damage across multiple counties. A state of emergency was declared for Calhoun County, due to widespread wind damage. Nearly 40,000 people across Calhoun County lost power as a result of wind and lightning damage. While no lives were lost, 2 injuries were reported, over 600 properties were damaged, and 76 homes and 4 businesses were destroyed in the Battle Creek area. The total damage estimates were over $30M, approximately $25M of which was in Calhoun County, where two persons were injured. Straight-line wind damage was reported in the counties of Calhoun, Eaton, Genesee, Ingham, Kalamazoo, Lapeer, Lenawee, Livingston, Oakland, Shiawassee, and Wayne.

July 11, 2011 – Western Michigan (Kent, Ottawa, and Kalamazoo Counties)

Two separate bow echoes moved across the western Lower Peninsula on July 11, producing numerous reports of wind damage. The first bow echo moved onshore north of Muskegon shortly after daybreak. The second, more destructive bow echo raced east from northern Illinois across far southern Lake Michigan and southern lower Michigan, resulting in numerous reports of downed trees and power lines. One person lost his life in Cutlerville when a tree fell in the garage he was in. Wind gusts up to 80mph were reported and the storm resulted in more than $8M damage—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.

January 19th, 2013 – Southeast Michigan

An intense Arctic Front swept through southeast Michigan during the late evening on January 19th, with westerly winds gusting as high as 60 mph across much of the area during the early morning hours on January 20th. Trees and power lines were blown down across various counties, leading to power outages for more than 120,000 DTE customers during the peak of the windstorm. The result was about $14 million in property damage, including $2 million in Wayne County, $1.5 million each in Oakland and Macomb Counties, $1 million each in Tuscola, Huron, Genesee, and St. Clair, $750,000 each in Lapeer, Livingston, Monroe, Sanilac, Shiawassee, and Washtenaw, and $500,000 in Lenawee County.

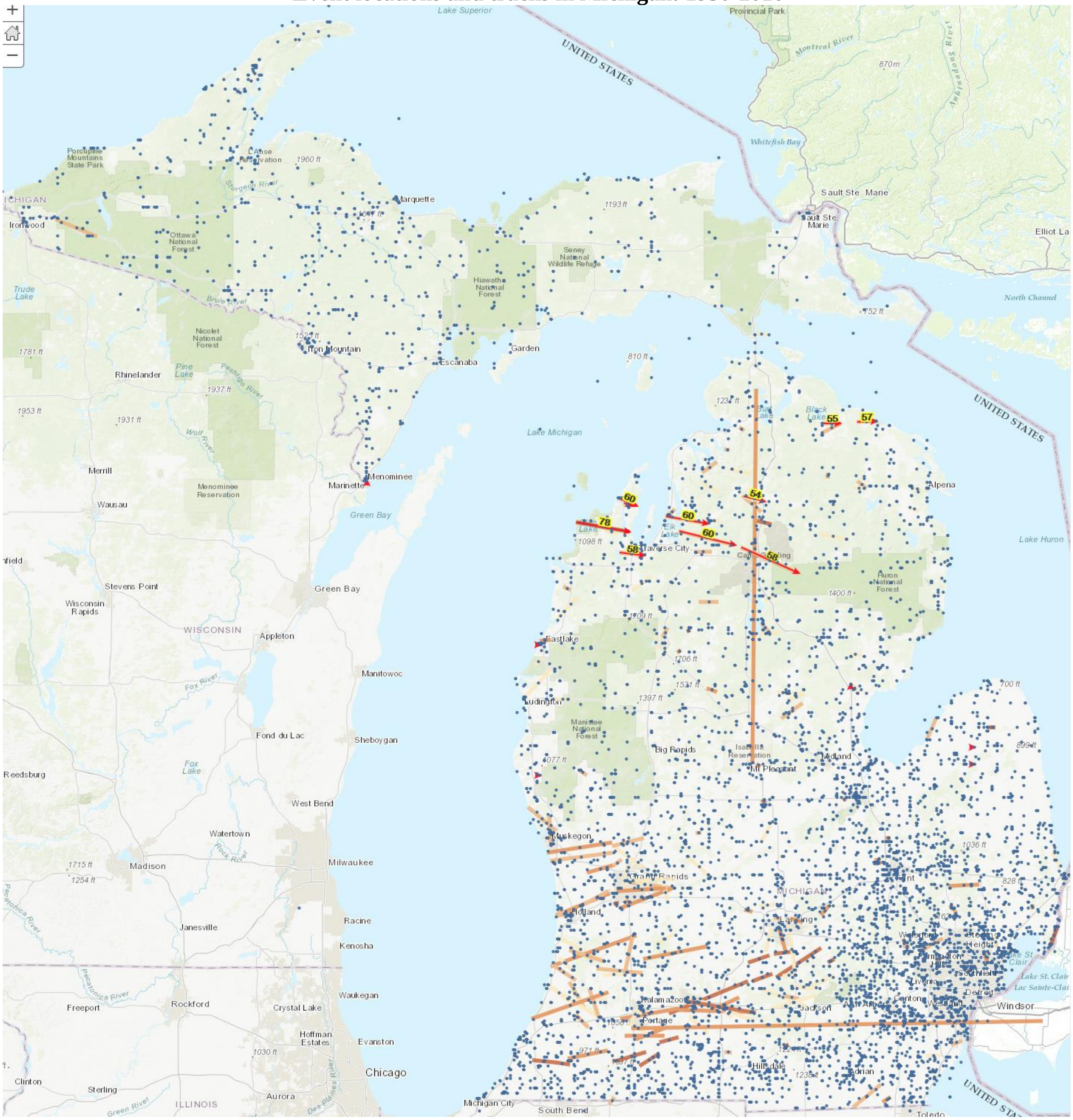
February 19, 2016 – Southeast Michigan

Strong winds from 50 to 60 mph caused trees, tree limbs, and power lines to come down in southeast Michigan. About 117,000 customers were without electrical power during the peak of the utility problems caused by this event. A total of $30.5 million in property damage was reported, involving the following counties: Livingston ($2M), Macomb ($7M), Oakland ($10M), Shiawassee ($500K), Washtenaw ($4M), and Wayne ($7M).

March 8, 2017 – Southern Lower Peninsula

Widespread wind peaked at 60 to 70 mph across the southern Lower Peninsula, without being a part of thunderstorm systems. These strong winds alone caused electric power failures that affected as many as 1 million Michigan residents. Numerous trees and tree limbs had fallen across power lines, and damaged homes and buildings. Two persons in Clare County were killed by a tree falling onto their vehicle while driving on M-115 near the Osceola county line in Freeman Township. Total damages amounted to about $525 million across the following counties: Allegan ($12M), Baraga ($60K), Barry ($10M), Bay ($7M), Calhoun ($10M), Clare ($5M), Clinton ($10M), Eaton ($10M), Genesee ($25M), Gratiot ($10M), Huron ($7M), Ingham ($10M), Ionia ($10M), Iron ($40K), Isabella ($10M), Jackson ($10M), Kalamazoo ($13M), Kent ($15M), Lake ($5M), Lapeer ($10M), Lenawee ($15M), Livingston ($25M), Macomb ($30M), Mason ($5M), Mecosta ($10M), Midland ($7M), Monroe ($15M), Montcalm ($10M), Muskegon ($15M), Newaygo ($10M), Oakland ($35M), Oceana ($10M), Osceola ($5M), Ottawa ($15M), Saginaw ($23M), Sanilac ($7M), Shiawassee ($7M), St. Clair ($25M), Tuscola ($7M), Van Buren ($10M), Washtenaw ($25M), and Wayne ($25M).

Michigan Severe Straight-Line Winds Track Map
Event locations and tracks in Michigan: 1950-2016



MSP Map produced with ESRI ArcGIS viewer.
Dots represent wind events, very light (yellow) lines were wind tracks 53 or below.
Darker lines go up to the severest category of windspeeds 87 and above.

Programs and Initiatives

Note: Many of the programs and initiatives designed to mitigate, prepare for, respond to, and recover from tornado effects have the dual purpose of also protecting against severe straight-line winds. As a result, there is some overlap in the narrative programs and initiatives descriptions for each respective hazard. This redundancy allows each hazard section to stand alone, eliminating the need to refer to other hazard sections for basic information.

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including storms that are likely to produce severe winds. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches/Warnings

The National Weather Service issues severe thunderstorm watches for areas where the meteorological conditions are conducive to the development of severe thunderstorms. People in the watch area are instructed to stay tuned to National Oceanic and Atmospheric Administration (NOAA) weather radio and local radio or television stations for weather updates, and watch for developing storms. Once radar or a trained SkyWarn spotter detects the existence of a severe thunderstorm, the National Weather Service will issue a severe thunderstorm warning. The warning will identify where the storm is located, the direction in which it is moving, and the time frame during which the storm is expected to be in the area. Persons in the warning area are instructed to seek shelter immediately.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

Public Warning Systems

Numerous communities in Michigan have outdoor warning siren systems in place to warn the public about impending tornadoes and other hazards. Most of these systems were originally purchased to warn residents of a nuclear attack, but that purpose was expanded to include severe weather hazards as well. These systems can be very effective at saving lives in densely populated areas where the siren warning tone is most audible. In more sparsely populated areas where warning sirens are not as effective, communities are turning to NOAA weather alert warning systems to supplement or supplant outdoor warning siren systems. Unfortunately, a large number of communities across the state do not have adequate public warning systems in place to warn their residents of severe weather or other hazards. Federal funding specifically allocated to assist communities in the purchase of public warning systems has effectively disappeared, leaving many communities unable to purchase adequate systems to warn their residents of impending danger.

Attempting to fill some of that funding void, the State of Michigan has used federal Hazard Mitigation Assistance (HMA) funds to assist local communities in purchasing public warning systems. To date, HMA funds have been used to support 73 completed early warning system projects totaling $3.4 million (of which $2.4 million were provided by federal funds). Along with outdoor warning sirens, these projects included weather radios, transmitter equipment, and stream gauge project types. Many communities supplement these systems with education programs to ensure that residents know what to do once they receive warning of an impending hazardous event. Because HMA funds must be used to fund a wide variety of hazard mitigation projects, the amount of funds available to fund warning systems is limited to a small percentage of the overall available grant funds allocated to the state. The HMA funds are usually provided on a 75% federal, 25% local cost share. A Presidential major disaster declaration is required to activate some forms of this funding (HMGP). However, the HMA has provided substantial assistance to enhance many communities' local public warning capabilities.

Severe Weather Awareness Week

Each spring, the Emergency Management and Homeland Security Division, Department of State Police, in conjunction with the Michigan Committee for Severe Weather Awareness, sponsors Severe Weather Awareness Week. This annual public information and education campaign focuses on severe weather events such as tornadoes, thunderstorms, lightning, hail, flooding and high winds. Informational materials on severe winds and other weather hazards are disseminated to schools, hospitals, nursing homes, other interested community groups and facilities, and the general public.

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Manufactured Home Anchoring

Manufactured homes are especially vulnerable to wind damage if they are not properly anchored down. As a result, a major national effort has been initiated to encourage the structural anchoring or "tie down" of manufactured homes. The Michigan Manufactured Housing Commission Administrative Rules (R 125.1602, Subsection 5) require new manufactured home installations in floodplains to be structurally anchored to a foundation. Through this requirement, the likelihood of damage from wind is also reduced. A unit that can be tipped by wind is far more likely to suffer from structural collapse, so anchoring is designed to prevent tipping. Unfortunately, many structures outside designated floodplains have not complied with this particular anchoring provision, although some communities may have supplemental requirements, and many owners voluntarily choose to anchor their homes. Local communities have the option of adopting an ordinance that requires anchoring of manufactured home installations located outside a designated floodplain. Individual mobile home parks may also require anchoring. State anchoring system standards are outlined in Administrative Rules R 125.1605 through R 125.1608.

Electrical Infrastructure Reliability

One of the major problems associated with severe winds is the loss of electric power. As mentioned previously, Michigan has had numerous widespread and severe electrical power outages caused by severe winds, and several of those outages have resulted in upwards of 500,000 electrical customers (more than 5% of the State's population) being without power for several hours to several days at a time. Wind-related damage to electric power facilities and systems is a concern that is being actively addressed by utility companies across the state. Detroit Edison, Consumers Energy and other major electric utility companies have ongoing programs to improve system reliability and protect facilities from damage by severe winds and other hazards. Typically, these programs focus on trimming trees to prevent the encroachment of overhead lines, strengthening vulnerable system components, protecting equipment from lightning strikes, and placing selected distribution lines underground. The Michigan Public Service Commission (MPSC) monitors power system reliability to help minimize the scope and duration of power outages.

Structural Bracing and Wind Engineering

One of the best ways to protect buildings from severe wind damage is to install structural bracing and metal connectors (commonly called hurricane clips) at critical connecting points in the frame of the structure. Typically, this involves adding extra gable end bracing at each end of the structure, anchoring the roof rafters to the walls with metal connector straps, and properly anchoring the walls and sill plate to the foundation. This extra bracing helps ensure that the roof stays on the structure, and the structure stays anchored on its foundation. Experience in high wind events has shown that once the roof begins to peel away from the walls, or the building begins to move off its foundation due to extreme lateral wind forces, major structural damage occurs. If damage continues unabated, complete destruction can occur.

Urban Forestry and Tree Maintenance Programs

Urban forestry programs can be very effective in minimizing storm damage caused by falling trees or tree branches. In almost every severe wind event, falling trees and branches cause power outages and clog public roadways with debris. However, a properly designed, managed, and implemented urban forestry program can help keep tree-related damage and impact to a minimum. To be most effective, an urban forestry program should address tree maintenance in a comprehensive manner, from proper tree selection, to proper placement, to proper tree trimming and long-term care.

Every power company in Michigan has a tree trimming program, and numerous local communities have some type of tree maintenance program. The electrical utility tree trimming programs are aimed at preventing encroachment of trees and tree limbs within power line rights-of-way. Typically, professional tree management companies and utility work crews perform the trimming operations. At the local government level, an increasing number of Michigan municipalities have actual urban forestry departments or agencies. The following municipalities are known to have such programs in place, according to the MDNR's Urban and Community Forestry Program: Adrian, Alma, Ann Arbor, Auburn Hills, Battle Creek, Bloomfield Township, Cadillac, Dearborn, Detroit, Grand Rapids, Grosse Pointe Park, Holland, Kalamazoo, Lansing, Livonia, Marquette, Milford, Monroe, Muskegon, Norway, Novi, Oak Park, Rochester Hills, Royal Oak, Southfield, Southgate, Traverse City, and Troy.

When proper pruning methods are employed, and when the work is done on a regular basis with the aim of reducing potential storm-related damage, these programs can be quite effective. Often, however, tree trimming work is deferred when budgets get tight or other work is deemed a higher priority. When that occurs, the problem usually manifests itself in greater storm-related tree debris management problems down the line.

Hazard Mitigation Activities for Severe Winds

- Increased coverage and use of NOAA Weather Radio, or comparable device-based notifications.
- Public early warning systems and networks.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines. (NOTE: Where appropriate. Burial may cause additional problems and costs when breakage or malfunction occurs, due to the increased difficulty in locating and repairing the problem.)
- Using appropriate wind engineering measures and construction techniques (e.g. structural bracing, straps and clips, anchor bolts, laminated or impact-resistant glass, reinforced entry and garage doors, window shutters, waterproof adhesive sealing strips, and interlocking roof shingles) to strengthen public and private structures against severe wind damage.
- Proper anchoring of manufactured homes and exterior structures such as carports and porches.
- Securing loose materials, yard, and patio items indoors, or where winds cannot blow them about.
- Construction of concrete safe rooms in homes and shelter areas in mobile home parks, fairgrounds, shopping malls, and other vulnerable public or event locations.

Assessments in Local Hazard Mitigation Plans

Severe winds were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Allegan, Antrim, Arenac, Benzie, Berrien, Branch, Calhoun, Charlevoix, Clinton, Crawford, Delta, Dickinson, Eaton, Emmet, Genesee, Gladwin, Grand Traverse, Gratiot, Huron, Ingham, Kalkaska, Keweenaw, Lake, Leelanau, Lenawee, Livingston, Luce, Mackinac, Macomb, Manistee, Marquette, Mason, Menominee, Midland, Missaukee, Muskegon, Oakland, Oceana, Oscoda, Presque Isle, Roscommon, Schoolcraft, Shiawassee, Tuscola, Van Buren, Washtenaw, Wayne, Wexford (47 counties, a decrease from 2014). This constitutes a majority of Michigan's 83 counties, which are located in every part of Michigan.

Extreme Temperatures

Prolonged periods of very high or very low temperatures.

Hazard Description

Temperature extremes are broken down into two categories: extreme heat and extreme cold. Either extreme can last for more than a week and are usually well-predicted by the National Weather Service. Both extreme heat and extreme cold can cause loss of life among vulnerable populations, damage to infrastructure, and disruptions to schools and businesses. Vulnerabilities to extreme heat and cold events can be elevated by lengthy power outages caused by severe storms or winter weather. Such weather events can knock out power (and air conditioning or heating systems) for long periods of time, increasing human vulnerability to extreme heat or cold.

Extreme cold is primarily associated with the wintery months from November to early April, and is categorized by temperatures remaining near or below 0°F. Extreme heat occurs during the warm months from May to September, and is marked by temperatures above 90°F.

Although all counties in Michigan are susceptible to harsh subfreezing temperatures, counties in the North Central and Upper Peninsula of the state typically have more annual days of extreme cold than the southern portions of Michigan, and a similarly more frequent occurrence of sustained low temperatures persisting for multiple days in a row. Periods of extreme cold are risky for those in both rural and in urban areas. Frostbite and hypothermia is common in rural areas where people are trapped outdoors and cannot adjust successfully to the temperatures. Even indoors, hypothermia is a concern for individuals living in inadequately heated apartments or rooms for lengthy periods of time. Loss of life can occur with either of these situations. Damage to buildings and pipelines can also occur as a result of extreme cold, resulting in expensive repairs and possibly days of business and school shutdowns.

Hazard Analysis

Counties in the southern half of the state have a higher average frequency of days exhibiting extreme heat. Urban areas are especially prone to days with soaring temperatures, with the glare and heat-absorbing properties from impervious concrete, asphalt, tar, and glass surfaces; "greenhouse" air pollutants trapping heat near the ground, and fewer trees within densely-developed areas. Outdoor workers, the elderly, and children need to be cautious for during oppressively hot conditions, as they are most at risk for heat exhaustion or even fatal heat strokes. Scorching weather also puts a strain on the energy demands for an area, as air conditioning becomes a necessity for vulnerable populations but power grids are more likely to be overwhelmed during the specific times when demand is at its highest. Possible shutdowns of schools, colleges, and industries can also result from such events.

Prolonged periods of extreme temperatures, whether extreme summer heat or extreme winter cold, can pose severe and life-threatening problems for Michigan's citizens. Although differing in their initiating conditions, the two hazards share a commonality in that they both tend to have a special impact on the most vulnerable segments of the population—the elderly, young children and infants, impoverished individuals, outdoor laborers, and persons who are in poor health. Due to their different characteristics, extreme summer heat and extreme winter cold hazards will mostly be discussed separately in this section. For both types of temperature extremes, however, a longer hot or cold spell makes the temperature effects much more severe on vulnerable populations—a longer duration tends to produce more severe effects. Fortunately, prolonged temperature extremes are much less common than events that involve temperatures briefly entering an extreme level and then returning to normal within the space of a day.

Many residents have the impression that the Upper Peninsula is far more vulnerable to cold and far less vulnerable to heat than the Lower Peninsula is. This is not strictly true, even though there is some variation in average temperatures by latitude. Although it is certainly true that most of the Upper Peninsula receives far more snowfall than the Lower Peninsula, the differences in temperature extremes are much less than the snowfall differences would suggest. Snowstorms are therefore best considered to be a distinct form of winter hazard that, along with severe winds, may exacerbate a situation involving extremely cold temperatures. Actual historical data is presented later in this chapter, showing that although average winter temperatures do tend to be as much as 12 degrees apart (Fahrenheit) between warmer Metropolitan Detroit and the colder inland area of the western Upper Peninsula, these things do vary substantially by proximity to the tempering influence of the Great Lakes. Ironwood (in the inland area of Gogebic

County) actually has colder average temperatures during the winter than the more northerly cities such as Houghton, since the latter benefits more from the weather-tempering effects of Lake Superior. The difference in average winter temperatures between Sault Ste. Marie and Grayling are barely noticeable (within 2 degrees Fahrenheit). During July, the coolest average temperatures are found around Sault Ste. Marie, while the warmest average temperatures, around Detroit, are just 8 degrees higher. Despite average temperatures tending to be a bit lower in the Upper Peninsula, the all-time high and low temperatures within Michigan were both recorded in the northeastern Lower Peninsula (Oscoda and Otsego Counties), rather than in Michigan's far north or south. And state-scale climate conditions tend to be quite important—the record high summer temperature recorded at the Ironwood weather station (Gogebic County) is 104 degrees Fahrenheit, which is actually a degree higher than the record high summer temperature at the station at Port Huron (St. Clair County). Gogebic County tends to be more exposed than most of Michigan to the temperature extremes that blow across Wisconsin from the Great Plains.

During the winter, there are larger geographic temperature differences throughout Michigan than there are during the summer. All parts of Michigan have become dangerously cold during winter and dangerously hot during summer. The main differences involve the frequency with which such extremes tend to occur and persist, on average. Residents in all parts of Michigan must take appropriate precautions during both the winter and non-winter temperature extremes identified in this analysis. This updated chapter now includes more information about the annual date ranges during which low temperatures (5°F or below) and high temperatures (90°F or above) have occurred at 22 observation stations positioned throughout the state, most of which have more than a century of official weather records.

Extreme Summer Heat is characterized by very high temperatures (above 90 degrees Fahrenheit) and/or humid conditions that cause an area's calculated Heat Index (see below) to reach similar "apparent" temperature levels. When persisting for more than just a couple days, this phenomenon is classifiable as a heat wave. The major threats from extreme summer heat are heat exhaustion and heatstroke (a major medical emergency). **Heat exhaustion** is a less severe condition than heatstroke, but it causes problems involving dizziness, weakness and fatigue. Heat exhaustion is often the result of a bodily fluid imbalance as a result of increased perspiration. Treatment generally consists of restoring fluids and staying indoors in a cooler environment until the body returns to normal. If heat exhaustion is not addressed and treated, it can advance to heatstroke, so medical attention should be sought immediately.

Heatstroke symptoms include a high body temperature (it can be 106 degrees or higher), dry skin, inadequate perspiration, paleness or reddening, confusion or irritability, and seizures. The victim may become delirious, stuporous, unconscious, or even comatose. Cooling is essential to preventing permanent neurological damage or death. Other, less serious risks associated with extreme summer heat are often exercise-related and include **heat cramps** (an imbalance of fluids that occurs when those who are unaccustomed to heat exercise outdoors) and **heat syncope** (a loss of consciousness by persons who are not acclimated to hot weather). Periods of hot weather also entail risks of dehydration, even for those who are not engaged in demanding physical activities. Non-caffeinated, non-alcoholic fluids are the best things to consume to maintain adequate hydration.

Although evaporation is a cooling mechanism for our bodies, evaporation of moisture (i.e. perspiration) doesn't occur as rapidly when the surrounding air already has a relatively high moisture content (humidity). Thus, humidity inhibits evaporation and inhibits the body's efforts to cool itself. Winds assist the evaporation of perspiration from skin and thus tend to assist in cooling the body. It is difficult for the body to precisely gauge actual outdoor temperatures—since it mainly senses the rate of heat gain or loss. A period of extreme heat is more debilitating when the air's humidity is high, and a period of extreme cold is similarly more dangerous when coupled with strong winds. For these reasons, temperature alone is usually only a limited indicator of the weather's likely threat to human health, and additional factors should also be considered. The additional factors of humidity and wind speed have provided the basis for two additional means of describing the extent of extreme temperatures' impact—the **Heat Index** (HI) and the **Wind Chill Temperature Index** (WCT). It is also very important to note that wind will only help to cool a person if the air temperature is significantly lower than the person's normal body temperature. A good rule of thumb is that something more than just a fan or breeze will be required for a person's health and comfort if the temperature of the blowing air starts to exceed 95 degrees. The blowing air is simply too close to the person's body temperature to have a benefit, and therefore can trick a person into enduring harmful heat effects and dehydration.

The following tables indicate the way that temperature, humidity, and wind speed probably feels to the average human body, and therefore suggest the types of temperature effects felt within Michigan's weather combinations. Although some of the resulting heat numbers may at first seem outrageous to describe Michigan temperatures, some of the extremes are actually comparable to what is felt in a sauna, which is often set at more than 140 degrees. Like saunas, such heat should not be felt by the body for more than brief periods of time, and since one of the body's cooling reactions is to increase the rate of blood circulation, this also adds to the burden placed on the heart muscle, and can be too much strain for some persons to bear. Yet, persons entering a hot car will often be placing themselves into even hotter conditions than those described in this table for outdoor air temperatures.

Wind Chill Chart

Wind (mph)	Temperature (°F)																	
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

The two indices are mathematically complex, and do not represent a simple linear relationship between the variables of temperature, humidity, or wind speed. Heat Index and Wind Chill calculators can be found online, such as the following Heat Index calculators at http://www.wpc.ncep.noaa.gov/html/heatindex.shtml, and a similar NOAA calculator for wind chill located at http://www.wpc.ncep.noaa.gov/html/windchillbody_txt.html.

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

Although these indices involve a fairly straightforward means of expressing the "feel" of the weather in terms of a temperature equivalent, conditions for each individual will still vary with the duration and type of weather exposure, variations in wind strength at a given location and moment, personal health, extent of acclimation, and the type of clothing worn. For example, exposure to full sunshine can increase heat index values by up to 15%. Also, cooler air holds less moisture, and dryer air readily allows the cooling evaporation of perspiration from skin. In other words, the heat index and wind chill index only involve a consideration of two important factors at a time, but they are still more useful than a consideration of temperature alone. The Heat Index table assumes shady conditions with a light wind. Actual indoor conditions may vary, trapping heat and/or humidity in some locations and making them potentially much more dangerous. Prolonged exposure, physical activity, and age all tend to increase the risks associated with heat. Conditions that might cause heat cramps in a teenager could be experienced as heat exhaustion by a middle-aged person, and as heat stroke by a senior citizen. Young infants are also vulnerable to heat effects, but may lack the means of communicating their needs and discomfort to others, or taking actions to correct their situation.

The following chart summarizes the potential effects felt under the highest Heat Index values:

Heat Index up through 89 degrees:
Caution (Fatigue possible with prolonged exposure and/or physical activity)

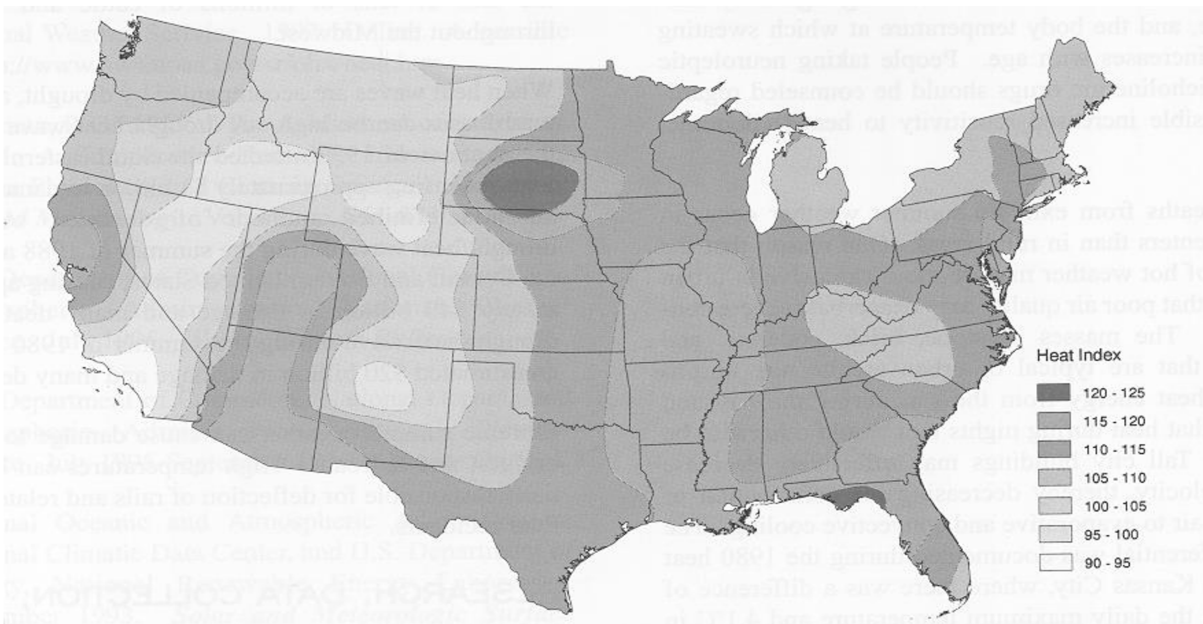
Heat Index in the 90 to 104-degree range:
Extreme Caution (Sunstroke, muscle cramps and/or heat exhaustion possible with prolonged exposure/activity)

Heat Index in the 105 to 129-degree range:
Danger (Sunstroke, muscle cramps, heat exhaustion is likely with prolonged exposure and physical activity)

Heat Index above 130 degrees:
Extreme Danger (Heat stroke or sunstroke is highly likely with prolonged exposure and/or physical activity)

Notice on the following map that Michigan's Heat Index can get as high as some places within the deep south that have a national reputation for their hot weather. For example, the highest temperature recorded in Florida was 109 degrees Fahrenheit, which is actually a few degrees lower than Michigan's record. Florida tends to be a bit more humid, though, on average, especially when compared to the Lower Peninsula, and has seen higher heat index values.

Severity and Extent of Extreme Summer Heat in the United States



Source: U.S. Department of Commerce; *Multi-Hazard Identification and Risk Assessment*, 1999, FEMA

In Michigan, heat advisories will tend to be announced when the heat index is calculated to exceed 100 degrees in an area for a period of at least 3 hours in duration. An excessive heat warning will be issued if the calculated heat index will be at least 105 degrees for three or more hours. These can be extended

It should be noted, however, that the temperature inside of vehicles without air conditioning can be dozens of degrees hotter than the outdoor temperature—an outdoor temperature might be "only" 90 or 100 degrees Fahrenheit, but people may then get into a car that exceeds 130 degrees. People vary in their capacity to tolerate extreme temperatures, and can find themselves in circumstances like these that threaten their health even if no official temperature advisory has been issued. Many hundreds of children have died (nationwide) in overheated cars during recent decades, probably because many persons don't realize how quickly a car interior can heat up on a hot, sunny day while they "briefly" go indoors while leaving a child in a closed car. The most common fatalities involve babies under 1 year old, who cannot keep cool as well as older persons, under the same temperature conditions. In less than 10 minutes, the internal car temperature can go over 100°F, and a child's body temperature rises much faster than an adult's. Parking in the shade with windows cracked open does not provide sufficient cooling to safeguard human health within a parked car on a hot day. A closed car can become hot enough to cause heatstroke on a sunny day, even when the outdoor air temperature is no higher than 70°F! The car and its windows act just like a poorly-designed greenhouse, quickly overheating the vehicle's interior beyond a level that young children can tolerate. Pet owners will also want to make note of this problem.

Heat History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	**Extreme Heat Events**	**Days with Extreme Heat**	**Injuries**	**Deaths**
Washtenaw	12	12	17	
Wayne	14	14	541	3
.Livingston	12	12	4	
Oakland	15	15	194	5
Macomb	13	13	60	
5 Co Metro region	**13 avg.**	**13 avg.**	**816**	**8**
Berrien				
Cass				
St. Joseph				
Branch				
Hillsdale				
Lenawee	12	12	2	
Monroe	12	12	2	
.Van Buren				
Kalamazoo				
Calhoun				
Jackson				
.Allegan				
Barry				
Eaton				
Ingham				
.Ottawa				
Kent				
Ionia				
Clinton				
Shiawassee	11	11	5	
Genesee	11	11	23	
Lapeer	11	11	1	
St. Clair	11	11	7	
.Muskegon				
Montcalm				
Gratiot				
Saginaw	11	11	19	
Tuscola	11	11	1	
Sanilac	10	10	1	
.Mecosta				
Isabella				
Midland	11	11	3	
Bay	11	11	1	
Huron	10	10	1	
34 Co S Lower Pen	**3.9 avg.**	**3.9 avg.**	**66**	

Continued on next page…

Part 2 of Extreme Heat History for Michigan Counties – arranged by geographic divisions

.Oceana				
Newaygo				
.Mason				
Lake				
Osceola				
Clare				
Gladwin	1	1		
Arenac	1	1		
.Manistee	1	1		
Wexford	1	1		
Missaukee	1	1		
Roscommon	1	1		
Ogemaw	1	1		
Iosco	1	1		
.Benzie	1	1		
Grand Traverse	1	1		
Kalkaska	1	1		
Crawford	1	1		
Oscoda	1	1		
Alcona	1	1		
.Leelanau	1	1		
Antrim	1	1		
Otsego	1	1		
Montmorency	1	1		
Alpena	1	1		
.Charlevoix	1	1		
Emmet	1	1		
Cheboygan	1	1		
Presque Isle	1	1		
29 Co N Lower Pn	**0.8 avg.**	**0.8 avg.**		
Gogebic	1	1		
Iron	1	1		
Ontonagon	1	1		
Houghton	2	1		
Keweenaw	1	1		
Baraga	1	1		
.Marquette	1	1		
Dickinson	1	1		
Menominee	1	1		
Delta				
Schoolcraft				
Alger	1	1		
.Luce				
Mackinac	1	1		
Chippewa	1	1		
15 Co Upp.Pen	**0.9 avg.**	**0.8 avg.**		
MICHIGAN TOT.	**234**	**33**	**882**	**8**
Annual average	**11**	**1.5**	**41**	**0.4**

Note: Includes the NCDC categories of "Excessive Heat" and "Heat."

Heat waves tend to have stagnant atmospheric conditions that trap pollutants in urban areas and thus compound the health effects faced by urban residents. Because the combined effects of high temperatures, high humidity, and trapped pollution are focused more intensely in urban centers, heatstroke and heat exhaustion are a greater problem in sizeable cities than in suburban or rural areas. Nationwide, an average of 134 deaths per year were attributable to extreme heat over the 30-year period from 1988 to 2017, according to http://www.nws.noaa.gov/om/hazstats.shtml). Fortunately, the average in Michigan has come down to just one per year, although there is still a potential for widespread casualties if a power outage occurs during a heat wave. Extreme summer heat is also hazardous to livestock, pets, and agricultural crops, and it can cause water shortages, exacerbate fire hazards, and prompt excessive demands for energy that can cause power failures. Roads, bridges, railroad tracks and other infrastructure are susceptible to damage from extreme heat (due to the effects of thermal expansion on materials). Scorching weather also puts a strain on the energy demands for an area, as the use of air conditioning increases greatly. Possible shutdowns of schools, colleges, and industries can occur during these times.

Air conditioning is probably the most effective measure for mitigating the effects of extreme summer heat on individuals. Unfortunately, those who do not live or work in air-conditioned environments will remain vulnerable, especially in major urban centers, where "cooling centers" may be provided to assist such persons. The use of fans to move air may help some persons feel more comfortable, but only until the temperature reaches the mid-90s, at which point fans will not prevent heat-related illnesses. Bathing with cool water is more effective, but moving to a cooler environment (a basement or air-conditioned location) is most effective—even if only for a few hours per day. Indoor temperatures may easily exceed outdoor temperatures, especially above ground level, where warmer indoor will rise to. Many apartment buildings have lower levels that can provide some relief from the hotter temperatures on the floors above.

To mitigate the extreme heat of summer, communities should have a contingency plan in place to protect those persons who are most vulnerable to the heat. These contingency plans should include: designating and supporting "cooling center" sites where people can go to get out of the heat; a hierarchy of closings for industries, businesses, and schools during shutdown periods; and a means of educating the public about the dangers of heat conditions. The monitoring of dangerous conditions can also be done through the National Weather Service website. A risk assessment should calculate the likelihood of such incidents and the number of days of extreme temperatures likely to be experienced in your community each year. It should also take account of past losses and harm caused by such events, and determine who or what is still vulnerable to such conditions today.

Heat waves severe enough to threaten health do not occur every year, and several relatively mild summers may intervene between major heat waves. The problem is complicated by the fact that long-term weather forecasts cannot reliably predict prolonged periods of extreme summer heat. Short-term forecasts of hot weather are more accurate, but often leave little time for mobilizing to effectively combat the hazard. Nevertheless, planning and preparedness activities can occur to mitigate the effects of this weather hazard.

Because of its geographic location in relation to the Great Lakes, Michigan is somewhat less susceptible to prolonged periods of extreme hot temperatures than are many other states. However, the Upper Midwest, in which Michigan is located, is definitely vulnerable to extreme temperature events. As a result, Michigan communities (and particularly urban centers) must always be prepared to respond to heat events in an organized, coordinated and expedient manner. Extreme summer heat poses the greatest danger to urban residents—especially the elderly, children, outdoor laborers, people with poor health, and people residing in homes without air conditioning. Michigan's urban communities must address extreme summer heat in their emergency preparedness efforts. Human service agencies, voluntary organizations, health departments, medical and health care facilities, and schools may have a role in response to a heat wave. The Michigan Department of Community Health, together with local health departments, medical and health care facilities, may have to establish specialized medical surge facilities to assist in the care of a large number of persons who may be affected in such events. In addition, the local media could be tapped to assist in information dissemination and community outreach efforts.

In an average year, Michigan has many days above 90° Fahrenheit. MDCH and NWS estimate between 1 and 5 deaths per year, on average, due to extreme heat. Although larger cities have been noted as having more risk from extreme heat, it should also be noted that residents in isolated rural locations may have trouble accessing air-conditioned places, or reaching designated cooling shelters. Such access may be easier for urban residents.

Extreme Winter Cold periods can, like heat waves, result in a significant number of temperature-related deaths. Each year in the United States, approximately 700 persons die as a result of severe cold temperature-related causes. This is substantially higher than the average of 175 heat-related deaths each year. It should be noted that a significant number of cold-related deaths are not the direct result of "freezing" conditions. Rather, many deaths are the result of illnesses and diseases that are negatively impacted by severe cold weather, such as stroke, heart disease and pneumonia. It could convincingly be argued that, were it not for the extreme cold temperatures, death would not have occurred at the time that it did due to the illness or disease alone. There are, in various parts of Michigan, an average of between 3 and 50 (or more) days per year at or below 0° Fahrenheit. Michigan also tends to have between 90 and 180 (or more) days per year in which the temperature is below the freezing point.

Hypothermia (the unintentional lowering of core body temperature), and **frostbite** (damage from tissue being frozen) are probably the two conditions most closely associated with cold temperature-related injury and death. Hypothermia is usually the result of over-exposure to the cold, and is generally thought to be clinically significant when core body temperature reaches 95 degrees or less. As body temperature drops, the victim may slip in and out of consciousness, and appear confused or disoriented. Treatment normally involves warming the victim (preferably performed by trained medical personnel) but frostbitten areas should not be rubbed. Although frostbite damage itself rarely results in death (which may occur due to hypothermia instead), in extreme cases it can result in the amputation of the affected body tissue.

Periods of extreme cold are risky for those in both rural and in urban areas. Frostbite and hypothermia is common in rural areas where people are trapped outdoors and do not adjust properly to the temperatures. Even indoors, hypothermia is a concern for individuals living in inadequately heated apartments or rooms. Loss of life can occur with either of these situations. Damage to buildings and pipelines can also occur in bitter cold conditions, resulting in expensive repairs and potential days of business and school shutdowns.

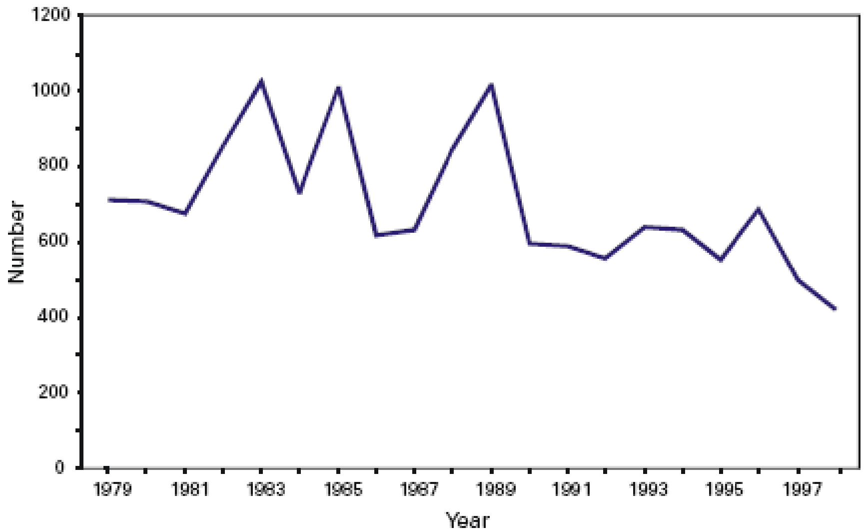
To mitigate the effects of the unfavorable cold temperatures, communities should make sure that housing codes are appropriate and that adequate furnaces are in place in apartment dwellings. Inspections of vulnerable and outdated infrastructure should be made in the fall season, before winter sets in. In addition, proper insulation of piped areas can prevent water main breaks.

In the wind chill chart, extremely low apparent temperatures can also be associated with an amount of exposure time that it takes to cause frostbite. Cells of the table that have darker shadings denote wind chill temperatures that can produce frostbite in 10 minutes or less. Cells with lighter shadings are associated with frostbite times of 30 minutes or less. Unshaded cells in the table should require longer exposure times to cause frostbite. Again, the chart displays only two factors that contribute heavily to risk, but risk can be increased for an individual in particular circumstances. For example, people should be aware that the drier air (common to winter weather) also allows a more rapid drop in temperature than is the case with warm summer air. As a cold front moves in, or as daytime high temperatures for the day change to nighttime low temperatures, the corresponding drop in temperature can be much greater when the humidity is low. Persons who are outdoors can rapidly find themselves in danger of hypothermia.

Hypothermia usually occurs in one of two sets of circumstances. One situation involves hypothermia associated with prolonged exposure to cold while participating in outdoor sports such as skiing, hiking or camping. Most victims of this form of hypothermia tend to be young, generally healthy individuals who may lack experience in dealing with extreme cold temperatures. The second situation involves a particularly vulnerable person who is subjected to only a moderate, indoor cold stress. A common example would be that of an elderly person living in an inadequately heated home. In such circumstances, hypothermia may not occur until days or perhaps weeks after the cold stress begins. Isolated rural locations may involve difficulties in reaching a heated space, or a designated warming shelter.

Deaths due to extreme winter cold are often not associated with a particular weather event. Rather, they are the result of a one-time over-exposure to severe cold weather (a hiker lost in the woods, or car failure in a rural area), or more commonly from continuous exposure to moderate cold temperatures by vulnerable persons (such as the elderly). In some cases, hypothermia deaths can be linked to severe winter weather such as snowstorms or blizzards, where the victim is caught unprepared for the extreme cold temperatures. As mentioned earlier, many cold temperature-related deaths involve the exacerbation of an existing, serious medical condition such as heart disease or pneumonia. In Michigan, approximately 70% of weather-related fatalities (about 40 deaths per year) are attributed to exposure to the cold (according to the Michigan Department of Community Health and the National Weather Service). The following 20-year table gives an indicator for the nation as a whole.

Number of Hypothermia-Related Deaths in U.S.: 1979-1998



Source: CDC Morbidity and Mortality Weekly Report

The special vulnerability of elderly persons to hypothermia has become apparent. Over half of the hundreds who die each year due to cold exposure are 60 years of age or older, even though this age group only represents about 20% of the country's population. This remarkable statistic may be due, in part, to an impaired perception of cold as well as the voluntarily setting of thermostats to relatively low temperatures. In addition, high energy costs and the relative poverty among some elderly people may discourage their setting thermostats high enough to maintain adequate warmth (just as it may cause others to limit their use of fans and air conditioning during summer heat waves). Because many elderly people live alone and do not have regular visitors, the cold conditions may persist for several days or weeks, thus allowing hypothermia to set in.

Babies and very young children are also very vulnerable to hypothermia. In addition, statistics indicate that death due to cold is more frequent among males than females in virtually all age groups. Part of that may be explained by differences in risk factors, and part may be due to different rates of cold exposure between activities performed by different sexes. Cold weather also increases blood viscosity, narrows small blood vessels, and increases blood pressure, all of which increase the risk of cardiovascular problems (e.g. a heart attack).

As explained in the general introduction to the weather hazards section of this plan, there should be no presumption made that temperatures will automatically be higher or lower in a southern or northern part of the state, despite the existence of certain trends and correlations. All parts of Michigan experience temperature extremes that threaten health. In fact, Michigan's two most extreme temperatures on record did not occur either in the extreme north of the Upper Peninsula or at the extreme south of the Lower Peninsula, but rather at locations in between – in the Northern part of the Lower Peninsula. The record low temperature of -51 was measured at Vanderbilt (located in Otsego County) and the record high of 112 was at Mio (located in Oscoda County).

Cold History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Extreme Cold Events	Days with Extreme Cold	Tot. property damage	Tot. crop damage	Injuries	Deaths
Washtenaw	14	14	$500,000	$1,300,000	10	
Wayne	20	19	$275,000		34	9
.Livingston	13	13	$25,000	$1,300,000	10	
Oakland	14	14	$25,000	$1,300,000	14	4
Macomb	15	15	$25,000	$1,300,000	11	3
5 Co Metro region	**15.2 avg.**	**15 avg.**	**$850,000**	**$5,200,000**	**79**	**16**
Berrien	3	3		$8,000,000		
Cass	3	3		$4,000,000		
St. Joseph	2	2				
Branch	2	2				
Hillsdale	2	2				
Lenawee	15	15	$1,025,000	$1,300,000	10	
Monroe	15	15	$25,000	$1,300,000	10	
.Van Buren						
Kalamazoo						
Calhoun						
Jackson						
.Allegan						
Barry						
Eaton						
Ingham						
.Ottawa						
Kent	1	1	$150,000			
Ionia						
Clinton						
Shiawassee	12	12	$25,000	$1,300,000	10	
Genesee	14	14	$25,000	$1,300,000	11	
Lapeer	13	13	$25,000	$1,300,000	10	
St. Clair	13	13	$25,000	$1,300,000	10	
.Muskegon						
Montcalm	1	1	$100,000			
Gratiot						
Saginaw	13	13	$525,000	$1,300,000	10	
Tuscola	12	12	$25,000	$1,300,000	10	
Sanilac	14	14	$25,000	$1,300,000	10	1
.Mecosta						
Isabella						
Midland	12	12	$25,000	$1,300,000	10	
Bay	13	13	$25,000	$1,300,000	10	2
Huron	12	12	$25,000	$1,300,000	10	
34 Co S Lower Pen	**5.1 avg.**	**5.1 avg.**	**$2,050,000**	**$27,600,000**	**121**	**3**

Continued on next page…

Part 2 of Extreme Cold History for Michigan Counties – arranged by geographic division

.Oceana	1	1		$2,000,000		
Newaygo						
.Mason						
Lake						
Osceola						
Clare						
Gladwin	3	3				
Arenac	3	3				
.Manistee	3	3		$10,000,000		
Wexford	3	3				
Missaukee	3	3				
Roscommon	4	4				
Ogemaw	3	3				
Iosco	3	3				
.Benzie	2	2		$15,000,000		
Grand Traverse	3	3		$15,000,000		
Kalkaska	3	3				
Crawford	4	4				
Oscoda	0	0				
Alcona	3	3				
.Leelanau	3	3				
Antrim	2	2		$10,000,000		
Otsego	3	3				
Montmorency	3	3				
Alpena	3	3				
.Charlevoix	3	3		$7,500,000		
Emmet	4	4		$5,000,000		
Cheboygan	4	4		$5,000,000		
Presque Isle	4	4		$5,000,000		
29 Co N Lower Pn	**2.4 avg.**	**2.4 avg.**		**$74,500,000**		
Gogebic	45	45				
Iron	42	42				1
Ontonagon	35	35				
Houghton	47	32				
Keweenaw	17	17				
Baraga	34	34				
.Marquette	33	33				
Dickinson	37	36				
Menominee	26	26				
Delta	28	28				
Schoolcraft	37	24				
Alger	37	24				
.Luce	19	18				
Mackinac	3	3				
Chippewa	5	5				
15 Co Upp.Pen	**30 avg.**	**27 avg.**				**1**
MICHIGAN TOTAL	**746**	**102**	**$2,800,000**	**$134,900,000**	**200**	**21**
Annual average	**35**	**4.8**	**$131,252**	**$6,323,536**	**9.4**	**1.0**

NOTE: Includes the NCDC categories of “Cold/Wind Chill,” “Extreme Cold,” and “Frost/Freeze.”

Nevertheless, there is some variation across Michigan in 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 tend to be issued when the Wind Chill Temperature is within the -15 to -24 range. In northern Michigan and the Upper Peninsula, advisories tend to be issued when the WCT is within the -20 to -29 range. Wind chill warnings tend to be issued when the WCT gets down to -25 or below, in southern Michigan, or when it gets down to -30 or below, in northern Michigan.

Maps on the following pages illustrate the average number of days above 90 degrees and the average number of days below zero degrees, Fahrenheit. Although they are based on the three decades from 1971 to 2001, they give an excellent indication of the "typical" annual risk and exposure to Michigan summer and winter temperature extremes, for all of Michigan's counties.

A different type of risk indicator is provided in the following table that lists record low and high temperatures for numerous weather stations across Michigan. For convenience, the listings are divided into three regions: the Southern Lower Peninsula, Northern Lower Peninsula, and Upper Peninsula. Note that these records are for specific stations, and do not necessarily represent all-time records for the counties or surrounding localities in that area. They should instead be taken as an indicator of the extremes to which various specific locations have experienced, across the state.

As already noted in the Introduction to the Weather Hazards section of this plan, although it makes sense to think in terms of three general Michigan regions for an analysis of trends and weather patterns, the extreme temperature hazard must be understood to be a significant one in every part of the state. This is true of both summer and winter temperature extremes. In general, however, "seasons" can be defined for these three regions, to denote when there is a serious risk of extreme temperature events. These "seasons" are based upon the historical occurrence of very high temperatures (above 90 degrees) and very low temperatures (near zero degrees, or below) and will here be generally defined:

	Extreme Heat Risk Season	**Extreme Cold Risk Season**
Southern Lower Peninsula	Early May to late September	Late November to early April
Northern Lower Peninsula	Late May to late September	Early November to April
Upper Peninsula	Late May to early September	Late September to May

NOTE: Extend the non-winter risk season to early October for the southernmost tiers of counties, such as Berrien and Wayne. Variation will be expected between counties, especially shoreline counties that have more moderate weather patterns, but the "seasons" described here may serve as good "rules of thumb." Although some areas have fewer at-risk months, all areas might be equally at risk when in the midst of each risk season. Even though there are differences and trends within and between regions, all parts of Michigan have repeatedly experienced both temperature extremes. The commonalities shared by Michigan's regions are often more important than their differences, when it comes to weather-hazard preparedness and mitigation.

NOTE: Do not use these "seasons" to define wind and tornado risks, since strong tornadoes have occurred in months such as October and April. Also, please note that **freezing rain and ice/sleet storms may occur** whenever the temperatures can reach the freezing point of 32°F, which is a much longer time period than the winter risk season defined here (effectively including almost the entire calendar year, regardless of location).

Historic Temperature Records at Various Michigan Locations

The counties listed below start with the southernmost tier in Michigan, and proceed generally northward, tier by tier. Big Rapids is situated on the very edge of the southern and northern regions, and its record low fits the northern region.

Southern Lower Peninsula	**Record Low Temperature**	**Record High Temperature**
Adrian (Lenawee County)	-26° (Jan. 20, 1892)	108° (7/14/1936, 7/24/1934)
Benton Harbor (Berrien County)	-19° (Nov. 25, 1950)	104° (7/21/2002, 7/30/1999)
Coldwater (Branch County)	-23° (Jan. 4, 1981)	108° (July 24, 1934)
Ann Arbor (Washtenaw County)	-23° (Feb. 11, 1885)	105° (July 24, 1934)
Bloomingdale (Van Buren Co.)	-23° (Feb. 3, 1996)	105° (7/5/1911, 7/13/1936)
Detroit (Wayne County)	-21° (Jan. 21, 1984)	105° (July 24, 1934)
Jackson (Jackson County)	-20° (1/18/1976, 1/19/1994)	103° (July 15, 1977)
Pontiac (Oakland County)	-22° (Feb. 5, 1918)	104° (7/6/1988, 7/8/1936, 7/16/1988, 7/24/1934)
Flint (Genesee County)	-25° (1/18/1976, 2/20/2015)	108° (7/8/1934, 7/13/1936)
Grand Rapids (Kent County)	-24° (Feb. 13 & 14, 1899)	108° (July 13, 1936)
Port Huron (St. Clair County)	-19° (Jan. 19, 1994)	103° (July 9, 1936)
Saginaw (Saginaw County)	-23° (Feb. 5, 1918)	111° (July 9, 1936)
Harbor Beach (Huron County)	-22° (Feb. 9, 1934)	105° (July 10, 1936)
Big Rapids (Mecosta County)	-36° (Feb. 11, 1899)	103° (7/30/1916, 7/13-14/36)

Northern Lower Peninsula	**Record Low Temperature**	**Record High Temperature**
Houghton Lake (Roscommon Co)	-34° (Feb. 17, 1979)	103° (June 19, 1995)
Alpena (Alpena County)	-37° (Feb. 17, 1979)	106° (July 13, 1936)
East Tawas (Iosco County)	-29° (2/1/1918, 2/20/1929)	106° (7/8-9/1936)
Gaylord (Otsego County)	-37° (Feb. 17, 1979)	101° (7/11/1921, 7/30/1916)
Gladwin (Gladwin County)	-39° (Feb. 20, 1979)	105° (July 13, 1936)
Traverse City (Gd. Traverse Co.)	-37° (Feb. 17, 1979)	105° (July 7, 1936)
Upper Peninsula	**Record Low Temperature**	**Record High Temperature**
Hancock (Houghton County)	-30° (2/9/1951, 2/10/1948)	102° (July 7, 1988)
Ironwood (Gogebic County)	-41° (1/17/1982, 2/12/1967)	104° (July 13, 1936)
Munising (Alger County)	-33° (Feb. 25, 1928)	103° (7/7-9/1936, 8/6/1947)
Sault Ste. Marie (Chippewa Co.)	-37° (2/8/1934, 2/10/1899)	98° (7/3/1921, 7/30/1916, 8/5-6/1947)
Statewide all-time records	-51° (Feb. 9, 1934) Vanderbilt (Otsego County)	112° (July 13, 1936) Mio (Oscoda Co.) and Stanwood (Mecosta Co.)

Source: Extreme Michigan Weather, by Paul Gross (2010, University of Michigan Press, Ann Arbor), updated with feedback from Michigan's regional NWS offices and from https://www.ncdc.noaa.gov/extremes/scec/records

The following table shows the historical trends in terms of calendar dates during which the earliest and latest record temperatures were recorded at each location (in parentheses). 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 below 5°F between November 28 and March 19, with the earliest date on record being November 23 and the latest recorded date being March 28. This kind of pattern had already been summarized within the "Extreme Cold Risk Season" of Late November to early April, for the Southern Lower Peninsula. (Those "risk seasons" include not just extreme temperatures, but other seasonal weather hazards such as heavy snow.)

The counties listed below start with the southernmost tier in Michigan, and proceed generally northward, tier by tier. Big Rapids is situated on the very edge of the southern and northern regions, and its record low fits the northern region.

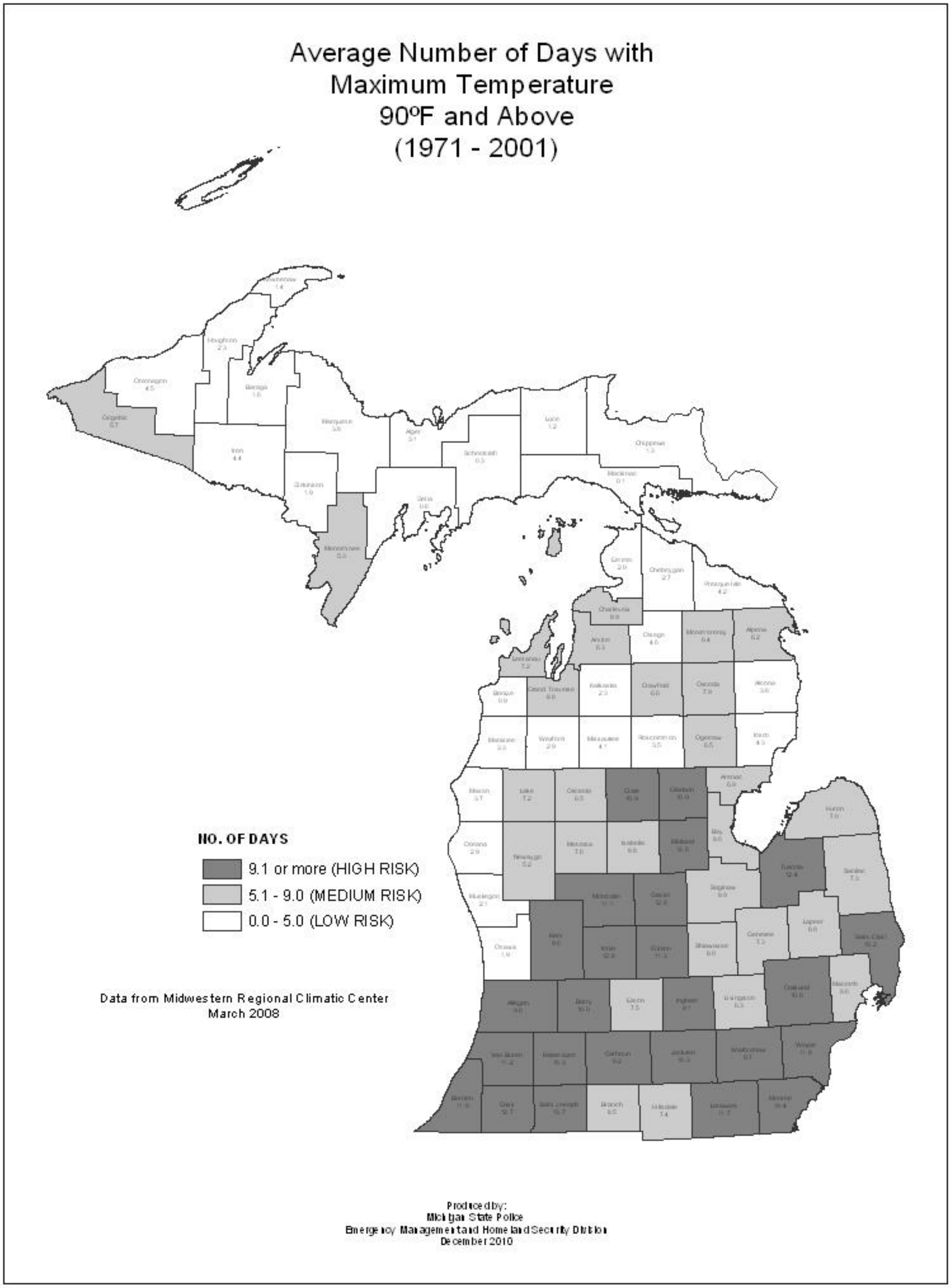
Historic Temperature Trends at Various Michigan Locations

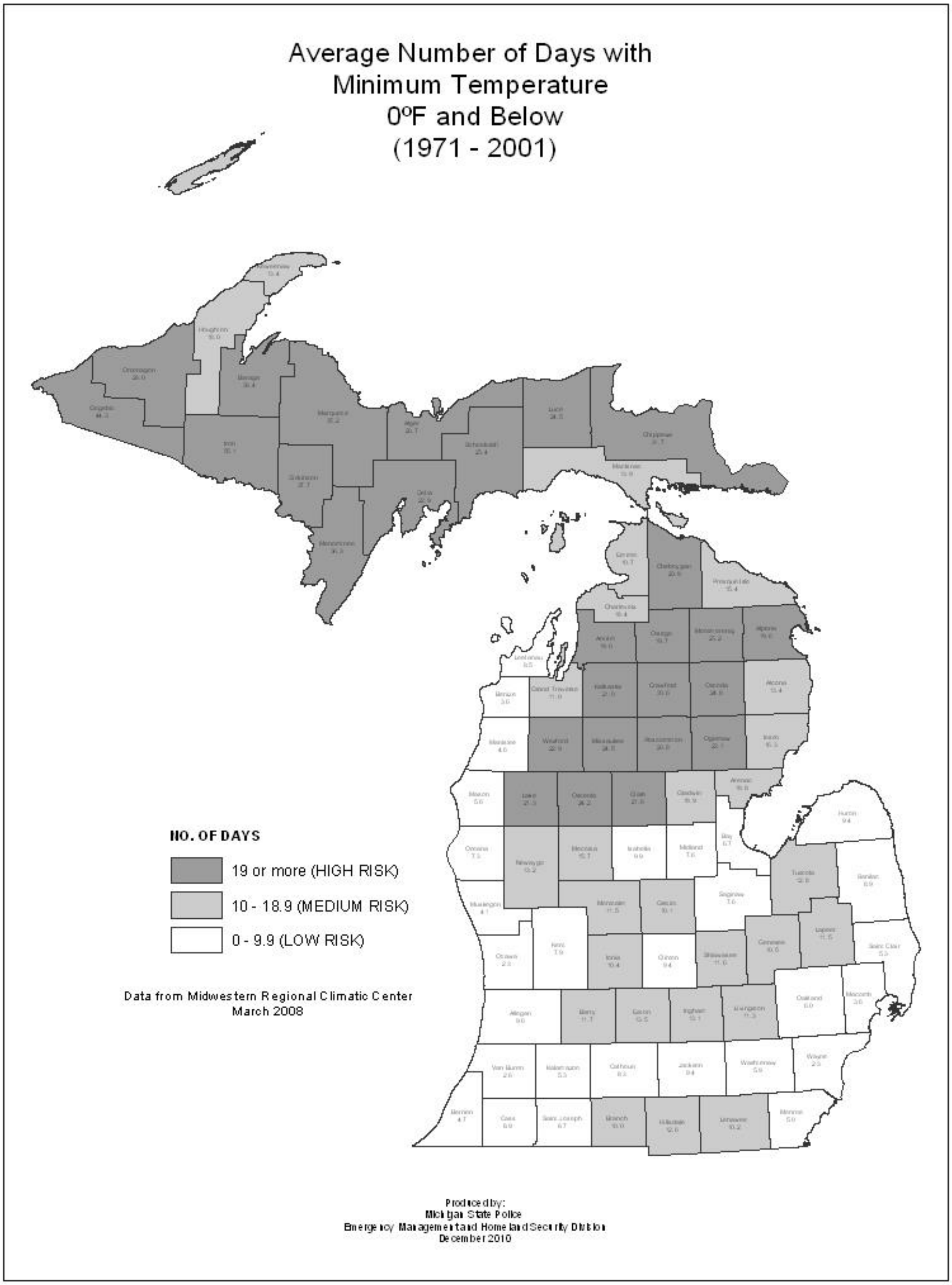
FORMAT: (Earliest date of extreme temperature) Regular period of risk (Latest date of extreme temperature)

Southern Lower Peninsula	**Low Temperatures (< 5°F)**	**High Temperatures (>90°F)**
Adrian (Lenawee County)	(Nov. 23) Nov.28-Mar.19 (Mar. 28)	(Apr. 24) May 15-Sept.29 (Oct. 8)
Benton Harbor (Berrien County)	(Nov. 21) Dec. 8-Mar. 3 (Mar. 26)	(Apr. 29) May 17-Sept. 27 (Oct. 7)
Coldwater (Branch County)	(Nov. 16) Dec. 2-Mar. 19 (Mar. 31)	(May 17) May 25-Sept. 19 (Sept. 29)
Ann Arbor (Washtenaw County)	(Nov. 24) Nov. 29-Mar. 10 (Mar. 31)	(May 5) May 26-Sept. 22 (Oct. 1)
Bloomingdale (Van Buren Co.)	(Nov. 18) Dec. 6-Mar. 17 (Apr. 8)	(May 2) May 25-Sept. 22 (Sept. 29)
Detroit (Wayne County)	(Nov. 21) Dec. 7-Mar. 11 (Mar. 29)	(May 5) May 26-Sept. 22 (Oct. 7)
Jackson (Jackson County)	(Nov. 16) Nov. 28-Mar. 14 (Apr. 7)	(May 8) May 15-Sept. 26 (Oct. 4)
Pontiac (Oakland County)	(Nov. 15) Nov. 24-Mar. 20 (Mar. 28)	(May 5) May 26-Sept. 22 (Oct. 8)
Flint (Genesee County)	(Nov. 24) Dec. 6-Mar. 15 (Mar. 31)	(May 5) May 26-Sept. 19 (Sept. 26)
Grand Rapids (Kent County)	(Nov. 23) Dec. 5-Mar. 20 (Apr. 7)	(Apr. 29) May 27-Sept. 25 (Sept. 29)
Port Huron (St. Clair County)	(Nov. 16) Dec. 8-Mar. 12 (Mar. 25)	(May 5) June 4-Sept.13 (Oct. 8)
Harbor Beach (Huron County)	(Nov. 16) Dec. 6-Mar. 13 (Apr. 1)	(May 5) June 1-Sept. 19 (Sept. 27)
Big Rapids (Mecosta County)	(Nov. 6) Nov. 23-Apr. 1 (Apr.7)	(May 18) June 4-Sept. 15 (Sept. 21)

Northern Lower Peninsula	**Low Temperatures (< 5°F)**	**High Temperatures (>90°F)**
Alpena (Alpena County)	(Nov. 6) Nov. 22-Apr. 7 (Apr. 9)	(Apr. 16) May 26-Sept. 18 (Oct. 8)
East Tawas (Iosco County)	(Nov. 15) Nov. 22-Mar. 26 (Apr. 4)	(Apr. 26) June 5-Sept. 4 (Oct. 9)
Gaylord (Otsego County)	(Nov. 6) Nov. 23-Apr. 9 (Apr. 26)	(May 15) June 10-Sept. 10 (Sept. 14)
Gladwin (Gladwin County)	(Nov. 5) Nov. 21-Mar. 27 (Apr. 9)	(Apr. 26) May 28-Sept. 15 (Oct. 9)
Traverse City (Gd. Traverse Co.)	(Nov. 6) Nov. 29-Mar. 29 (Apr. 8)	(Apr. 29) May 27-Sept. 18 (Sept. 29)
Upper Peninsula	**Low Temperatures (< 5°F)**	**High Temperatures (>90°F)**
Hancock (Houghton County)	(Nov. 2) Nov. 21-Apr. 6 (Apr. 19)	(May 16) June 12-Aug. 1 (Sept. 15)
Ironwood (Gogebic County)	(Oct. 24) Nov. 6-Apr. 10 (Apr. 18)	(May 2) June 9-Sept. 15 (Sept. 15)
Munising (Alger County)	(Oct. 30) Nov. 27-Apr. 10 (Apr. 20)	(May 5) May 27-Aug. 21 (Sept. 18)
Sault Ste. Marie (Chippewa Co.)	(Nov. 13) Nov. 19-Apr. 1 (Apr. 19)	(May 19) June 22-Aug. 15 (Sept. 12)

Source: Extreme Michigan Weather, by Paul Gross (2010, University of Michigan Press, Ann Arbor)


Average Number of Days with
Maximum Temperature
90ºF and Above
(1971 - 2001)
NO. OF DAYS
9.1 or more (HIGH RISK)
5.1 - 9.0 (MEDIUM RISK)
0.0 - 5.0 (LOW RISK)
Data from Midwestern Regional Climatic Center
March 2008
Produced by:
Michigan State Police
Emergency Management and Homeland Security Division
December 2010


Average Number of Days with
Minimum Temperature
0ºF and Below
(1971 - 2001)
NO. OF DAYS
19 or more (HIGH RISK)
10 - 18.9 (MEDIUM RISK)
0 - 9.9 (LOW RISK)
Data from Midwestern Regional Climatic Center
March 2008
Produced by:
Michigan State Police
Emergency Management and Homeland Security Division
December 2010

These tables show all the record low and high temperatures at various weather stations across Michigan. It can be noted that the majority of record low temperatures occurred in January and February, and the majority of record high temperatures took place in July. This pattern holds true across all of Michigan's regions. It should also be noted that lower-lying areas often experience colder temperatures, since colder air is denser and heavier and thus tends to sink to lower areas. Local variations of that type help to explain why the absolute coldest and hottest temperature extremes ever recorded in Michigan are more extreme than the various records listed for specific weather stations.

The tempering effects of the Great Lakes also help moderate the impact of the severe cold weather normally prevalent in the Midwest during the winter months. Even so, Michigan still endures many days of extremely cold temperatures in an average winter, and prolonged periods of extreme cold are not uncommon during the months of January and February. During those months especially, increased outreach to elderly persons - particularly those living alone - is certainly warranted. In addition, communities should be particularly cognizant of the vulnerability of elderly as well as very young persons when power outages occur due to ice and snowstorms. When outages are expected to last for several hours or more, consideration should be given to opening warming shelters. Once power is restored, outreach to the elderly may be necessary to ensure that furnaces have been re-started and are working properly.

Extreme cold temperatures are a universal hazard in Michigan. Whereas heat waves tend to impact urban centers more than suburban or rural areas, cold temperatures are an "equal opportunity" killer. Every community in Michigan is vulnerable, regardless of location or size. It must also be noted that many of the agricultural sectors of Michigan are vulnerable to crop losses because of extreme cold events. A couple of severe recent events have involved unusually warm temperatures, which plant life may treat as a return of Spring, followed by a re-freeze when the plants have made themselves more vulnerable and which can therefore be devastating to them.

Impact on the Public, Property, Facilities, and Infrastructure

Extreme temperatures can have direct impacts on personal health and productivity, which may collectively lead to reductions in economic activity and travel (e.g. tourism, shopping). Extreme temperature events tend to cause greater energy use, which can involve not only higher energy costs but can also result in infrastructure failures due to limitations in the capacity of the utility system. About 900 annual deaths nationwide have been attributed to extreme temperatures (mostly from extreme cold, involved in about 700 deaths), ranking this hazard as the second leading cause of fatalities (behind structural fires). The main impacts upon property, facilities, and infrastructure come from the damaging effects of frozen pipes. These can range from small internal building pipes to large utility mains. Freezing can cause leaks or complete structural failure of the pipe. Water supplies are then lost and can cause extensive structural damage. Water main breaks can erode underground materials and cause ground and road subsidence.

Impact on the Economic Condition of the State

Extreme temperature events tend to be transient, but they may discourage travel and outdoor activities and thus reduce the turnout for large spectator events (e.g. fairs and festivals, sports matches, or music concerts). Where such events do attract large crowds during periods of extreme temperatures, medical needs may be increased. For the most part, there is not a large economic impact upon Michigan's economy from these events. Their risks are well-known and often controllable with proper clothing and provisions. Organizers of outdoor events must be familiar with the risks of adverse weather and temperatures, and the means by which their event can still succeed in spite of those risks. However, at a local level, businesses can indeed be by the impact of heat waves and deep freezes upon their operations. But often, customers still spend money on supplies and entertainment—they just might change the time and place of their spending a bit, avoiding the worst periods of extreme temperatures. Other businesses tend to make additional money during these same times, and so the overall effect upon the state's economy is not known to be a large one.

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

Heat and 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 (and maintenance) tends to become necessary under conditions of extreme cold. Frozen pipes may inhibit or limit responders' access to water that is needed to fight fires, and extra activities and caution may be needed around wintry fire zones where water may have frozen and made footing treacherous for emergency workers (and others). However, the interruption of water supply can be of great concern to certain businesses, institutions, and events—especially those involving human services for vulnerable populations, or those that are very important for an area's production and employment.

Impact on the Environment

Periods of extreme heat or cold can affect the environment in several ways. When the temperature rises, power consumption increases, as households and public buildings require more energy to run air conditioning. Agricultural areas also use more pumped water as irrigation is increased. More coal is burned to fulfill the rising demand and thus, more greenhouse gases and toxins are released into the air.

Long-term environmental damage includes greenhouse gas emissions that cause the earth's temperature to rise even further, in what may be described as a "vicious circle." The melting of glaciers in the arctic region will, along with the thermal expansion of ocean waters, increase the sea level, erode and flood coastal areas, and cause the extinction of many species.

Impact on Public Confidence in State Governance

Questions may arise about the amount of utility assistance, provision/promotion of heating/cooling centers, etc. that governments are meant to provide, and whether there are identifiable and unjustified inequities in the extent and quality of resources and infrastructure provided to different groups and locations throughout the state. Inequities might be attributed to shortcomings in government efficacy and intentions, rather than to limited resources and the historical aspects of differential development patterns.

Climate Change Considerations

Certain indicators of climate change in Michigan have already been observed. For example, in daily record temperature data, Michigan's new heat records outnumbered new cold records by 3 to 1 during the 1990s, and by 6 to 1 during the 2000s. Extreme heat problems are expected to increase in the future, and the MSP/EMHSD is coordinating with other agencies to assess the likely impacts of warming trends. It has long been known that although Michigan's winter season has been shortening, its winters will not disappear! Instead, a surprising pattern has recently been seen in which lessened differences in temperature between polar and temperate regions (due to the warming of the arctic and polar regions) can make it easier for a polar weather front to swing southward across the United States. Although this jet stream movement occurs every winter as a normal part of Michigan's seasonal patterns, the 2013-2014 season showed an unexpectedly challenging aspect of the "polar vortex" phenomenon, in which a series of challenging weather events—ice storms, persistently cold temperatures, freezing rain, and heavy snowstorms—seemed to affect the state with increasing rapidity. Historical facts show that Michigan has experienced colder temperatures in the past (although specific records for individual days and locations will continue to be set over time), but one of the new patterns connected with climate change involves a lesser amount of time for persons to become acclimated to the cold weather—especially in the southern part of the Lower Peninsula. Increasingly mild fall months from October to early December may seem to suddenly give way to bitter cold, winds, ice, and snow, with the shorter winter season providing less time for people to adjust to the frigid weather. (By the calendar, winter is always three months long, but Michigan has long experienced winter weather conditions during months that are normally classified as part of Fall and Spring. One of the most prominent ways in which climate change has affected Michigan is in the shortening of its wintry weather, so that its seasons are becoming more closely aligned to those technically designated on the standard calendar as "winter.")

Significant Heat Waves Affecting Michigan

Following are brief synopses of some of the more significant heat waves that have affected Michigan in recent decades:

July 1936 – Michigan

During the second week of July 1936, a terrible heat wave struck Michigan, and particularly Detroit, with temperatures exceeding 100 degrees for up to seven days in a row (this varied by location—for example, Detroit had 7, West Branch and Alpena had 6, and Traverse City had 5). The temperature peaked at 112 degrees in Mio, setting a state record that still stands today. The extreme heat was an "equal opportunity" killer, causing many healthy adults to succumb to the heat at work or in the streets. Also, because most people relied on iceboxes to keep their food fresh, many heat-related deaths and illnesses occurred when the ice melted, causing the food to spoil. Statewide, 570 people died from heat-related causes, including 364 in Detroit. Nationally, the heat wave caused 5,000 deaths. Notice that these casualties disproportionately affected the large city of Detroit, and that Michigan was over-represented in terms of its population (11.4% of the national deaths were in Michigan).

August-September 1953 – Michigan

This summer included eleven days in a row with temperatures of 90 degrees or higher in Southeast Michigan, nine of which were 95 degrees or hotter, and also including two days that each hit 100 degrees.

July 1964 – Michigan

A heat wave lasted for twelve days, with temperatures all exceeding 90 degrees in Southeast Michigan. The highest such temperature was 95 degrees.

Summer 1988 – Central and Eastern U.S.

The 1988 drought/heat wave in the Central and Eastern U.S. also greatly impacted Michigan. Nationwide, the drought caused an estimated $40 billion in damages from agricultural losses, disruption of river transportation, water supply shortages, wildfires, and related economic impacts. The heat wave that accompanied the drought conditions was particularly long in Michigan – 39 days with 90 degree or better heat – eclipsing the previous record of 36 days recorded in the "dust bowl" days of 1934. During that 39-day stretch, the temperature in Southeast Michigan topped the 100-degree mark on 5 occasions, including a peak of 104 degrees on June 25. Nationwide, the 1988 drought/heat wave caused an estimated 5,000 to 10,000 deaths. (Again, the range of estimates is due largely to varying interpretations of "heat-related" death.)

July 1995 – Central and Eastern U.S.

During the period from July 11-27, 1995, the Central United States and many East Coast cities experienced a devastating heat wave. According to the National Oceanic and Atmospheric Administration, that 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, and water suppliers reported very low levels of water in storage. In Milwaukee, Wisconsin, 85 heat-related deaths were reported during the July 11-27 period. Michigan experienced 28 heat-related fatalities in 1995, most of them occurring during the intense heat period in July. In addition to this tremendous human toll, the intense heat also caused the loss of tens of millions of cattle and poultry throughout the Midwest. This was the hottest summer on record for Southeast Michigan, in terms of having the highest average temperature in Detroit (74.5 degrees). The average August temperature was even higher, at 77.1 degrees, which also set a new record.

July 1999 – Midwest and East Coast

The July 1999 heat wave that struck the Midwest and East Coast 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 degrees for much of the month and humidity levels were oppressively high. Numerous persons with heat-related problems (ranging from dehydration to heat stroke) were treated at hospitals in Detroit and other cities across the state throughout the heat wave.

June-August 2001 – Midwest and Central Plains

Extreme heat and humidity in the Midwest and Central Plains during parts of June, July and August sent heat stress index readings soaring well above 100 degrees Fahrenheit on many days. Communities across the region were forced to open "cooling centers" and take other steps in an attempt to avoid heat-related deaths among vulnerable segments of the population. Despite those efforts, heat-related deaths occurred in many areas – and unfortunately Michigan was no exception. In mid-June, three elderly residents of a Detroit-area nursing home died and five more were hospitalized due to heat-related stress. (Note: the deaths prompted a bill within the Michigan Legislature to require all nursing homes in Michigan to have air conditioning in resident rooms and common areas.) On August 1 and August 8, heat advisories were issued for many counties in the southern Lower Peninsula, with heat indices at 105 degrees for some jurisdictions on the former date, and 110 degrees for some jurisdictions on the latter date. The National Climatic Data Center reports one death and 200 "injured" during early August, from excessive heat.

Late June and early July 2002 – Metro Detroit

About 25 persons were reportedly treated for heat stroke at the beginning of July, fifteen of whom were in Wayne County and 5 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 90s. The heat index during the first four days of July was above 100°F.

June 2003 – Michigan

Summer heat was part of the reason that Red Flag warnings were issued for two counties in the Upper Peninsula, warning of extreme wildfire risk. This was the same summer that saw a massive heat wave strike Europe and cause an estimated 21,000 deaths there. Paris, France recorded its highest temperatures since records had begun in 1873. Fortunately, Michigan did not experience those sorts of extreme problems.

Summer, 2006 – Southeastern Michigan

The National Climatic Data Center reports that 315 "injuries" occurred as a result of heat in Michigan—75 occurring on May 29, and 240 in late July and early August, although most of the latter were mild cases involving dehydration, some heat exhaustion, and only 6 known cases of heat stroke. A 5 day period of temperatures at or above 90 degrees started on July 29 for Southeastern Michigan. The heat index averaged between 105 and 110 degrees, and various temperature records were tied. A large number of cooling centers were provided for residents in need, and preparedness was very good, perhaps because the earlier May 29 event had provided a milder warning event that alerted communities to the potential for heat problems. In that earlier case, on Memorial Day, temperatures went as high as the mid-90s (with a temperature of 98 reported at Midland), and outdoor parade events caused many to swoon and be treated for dehydration and heat exhaustion.

August 2007 – Michigan

Red Flag warnings were issued for many Upper Peninsula counties, with extreme heat one of the main causes of the wildfire risk.

July 4, 2010 – Southeast Michigan

A heat wave lasted for five days across the Metropolitan Detroit region. Two heat deaths were reported: one an elderly man without air conditioning in Grosse Pointe Farms (Wayne County), and the other a middle-aged homeless woman who died of hyperthermia in her car in Waterford Township (Oakland County). High temperatures were all in the low 90s each day, with heat indices in the upper 90s, but evening temperatures did not go below 70 degrees to help people recover from the effects of heat.

July 17, 2011 to July 22, 2011 – Southeast Michigan (Oakland and Wayne Counties)

A mid-July heat wave helped cap off the warmest month on record at Detroit. Three direct deaths were reported due to the heat wave, as heat indices were above 100 degrees. A 37-year-old Highland Township (Oakland County) man died from several factors including an enlarged heart, obesity and hyperthermia. A 60-year-old man died in Wayne County from hyperthermia, as he was found in his car with the windows rolled up. A 57-year-old man was also found dead due to hyperthermia in his Redford Township (Wayne County) group home.

June 28 to July 7, 2012 – Southeast Michigan (Wayne, Oakland, Macomb, Washtenaw, Genesee, Saginaw)

High temperatures climbed to around 100 degrees across much of southeast Michigan during the afternoon hours of June 28th, with heat indices climbing between 100 and 110 degrees. This led to an increase in heat-related hospitalizations. Temperatures slowly came down during the evening hours, with drier air slowly filtering in. Although Friday June 29th ended up being hot, with high temperatures in the low to mid 90s, the dry air helped to keep heat indices short of 100 degrees. This was followed almost immediate by an extended heat wave that gripped southeast Michigan during the first week of July, with temperatures topping out around 100 degrees on multiple days. Detroit set a record high on July 4th, reaching 102 degrees. Heat indices peaked around 110 degrees on July 4th and July

6th. Although no known heat deaths were reported, over 700 heat-related emergency room visits were reported statewide. Southeast Michigan tallies included 39 heat injuries in Wayne County, 28 in Oakland County, 20 in Macomb County, 13 in Genesee County, 10 in Saginaw County, and 5 in Washtenaw County.

July 14-19, 2013 – Southeast Michigan (Wayne, Oakland, Macomb, Washtenaw, Genesee, Saginaw)

A six-day heat wave impacted Southeast Michigan from July 14 through 19, with high temperatures ranging from the upper 80s to mid-90s. Heat Indices were mostly in the 90s, but Detroit Metro area hospitals reported an increase of 173 heat related illnesses during this stretch—80 in Wayne County, 50 in Oakland County, 25 in Macomb County, and 6 in each of Washtenaw, Genesee, and Saginaw Counties.

(**NOTE:** 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 $20 billion in agricultural damage. A drought and heat wave in 1999 caused a nationwide total of more than $1 billion in damage—mainly to agricultural crops in the Eastern U.S. The "dust bowl" conditions of the 1930s are widely known and described in practically any U.S. history text. The most damaging drought / heat wave in the past few decades, however, was that of 1988, which affected the Central and Eastern United States. That event caused $40 billion in damage, in addition to contributing to many deaths. See the Drought section for more information.)

Agricultural Disaster Declarations Involving Heat and Cold

2012-2018

Number	Declared	Description	Counties	In Area 1	In Area 2	In Area 3	In Area 4
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
20 TOTAL EVENTS Declared by the U.S. Secretary of Agriculture:				**10**	**11**	**14**	**7**

NOTE: The four columns on the right refer to the "General Geographic Divisions" in the Michigan Profile Chapter and its accompanying map: Area 1 (Upper Peninsula), Area 2 (Northern Lower Peninsula), Area 3 (Southern Lower Peninsula), Area 4 (Metropolitan Detroit).

Significant Episodes of Extreme Cold Temperatures in Michigan

February 10 to 13, 1899 – Central and Western Lower Peninsula

Record low temperatures occurred multiple days in a row. At Baldwin (Lake County), four days in a row had record low temperatures: -36, -49, -48, and -37 degrees Fahrenheit. Grand Rapids also noted four days in a row that set all-time records: -21, -21, -23, and -24 degrees. At Big Rapids (Mecosta County), three days in a row set records: -33 degrees, -36 degrees, and -34 degrees. Similarly, Hastings and Muskegon also set records for three days in a row: the former with -26, -31, and -24, and the latter with -30, -29, and -22 degrees.

February 9, 1934 – Vanderbilt (Otsego County)

The coldest recorded temperature in Michigan was at this location in the northern Lower Peninsula—at 51 degrees below zero!

February 17, 1979 – Northern Michigan

This was one of the coldest days that ever occurred in Michigan, in terms of the widespread presence (across 14 monitoring locations) of top-ten coldest temperatures. At Trout Lake (Chippewa County), the low was -43 degrees. At Harrisville (Alcona County), it was -20 degrees. To the west, at Traverse City, the temperature went down to -37. At Standish (Arenac County), the low was -24 degrees, and at Houghton Lake, it was -34.

December 1993 to May 1994 – Upper Peninsula and Northern Lower Peninsula

This was the deep freeze disaster that was federally declared (#1028) and can be read about in the corresponding disaster report that appears in Attachment F of the 2011 Michigan Hazard Mitigation Plan. Ten counties (Gogebic, Ontonagon, Houghton, Marquette, Delta, Schoolcraft, Chippewa, Mackinac, Cheboygan, and Charlevoix) were declared disaster areas when record low temperatures caused the freezing and breakage of more than 3,200 water and sewer lines. Service to 18,700 homes was disrupted. Public costs were estimated at more than $12 million.

December 9, 1995 – Detroit

Winds averaged 20 to 25 mph and resulted in Wind Chill Temperatures of -30 to -35 degrees. Three deaths occurred from hypothermia in Detroit—two at street locations and one in a van. (The next morning, a man was also found frozen to death near his disabled vehicle 30 miles southeast of Ontonagon, where overnight low temperatures were -15 degrees and wind chill temperatures reached -60.)

February 3 to 5, 1996 – Stephenson (Menominee County)

There were three days in a row with record low temperatures in this area. The temperatures went down to -45, -44, and -41 at a spot 8 miles west-northwest of Stephenson, near the southern tip of the Upper Peninsula. On February 1, a few days before this event, a cold-related death was reported in Southeast Michigan, involving an elderly man who had wandered away from a nursing home in Detroit. That area of the state also experienced extreme cold, with Detroit's low on February 3 reaching -7 degrees. The temperature at Flint was zero degrees Fahrenheit, or below, for seven days in a row from January 31 to February 6.

January 17 to 19, 1997 – Southeast Michigan

The coldest weather of the winter occurred and resulted in two deaths from hypothermia—one in Bay City and the other (on January 12) in Warren. Low temperatures reached -6 at Detroit Metro Airport, and -9 at Flint's Bishop Airport.

January 1999 – Saginaw County

As a prelude, December 30, 1998 saw a damaging event at Saginaw Valley State University, when a sprinkler system pipe froze and burst, causing half a million dollars in damage at Brown Hall. Water was as deep as 3 to 4 inches in some offices by the time the break was discovered on New Year's Eve. Then, with January came more widespread events involving extreme cold. In Southeast Michigan, 3 persons died and 29 were confirmed as injured, as a cold blast crept around the sheltering Great Lakes and struck the southern Lower Peninsula. Temperatures went down to -13 at Ann Arbor and Tecumseh, and -10 in surrounding areas of Washtenaw, Lenawee, and Wayne Counties. The three deaths occurred in Oakland County on January 4. Confirmed injuries involved frostbite cases from a few hospitals in Oakland and Wayne Counties, and should be understood to represent only a small portion of the actual total from this event. On the early morning of January 11, a daily low temperature of -4 degrees was recorded, and on that day more than 120 water main breaks took place in the City of Detroit. A very large water main also ruptured in downtown Adrian, causing a shortage for 22,000 residents. Property damage was estimated at $1.3 million.

December 21 to 29, 2000 – Southeast Michigan (including the thumb area)

In late December 2000 after heavy snow had ended, extreme cold temperatures invaded southeast Michigan, including portions of the thumb region. Temperatures never got out of single digits on the 22nd, with Detroit seeing a high of only 4 degrees, after a morning low of -3. Flint wasn't much better, recovering from a low of -5 to reach 8 degrees in the afternoon. Christmas morning had a morning low of -13 degrees at Flint, setting an all-time record for the month of December. Three nights later, Flint would give the new record a run for its money, coming up just short with a low of -11 on the 28th. The arctic weather would take a toll on pipes. Both Ypsilanti High School and Chelsea High School had pipes burst over Christmas weekend, damaging classrooms. Several buildings on the University of Michigan campus in Ann Arbor had similar ruptures, including the School of Dentistry and Wolverine Tower. The cold also hampered shipping interests. 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. Icebreaker assistance was needed to free the freighters. Ferry service on the St Clair River between Michigan and Canada was also interrupted due to ice jams. The end result was the 4th coldest December of all time in Detroit, and the 2nd coldest at both Flint and Saginaw. No other December on record comes close to this combination of heavy snow and brutal cold.

January 2003 – Lower Peninsula

Temperatures averaged well below normal across the Great Lakes region for much of January. For a three week period, the temperature never rose above freezing. Temperatures fell below zero for several nights during this period. Frozen pipes and water main breaks occurred in many areas of Detroit and its suburbs. The cities of Flint (Genesee County) and Saginaw also had several reports of water main breaks. Several area schools had to cancel 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.

February 3 to 6, 2007 – Southeast Michigan

The worst cold wave event since the 1990s struck the region on February 3 and did not let up until February 6. Temperatures went as low as -7 at Saginaw and -5 at Flint, and winds of 15 to 25 mph included gusts of up to 35 mph. Wind Chill Temperatures ranged from -15 to -25 throughout almost the entire event, 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, and flooding occurred in cases where these involved sprinkler system pipes. Total damages were estimated at $425,000. According to AAA, there were more than 20,000 vehicle service calls from Michigan due to the cold weather—more than had been seen for nearly 10 years.

February 9-11, 2008 – Upper Peninsula

Temperatures of 5 to 15 below zero combined with around 35 mph wind gusts drove bitterly cold wind chill values down to 25 to 40 below zero over much of Upper Michigan from the night of the 9th into the morning of the 11th. The powerful Arctic cold front pushed through the Upper Great Lakes on the afternoon and evening of the 9th and also produced blizzard conditions with lake effect snow and blowing snow over portions of Upper Michigan into the 10th. Many schools were either canceled or delayed on the 11th. AAA Michigan reportedly responded to numerous motorists' calls of dead batteries or fuel line freezes during the extreme cold. An elderly Alzheimer's patient was found dead, five blocks from his home in Leland (Leelanau County).

January 14-18, 2009 – Southeastern Michigan

An arctic air mass become firmly established over the Great Lakes region on January 14th and persisted through the 18th, producing the winter season's coldest temperatures. Temperatures fell below zero all four days, with wind chill values in the 5 to 30 below range during the majority of the time. Detroit's low temperatures for January 14-18th were as follows: -3, -3, -15, -11. Wind chill values also plummeted to 20 to 40 below zero from late evening on the 13th through the morning of the 16th throughout much of the Upper Peninsula.

April 27, 2012 – Lower Michigan – Late Freeze

A killing freeze caused extreme damage to agriculture in the Lower Peninsula, particularly in the fruit belt of its northwest. Traverse City saw low temperatures of 25 degrees on April 27th, 31 degrees on the 28th, and 26 degrees on the 29th. Although these values were not greatly colder than normal lows, because of a stretch of unprecedented warmth in mid-March which had included five consecutive 80-degree days (17th-21st) that had caused fruit trees to bud out far ahead of schedule, these trees were left vulnerable when more normal April temperatures returned. The tart cherry crop was a total loss, while other orchard fruits such as sweet cherries, apples, pears, and peaches saw losses of more than 90% of the expected crop. Total losses were estimated at $132.8 million, with the following estimated breakdowns from NOAA, provided by county: Leelanau $37.5 million, Benzie $15 million, Grand Traverse $15 million, Antrim $10 million, Manistee $10 million, Berrien $8 million, Charlevoix $7.5 million, Emmet $5 million, Cass $4 million, and $1.3 million each for Bay, Genesee, Huron, Lapeer, Lenawee, Livingston, Macomb, Midland, Monroe, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, Tuscola, and Washtenaw.

January 21-22, 2013 – Gogebic and Ontonagon Counties

Arctic air entered the area and wind chill values reportedly went at least as low as -40°F at Ironwood, on both mornings from January 21 to 22, 2013. In neighboring Ontonagon County, wind chill values were estimated to be nearly as cold, from -35 to -40 degrees Fahrenheit. Area schools were closed for those two days, because of the extreme cold.

Early 2014 – Statewide

Several times during the 2013-2014 winter season, very low temperatures were felt across the state, for periods of time that placed many persons at risk. This sometimes coincided with ice storms, power failures, propane shortages, and transportation blockages that caused the effects of the extreme cold temperatures to be more pronounced. The media made the term "polar vortex" popular during these extreme temperature events. On January 5 through 9, 2014, much of the Upper

Peninsula endured an air mass that was far below normal winter temperatures, with wind chill values consistently between 30 and 50 degrees below zero. The worst was at Ironwood (a wind chill reading of 54 below zero), where the highest temperature on the day of January 6 was 15 degrees below zero. Various Upper Peninsula schools were closed for two to three days during this cold spell (and later during the month and season). The deep cold reached many other Michigan counties by January 6, and although the wind chill values there were less extreme than the Upper Peninsula's, they were still dangerously low, such as -33°F at West Branch, Houghton Lake, Cassopolis, and Hillsdale. Actual temperatures were below zero, with Detroit Metropolitan Airport bottoming out at -14°F on January 6 and 7 (both of which were record lows for that location on those dates).

Mid-Late February, 2015 – Northwest Lower Peninsula, then Upper Peninsula

February 13 to 14 saw the coldest air of the winder entering the Traverse Bay region and causing wind chills from -30 to -40, with the Upper Peninsula going as much as 10 degrees below that. After a couple milder days, February 18 then saw a very cold Arctic air mass move in across the Upper Peninsula, causing schools to close for three days across much of the peninsula as gusty winds combined with sub-zero temperatures. Wind chill values were in the -25 to -35 range in various areas from February 18 to 20, and included many counties in the Northern Lower Peninsula on February 19, which saw even colder wind chills in the -30 to -40 range (the lowest at -43 near the City of Cadillac, in Wexford County.) Subsequent warming was felt on February 21, but similar cold returned on subsequent mornings from February 22 to 23. Arctic air returned again on the morning of February 26 and caused schools to close. The southernmost regions of the state did not feel these extremes.

Early January, 2017 – Upper Peninsula

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

Early January, 2018 – Southeastern Lower Peninsula

From January 1 to 7, a prolonged cold spell affected Southeast Michigan, causing 4 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. 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.

January 28 to February 2, 2019 – Statewide Winter Emergency

A series of heavy snowfall events began this week-long event. On Monday, January 28, much of the state faced the start of a blizzard, with snowfall ranging up to over a foot in depth as sustained winds began (with gusts up to 40 mph) and were soon accompanied by a dangerous drop in temperatures. An extremely large number of schools throughout the state were closed as a result of the snowfall, and then remained closed for most of the week as the combination of sustained sub-zero temperatures and strong winds produced dangerously low wind-chill values throughout the state. Wind-chill values below -30 degrees Fahrenheit were common throughout Michigan for multiple days, and often dipped below -40. In additional to numerous local states of emergency, non-essential State Government offices were closed for more than half a day on Monday, and for the entire day on Wednesday and Thursday. Governor Gretchen Whitmer's State of Emergency declaration took effect on January 29, anticipating the dangerous impacts of the deep freeze that had been forecast by the National Weather Service. At least three deaths were attributed to weather exposure, and special shelters and over a hundred warming centers were activated at many locations around the state. Additional hospitalizations took place, not just as a direct result of the cold, but also to treat for carbon monoxide exposures resulting from makeshift efforts to heat residents' homes. Hundreds of local and county government offices were closed for at least one or two days during the week, as well.

Driving conditions were treacherous and slow. Highway M-40, southeast of Holland (Allegan County) became backed up. A 24-car pileup occurred on I-196 near Zeeland (Ottawa County), resulting in the temporary closure of that expressway. Other expressway closures occurred during the event, including I-496 and northbound US-127 in Lansing, US-131 in Allegan County, and M-37 South of White Cloud, in Newaygo County. Newaygo County also saw the Muskegon River reach a moderate flood level in Bridgeton Township and the City of Newaygo, as the result of an ice jam. Some 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—Benzie County's Platte River near the Village of Honor threatened 20 homes and cottages, Berrien County near M-139 saw minor flooding near Riverfront Campground and in Niles. Excessive delays were reported at the Detroit Metropolitan Airport (Wayne County), as well as the Blue Water Transit bus system (St. Clair County) shutting down from January 30 to 31. Visibility was often a problem, with white-out conditions resulting from the blizzard.

On Wednesday, January 30, at 10:33am, a fire occurred at an important Consumer's Energy facility in Armada Township (Macomb County), and when the impacts of this fire were calculated to eventually lead toward natural gas shortages, the head of that major utility, followed by the Governor, appealed to both residential and industrial customers to voluntarily reduce their use of natural gas. By voluntarily reducing thermostat levels to the recommended 65 degrees or below, until the end of the day on January 31, and temporarily scaling back production activities at certain facilities, this collective effort succeeded in preventing the complete interruption of gas delivery that otherwise was expected to occur. The problem did not involve a supply of natural gas, but only the constraints that the fire had caused in the ability to deliver that gas throughout the state's network. Temporary power failures occurred in some locations, affecting thousands of residents and businesses but fortunately not lasting very long. Other midwestern states also authorized state emergency and disaster declarations during this event. By Friday, February 1, temperatures went back above zero, and Michigan's State of Emergency expired on February 2, 2019.

Programs and Initiatives

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

Extreme Summer Heat

Excessive Heat Events Guide Book – A product of the Environmental Protection Agency, in conjunction with FEMA, NOAA, and the Center for Disease Control and Prevention, this booklet can be obtained online at http://www.epa.gov/heatisland/about/heatguidebook.html. It provides an overview of heat impacts, sources of risk, notification and response programs, and recommendations.

Summer Heat Contingency Planning – In the aftermath of the extreme summer heat events of 1980 and the early 1990s, many major cities began to develop contingency plans for addressing heat-related hazards. The major elements of these plans include: 1) enhanced weather monitoring to better predict periods of extreme heat; 2) increased outreach to the elderly and other vulnerable individuals; 3) establishment of "cooling centers" for those most affected by the heat; and 4) enhanced public information campaigns to inform people of the perils of extreme summer heat and the resources available to them. In Michigan, cities such as Detroit and Lansing, among others, now address extreme summer heat contingencies in their emergency planning efforts.

Low Income Home Energy Assistance Program / State Emergency Relief Program – The LIHEAP is a federally-funded program to help eligible low-income households meet their home heating or cooling needs. The money is used to help pay high utility bills or buy fans or air conditioners for persons considered at risk from extreme summer heat and it helps to pay for heat and weatherization during extreme winter cold. In 2003, about 4.6 million Americans received over $1.5 billion in assistance under the LIHEAP. Michigan received $40.8 million of that money to help aid low income citizens with heating expenses. In Michigan, the state Department of Human Services processes applications for eligible residents. In addition, the State Emergency Relief (SER) Program can also be used to alleviate the dangers of extreme heat and cold for Michigan families by providing financial assistance for home heating, electric and water bills.

<u>Extreme Winter Cold</u>
Since illness and death from hypothermia are not only seen in association with prolonged periods of cold temperatures, efforts to prevent hypothermia must be ongoing throughout periods of cooler weather. Because elderly persons are particularly vulnerable to hypothermia, prevention efforts must be primarily directed to them. Family, friends, neighbors, and local governmental and voluntary agencies can help ensure that all dwellings in which elderly persons reside are properly heated. This may require that a regular outreach program be established for this purpose. Local communities should also have adequate housing codes that require dwellings to have furnaces capable of maintaining sufficient room temperature for the winter conditions that will normally be expected. Governmental authorities, voluntary agencies and utilities can also assist those elderly persons that cannot pay all or part of their heating bills by providing financial assistance and/or making special arrangements for payment. Finally, governmental and voluntary agencies should, in conjunction with local media, continue to address the dangers associated with cold temperatures through regular public information and awareness campaigns. The combination of all these activities certainly will not prevent all cold temperature-related injuries and deaths, but it will go a long way toward preventing a large share.

<u>All Hazards Resources for Rural Communities</u>
The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Hazard Mitigation Activities for the Extreme Temperatures Hazard

- Organizing outreach to vulnerable populations during periods of extreme temperatures, including establishing and building awareness of accessible heating and/or cooling centers in the community, and other public information campaigns about this hazard.
- Increased coverage and use of NOAA Weather Radio.
- Provide and publicize designated heating and cooling centers within the community, where persons in need may go to obtain relief from outdoor temperatures.

Emphasis in Local Hazard Mitigation Plans

Extreme temperatures were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Alger, Barry, Berrien, Cass, Charlevoix, Cheboygan, Genesee, Gogebic, Lake, Lapeer, Mackinac, Marquette, Mason, Menominee, Monroe, Montmorency, Muskegon, Oceana, Otsego, St. Clair, Tuscola, Wayne (22 counties, an increase from 2014).

Severe Winter Weather Hazards

Severe winter weather hazards include snowstorms, blizzards, extreme cold, and ice and sleet storms. As a northern state, Michigan is vulnerable to all of these winter hazards. Most of the severe winter weather events that occur in Michigan have their origin as Canadian and Arctic cold fronts that move across the state from the west or northwest, although some of the most significant winter storms have their origins from the southwest, in combination with Arctic air masses. As the maps in the following chapters show, Michigan averages moderate to heavy snowfall and extreme cold, averaging 90-180 days per year below freezing in the Lower Peninsula, and over 180 days below freezing in most of the Upper Peninsula. (For record snowfall amounts and a description of Michigan's four general "regions," please refer to the relevant table and text in the Introduction to the Weather Hazards section in this document.)

The chapters that follow provide greater detail on ice and sleet storms, and snowstorms and blizzards. The extreme temperatures chapter, earlier in this document, provides a more detailed overview of the severe cold temperatures hazard.

Winter storm hazards plague Michigan annually during its extreme cold risk season. No area of the state is immune to severe winter conditions that can clog or paralyze the transportation network, cause widespread power outages, and slow normal daily activities to a standstill. Each community should be prepared for the harsh landscape created by snow and ice extremes. One way to understand the approaching risks of winter weather comes in the form of daily forecasts, watches, and warnings from the National Weather Service. The website for the NWS is www.weather.gov, which covers all regions in Michigan. To obtain recent county-level historical data since 1993 for both severe snowstorms and ice and sleet storms, visit the National Centers for Environmental Information Storm Events website: https://www.ncdc.noaa.gov/stormevents/**.**

Winter Weather Hazards (General)

- Increased coverage and use of NOAA Weather Radio.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines, where appropriate.
- Establishing heating centers/shelters for vulnerable populations.

Emphasis in Local Hazard Mitigation Plans

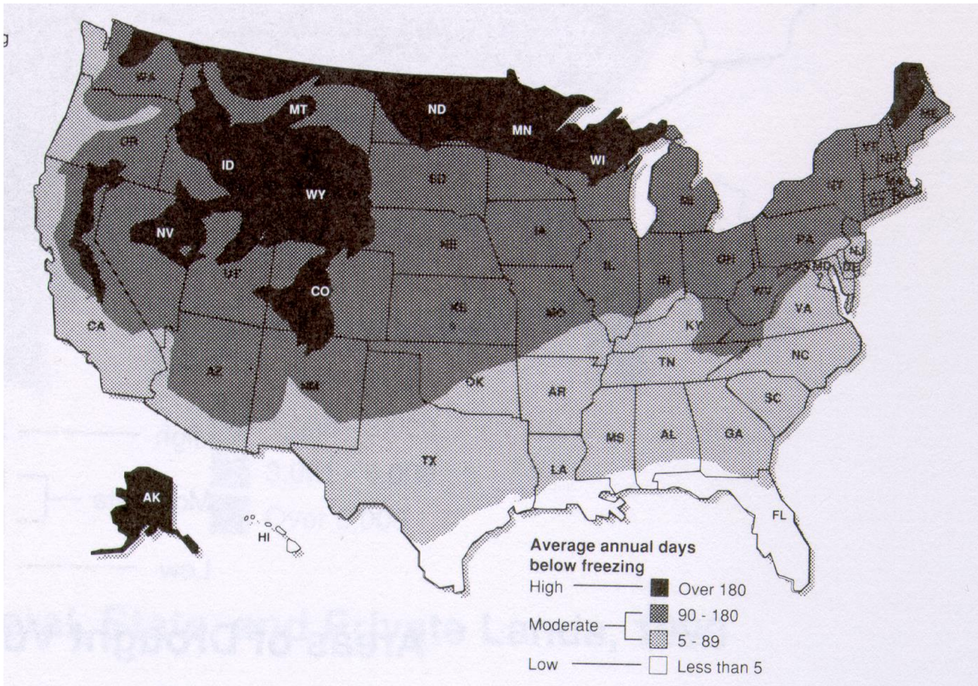
Severe Winter Weather was identified as one of the most significant hazard in local hazard mitigation plans for the following counties: Alger, Alpena, Antrim, Barry, Bay, Benzie, Berrien, Branch, Calhoun, Cass, Charlevoix, Cheboygan, Chippewa, Clinton, Delta, Dickinson, Eaton, Emmet, Gladwin, Grand Traverse, Gratiot, Hillsdale, Huron, Ingham, Ionia, Kalamazoo, Kalkaska, Kent, Lake, Lapeer, Leelanau, Livingston, Luce, Mackinac, Macomb, Manistee, Marquette, Mason, Mecosta, Menominee, Midland, Missaukee, Monroe, Montcalm, Montmorency, Muskegon, Oakland, Oceana, Ogemaw, Osceola, Oscoda, Otsego, Ottawa, Presque Isle, Roscommon, St. Clair, Schoolcraft, Shiawassee, Tuscola, Van Buren, and Wexford (61 counties, an increase from 2014).

The amount of snowfall does vary greatly throughout Michigan. Although snowfall amounts are highest in the Upper Peninsula and near various parts of the Lake Michigan shoreline (due to the "lake effect" of moistening nearby air), it is important to note that every county in Michigan experiences severe winter weather. The risk of ice storms is a bit greater in the southern parts of the state, where temperatures cycle across the freezing mark for a larger average amount of time each year, but ice storms are also a risk in every county of the state. The impacts from ice storms are far greater than for sleet. Sleet usually causes temporary hazards for transportation, but ice storms also tend to cause power failures and structural damage far beyond anything that sleet has caused. A blizzard is a heavy snowstorm that includes winds strong enough to cause drifting snow and visibility problems, and this also causes serious transportation risks. Some of Michigan's most serious highway transportation accidents (q.v.) are caused by winter weather. Infrastructure failures (q.v.) are also a serious hazard but are much more serious when they occur during cold winter weather.

The two chapters in this section will describe the risks for ice, sleet, snowstorms, and blizzards.

Average Annual Days Below Freezing in the U.S.

Source: Council of State Governments; Federal Emergency Management Agency



Michigan: Annual Temperature and Precipitation Statistics

Time period	Average temperature	Average daily minimum temperature	Average daily maximum temperature	Average annual precipitation (inches)	Palmer Drought: 12-Month Z-Index
20th Century average	43.6	33.4	53.7	31.1	-0.03
2000	45.0	35.0	55.0	33.0	+0.28
2001	46.8	37.1	56.5	35.2	+0.37
2002	45.7	36.0	55.4	30.9	-0.32
2003	44.0	33.7	54.2	31.1	-0.19
2004	44.6	34.6	54.5	35.4	+0.59
2005	46.0	35.9	56.2	29.9	-1.08
2006	47.0	37.4	56.6	35.9	+0.60
2007	46.1	35.9	56.2	30.7	-0.95
2008	44.0	34.0	54.1	36.9	+1.12
2009	43.8	33.8	53.7	33.9	+0.69
2010	47.1	37.3	56.9	31.2	-0.29
2011	45.6	36.0	55.3	36.8	+0.69
2012	48.4	38.2	58.7	31.0	-0.73
2013	44.1	34.4	53.7	38.2	+1.19
2014	41.9	32.1	51.6	36.7	+1.22
2015	45.1	35.0	55.2	31.8	-0.28
2016	47.4	37.7	57.0	35.9	+0.34
2017	46.3	36.8	55.8	39.3	+1.26
Average since 2000	45.5	35.6	55.4	34.1	+0.25

Source: NOAA's National Centers for Environmental Information website: https://www.ncdc.noaa.gov/cag/statewide/time-series

Ice and Sleet Storms

A storm that generates sufficient quantities of ice or sleet to result in hazardous conditions and/or property damage.

Hazard Description

Although ice storms and sleet storms have been combined in this chapter, they are two different phenomena. Ice storms, also known as freezing rain, coat roads, trees, power lines, and buildings with thick, heavy, and slick surfaces. Ice storms are sometimes incorrectly referred to as **sleet storms**. Sleet consists of small, already-frozen rain drops (ice pellets) that bounce when hitting the ground or other objects. These small pellets of ice then accumulate on surfaces, causing potential harm to transportation and electrical systems. Sleet does not stick to trees and wires like freezing rain does, but sleet in sufficient depth does cause hazardous driving conditions.

By contrast, **ice storms** are the result of cold rain that freezes on contact with a surface, coating the ground, trees, buildings, overhead wires and other exposed objects with ice, sometimes causing extensive damage as the accumulated weight causes tree branches and cables to break and power systems to fail. Power may be lost for several days, resulting in significant economic losses and the disruption of essential services in affected communities. Damages and expensive utility failures from downed tree limbs and utility lines make ice storms a far more serious hazard than sleet.

Ice storms usually have a regional effect, and may occur in any part of Michigan. Groups of counties are often affected by the same event. Ice storms can be accompanied by snowfall, in which the ice is camouflaged and covered up by snow, creating treacherous transportation conditions. Both ice and sleet occur when the temperature is close to 32°F, but can be far more severe when the temperature drops to the 20s. The southern parts of the state have annual winter temperatures closer to 32°F, so the prevalence for ice and sleet storms currently seems more likely there than in more northerly areas. Since ice storms have been so much more destructive than sleet, they are the main focus of this chapter.

Hazard Analysis

The table below illustrates the frequency distribution of ice and sleet storms in Michigan for the period 1970-July 2018. All events occurred between November and April. Only about 1/8 of the events involved sleet, and all the property damage, crop damage, and casualties listed in the NWS database source were caused by ice storms.

By observing winter storm watches and warnings, adequate preparations can usually be made to reduce the impacts of ice and sleet conditions on Michigan communities. The primary challenges facing community agencies and officials are providing mass care and sheltering for residents left without heat or electricity, and mobilizing sufficient resources to clear trees and other debris from roadways. As shown on the following pages, different areas of the state have far greater ice storm damages than others. The more urbanized and southern areas have suffered far more damage than Michigan's more rural and northern areas. Planning and preparedness efforts should include the identification of mass care facilities and necessary resources such as cots, blankets, food supplies and generators, as well as debris removal equipment and services. In addition, communities should develop and maintain debris management procedures (to include the identification of multiple debris storage, processing and disposal sites) so that the tree and other storm-related debris can be handled in the most expedient, efficient, and environmentally safe manner possible.

Michigan's Ice and Sleet Storms by Month
1970 – July 2018

AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	TOTAL
0	**0**	**0**	**3**	**12**	**18**	**12**	**14**	**8**	**0**	**0**	**0**	**67**
0%	**0%**	**0%**	**4%**	**18%**	**27%**	**18%**	**21%**	**12%**	**0%**	**0%**	**0%**	**100%**

Source: National Weather Service; Storm Data, National Centers for Environmental Information. Each listed date of occurrence (rather than each of the county event listings) was counted as one case, and these counts supplemented those from the previous edition of this document. Percentages are rounded off.

Ice/Sleet Storm History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Ice/Sleet Events	Days with Event	Tot. property damage	Tot. crop damage	Deaths	Injuries
Washtenaw	3	3	$3,400,000			1
Wayne	4	4	$5,000,000			1
.Livingston	4	4	$5,310,000			
Oakland	5	5	$107,452,000		1	2
Macomb	5	5	$57,325,000			
5 Co Metro region	**4 avg.**	**4 avg.**	**$178,487,000**		**1**	**4**
Berrien	5	5	$30,000			
Cass	5	5	$30,000			
St. Joseph	6	6	$30,000			
Branch	5	5				1
Hillsdale	5	5				
Lenawee	4	4	$2,530,000			
Monroe	4	4	$4,540,000			
.Van Buren	3	3	$25,000			
Kalamazoo	3	3	$75,000			
Calhoun	4	4	$1,030,000			
Jackson	4	4	$1,030,000			
.Allegan	3	3				
Barry	4	4	$5,025,000			
Eaton	5	5	$5,325,000			
Ingham	5	5	$5,340,000			
.Ottawa	5	5	$500,000			
Kent	5	5	$1,000,000			
Ionia	5	5	$330,000			
Clinton	5	5	$1,330,000			
Shiawassee	5	5	$3,000,000			
Genesee	5	5	$3,110,000			
Lapeer	5	5	$4,075,000			
St. Clair	5	5	$12,100,000			
.Muskegon	3	3	$200,000			
Montcalm	5	5	$200,000			
Gratiot	4	4	$1,250,000	$5,000		
Saginaw	9	9	$4,010,000			
Tuscola	6	6	$3,020,000			
Sanilac	4	4	$3,030,000			
.Mecosta	5	5	$350,000	$5,000		
Isabella	5	5	$350,000	$5,000		
Midland	7	7				
Bay	7	7				
Huron	4	4	$25,000			
34 Co S Lower Pen	**5 avg.**	**5 avg.**	**$62,890,000**	**$15,000**		**1**

Continued on next page…

Part 2 of Ice/Sleet History for Michigan Counties – arranged by geographic division

.Oceana	3	3	$200,000			
Newaygo	3	3	$200,000			
.Mason	2	2	$200,000			
Lake	2	2	$200,000			
Osceola	5	5	$450,000	$5,000		
Clare	5	5	$350,000	$5,000		
Gladwin	3	3	$60,000			
Arenac	2	2	$50,000			
.Manistee	4	4				
Wexford	3	3				
Missaukee	2	2				
Roscommon	3	3				
Ogemaw	3	3	$5,000			
Iosco	4	4	$50,000			
.Benzie	4	4				
Grand Traverse	4	4				
Kalkaska	4	4				
Crawford	1	1				
Oscoda	2	2				
Alcona	3	3				
.Leelanau	4	4				
Antrim	3	3				
Otsego	3	3				
Montmorency	3	3				
Alpena	2	2				
.Charlevoix	3	3				
Emmet	4	4				
Cheboygan	4	4				
Presque Isle	4	4				
29 Co N Lower Pen	**3 avg.**	**3 avg.**	**$1,765,000**	**$10,000**		
Gogebic	4	4	$100,000			
Iron	3	3				
Ontonagon	4	4		$100,000		
Houghton	4	3				
Keweenaw	3	3	$100,000			
Baraga	3	3				
.Marquette	4	4				
Dickinson	5	5				
Menominee	4	4				
Delta	4	4				
Schoolcraft	6	6				
Alger	4	4				
.Luce	5	5				
Mackinac	3	3				
Chippewa	3	3				
15 Co Upper Pen	**4 avg.**	**4 avg.**	**$200,000**	**$100,000**		
MICHIGAN TOTAL	**336**	**40**	**$243,342,000**	**$125,000**	**1**	**5**
Annual average	**15.8**	**1.9**	**$11,408,120**	**$5,860**	**0.5**	**0.2**

There is an average of about 16 significant storm events in Michigan each year (not all of which are direct damaging on a community level). Many events are multi-county events, with damages from a wide area merely estimated within each country, and therefore the state and county totals in the table may not add together neatly. Many ice storm deaths are actually caused by automobile accidents, heart attacks from overexertion, downed power lines, carbon monoxide poisoning, and other secondary effects that may be difficult to distinguish from other causes. In terms of property damage, major ice storm events have, according to NCDC records, caused about $243 million in damages since 1996 (averaging about $11 million per year), and the April 2003 ice storm was particularly severe, reportedly causing the majority of that amount by itself. Geographically, a clear pattern is evident in the table—although a similar number of events occur throughout the state (between 3 and 5 per year), damages are most severe frequent in the Detroit Metropolitan Area, followed by the rest of the southern Lower Peninsula, the Northern Lower Peninsula, and lastly, throughout the Upper Peninsula. Ice/sleet damage is less likely in the northern areas than in the southern ones, according to these historical records. This pattern holds true even when population differences are taken into account.

Impact on the Public, Property, Facilities, and Infrastructure

Ice and sleet storms tend to cause power or other infrastructure failures that interfere with residents' activities, comfort, and safety (often through the impact of infrastructure failures on needed medical and emergency response capabilities). Direct physical effects may include frostbite, hypothermia, and other medical conditions, and thus require some citizens to be provided with warm clothing and shelter. Certain types of building designs are susceptible to structural failure from the accumulation of ice or snow on their roofs. Traffic efficiency and road capacity tends to be impeded by these weather events, which cause a large increase in the risks involved in all modes of travel. Injurious accidents may include simple pedestrian falls (due to the difficulty of balancing and walking on ice-coated surfaces), or large-scale transportation accidents (such as multi-car interstate pileups).

Impact on the Economic Condition of the State

Widespread infrastructure failures can cause major employers and transportation systems to come to a standstill until power and highway routes are restored. Even temporary disruptions which occur at a critical time in production or transportation may cause business losses to occur. Routine power interruptions usually do not last long, under ordinary operating conditions, but ice storms have been associated with some long power outages, in which customers had been without service for over a week and must try to find some alternative means to fulfill their needs during that time. The primary economic impact of ice storms takes the form of infrastructure failures and transportation delays, although there is also a risk of incurring additional costs from injuries and damages during highway crashes, structural collapses, and on-the-job injuries. Ice storms may also cause significant economic losses within Michigan's agricultural sector, such as the fruit industry.

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

Responders are asked to be outdoors during winter weather events in which most citizens prefer to take shelter. In addition to the risks from winds, obscured vision, impaired control of vehicles, power failures and blocked roadways, winter storm events also expose responders to extremely cold temperatures for long periods of time, and may thus compound the difficulties, risks, and expenses of response. Fatigue can more easily become a problem under wintry conditions. Icy conditions make various travel and outdoor operations treacherous. Services and operations that rely upon utilities' electrical power (i.e. that do not have sufficient independent back-up capacity from generators, local grids, batteries, or other alternative sources) can be significantly impaired, and smooth operations and service delivery may continue for a while after power supplies have been restored, since there are usually transitional activities to shift operations back to normal. During severe winter weather, utility workers often need assistance or prioritization in the removal of debris and the clearance of roads so that they can restore power to areas where utilities had been disrupted.

Impact on the Environment

Dangerous ice storms coat surfaces with layers of ice and usually cause damage to trees, as the weight of accumulated ice brings down limbs and branches, or even entire trees. When soil is not already frozen, ice loads can cause root damage to forest trees. Widespread ice damage to forested lands could disrupt some species' habitats, composition, and ecosystem diversity. Dried dead trees may be more prone to fire, exacerbating wildfires during other seasons if not removed properly. Dead trees can become breeding areas for beetles and other pests that can harm healthy trees. Floods often occur when ice melts, and those can cause environmental effects (as described in the flooding section). Transportation accidents or infrastructure failures may result in local contamination of the land, air, and water, if hazardous materials are released as a result.

Impact on Public Confidence in State Governance

The main ice storm issues regarding public confidence in government predominantly involve: (1) the ability of the infrastructure of the impacted area to withstand the ice or sleet event and continue to serve area residents, and (2) the ability of the government(s) to efficiently clear away ice and sleet from areas that are most vitally needed for transportation and other shared public uses (e.g. schools, hospitals). If any shortcomings or failures in one or both of these functions are too evident to citizens (or mass media providers), then the capacity, efficiency, and adequacy of government(s) may be called into question. In many areas, the State and different forms of local governments and agencies will have different types of responsibilities, and where problems arise in the coordination or clarity of these governments' actions and responsibilities, discontent can reasonably be expected to be expressed by citizens.

Climate Change Considerations

Climate change effects seem likely to cause an increase in the number of ice and sleet storm events, at least across the southern part of Michigan. The reason involves average temperatures in and around the winter months that are closer to the freezing point, at which ice and sleet events typically occur. Instead of winter arriving and precipitation remaining in the form of snow, Michigan winters have involved many thawing episodes, followed by refreezes which cause treacherous ice cover upon frozen surfaces, weight down cables and tree branches, and cause infrastructure failures. Even though Michigan's winter season has been shortening a bit over time, winters remain hazardous because the increasing level of precipitation more often takes the form of major snow events, and provides a lot more moisture for refreezing after the warmer thawing periods have taken place.

Significant Ice and Sleet Storms in Michigan since 1976

March 2-7, 1976 – Central Lower Michigan

During the period from March 2-7, 1976, an ice storm with accompanying high winds and tornadoes struck a 29-county area in the central Lower Peninsula. This storm, one of the worst to ever hit the state, caused over $56 million in damage, plus widespread power outages. The storm impacts were so severe that a Presidential Major Disaster Declaration was granted for the 29 affected counties, to assist in their recovery from the storm. The declared counties were: 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.

April 8, 1979 – Southern Lower Michigan

On April 8, 1979, an ice storm struck Lower Michigan, south of a line from Grand Haven to Bay County. The storm left 240,000 utility customers without power for several days. In addition, numerous injuries resulted from the downed power lines.

January 1, 1985 – Southern Lower Michigan

On January 1, 1985, a severe ice storm struck a 13-county area in the southern Lower Peninsula. Freezing rain accumulating up to one inch in thickness downed tree limbs, trees and power lines, blocked roads, and caused widespread power outages. There were three deaths and eight injuries directly related to the ice storm. Approximately 13,000 homes and 260 businesses sustained damage (including some counted as destroyed), with losses estimated at nearly $25 million. 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 10 days. At the height of the power outage, 28 public shelters were opened and provided shelter to nearly 1,000 residents who had lost power or heat. Several nursing homes and adult foster care facilities had to be evacuated after losing power or heat. Total public and private damage from this ice storm was estimated at nearly $50 million. A Governor's Disaster Declaration (and State of Emergency) was issued to mobilize state resources to assist in the storm response and recovery. The designated disaster area included the counties of Allegan, Barry, Berrien, Calhoun, Eaton, Genesee, Ingham, Jackson, Kalamazoo, Lapeer, Livingston, Oakland, and Van Buren.

March 13-14, 1997 – Central and Southeast Michigan

In the late evening hours of March 13, 1997, an ice storm struck the central and southeastern Lower Peninsula, causing widespread power outages, icy roads, downed trees, and numerous school closings. Many of the counties in the southern third of Michigan were impacted by the storm. North of Detroit, nearly all the precipitation fell in the form of freezing rain, in amounts ranging from 0.8 to 1.5 inches. Farther south, precipitation amounts ranged from 1.5 to nearly 2.5 inches. Wayne, Oakland, and Macomb County damages amounted to about $4 million each. Washtenaw damage tallies were $3 million, Livingston County suffered $2 million in damages, and Lenawee County damages totaled $1 million, as did Monroe County. In the storm's aftermath, 514,000 Detroit Edison and Consumers Energy electrical customers were without power, several thousand of whom went without for as long as 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 due to the lack of power. Response efforts were severely hampered by snow and windy conditions the following day. In addition to fallen power lines, falling trees damaged dozens of cars and houses throughout the area. Most schools were closed, and there were numerous auto accidents.

April 3-5, 2003 – West and Central Lower Michigan

A major ice storm affected much of southern Lower Michigan, causing hundreds of thousands to lose power. The weight of the ice brought down thousands of trees and limbs, and hundreds of power lines. Many persons lost power for several days, and some who lived in outlying areas were without power for a week. The ice storm resulted in several million dollars' worth of damage across the area. Most of the counties across the central and southern Lower Peninsula received a total of ½ to 1½ inches of ice. It was one of the biggest ice storms to affect lower Michigan in the previous 50 years. Damage totals amounted to $1 million in Kent County, $1 million in Lapeer County, $10 million in St. Clair County, $50 million in Macomb County, and $100 million in Oakland County, where 1 death and 2 injuries also occurred (due to falling trees and branches). Additional casualties stemmed from traffic accidents—about two dozen injuries and one death, the latter from a car skidding into a ditch filled with water. Three persons also died from carbon monoxide poisoning, due to the use of poorly ventilated generators.

February 16, 2006 – Central Lower Michigan

A major ice storm affected much of central Lower Michigan. There were numerous reports of ice accumulations of up to one-inch thickness. This glazing caused widespread tree damage and thousands of power outages. Some persons were without power for several days, resulting in the opening of numerous temporary shelters due to the extreme cold in the wake of the ice storm. Total damages were in excess of $2 million. $1 million in damage took place in Gratiot County, and $1 million in Saginaw County.

January 14-15, 2007 – Southern Lower Michigan
A major ice storm affected an area from the extreme southwestern part of the Lower Peninsula northeast into the Flint and Detroit metro areas. There were numerous reports of ice accumulations up to one half inch. This glazing caused widespread tree damage and over 150,000 structures to be without power. Total damages exceeded $2 million.

March 1-2, 2007 – Southeast Michigan
In Huron County, a high-impact ice storm resulted in ice accumulations up to 3 inches thick on power lines and trees. Northern counties were also hard-hit, such as Iosco, Oscoda, and Otsego. Most of the damage occurred between 10 pm on March 1 and 1am on March 2. 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. Hundreds of traffic accidents took place, including some that were serious and resulted in 6 injuries and one death. Property damage alone amounted to $1.5 million (mostly in Huron County).

February 20-21, 2011 – Lenawee and Monroe Counties
At the end of a large snowstorm (producing 5 to 10 inches of snow across the majority of southeast Michigan), the snow turned to ice near the Ohio border as a major ice storm occurred. Downed trees and power lines occurred across Lenawee and Monroe Counties, due to ice accumulations of ½ to 1 inch. Power outages lasted for up to 4 or 5 days. Property damage amounted to $1.5 million in Lenawee County, and $3.5 million in Monroe County.

December 21-22, 2013 – Southeastern and South-Central Lower Peninsula
On the weekend before Christmas, a large winter storm swept across part of the Lower Peninsula. Existing moist air and an Ontario cold front combined to produce an extensive area of freezing rain from the northwest of Detroit over to Lansing and up to Saginaw. Over 200,000 homes and businesses lost power, some remaining without it during the Christmas holiday. Ice accumulations in some areas were a half-inch or even three-quarters of an inch thick. The weight caused stressed and broken tree branches and utility lines. Unsafe travel conditions caused Shiawassee County to declare a local state of emergency. Total damages were estimated at $29 million, across the counties of Genesee, Lapeer, Livingston, Macomb, Oakland, Saginaw, Sanilac, Shiawassee, St. Clair, and Tuscola. An additional $18 million in damages were estimated within the central Lower Peninsula counties of Allegan, Barry, Calhoun, Clinton, Eaton, Ingham, Ionia, Jackson, and Kent. Ice accumulations there tended to be between one-half and three-quarters of an inch. Total statewide damages in terms of estimated insured losses were reported to add up to $60 million. An additional problem arose among those who required heating fuels to be delivered during this weather—unplowed snow caused delays in the delivery of these fuels. In addition to a tight supply of propane, in particular, drivers found that each residence might require two or three times the normal time in order to access the property and its fuel tank.

April 26, 2017 – Central and Western Upper Peninsula
Freezing rain fell over portions of the Upper Peninsula on April 26 and 27, 2017. Physical damages were reported in Gogebic, Houghton, Keweenaw, and Ontonagon Counties, but slick roads and surfaces also affected Alger, Baraga, Iron, and Marquette Counties. Moderate to heavy ice accumulation caused extensive tree damage in the higher-elevation areas within Gogebic County (north of Bessemer and Wakefield), and Ontonagon County (also damaging trails within the Porcupine Mountains State Park). Schools were closed throughout Keweenaw County on April 27, after power lines were affected, as well as in many parts of northern Houghton County, due to icy roads. Total property damages were estimated at $350,000.

April 14-15, 2018 – Lower Peninsula
A late-season winter storm included high winds, heavy rain, sleet, and freezing rain. The highest wind gusts occurred on April 14, and in the early morning hours of April 15, heavy sleet and freezing rain plagued a wide area of the Lower Peninsula. Numerous accidents and roadway slide-offs were reported. A serious head-on accident on M-21 shut that highway down in both directions. Ice accumulations varied, but were as much as ½ inch, and sleet accumulations reached 1 to 2 inches in some areas. A total of 450,000 electrical customers across Michigan experienced outages because of this winter storm. Most customers had their power restored by the evening of April 15. The Metropolitan Detroit area suffered the worst property damages (NOTE: not included in the preceding two-page table). Oakland and Washtenaw County damages were estimated at $6 million per county. Wayne, Macomb, and Monroe damages at $5 million per county. The grand total of property damage from this event is currently estimated at $45 million, statewide. (Such estimates are subject to eventual revision.)

Programs and Initiatives
Note: Many of the programs and initiatives designed to mitigate, prepare for, respond to, and recover from snowstorms have the dual purpose of also protecting against ice and sleet storms. As a result, there is some overlap in the narrative programs and initiatives descriptions for each respective hazard. This redundancy allows each hazard section to stand alone, eliminating the need to refer to other hazard sections for basic information.

<u>National Weather Service Doppler Radar</u>

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including weather systems that are likely to produce ice and sleet. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting precipitation types, ensuring more accurate prediction of winter weather.

<u>National Weather Service Watches/Warnings</u>

Sufficient warning can do much to reduce the damage from ice and sleet storms by permitting people to prepare properly. The National Weather Service uses the terms "ice storm," "freezing rain," and "freezing drizzle" to warn the public when a coating of ice is expected on the ground and on other exposed surfaces. The qualifying term "heavy" is used to indicate ice coating which, because of the extra weight of the ice, could cause significant damage to trees, overhead wires, and other exposed objects.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

MI-Ready Initiative

Various educational publications are offered to audiences of all ages, providing information about emergency preparedness and hazard mitigation: https://www.michigan.gov/msp/0,4643,7-123-72297_60152_68558---,00.html .

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Electrical Infrastructure Reliability

One of the major problems associated with ice storms is the loss of electric power. Michigan has had numerous widespread and severe electrical power outages caused by ice storms, several of which have resulted in a power loss to 250,000 – 500,000 electrical customers for several hours to several days at a time. Ice-related damage to electric power facilities and systems is a concern that is being actively addressed by utility companies across the state. Detroit Edison, Consumers Energy and other major electric utility companies have active, ongoing programs to improve system reliability and protect facilities from damage by ice, severe winds, and other hazards. Typically, these programs focus on trimming trees to prevent encroachment of overhead lines, strengthening vulnerable system components, protecting equipment from lightning strikes, and placing new distribution lines underground. The Michigan Public Service Commission (MPSC) monitors power system reliability to help minimize the scope and duration of power outages.

Urban Forestry/Tree Maintenance Programs

Urban forestry programs can be very effective in minimizing ice storm damage caused by falling trees or tree branches. In almost every ice storm, falling trees and branches cause power outages and clog public roadways with debris. However, a properly designed, managed and implemented urban forestry program can help keep tree-related damage and impact to a minimum. To be most effective, an urban forestry program should address tree maintenance in a comprehensive manner, from proper tree selection, to proper placement, to proper tree trimming and long-term care.

Every power company in Michigan has a tree trimming program, and numerous local communities have some type of tree maintenance program. The electrical utility tree trimming programs are aimed at preventing encroachment of trees and tree limbs within power line rights-of-way. Typically, professional tree management companies and utility work crews perform the trimming operations. At the local government level, only a handful of Michigan communities have actual urban forestry departments or agencies. Often, crews from the area public works agency or county road commission perform the bulk of the tree trimming work.

When proper pruning methods are employed, and when the work is done on a regular basis with the aim of reducing potential storm-related damage, these programs can be quite effective. Often, however, tree trimming work is deferred when budgets get tight or other work is deemed a higher priority. When that occurs, the problem usually manifests itself in greater storm-related tree debris management problems down the line.

Hazard Mitigation Alternatives for Ice and Sleet Storms

- Increased coverage and use of NOAA Weather Radio.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines. (NOTE: Where appropriate. Burial may cause additional problems and costs in case of breakage, due to the increased difficulty in locating and repairing the problem.)
- Establishing heating centers/shelters for vulnerable populations.
- Home and public building design and maintenance to prevent roof and wall damage from "ice dams."

Tie-in with Local Hazard Mitigation Planning

Ice and/or sleet storms were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Alger, Berrien, Charlevoix, Delta, Hillsdale, Jackson, Lenawee, Livingston, Macomb, Mecosta, Menominee, Schoolcraft, and Tuscola (13 counties, a decrease from 2014, but since many local plans referred generally to winter weather risks rather than distinguishing between ice, sleet, and snowstorms, these lists should merely be considered approximate indicators of local priorities for these hazards.)

Snowstorms and Blizzards

*A **snowstorm** is a period with the rapid accumulation of snow often accompanied by high winds, cold temperatures, and low visibility. A **blizzard** includes strong winds (over 35 mph), drifting snow, low temperatures, and blowing snow that reduces visibility.*

Hazard Description

As a result of being surrounded by the Great Lakes, Michigan experiences large differences in snowfall over relatively short geographic distances. The average annual snowfall accumulation in different areas ranges from 30 to 200 inches of snow. The highest accumulations are in the northern and western parts of the Upper Peninsula, as areas such as Houghton have received over 350 inches of snow in a single year (356.2 inches fell at Houghton in 1989). In Lower Michigan, the highest snowfall accumulations occur near Lake Michigan and in the higher elevations of northern Lower Michigan. Many areas in the northwest portion of the Lower Peninsula average greater than 100 inches of snow annually. On the low end of snowfall totals, areas in the east central and southeastern portions of the state receive less than 50 inches of snow per year. Communities in West Michigan typically receive 60-100 inches of snow. A map appears on the next page, and more detailed information can be found at the State Climatologist's web site: https://climate.geo.msu.edu/climate_mi/ .

Blizzards are the most dramatic and perilous of all snowstorms, characterized by low temperatures and strong winds (35+ miles per hour) bearing enormous amounts of snow. Most of the snow accompanying a blizzard is in the form of fine, powdery particles that are wind-blown in such great quantities that, at times, visibility is reduced to only a few feet. Blizzards have the potential to result in property damage and loss of life. Just the cost of clearing the snow can be enormous.

Snowstorms can be very dangerous for a community over a period of days or weeks. Heavy snows can shut down towns and cities for several days if snow is persistent and cannot be cleared in a timely fashion. Pre-planning for snow storage areas will be helpful. Roof failures may occur as the weight of the snow and area of snow cause damage to homes and buildings. Motorists and passengers in cars can be stranded in rural areas and die of exposure because of inadequate preparation for conditions.

Some areas suffer greater flood risks because thick snow cover can rapidly melt off during rainstorms, causing rapid drainage of waters toward cities and into drains and rivers. Partially melted snow and ice may cause blockages within these water channels, causing liquid waters to back up or divert sideways and over banks where they damage property and roadways.

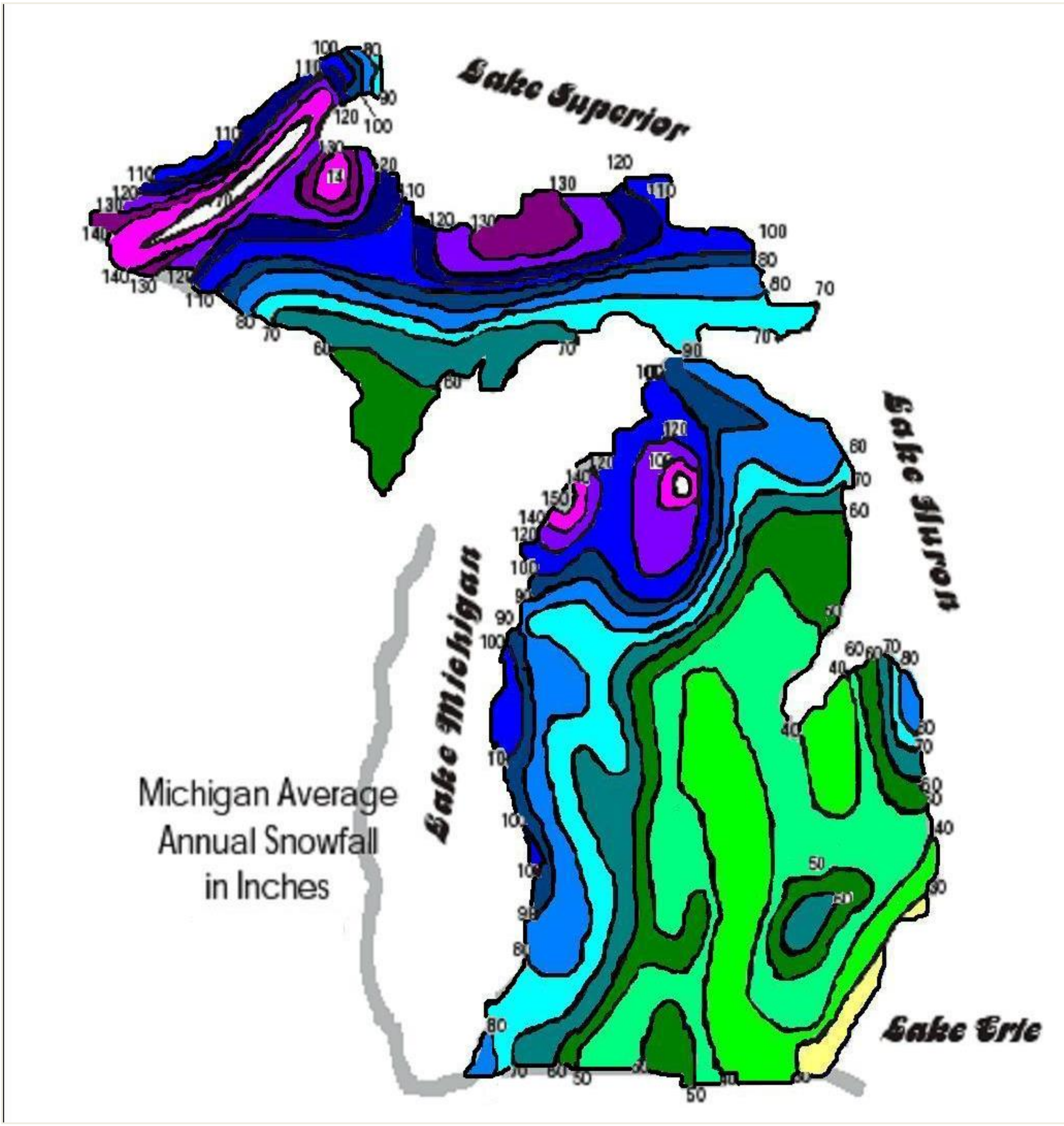
Urban areas can be especially susceptible to electrical power outages and problems with snow removal, due to their infrastructure's complexity and the limited space available for snow clearance and storage. Rural areas may have roads become inaccessible for some time, but these areas often have residents that are more equipped to independently handle power outages and temporary isolation. For example, a higher percentage of them may own snowmobiles and durable trucks and off-road vehicles with four-wheel drive and special treads designed for snow traction. Information about snow cover and types, which may be useful either for an analysis of the snowstorm hazard, or in an analysis of snowmelt-related flood risks, may be found at http://www.nohrsc.nws.gov.

Hazard Analysis

The snowfall map that follows shows that the western Upper Peninsula experiences the most snowstorms and snowfall in Michigan each year. The western half of the Lower Peninsula also experiences heavy snowfall and a relatively large number of snowstorms. One reason for this is the "lake effect," a process by which cold winter air moving across Lakes Michigan and Superior picks up moisture from the warmer lake waters, resulting in larger snowfall amounts in the western part of the state.

Michigan Average Annual Snowfall

Source: Michigan Committee for Severe Weather Awareness



Please refer to the table in the Introduction to the Weather Hazards section to find a table of record snowfall amounts (per event) at various locations across Michigan, and for a description and comparison of the state's four general "regions," as defined in this document. In general, the snowstorm season of the Southern Lower Peninsula runs from November to April each year. (Although snow occasionally does fall outside of this "season," such snowfall would be comparatively light, rather than the sort of snowstorm event that is here being considered as a hazard.) The snowstorm season for the Upper Peninsula runs from late September to May. This does not mean that all of these months necessarily receive significant snowfall each year. Instead, the "season" denotes the part of each year when a significant snowstorm may occur. A significant snowstorm is here defined as at least several inches of snow accumulation in a single event.

Snowstorm History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Snow Storm Events	Days with Snow Storms	Tot. property damage	Tot. crop damage	Injuries	Deaths
Washtenaw	51	51	$225,000			
Wayne	46	46	$960,000			
.Livingston	53	53	$129,000		3	
Oakland	55	55	$400,000		3	
Macomb	43	43	$170,000			
5 Co Metro region	**50 avg.**	**50 avg.**	**Total $1,884,000**		**6**	
Berrien	108	108	$20,000			
Cass	93	92				
St. Joseph	60	60				
Branch	55	55				
Hillsdale	50	50				
Lenawee	50	48	$505,000			
Monroe	40	40	$45,000			
.Van Buren	124	124	$50,000			
Kalamazoo	89	89	$50,000			
Calhoun	59	59	$2,250,000			
Jackson	53	53	$1,225,000			
.Allegan	145	144	$25,000			
Barry	70	70	$50,000			
Eaton	52	52	$1,050,000			
Ingham	51	51	$1,050,000			
.Ottawa	136	136	$250,000			
Kent	98	98	$50,000			
Ionia	54	53	$25,000			
Clinton	44	44	$1,025,000			
Shiawassee	45	45	$10,000			
Genesee	56	56	$1,650,000		1	
Lapeer	54	54	$10,000			
St. Clair	65	65	$45,000			
.Muskegon	112	112				
Montcalm	63	62	$80,000			
Gratiot	51	50	$75,000			
Saginaw	53	53	$25,000			
Tuscola	51	51				
Sanilac	69	69	$5,000			
.Mecosta	59	58	$40,000			
Isabella	51	50	$290,000			
Midland	49	48				
Bay	50	49	$25,000			
Huron	59	59	$1,500,000			
34 Co S Lower Pen	**68 avg.**	**68 avg.**	**Total $11,425,000**		**1**	

Continued on next page…

Part 2 of Snowstorm History for Michigan Counties – arranged by geographic division

.Oceana	109	108				
Newaygo	76	76	$25,000			
.Mason	107	106				
Lake	78	77	$375,000			
Osceola	58	57	$510,000			
Clare	53	52	$300,000			
Gladwin	40	39				
Arenac	42	42				
.Manistee	83	82	$350,000			
Wexford	62	62	$283,000			
Missaukee	70	70	$185,000			
Roscommon	56	56	$100,000			
Ogemaw	50	50	$50,000			
Iosco	49	48				
.Benzie	89	89	$600,000	$2,000,000		
Grand Traverse	108	108	$612,000	$5,000,000		
Kalkaska	118	118	$290,000			
Crawford	75	75	$255,000			
Oscoda	51	51	$100,000			
Alcona	44	44	$3,000			
.Leelanau	115	115	$653,000	$13,000,000		
Antrim	139	139	$267,000			
Otsego	114	113	$337,000			
Montmorency	55	55	$165,000			
Alpena	63	63	$110,000			
.Charlevoix	126	126	$295,000			
Emmet	105	105	$204,000			
Cheboygan	84	84	$206,000			
Presque Isle	61	61	$258,000			
29 Co N Lwr Pen	**79 avg.**	**78 avg.**	**Total $6,533,000**	**$20,000,000**		
Gogebic	232	232	$65,000		1	
Iron	99	99	$605,000			
Ontonagon	272	271	$16,000		2	1
Houghton	366	318	$88,000			
Keweenaw	205	203				
Baraga	191	188	$66,000			
.Marquette	261	258	$276,000			1
Dickinson	97	97	$30,000			
Menominee	102	102	$32,000			
Delta	148	148	$75,000			
Schoolcraft	218	178	$105,000			
Alger	287	282	$11,000			
.Luce	173	171	$3,500			
Mackinac	66	65	$50,000			
Chippewa	108	108	$90,000			
15 Co Upp. Pen	**188 avg.**	**181 avg.**	**Total $1,512,500**		**3**	**2**
MICH. TOTAL	**7,673**	**1,356**	**$21,354,500**	**$20,000,000**	**10**	**2**
Annual average	**360**	**64**	**$1,001,121**	**$937,620**	**0.5**	**0.1**

NOTE: Includes the NCDC categories of “Blizzard,” “Heavy Snow,” “Lake-Effect Snow,” “Winter Storm,” and “Winter Weather.”

Michigan had historically seen a major regional or statewide snowstorm approximately every 5 years. Local events are more frequent. Climatic trends provide evidence that Michigan snowstorms will increase. Although precipitation has gradually been increasing in Michigan, the proportion of this precipitation that falls in the form of snow rather than rain or sleet is trickier to predict. Total casualties can be difficult to assess because many deaths are caused by automobile accidents, heart attacks from overexertion, and other secondary impacts that may be difficult to specify as solely weather-related. The NCDC data in the preceding table shows some clear geographic effects in historical snowstorm patterns. One is the lake effect—in the table, a dot appears just before the name of the westernmost county in each tier of counties listed from south to north, and these westernmost counties, which are close to Lake Michigan, have greater snowfall events, with the numbers generally declining from county to county as one proceeds eastward across each tier. Within this 21-year historical average, these counties range from about 7 snowstorm days per year down to only about 2. In parts of the Upper Peninsula, there is an average of up to 15 snowstorms per year.

By observing winter storm watches and warnings, adequate preparation can usually be made to reduce the impact of snowstorms on Michigan communities. The primary challenges facing community officials include providing for the mass care and sheltering of residents left without heat or electricity, and mobilizing sufficient resources to clear blocked roads. Severe snowstorms periodically affect every Michigan community. Therefore, every community should plan and prepare for severe snowstorm emergencies. That planning and preparedness effort should include the identification of mass care facilities and necessary resources such as cots, blankets, food supplies and generators, as well as snow clearance and removal equipment and services. Pre-planning for snow storage areas will be helpful. In addition, communities should develop debris management procedures (to include the identification of multiple debris storage, processing and disposal sites) so that the tree and other storm-related debris can be handled in the most expedient, efficient, and environmentally safe manner possible.

Heavy snows can shut down towns and cities for a period of a few days if snow is persistent and cannot be cleared in a timely fashion. Roof failures may occur as the weight and volume of snow cause damage to homes and buildings. Urban areas are especially susceptible to outages and problems with snow removal, while rural areas may have roads that are inaccessible for some time (but can also have residents who are more prepared to handle power outages and temporary isolation). Motorists and passengers in cars can be stranded in rural areas and die of exposure if their preparation was inadequate for the weather conditions.

Impact on the Public, Property, Facilities, and Infrastructure

Snowstorms present hazards that can be similar to moderate-level ice storms, but snowstorms occur much more frequently. The geographic pattern for snowstorm damage is less clear than that for ice storms, with snow causing far less damage in major cities than ice does. Transportation problems tend to be substantial, requiring the clearance of snowy "debris" out of roadways and runways into some space where it is out of the way. The work required to move accumulated snow (which may "drift" to significant heights or be blown back in place by wintry winds) can often overwhelm the capacities of both individual residents as well as public workers and local budgets. Structures with roofs that are flat or inadequately sloped are often vulnerable from the weight of accumulated snow, which may cause damage and collapse. Other roofs can be vulnerable to "**ice dams**" that cause damaging leaks as melting snow pools behind accumulated ice and seeps into a structure's roof, walls, attics, and ceilings. Design adjustments can prevent ice dam leak impacts. Most infrastructure is safe underground, but accumulated snow can cause tree branches to bend and break across utility lines, interrupting service.

Impact on the Economic Condition of the State

Snowstorms are an annual event throughout the state, and the vast majority of Michigan's residents, businesses, and governments are well-acquainted with the phenomenon. Economic impacts usually involve transportation delays or occasional, temporary power failures. Most of these are already taken into account by businesses, school districts, and other facilities, who often have standard procedures and techniques to adapt to these delays and inconveniences until the snowstorm recovery period has run its course. The most vulnerable zones in Michigan (e.g. the Western Upper Peninsula) often have a more challenging recovery period, but also tend to have higher levels of awareness and preparedness, to offset those risks. The use of insurance and the careful determination of municipal budgets to allow for snow impacts will, in the majority cases, be sufficient to prevent snowstorms from having a severe impact upon major businesses, school districts, and municipal services.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Responders are asked to be outdoors during winter weather events in which most citizens prefer to take shelter. In addition to the risks from winds, obscured vision, impaired control of vehicles, power failures and blocked roadways, winter storm events also expose responders to extremely cold temperatures for long periods of time, and may thus compound the difficulties, risks, and expenses of response. Fatigue can more easily become a problem under extreme temperature conditions, either during winter weather emergencies or during extreme summer heat and humidity. Snow can impede facility access and make travel and outdoor activities treacherously slippery, perhaps in some cases delaying access and responders' ability to make repairs to affected sites. The main continuity of operations concerns involve transportation difficulties and infrastructure failures, particularly electrical and communication services. Service delivery impacts are similar. During severe winter weather, utility workers often need assistance or prioritization in the removal of debris and the clearance of roads so that they can restore power to areas where utilities had been disrupted.

Impact on the Environment
Heavy snowstorms and severe blizzards can damage trees, as the weight of heavy snow accumulations bend or break limbs, branches, or even entire trees that were already weakened. Dried dead trees or detached branches more readily catch fire, providing potential wildfire fuel during other seasons if not removed properly. Dead trees can become a breeding ground for beetles or other pests that can harm healthy green trees in non-winter seasons. Animal deaths can occur as a result of immobility, injury, infections, frost bite, hypothermia, etc. Floods often occur when snow melts, and can cause environmental effects (as described in the flooding section). Erosion from the drainage of melted snow can occur, affecting beaches and soils. Draining meltwaters can carry pollutants from land surfaces, just as floodwaters can. Some snow may have accumulated a variety of contaminants from the atmosphere and roadways, contributing to water pollution when it melts off. Snow control upon roadways and urban surfaces often involves salts and other minerals, which can affect the ecosystems in some streams, marshes, ground water, ponds, and lakes, creating difficult conditions for fish and other species, including bottom-dwelling fish fodder. The gradual contamination of soil and groundwater can also result in vegetative stress and decreased productivity. Contaminated sediments can accumulate in the tissues of organisms and be conveyed to other parts of the food chain. The typical and cumulative effect of these general ideas is not considered to be particularly serious in the case of snowstorms, however.

Impact on Public Confidence in State Governance
For this hazard, the main issues regarding public confidence in government predominantly involve: (1) the ability of the infrastructure of the impacted area to withstand the winter storm event and continue to serve area residents, and (2) the ability of the government(s) to efficiently clear away snow and ice from areas that are most vitally needed for transportation and other shared public uses (e.g. schools, hospitals). If any shortcomings or failures in one or both of these functions are too evident to citizens (or mass media providers), then the capacity, efficiency, and adequacy of government(s) may be called into question. In many functional areas, the State and its various local governments and agencies will have different types of responsibilities, and where problems arise in the coordination or clarity of these governments' actions and responsibilities, discontent can reasonably be expected to be expressed by citizens.

Climate Change Considerations
The effect of climate change upon Michigan is expected to cause an increase in the amount of precipitation during the next few decades. Even though the length of Michigan winters has been decreasing, the season remains an intense one, and periods of deep freeze may actually become more likely as temperature differences narrow between the arctic, polar, and tropical air masses during the Northern Hemisphere's winter season. During the winter months, the increase in precipitation means that snowfall events will tend on average to be more intense. More snowfall is likely to happen at a time, in the form of significant snowstorm events (e.g. 8 or more inches, higher snowdrifts, cancelled school sessions, etc.).

Michigan meteorologist Paul Gross notes that "contrary to what most would expect, the warming climate is causing an increase in snowfall in those winters where the storm track brings more frequent winter storms to the Great Lakes. In Detroit, for example, five of the ten all-time snowiest winters have occurred since 2004, two of the top-five highest combined snowfall in back-to-back winters have occurred since 2007, the all-time snowiest start of a season through the end of January occurred in 2013-2014 and, as of the date of this report, the winter of 2013-2014 was already in the top five for most consecutive days with at least one inch of snow on the ground."

Historically Significant Snowstorms of General Interest in Michigan and Across the United States

Winter 1888 - Northern U. S.

The fabled Winter of 1888 was devastating to much of the northern United States, with snow, freezing temperatures, and severe winds responsible for the deaths of hundreds of people and thousands of cattle across the Dakota Territory, Minnesota, Wisconsin, and Michigan's Upper Peninsula. As bad as conditions were in the Midwest, however, one single snowstorm will forever characterize that brutal winter. The famous Blizzard of 1888 struck the eastern seaboard on March 12, 1888, dumping 40-50 inches of snow in New York and creating 30 to 40-foot snowdrifts in parts of southern New England. Snowdrifts were reported over the tops of houses from New York to New England, including some three-story houses. One town in New York had a snowdrift that measured 52 feet in height. Over 400 people died in the blizzard, including 200 in New York City alone. Wind gusts up to 80 miles per hour were reported, which contributed greatly to the tremendous drifting and high number of deaths.

November 7-12, 1913 - Eastern Great Lakes (primarily Lake Huron)

Although severe winter storms on the Great Lakes are common in November, the fall storm of November 7-12, 1913 is considered the greatest ever to strike the Great Lakes. No other Great Lakes storm in modern history compares to the November 1913 storm in terms of death and destruction. The November 1913 storm development was similar to the monster storm that struck Michigan on January 26-27, 1978 (see below). Both storms were considered a "white hurricane" because of its tremendous size and strength. Winds up to 62 miles per hour and blizzardly snow struck Port Huron on November 8-9, while in Detroit wind gusts of 70 miles per hour were reported. Port Huron was buried with heavy snow and snow squalls, creating four to five-foot drifts that immobilized the city. The heavy snow pummeled many other shoreline communities as well. On Lake Huron, sailors reported continuous, battering waves at least 35 feet high. The constant barrage of water severely battered various ships and eventually led to their demise. Forty ships were believed to have sunk in that storm, with at least 235 sailors lost. Of the 40 vessels, eight were large lake freighters that went down with all aboard.

More Recent Major Snowstorms in Michigan

January 15-20, 1950 – Upper Peninsula

The snow at Calumet was measured at 46.1 inches and set an Upper Peninsula record for the most snow falling within a single storm.

January 26-28, 1967 – Lower Peninsula

From January 26-28, 1967, a snowstorm dumped 24 inches of snow in Mid-Michigan, causing Lansing and many other communities to virtually come to a standstill. The storm contributed to 17 deaths across the region. Hundreds of motorists were stranded in their cars and had to be rescued by the National Guard and local law enforcement. The heavy snowfall caused the collapse of roofs on numerous homes and businesses, and shut down public transportation services. Several public shelters were opened to accommodate those stranded by the snow or without heat or electricity due to downed power lines.

January 26, 1977 – Southern Michigan

Beginning on January 26, 1977, a major snowstorm affected vast portions of southern Michigan. Strong winds caused extensive drifting of snow, blocking many roads. Many residents were isolated in rural residences or stranded in public shelters. This storm resulted in a Presidential Emergency Declaration for 15 counties in the southern part of the state: Allegan, Barry, Berrien, Cass, Chippewa, Hillsdale, Kalamazoo, Kent, Monroe, Muskegon, Newaygo, Oceana, Ottawa, St. Joseph, and Van Buren.

January 26-27, 1978 – Statewide

Following a week after a major snowstorm on January 21, from January 26-27, 1978, a severe snowstorm again struck the Midwest, and Michigan was at the center of the storm. Dubbed a "white hurricane" by some meteorologists, the storm measured 2,000 miles by 800 miles and produced winds with the same strength as a small hurricane along with tremendous amounts of snow. In Michigan, up to 34 inches of snow fell in some areas, and winds of 50-70 miles per hour piled the snow into huge drifts. At the height of the storm, it was estimated that over 50,000 miles of roadway were blocked, 104,000 vehicles were abandoned on the highways, 15,000 people were being cared for in mass care shelters, and over 390,000 homes were without electric power. In addition, 38 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 being cared for in shelters, 70,000 vehicles were stranded, and 52,000 homes were still without electricity. This storm resulted in a Presidential Emergency Declaration **for the entire state**, to provide assistance with snow clearance and removal operations.

December 9-12, 1995 – Sault Ste. Marie (Chippewa County)

On December 9, 1995, a snowstorm moved across the Upper Peninsula and stalled near Sault Ste. Marie for nearly 24 hours, dumping a record 28 inches of snow on the city. That eclipsed the city's previous 24-hour snowfall record (15.2 inches, in 1988) by more than one foot. By the time the storm system passed on December 12, Sault Ste. Marie had received a total of 61.7 inches of snow. The excessive snowfall presented a great threat to public safety. Most city streets were impassable to emergency vehicles, and drifted and piled snow buried hundreds of fire hydrants and restricted visibility at intersections. Schools and most businesses were closed due to the difficult conditions. A Governor's Emergency Declaration was granted for Chippewa County on December 13, to provide assistance with snow clearance and removal activities. The Michigan National Guard was activated, along with work crews from the Michigan Department of Transportation and the Michigan Department of Corrections, to clear and remove snow. (The Guard alone removed more than 150,000 cubic yards of snow in five days.) The Michigan Family Independence Agency and Michigan Office of Services to the Aging provided assistance to senior citizens and other homebound individuals. The Michigan Department of Environmental Quality waived regulations to allow the disposal of clean snow into the St. Mary's River. Other areas that received heavy snowfall in this storm event included Munising (53 inches), Ontonagon (43 inches), and Silver City and Houghton (each 34 inches).

December 20, 1996 – Southwestern Lower Peninsula

On December 20, 1996, heavy snow rapidly became lake enhanced and dumped storm totals up to 20 inches in the southwestern Lower Peninsula. Schools were closed for up to two days in some areas. Some secondary roads were blocked until road crews could get control of the situation.

January 10-12, 1997 – Western Lower Peninsula

During a three-day period from January 10-12, 1997, heavy snow of 12 inches or more was reported in all areas of Ottawa and Kent Counties. In neighboring Allegan County, the snow was measured at 28 inches on Friday evening and 40 inches by Saturday afternoon. Far to the north, Grand Traverse County received 12 to 18 inches. Throughout the affected area, schools were used as emergency shelters for stranded motorists. Secondary roads across the area were blocked from Friday night into Saturday, and interstates were also closed for a few hours late Friday into Saturday. From the 10th through 12th, traffic accidents occurred at the rate of 50 to 100 per county, per day.

March 13-15, 1997 – Upper Peninsula

Beginning on the afternoon of March 13, 1997, and continuing until the morning of March 15, a snowstorm moved across the Upper Peninsula, dumping 20-30 inches of heavy snow in many communities. Although the Upper Peninsula is accustomed to heavy snows throughout the winter, this storm produced snowfall totals that were significant even for that region. In Marquette, nearly 33 inches of new snow fell. In a 24-hour period between March 13-14, Marquette received 28 inches of snow, breaking the 24-hour snowfall record set back in March 1986. The storm also produced a record snow depth of 63 inches at Marquette County Airport, surpassing the previous record of 59 inches recorded in March 1976. The storm dropped 29 inches of snow at Phoenix in Keweenaw County, 25 inches at Herman in Baraga County, and 21 inches at Shingleton in Alger County. Numerous other communities across the region received between 16 and 20 inches of new snow.

October 26-27, 1997 – Southern Lower Michigan

An early season snowstorm crossed southern Lower Michigan on October 26, 1997, dumping 2-8 inches of heavy, wet snow. Because of the significant amount of foliage still left on the trees, the added weight of the heavy snow caused many trees and tree branches to break, resulting in numerous power outages and reports of property damage from downed trees. At the height of the storm, over 330,000 electrical customers statewide were left without power—195,000 in the Grand Rapids area alone. Total property damage was estimated at $1.2 million. Because of the widespread power outages (some of which lasted 36-72 hours), shelters were established in several communities to care for senior citizens and others vulnerable to the cold. The storm forced the closure of many schools and businesses throughout the impacted area.

January 2-4, 1999 – Southern Lower Peninsula

In the early morning hours of January 2, 1999, a severe winter storm moved across the western and southern portions of Michigan. The storm grew in intensity and size, producing record or near-record snowfall that affected much of the southern two-thirds of the Lower Peninsula by the late evening hours of January 3. High winds and frigid temperatures created blizzard conditions that lasted until late in the day on January 4 in some areas. Subsequent storms over the next several days dumped an additional foot of snow in many areas of the state, resulting in snowfall of historic proportions in several Michigan communities. Combined, these winter storms produced the worst winter conditions to hit Michigan since the statewide blizzard that occurred in January 1978 (see description above).

The effects of the blizzard on the city of Detroit were the focus of national media attention. Detroit and surrounding communities received nearly two feet of snow during the blizzard. The unusually intense snowfall, coupled with the frigid temperatures and blowing and drifting snow, severely hampered snow removal operations within Detroit. The City's inability to plow residential streets created public health and safety concerns in many areas due to lack of access for police, fire, and other emergency vehicles. The unplowed streets and sidewalks also forced the Detroit school system to close for several days, idling more than 180,000 students. The heavy snowfall collapsed numerous commercial building roofs in Detroit and throughout southeast Michigan. In addition, ice dams on residential roofs were a widespread problem, damaging tens of thousands of structures. The record snowfall also hampered mail delivery, affected the ability of residents to travel to and from work, and negatively impacted business activity and tourism.

At Detroit Metropolitan Airport, the severe winter conditions forced the cancellation of hundreds of flights over the three-day period from January 2-4, stranding thousands of travelers without adequate accommodations. Numerous planes landed at the airport, only to sit on the runway apron for hours at a time—unable to unload passengers because the snow could not be cleared from the gates fast enough or there simply were not enough open gates or personnel to handle the large influx of planes. This situation also drew the attention of the national media and cast a negative shadow over the airline and airport operations. A Presidential Emergency Declaration was granted for the 31 Michigan counties that received record or near-record snowfall, making available Federal snow removal assistance under the Federal Emergency Management Agency's (FEMA) Public Assistance Grant Program. These counties were: Alcona, Allegan, Arenac, Barry, Berrien, Cass, Crawford, Ionia, Iosco, Jackson, Kalamazoo, Kent, Lenawee, Macomb, Marquette, Mecosta, Monroe, Montmorency, Muskegon, Newaygo, Oakland, Oceana, Ogemaw, Osceola, Oscoda, Otsego, Ottawa, St. Joseph, Van Buren, Washtenaw, Wayne.

January 12-14, 1999 – Southeastern Lower Peninsula

Large snowfall amounts caused difficulty in finding places to store the snow. Roofs collapsed under the weight of snow and especially caused expensive damage to a shopping center and numerous businesses across the Detroit metropolitan area. Ice dams caused many leaking roofs (estimated in the tens of thousands), including damage to rare documents in the Clements Library of the University of Michigan in Ann Arbor. Estimated direct property damage amounted to a total of $1.8 million, especially within the counties of Wayne, Oakland, Washtenaw, and Macomb (plus some in Livingston, Monroe, and Lenawee). Three injuries were reported in Oakland County.

November 20, 2000 – Southwestern Lower Peninsula

On November 20, 2000, the first snow storm of the season for the Grand Rapids area produced a record 24-hour snowfall of 11.5 inches at the National Weather Service office in Grand Rapids, breaking the old record of 10.4 inches. Lake-effect snow continued through the night and during the morning hours of the 21st, and 1 to 2 feet of snow fell across parts of Ottawa County. Allegan County also received 24 inches.

December 11-31, 2000 – Central and Southern Lower Peninsula

In the early morning hours of December 11, 2000, a severe winter storm moved through the state, inflicting its heaviest effects on the southern two-thirds of the Lower Peninsula before moving out of the state on the morning of December 12. That storm produced record or near-record 24-hour snowfall levels in 31 counties, paralyzing the entire region. High winds and frigid temperatures created blizzard conditions that lasted until late in the day on December 13 in some areas. The storm produced great hardships for many Michigan communities. Schools across much of the southern Lower Peninsula were closed for several days, the storm forced the cancellation of hundreds of airline flights, and many businesses were forced to close at the height of the Christmas shopping season (the most profitable shopping period of the year). Damage in Genesee County was estimated at $1.1 million, as the roof of a manufacturing company collapsed and injured one person. During the storm, 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. Around Caro (Tuscola County), 41 automobile accidents took place, including an 18-car pile-up that required responders to make use of snowmobiles. 16.3" of snow had fallen around Caro.

Another series of winter storms the following week dumped an additional foot or more of snow across the same area, increasing snow depths in many counties to two feet or more. The tremendous snow depths caused a host of public health and safety concerns across the region. The snow fell at such a steady rate in many areas that public works crews worked at maximum capacity for two weeks—often around the clock—just to keep pace. The weight of the accumulated snow caused numerous collapsed roofs on homes and businesses, and ice dams and water seepage damaged thousands of structures well into January 2001. In addition, several house fires erupted when water from melting snow and ice seeped into electric meter boxes.

The cumulative effects of the heavy snowfall, high winds, and severe cold temperatures that began on December 11 caused problems across the region for the next several weeks. The sheer volume of snow made it difficult to handle, and the process of clearing it out of the way became difficult and expensive, as there was almost no place to put it. Many communities used the majority of their annual snow-removal budget and their road salt supply to combat these storms. The winter storms of December 2000 produced the worst winter conditions to hit Michigan since the statewide blizzards that occurred in January 1978 and January 1999. In Flint and Saginaw, the December 2000 snowfall set an all-time record for ANY month. In many other areas, it set all-time records for the month of December.

A Presidential Emergency Declaration was granted for the 39 Michigan counties that received record or near-record snowfall or incurred significant cumulative effects, making available Federal snow removal assistance under FEMA's Public Assistance Grant Program. These counties were: Allegan, Barry, Bay, Berrien, Branch, Calhoun, Cass, Clare, Clinton, Eaton, Genesee, Gladwin, Gratiot, Hillsdale, Huron, Ingham, Ionia, Isabella, Jackson, Kalamazoo, Kent, Lapeer, Livingston, Macomb, Mecosta, Midland, Montcalm, Muskegon, Oakland, Osceola, Ottawa, Saginaw, St. Clair, St. Joseph, Sanilac, Shiawassee, Tuscola, Van Buren, Washtenaw.

January 5, 2001 – Livingston and Oakland Counties

Three persons were injured in Brighton when the weight of accumulated snow caused an awning-style roof to collapse along the edge of a warehouse ($75,000 damage). Later in the day, a man died in Waterford Township by falling from his roof while trying to shovel snow from it.

December 23-29, 2001 – Southwestern and Northern Lower Peninsula

From December 23-29, 2001, Grandville (in Kent County) received 26 inches of snow. Up to 15 inches of snow fell in Grandville in less than 24 hours and around 24 to 26 inches of snow fell in a band from Ottawa County southwest to Allegan County. Even more lake effect snow redeveloped on the 28th and continued through the 29th, producing additional snowfall of 8 to 22 inches across the area. Across the Grand Rapids area, 12 to 18 inches of snow was common. Total snowfalls set new weekly snowfall records in several locations across southwest Michigan. Grandville (Kent County) ended up with 70.2 inches of snow for the week, which was the greatest reported snowfall total across the area. The National Weather Service Forecast Office in Grand Rapids (Kent County) had a storm total snowfall of 50.6 inches for the week. Particularly heavy snow accumulations for that week occurred along the US-131 corridor from Grand Rapids down through Allegan County, where two to four feet of snow fell. The cities of Petoskey and Charlevoix broke their 2 and 3-day snowfall total records with amounts of 44 and 60 inches and 27 and 39 inches, respectively. Traverse City matched their existing 2-day snowfall record (20.5 inches) from the 28th through the 29th. Many other areas saw snowfall totals of a foot or more during the last week of December.

January 29-30, 2002 – Southern Lower Peninsula

Severe winter weather battered much of the Lower Peninsula for two days during the end of January 2002, 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. AAA Michigan served more than 2,850 motorists by late afternoon on January 30. Detroit Metropolitan Airport cancelled more than 170 departures and 183 arrivals, due to weather conditions.

March 2, 2002 – Lower Peninsula

On March 2, 2002, a winter storm produced 12-18 inches of heavy snow across most of the Lower Peninsula. The maximum snowfall reported was in Ludington (Mason County), where 18 inches of snow fell. The snow was particularly wet and heavy, and numerous tree limbs and power lines had fallen in the area.

February 7 and 12, 2003 – Southwestern Lower Peninsula

On February 7, 2003, 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. Those involved in the crash stated that the heavy lake-effect snow had reduced visibility and caused poor road conditions. Near the I-94 and I-196 interchange, visibility was minimal, and a chain collision ensued among cars that were travelling too quickly and closely together. Only five days later, on February 12, 2003, an Alberta clipper produced heavy snow across western Lower Michigan. The heaviest snowfall report was received from Walker (Kent County), where 14 inches of snow fell. From 6 to 12 or more inches of snow fell across other parts of Ottawa and Kent Counties.

January 19-20, 2004 – Northwestern Lower Peninsula

Heavy lake-effect snow came in from Lake Michigan, with gusty northwest winds causing blowing and drifting snow. The most persistent band of snow stretched from central Leelanau County (drifts of 5-6 feet across M-72) eastward toward Interlochen (western Grand Traverse County), which had around 20 inches of snow.

January 27, 2004 – Central Lower Peninsula

On January 27, 2004, six to ten inches of snowfall occurred across much of central Lower Michigan. Up to 14 inches of snow accumulated northeast of Grand Rapids, in Montcalm County. Visibility was near zero when a pile-up involving about 50 cars and trucks occurred on I-96 near Portland, shutting down both sides of the highway. There was only one injury reported and the highway was reopened about three hours later. Police in the tri-county area had responded to more than 200 accidents during the day.

November 24-25, 2005 – Northern Lower Peninsula

Lake effect snow quickly developed and became intense by the afternoon of Thanksgiving Day throughout much of the northern portions of the Lower Peninsula. Near-blizzard conditions developed, with wind gusts of 25 to 35 mph inland and 50 mph near the coastlines, lowering visibilities near zero at times. Total snowfall amounts of 12 to 18 inches were common in the areas of Otsego, Kalkaska, and Antrim Counties. Holiday travel was severely hampered by the falling, blowing, and drifting snow. Numerous accidents occurred on area highways.

February 3-4, 2007 – Southwest Lower Peninsula

The combination of lake-effect snow (and snow already on the ground) with very strong winds resulted in blizzard conditions across the western Lower Peninsula on February 3rd. The maximum snowfall total for a twelve-hour period was eight inches, and the maximum snowfall total for a 24-hour period was 12 inches. The highest snowfall total for the entire event was 17 inches, in Grandville (Ottawa County). The Gerald R. Ford International Airport in Grand Rapids (Kent County) reported visibility at or under a quarter-mile, from 9:30 a.m. through 8 p.m. on Saturday February 3rd. Numerous other observation sites across the western Lower Peninsula also reported blizzard conditions. The blizzard conditions resulted in numerous road closures, power outages, and car accidents.

February 25-26, 2007 – Northern Lower Peninsula

A low-pressure system stalled out over the Southwest Great Lakes region resulting in a fairly extensive period of accumulating snowfall and gusty east winds in much of the Northern Lower Peninsula. The heaviest snowfall stretched from Cadillac to Lake Ann, with totals of 12 to 15 inches. Blustery winds produced considerable blowing and drifting snow. Wexford County officials reported that more than 50 vehicles slid off area roads. Numerous schools were closed on the 26th.

February 6-7, 2008 – Saginaw County

Widespread heavy snowfall of 8 to 12 inches occurred along and north of the I-69 corridor in eastern Michigan. The largest snow total (16 to 18 inches) occurred in Saginaw County, the most seen there since the blizzard of 1978. County road crews could not keep up with the snow, which fell at a rate of 2-4 inches per hour. Two to three-foot snow drifts left at least 50 cars stranded.

February 10, 2008 – Southwest Michigan

A blizzard event involved a combination of extreme cold, frequent wind gusts up to 40 mph, whiteout conditions, heavy snow, and blowing snow. There was a fifty-car pileup on I-196 in Ottawa County, causing 20 persons to receive treatment for minor injuries. Snowfall totals were the greatest over Allegan and Van Buren Counties. Snow drifts of 3 to 5 feet deep were common in rural areas. Property damage was estimated at $250,000 in Ottawa County.

December 21-22, 2008 – Western Lower Peninsula

From December 21 to 22, 2008, 6 to 12 inches of snow fell in Kent and Ottawa Counties, accompanied by wind gusts up to 45 mph. This resulted in two to three-foot snow drifts across portions of the area, and dangerous travel conditions. Farther north, Wellston (Manistee County) ended up with 23 inches of snow in 24 hours, and many Northern Lower Peninsula areas received similar amounts. At the height of the storm, several stretches of highway were shut down due to multiple vehicle accidents.

December 3-4, 2009 – Grand Rapids Area

From December 3 to 4, 2009, over a foot of snow was reported across portions of Ottawa County, with 15 inches falling in Marne and 14 inches in Coopersville. Several inches of slushy snow accumulated on roads in Muskegon and Kent Counties. The following week, four to eight more inches of snow, in conjunction with wind gusts to 40 mph, created near-blizzard conditions at times, resulting in very hazardous travel conditions with numerous traffic accidents.

December 9-11, 2009 – Northern Lower Peninsula

From December 9 to 11, 2009, heavy snowfall and blizzard conditions were common across all of Northern Michigan. The snow transitioned to lake-effect snow that night, and lasted into the 11th in some of the snow belts. Gaylord had its 2nd-largest three-day snowfall since 1950, with 21.8 inches. There was a considerable amount of wind, with some gusts over 50 mph, causing blowing and drifting snow. Almost all school districts were closed on the 9th, and some schools called off classes for three consecutive days. Numerous traffic accidents were reported.

February 9-10, 2010 – Ottawa County

From February 9-10, 2010, six to ten inches of snow fell across Ottawa County. The storm coincided with Michigan's winter "Count Day," used to determine base funding for local public-school systems. Many school systems closed due to the snowstorm. Several significant accidents occurred on the region's primary arterial roads. I-94 was closed for several hours, due to jackknifed trucks. There was also a multiple vehicle pileup on I-196.

February 1-2, 2011 – Southern Lower Peninsula

From February 1-2, 2011, a major winter storm occurred throughout much of the Lower Peninsula. The blizzard included 10 to 15 inches of snow and wind gusts over 40 mph, producing whiteout conditions and snowdrifts of 3 to 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. Most main roads were plowed by the next day, but some side streets were not cleared for a couple more days.

November 29-30, 2011 – Central Southern Lower Peninsula

A snowstorm dumped 8 to 10 inches of snow across multiple counties in central Michigan. The heavy wet snow, plus strong winds, caused many trees, limbs, and power lines to fall, leaving 30,000 persons without power. Numerous traffic accidents occurred, and a gas station awning collapsed in Haslett (Ingham County) under the weight of the snow. Property damages totaled $1 million in each of the following counties: Jackson, Calhoun, Ingham, Eaton, and Clinton. In Eaton County, two fallen trees partially blocked Billwood Highway in Windsor Township.

March 2-3, 2012 – Northern Lower Peninsula

A high-impact snowstorm brought snowfall totals that ranged from 6 to 14 inches across most of the Northern Lower Peninsula, with higher amounts in some areas and a maximum of 20 inches near Lake Ann (Benzie County). The snow was very wet and heavy, causing many trees and power lines to fall. Power outages were widespread, and the majority of the region's residents lost power at some point during or after the storm, sometimes for as long as a week. In Benzie County, 95% of residents lost power, property damages totaled $600,000, and crop damages totaled $2 million. In Grand Traverse County, $600,000 in property damage was done, along with $5 million in crop damage. Substantial damage was done to fruit trees, especially cherry trees. In Leelanau County, $650,000 in property damage and $13 million in crop damage was reported. Many communities opened shelters, to aid those whose homes had no power or heat. Additional property damage was reported in the following counties: Manistee ($350,000); Wexford, Kalkaska, Antrim, Charlevoix, and Presque Isle ($250,000 per county); Otsego ($215,000); Crawford, Emmet, and Cheboygan ($200,000 per county); Missaukee and Montmorency ($150,000 per county); Roscommon, Oscoda, Alpena, and Lake ($100,000 per county); and Ogemaw, Chippewa, and Mackinac ($50,000 per county).

January 30-31, 2013 – Upper Peninsula

Heavy snow moved across the Upper Peninsula. Traffic accidents included an injury involving a snowmobile-car collision in Gogebic County, in conditions of poor visibility. Property damage was estimated at $8,000. A weather spotter in Bessemer measured 7.5 inches of snow there within 24 hours.

February 24-25, 2016 – Western and Central Southern Lower Peninsula

A major winter storm produced heavy wet snow overnight. Total accumulations across many Lower Peninsula Counties ranged from 6 to 14 inches, which caused scattered power outages as a result of snow weighing down branches near utility lines. An estimated $175,000 in property damage was shared (i.e. $25,000 each) across the following counties: Barry, Calhoun, Eaton, Ingham, Jackson, Kalamazoo, Van Buren.

March 3, 2017 – Schoolcraft County

Lake-effect snow produced dangerous conditions on Highway US-2 near Gulliver (Southern Schoolcraft County), where poor visibility contributed to a fatal car accident involving a pickup truck and a semi-truck. A passenger in the pickup truck was killed and the driver was injured. Two persons in the semi-truck were also taken to the hospital for treatment. Property damages were estimated at $100,000.

January 28 to February 2, 2019 – Statewide Winter Emergency

A series of heavy snowfall events began this week-long event. On Monday, January 28, much of the state faced the start of a blizzard, with snowfall ranging up to over a foot in depth as sustained winds began (with gusts up to 40 mph) and were soon accompanied by a dangerous drop in temperatures. An extremely large number of schools throughout the state were closed as a result of the snowfall, and then remained closed for most of the week as the combination of sustained sub-zero temperatures and strong winds produced dangerously low wind-chill values throughout the state. Wind-chill values below -30 degrees Fahrenheit were common throughout Michigan for multiple days, and often dipped below -40. In additional to numerous local states of emergency, non-essential State Government offices were closed for more than half a day on Monday, and for the entire day on Wednesday and Thursday. Governor Gretchen Whitmer's State of Emergency declaration took effect on January 29, anticipating the dangerous impacts of the deep freeze that had been forecast by the National Weather Service. At least three deaths were attributed to weather exposure, and special shelters and over a hundred warming centers were activated at many locations around the state. Additional hospitalizations took place, not just as a direct result of the cold, but also to treat for carbon monoxide exposures resulting from makeshift efforts to heat residents' homes. Hundreds of local and county government offices were closed for at least one or two days during the week, as well.

Driving conditions were treacherous and slow. Highway M-40, southeast of Holland (Allegan County) became backed up. A 24-car pileup occurred on I-196 near Zeeland (Ottawa County), resulting in the temporary closure of that expressway. Other expressway closures occurred during the event, including I-496 and northbound US-127 in Lansing, US-131 in Allegan County, and M-37 South of White Cloud, in Newaygo County. Newaygo County also saw the Muskegon River reach a moderate flood level in Bridgeton Township and the City of Newaygo, as the result of an ice jam. Some 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—Benzie County's Platte River near the Village of Honor threatened 20 homes and cottages, Berrien County near M-139 saw minor flooding near Riverfront Campground and in Niles. Excessive delays were reported at the Detroit Metropolitan Airport (Wayne County), as well as the Blue Water Transit bus system (St. Clair County) shutting down from January 30 to 31. Visibility was often a problem, with white-out conditions resulting from the blizzard.

On Wednesday, January 30, at 10:33am, a fire occurred at an important Consumer's Energy facility in Armada Township (Macomb County), and when the impacts of this fire were calculated to eventually lead toward natural gas shortages, the head of that major utility, followed by the Governor, appealed to both residential and industrial customers to voluntarily reduce their use of natural gas. By voluntarily reducing thermostat levels to the recommended 65 degrees or below, until the end of the day on January 31, and temporarily scaling back production activities at certain facilities, this collective effort succeeded in preventing the complete interruption of gas delivery that otherwise was expected to occur. The problem did not involve a supply of natural gas, but only the constraints that the fire had caused in the ability to deliver that gas throughout the state's network. Temporary power failures occurred in some locations, affecting thousands of residents and businesses but fortunately not lasting very long. Other midwestern states also authorized state emergency and disaster declarations during this event. By Friday, February 1, temperatures went back above zero, and Michigan's State of Emergency expired on February 2, 2019.

Programs and Initiatives

Note: Many of the programs and initiatives designed to mitigate, prepare for, respond to, and recover from ice and sleet storms have the dual purpose of also protecting against snowstorms. As a result, there is some overlap in the narrative programs and initiatives descriptions for each respective hazard. This redundancy allows each hazard section to stand alone, eliminating the need to refer to other hazard sections for basic information.

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including weather systems that are likely to produce hazardous winter conditions. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches, Warnings and Advisories

The National Weather Service issues winter storm watches and winter weather warnings to notify the public of severe winter weather conditions. A watch indicates that severe winter weather conditions (freezing rain, sleet, or heavy snow) may affect an area, while a warning indicates that severe winter weather conditions are imminent.

Winter Storm Watches and Winter Storm Warnings are issued for rare winter storms that occur only a couple times per year, and may not occur at all in a given winter. These storms present a significant disruption to daily life, cause life-threatening conditions, and typically take several days to a week to recover from. Life-threatening conditions typically can only be avoided by staying home.

Blizzard Watches, Blizzard Warnings, Ice Storm Watches, and Ice Storm Warnings are issued for extremely rare winter storms that occur only once every 15 to 30 years or so and typically result in the cessation of all normal activities for many days to well over a week. These storms are extremely dangerous and life-threatening. People are typically forced to shelter in place without power and/or cannot leave their home for at least a couple of days, due to significant weather impacts.

The National Weather Service issues Winter Weather Advisories for commonly experienced, inconvenient winter conditions like snow, light freezing rain, blowing snow, and wind chill, among others. Winter Weather Advisories mean that conditions are easily mitigation and, if caution is exercised, life-threatening conditions can be avoided.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

MI-Ready Initiative

Various educational publications are offered to audiences of all ages, providing information about emergency preparedness and hazard mitigation: https://www.michigan.gov/msp/0,4643,7-123-72297_60152_68558---,00.html .

Student Tools for Emergency Preparedness (STEP)

The Student Tools for Emergency Planning program, known as STEP, is a simple and effective preparedness education project developed by the Federal Emergency Management Agency (FEMA). STEP is designed to educate fifth-graders on the importance of preparing for emergencies and to provide them with knowledge to help their families prepare. The STEP program is free to fifth grade classes, with the goal of teaching emergency preparedness to more than 10,000 students statewide.

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Electrical Infrastructure Reliability

One of the major problems associated with any winter weather hazard (including snowstorms) is the loss of electric power. Although the problem is not quite as chronic in Michigan as it is with ice storms, snowstorms have nonetheless caused several widespread and severe electrical power outages. Weather-related damage to electric power facilities and systems is a concern that is being actively addressed by utility companies across the state. Detroit Edison, Consumers Energy and other major electric utility companies have active, ongoing programs to improve system reliability and protect facilities from damage by snow, ice, severe winds, and other hazards. Typically, these programs focus on trimming trees to prevent encroachment of overhead lines, strengthening vulnerable system components, protecting equipment from lightning strikes, and placing new distribution lines underground. The Michigan Public Service Commission (MPSC) monitors power system reliability to help minimize the scope and duration of power outages.

Urban Forestry/Tree Maintenance Programs

Urban forestry programs can be very effective in minimizing snowstorm damage caused by falling trees or tree branches. In almost every severe snowstorm, falling trees and branches cause power outages and clog public roadways with debris. However, a properly designed, managed and implemented urban forestry program can help keep tree-related damage and impact to a minimum. To be most effective, an urban forestry program should address tree maintenance in a comprehensive manner, from proper tree selection, to proper placement, to proper tree trimming and long-term care.

Every power company in Michigan has a tree trimming program, and numerous local communities have some type of tree maintenance program. The electrical utility tree trimming programs are aimed at preventing encroachment of trees and tree limbs within power line rights-of-way. Typically, professional tree management companies and utility work crews perform the trimming operations. At the local government level, only a handful of Michigan communities have actual urban forestry departments or agencies. Rather, crews from the public works agency or county road commission perform the bulk of the tree trimming work.

When proper pruning methods are employed, and when the work is done on a regular basis with the aim of reducing potential storm-related damage, these programs can be quite effective. Often, however, tree trimming work is deferred when budgets get tight or other work is deemed a higher priority. When that occurs, the problem usually manifests itself in greater storm-related tree debris management problems down the line.

Hazard Mitigation Activities for Snowstorms

- Increased coverage and use of NOAA Weather Radio.
- Tree trimming and maintenance to prevent limb breakage and safeguard nearby utility lines. (Ideal: Establishment of a community forestry program with a main goal of creating and maintaining a disaster-resistant landscape in public rights-of-way.)
- Buried/protected power and utility lines. (NOTE: Where appropriate. Burial may cause additional problems and costs in case of breakage, due to the increased difficulty in locating and repairing the problem.)
- Establishing heating centers/shelters for vulnerable populations.
- Proper building/site design and code enforcement relating to snow loads, roof slope, snow removal and storage, etc.
- Agricultural activities to reduce impacts on crops and livestock.
- Pre-arranging for shelters for stranded motorists/travelers, and others.
- Using snow fences or "living snow fences" (rows of trees or vegetation) to limit blowing and drifting of snow over critical roadway segments.

Emphasis in Local Hazard Mitigation Plans

Snowstorms were identified as one of the most significant hazards in various local hazard mitigation plans but since many of them referred generally to winter weather risks rather than distinguishing between ice, sleet, and snowstorms, please refer to the list at the end of the introductory section on severe winter weather for a listing that includes snowstorms.

FOG

Fog: Condensed water vapor in cloudlike masses, lying close to the ground and limiting visibility.

Hazard Description

Fog forms near the ground when water vapor condenses into tiny liquid water droplets that remain suspended in the air. Many different processes can lead to the formation of fog, but the main factor is water-saturated air. Two ways that air can become saturated are by cooling it to its dew point temperature or by evaporating moisture into it to increase its water vapor content. Although most fog, by itself, is not generally a hazard because it does not actually apply damaging forces, the interaction between humans and fog can be a dangerous situation, sometimes resulting in disastrous consequences. It must be noted, however, that **freezing fog** (a hazard for which the National Weather Service issues special statements) <u>can</u> cause direct harm by causing slickness on roadways, walkways, bridges, and highway ramps, and therefore leading to serious transportation accidents (examples are provided later in this chapter). One of the main risks involves morning school buses and the safety of students and their parents while waiting near roadways under conditions of very low visibility.

<u>Haze and Smog</u>

Haze occurs when dust, smoke and other pollutant particles obscure the normal clarity of the sky. It occurs when dust and smoke particles accumulate in relatively dry air. When weather conditions block the dispersal of smoke and other pollutants, they concentrate and form a usually low-hanging shroud that impairs visibility and may become a respiratory health threat, as well as make safe driving more difficult. Dense haze caused by industrial pollution is also known as **smog**. This hazard may cause public health problems and might become a greater hazard in the future, if the effects become severe enough. Air quality has generally improved since the effects of the Clean Air Act, other legislation, regulatory measures, and shifts away from heavy industry in Michigan's economy.

Smoke-producing materials may have an effect that seems visually comparable to fog, or worse. For example, wildfires, hazardous materials incidents, structural fires, major transportation accidents, or industrial accidents may produce clouds of smoke that can obscure visibility and increase the risk of transportation accidents. All smoke is unhealthy for humans to inhale, but a limited amount of inhalation sometimes seems to have no health effects. Where people are uncertain about the nature of the materials that are being burned to produce smoke, they should avoid breathing it in as much as possible (for example, smoke from an industrial fire will be more dangerous than smoke from an ordinary campfire). Dangerous smoke should be considered part of a **hazardous materials incident**. Please refer to that chapter in this document, for more information.

Hazard Analysis

Most attention rightfully gets focused upon severe and high-impact meteorological events, such as thunderstorms and tornadoes. Fog is not so easy to classify as a severe and high-impact hazard, although it has caused costs and casualties in the transportation sector, especially—sometimes with deadly consequences. Fog has played a contributing role in several multi-vehicle interstate highway pileups during recent years. While statistics suggest that highway accidents and fatalities, in general, have fallen, that trend is not evident with respect to accidents and fatalities caused by fog. The vast majority of automotive accidents are caused by unsafe driving habits and risk-taking behaviors, such as following too closely behind another vehicle, driving too fast for weather and visibility conditions, and being unduly distracted by the use of phones and other electronic luxuries while on the road. Airplanes have their own inherent vulnerabilities when foggy conditions develop and make a safe landing more difficult.

Fog can be very dangerous when it reduces visibility. Although some forms of transport can penetrate fog using radar, road vehicles have to travel slowly and use their lights to become visible to each other. Localized fog is dangerous if drivers are surprised by it. At airports, some efforts have been made to develop methods (such as using heating or spraying salt particles) to aid fog dispersal, especially at temperatures near or below freezing.

One severe fog event is estimated to occur in Michigan approximately every two years. Property damage can be significant for vehicles, although real property and structures are usually unaffected. Fog has not yet been identified as one of the most significant hazards in any of Michigan's local hazard mitigation plans.

Fog History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

County or area	Fog Events	Days with Fog	Injuries	Deaths
Washtenaw	2	2		
Wayne	2	2		
.Livingston	1	1		
Oakland	1	1		
Macomb	1	1		
5 Co Metro region	**1.4 avg.**	**1.4 avg.**		
Berrien				
Cass				
St. Joseph				
Branch				
Hillsdale				
Lenawee				
Monroe	2	2		
.Van Buren	1	1		
Kalamazoo	1	1		
Calhoun	1	1		
Jackson	1	1		
.Allegan	1	1		
Barry	1	1		
Eaton	1	1		
Ingham	1	1		
.Ottawa	1	1		
Kent	1	1		
Ionia	1	1		
Clinton	1	1		
Shiawassee	1	1		
Genesee				
Lapeer	2	2	1	1
St. Clair	1	1		
.Muskegon				
Montcalm				
Gratiot				
Saginaw	1	1		
Tuscola				
Sanilac	1	1		
.Mecosta				
Isabella				
Midland	1	1		
Bay	1	1		
Huron				
34 Co S Lower Pen	**0.6 avg.**	**0.6 avg.**	**1**	**1**

Continued on next page…

Part 2 of Fog History for Michigan Counties – arranged by geography

.Oceana				
Newaygo				
.Mason				
Lake				
Osceola				
Clare				
Gladwin				
Arenac				
.Manistee	1	1		
Wexford				
Missaukee				
Roscommon				
Ogemaw				
Iosco				
.Benzie				
Grand Traverse				
Kalkaska				
Crawford				
Oscoda				
Alcona				
.Leelanau				
Antrim				
Otsego				
Montmorency				
Alpena				
.Charlevoix				
Emmet				
Cheboygan				
Presque Isle				
29 Co N Lower Pen	**0.03 avg.**	**0.03 avg.**		
Gogebic	4	4		
Iron	2	2		
Ontonagon	4	4		
Houghton	9	6		
Keweenaw	5	5		
Baraga	5	5		
.Marquette	5	5		
Dickinson	4	4		
Menominee	3	3		
Delta	4	4		
Schoolcraft	8	4		
Alger	4	4		
.Luce	4	4		
Mackinac				
Chippewa				
15 Co Upp.Pen	**4.1 avg.**	**3.6 avg.**		
MI TOTAL	**91**	**22**	**1**	**1**
Annual avg.	**4.3**	**1.0**	**0.05**	**0.05**

NOTE: Includes the NCDC categories of “Dense Fog” and “Freezing Fog.”

Impact on the Public, Property, Facilities, and Infrastructure
The primary risks from fog involve the dangers of traveling under conditions of limited visibility. Although some modes of transportation, such as aircraft, are well-regulated, other modes, including simple pedestrian travel, may involve risks that have not been properly accounted for by those who are focused merely on reaching their destination as quickly as possible. The most substantial impacts have recently involved drivers whose bad habits (primarily that of not maintaining safe speeds and adequate following distances) proved to be simply unsustainable under conditions of reduced visibility, resulting in severe crashes and subsequent roadway obstructions. In some circumstances, these conditions of reduced visibility can arise very quickly, although careless drivers, in their desire for fast travel conditions, may erroneously try to ignore the risks from reduced visibilities, either in a calculated gamble or in the hope that the condition will suddenly correct itself before any harm is caused. Either pattern places the fault more upon the habits and expectations of human risk-takers than upon the inherent dangers of fog itself. Impacts upon lives and property tend to be the fault of human recklessness rather than actual direct fog effects. Impacts upon facilities and infrastructure probably only occur as a result of transportation accidents, with the potential exception of the slickness caused by freezing fog.

Impact on the Economic Condition of the State
The main effect of fog is to limit visibility and cause transportation delays. These delays are only temporary, and not expected to be any more of a problem than other routine weather events, such as rain, storms, and snow. Some local areas are more susceptible to fog than others, and these are usually more rural locations that have fewer streetlights but also a much smaller population and lower levels of traffic. The areas of greatest vulnerability may be in the locations where a heavily travelled stretch of highway passes through a rural zone that is prone to heavy, low-lying fog banks. Some of these are located along shorelines, but some are located in inland areas. The overall economic impact of this hazard is calculated to be minimal, however. Anyone traveling in fog should be diligent and cautious, should use lights so that others can see their vehicle, and should travel no faster than visibility conditions can safely permit.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
In certain circumstances that require an emergency response, heavy fog may cause impediments and risks that would not normally be present. This is especially true in cases involving high-speed mechanized transportation that requires good visibility to maintain adequate and safe control and maneuvering ability, and for situations that involve search and rescue operations, for which visibility may be very important in locating and assisting victims. Response activities involving aircraft, for example, may be impaired or harmfully delayed by fog. Delays in the transport and delivery of personnel and supplies may also occur. These delays are usually temporary, often just limited to a few hours in the early morning, in specific rural or suburban locations where fog is more likely to form and thicken. Local responders are usually familiar with such areas and conditions, and adapt accordingly. However, there has been a clear increase in school delays due to fog within recent years, due to the risks that morning fog presents to school bus transportation and the safety of students and parents waiting near roadways under conditions of very low visibility.

Impact on the Environment
Fog on its own does not directly impact the environment. However, by reducing visibility and creating dangerous traveling conditions, fog may increase the chance of a transportation accident involving a chemical release that may then cause great harm to the environment by releasing toxins into the soil, groundwater or air. (Please refer to the chapter on hazardous materials, in the Technological-Industrial Hazards section of this plan.)

Impact on Public Confidence in State Governance
This hazard is not expected to cause serious impacts upon public perception of the State's governance, so long as the cautionary messages issued by the National Weather Service and other agencies are received and understood, and so long as major transportation agencies and facilities maintain and follow adequate safety procedures during fog events. One reason for the estimated lack of impact on public confidence is that (1) the hazard is typically a localized one and not normally presumed to be dealt with at a State level, (2) public announcements tend to be clearly stated when visibility gets too low and causes risks, and (3) the airline industry operates under regulations (and also uses special equipment) to alleviate the risks from fog. The most serious incidents in Michigan, in which extensive chain-reaction car crashes have occurred on interstate highways, could arguably be connected with too lax of enforcement of fundamental traffic laws (primarily the infractions of following too closely and speeding), but a large proportion of the

public, which persists in such unsafe and often unconscious driving habits, may not perceive, understand, or agree with the hypothetical connection between these conditions.

Recent Significant Fog-Related Incidents in Michigan

January 11 to 13, 1995 – Michigan's Lower Peninsula

In January 1995, dense fog blanketed much of Lower Michigan from the evening of the 11th through the morning on the 13th. Numerous traffic accidents occurred during this fog, resulting in four fatalities. School openings were delayed in parts of southwest Michigan as visibilities dropped to near-zero. Low visibilities caused most of the flights at Detroit's metro airport to be cancelled, delayed, or diverted on the 12th. About seventy-five flights were also delayed or cancelled at Kent County International Airport in Grand Rapids.

October 25 to 26, 2000 – Southeastern Metro Areas

On the morning of October 25, dense fog dropped visibilities to only about an eighth of a mile at the MBS International Airport (Saginaw County), causing most of the morning flights to be cancelled. In addition, several area school districts delayed the start of classes that morning. On the following morning, October 26, dense fog had a similar effect upon Metropolitan Detroit, causing dozens of flights to be delayed at the Detroit Metro Airport, and slowing the traffic of morning commuters on the area's roads and highways.

October 11 to 12, 2002 – Lapeer County

At certain times, dense fog reduced visibility to near zero in many locations. A 17-year-old teenager was killed in Goodland Township when his pickup truck collided with a dump truck that was hauling a trailer. In a separate incident, a slightly older 19-year-old driver failed to stop at a sign and struck a school bus, resulting in one injury.

January 12, 2005 – Ingham County

Up to 200 vehicles collided on an expressway, in a chain of crashes blamed on heavy fog in Ingham County on January 12, 2005. Two people were killed and thirty-seven others were taken to local hospitals. It was the worst crash in mid-Michigan in recent years, shutting down both lanes of Interstate 96 between Okemos and Webberville for several hours. The dense fog cut visibility to around ten feet during rush hour.

September 13, 2006 – Shiawassee County

Dense fog was reported to have "caused" three semi-trucks to roll over, a separate car crash, and an additional car fire on I-69. As a result, that expressway had to be shut down in both directions between M-71 and the Grand River exit (a distance of about 4.5 miles), until the accidents could be cleared. A total of seven persons were injured in these crashes.

November 24, 2006 – Monroe County

In November 2006, freezing fog caused zero visibility and created extremely dangerous driving conditions that led to numerous vehicle collisions. A semi-truck rollover accident resulted in the death of one man. Portions of I-275 were shut down for several hours due to the accident. Ten injuries were (indirectly) associated with the hazardous fog on this day.

January 12, 2009 – Southern Lower Peninsula

The National Weather Service issued an advisory (for 17 counties) about freezing fog that would not only reduce visibility, as normal fog does, but would also freeze upon some roadways and "aggravate already slick conditions."

May 22, 2010 – Manistee County

Dense fog inhibited visibility in Manistee County. At the entrance to Manistee Harbor, a fishing boat struck a pier, took on water, and submerged. Seven persons were rescued from the water, but there were two injuries and a death that still resulted (plus four persons who were less seriously harmed and merely required on-site medical treatment).

January 21 to 22, 2018 – St. Joseph County

Warm, moist air moved over an extensive winter snowpack during a melting spell, resulting in dense fog that reduced visibility to nearly zero in many areas (and to less than a quarter mile throughout the county). The fog at least partially contributed to an accident at Pleasant and Summit Roads (St. Joseph County), in which a driver failed to see a stop sign and collided with another vehicle. One person was killed and two were injured. Although the fog was heavy, Michigan's basic speed law clearly states that drivers must not travel at any speed that is unsafe for the given weather conditions in an area.

Programs and Initiatives

National Weather Service Doppler Radar

National Weather Service Doppler Weather Radar can now more easily detect severe weather events that threaten life and property—including heavy fog or freezing fog. Most significantly, the lead time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WSR-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

Automated Surface Observation System (ASOS)

In the 1980s the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD) were faced with the need to find cost-effective ways to provide pilots with critical weather information. With NWS in the lead role, these federal agencies began development of automated sensors that were intended to eventually replace human weather observers. This automated sensor development culminated in the fielding of two systems: The Automated Weather Observation System (AWOS) and the Automated Surface

Observation System (ASOS). AWOS and ASOS sensors provide continuous measurements of ceiling, visibility, temperature, dew point, wind speed and direction, and precipitation. All ASOS sites and some AWOS sites also have lightning detection and reporting, courtesy of the Automated Lightning Detection and Reporting System (ALDARS). Beginning in 1992, ASOS sites started to replace manual surface aviation observations. There are currently more than 900 federally sponsored ASOS sites around the country, and 24 of them are in Michigan. Fog is considered to be an obstruction to visibility when the temperature and dew points are within 5°F of each other. When the difference is more than five degrees, haze is reported.

Automated Weather Observing System (AWOS)
The Automated Weather Observing System (AWOS) is a suite of sensors, which measure, collect and disseminate weather data to help meteorologists, pilots and flight dispatchers prepare and monitor weather forecasts, plan flight routes, and provide necessary information for correct takeoffs and landings. An AWOS provides minute-to-minute updates that are usually provided to pilots by a VHF radio on a frequency between 118 and 136 MHz. An AWOS is categorized as either federal or non-federal. A federal AWOS was purchased and is currently maintained by the FAA. A non-federal AWOS is purchased and maintained by state, local, and private organizations. The sensors measure weather parameters such as wind speed and direction, temperature and dew point, visibility, cloud heights and types, precipitation, and barometric pressure. The AWOS does not predict weather, but may send current information to weather offices where forecasts are produced using this information along with computer model outputs, satellite photos and radar images. There are currently twenty-eight Automated Weather Observing Systems in Michigan.

Information Broadcast by an AWOS III

Airport Identifier	Zulu Time
Sky Conditions	Visibility
Wind Speed	Wind Direction
Temperature	Dew Point
Altimeter Setting	Remarks
Density Altitude	Wind Gusts

Advanced Weather Interactive Processing System (AWIPS II)
Updated earlier in this decade, the Advanced Interactive Processing System (AWIPS) is an interactive computer software system with a full suite of satellite imagery used to analyze meteorological and hydrological data. This system is used by the National Weather Service (NWS) to predict weather patterns, prepare forecasts, and issue weather-related warnings. AWIPS has been the foundation of the NWS operations for the 21st Century.

Lighthouses
Lighthouses are key parts of the infrastructure for water transportation, especially when dealing with the dangerous element of fog. Michigan has more lighthouses than any other U.S. state, by quite a large margin. In addition to traditional lighthouses, Michigan has many minor aids to navigation, in the form of cylindrical steel towers with navigation beacons at the top. These are known as D9 towers (named after the ninth Coast Guard district). Some of the D9 towers are regarded locally as being lighthouses, but most are not. Below is a list of lighthouses in Michigan that are still operational.

Operational Lighthouses in Michigan

Name	Lake	Name	Lake
Detroit River Bar Point Shoal Light	Erie	Minneapolis Shoal Light	Michigan
Cheboygan River Range Front Light	Huron	Muskegon South Breakwater Lights	Michigan
Detour Reef Light	Huron	North Manitou Shoal Light	Michigan
Fort Gratiot Light	Huron	Escanaba Light	Michigan
Forty Mile Point Light	Huron	Fourteen Foot Shoal Light	Michigan
Harbor Beach Light	Huron	Point Betsie Light	Michigan
Martin Reef Light	Huron	Poverty Island Light	Michigan
Middle Island Light	Huron	Frankfort North Breakwater Light	Michigan
Poe Reef Light	Huron	Grand Haven South Pier Head Lights	Michigan
Pointe Aux Barques Light	Huron	Grays Reef Light	Michigan
Port Austin Reef Light	Huron	Seul Choix Pointe Light	Michigan
Port Sanilac Light	Huron	Skillagalee Light	Michigan
Presque Isle Lights	Huron	South Haven South Pierhead Light	Michigan
Round Island Passage Light	Huron	St. Helena Island Light	Michigan
Sturgeon Pointe Light	Huron	St. James Light	Michigan
Tawas Pointe Light	Huron	White Shoal Light	Michigan
Thunder Bay Island Light	Huron	Lake St. Clair Light	St. Clair
Alpean Light	Huron	St. Clair Flats South Channel Range	St. Clair
Spectacle Reef Light	Huron	Au Sable Light	Superior
Round Island Light	Mackinac Straits	Big Bay Point Light	Superior
Little Rapids Cut Range Light	St. Mary's River	Passage Island Light	Superior
Big Sauble Point Light	Michigan	Rock of Ages Light	Superior
Charlevoix Light	Michigan	Gull Rock Light	Superior
Charlevoix South Pier Light	Michigan	Huron Island Light	Superior
Holland Harbor (South Pier Head Light)	Michigan	Isle Royale Light	Superior
Lansing Shoal Light	Michigan	Keweenaw Waterway Entrance Light	Superior
Little Point Sable Light	Michigan	Manitou Island Light	Superior
Ludington North Breakwater Light	Michigan	Marquette Harbor Light	Superior
Manistee Light	Michigan	Mendota Light	Superior
Manistique (East Breakwater) Light	Michigan	Munising Range Lights	Superior
Menominee Light	Michigan	Eagle Harbor Light	Superior
		Whitefish Pointe Light	Superior

<u>Michigan Lighthouse Assistance Program Grants</u>
The Michigan Lighthouse Assistance Program was established by the Michigan legislature in 1999 to assist local groups in preserving and protecting lighthouses. The program arose from the efforts of the Michigan Lighthouse Project, out of concern for the disposal of some 70 lighthouses by the U.S. Coast Guard. Two-thirds of Michigan's lighthouses currently under federal ownership are scheduled for disposal within the next decade. The grant program is managed through the State Historic Preservation Office and the Michigan State Housing Development Authority.

Hazard Mitigation Activities for the Fog Hazard

- Increased coverage and use of NOAA Weather Radio.
- De-icing measures (for freezing fog), as would be used for other ice-related hazards.

Emphasis In Local Hazard Mitigation Plans

None of the local hazard mitigation plans have yet stated that the fog hazard is one of the most significant in their jurisdictions.

I. Natural Hazards
B. Hydrological Hazards

The following outline summarizes the significant hydrological hazards covered in this section:

1. Flooding
   - a. Fluvial (Riverine) and Similar Floods
     including erosion, flooded surface drains, undersized and failed bridges and culverts, sedimentation, ice and log jams
   - b. Pluvial and Urban Flooding
     including ponding problems, drainage system inadequacies (capacity, power supply, structural failure), basement backflow
   - c. Great Lakes Shoreline Hazards
     including seiches, meteotsunamis, ice surges, harmful algal blooms, rip currents, Great Lakes erosion and recession
   - d. Dam and Levee Failures
2. Drought

More of Michigan's documented disaster damages, on average, now come from flooding than from any other natural cause. This section of the Michigan Hazard Analysis now includes multiple chapters that deal with different types of flooding and water-related issues. The key problems involve water quantity and water quality. The quantity problem can either involve too much water (accumulating too quickly), resulting in flood events, or too little water (accumulating too slowly), which results in a drought. Although this revised 2018 document now presents four chapters that describe and analyze different aspects of Michigan's flood risks, it is likely that persons interested in one type of flooding will find useful information in the other three chapters. Reading them together is recommended.

One way to think of floods would be to consider the **water's source and hydrology** (rivers, lakes, channels, rains, snowmelt, development runoff, combined sanitary and storm sewer systems, illicit deposits, dams, levees, impoundments), water management **system characteristics** (sewage system components and capacities, choke points, flaws, wear, power needs, retention and detention areas, blue and green infrastructure), and water **impacts** (overflows, clogging and blockage, basement backup, erosion, structural failures, steep slopes with associated landslide and mudslide risks, flood depths, flood duration, blocked road and access points, deteriorated water quality, contamination, and health impacts, post-flood molds and mildew).

In this document, flood issues are primarily classified in terms of the geographic and drainage characteristics of a flood event, placing diverse types of floods into three substantive chapters—riverine (**fluvial**) flooding, urban (**pluvial**) flooding, and Great Lakes shoreline hazards (which includes flooding plus some additional concerns). The term fluvial here means floods associated with rivers and drainage systems that flow into those rivers. The term pluvial generally refers to floods associated with precipitation—mostly rainfall, but often including snow and ice as they melt—which collects in low-lying areas to form ponds or other temporary pools of water, faster than those waters can drain into the ground or into stormwater sewer systems. **Erosion** hazards are also considered within these chapters, because although there are multiple forms of erosion, the kind that involves material carried away by water is the most serious kind that Michigan faces, from an Emergency Management perspective. (Those who are interested in topsoil erosion should refer instead to documents produced by other agencies, such as the Michigan Department of Agriculture and Rural Development and the Michigan Department of Environmental Quality.)

The traditional flood analysis in most emergency management documents has focused upon officially mapped floodplains, which are centered upon well-known water channels and fairly predictable fluctuations in their water levels. Michigan's 21st Century trends have demonstrated that it is now just as important to consider broader types of pluvial flooding, especially our urban flood hazards which have produced two of Michigan's most damaging natural disasters in each decade of the new century (federal disaster #1346 in September 2000 and federal disaster #4195 in August 2014, both causing widespread damage throughout Metropolitan Detroit). It is now documented that a great amount of our country's flood damage occurs outside of NFIP-recognized floodplain areas. (In other words, many flood impacts occur in places that are far from streams and lakes.) In particular, **flood insurance** should be considered by all communities and their residents and property owners, not just those that are located in the officially mapped floodplain areas. (For those who are hooked into a sewer system, their homeowner's insurance should include coverage for basement sewer back-ups.) In many cases, melting snow, heavy rains, and runoff waters collect in low-lying areas that are inadequately drained, causing floods that damage structures and inhibit the function of roads and infrastructure. In other cases, some type of breakdown in an area's pumping or drainage infrastructure may result in a damaging flood, including system **backflow** that causes damage and health risks when waters flow into the basements of structures connected to the sanitary sewer system.

Pluvial and infrastructure-related floods often occur in well-developed urban or suburban areas, and therefore are often called **urban flooding**. It tends to occur due to either (1) a breakdown in infrastructure or (2) inadequate planning and design standards on the part of builders, developers, engineers, architects, and planners. Land development within a broader urban area often outpaces the improvements to the sewer systems that had historically been installed within the central cities of that area. The original system's design was considered appropriate for the expected functions of each central city, but over time had become overburdened with the effects of considerable "suburban" developments located either upland or upstream. Runoff waters flow into the system at higher speeds and quantities than the original designs had been calculated to handle. In other cases, inadequate or deteriorating components exist at the connections between the drainage/sewage system and the structures they serve. Leaks, inadequate backflow preventers, drain openings clogged with leaves or other debris, the inadequacies of combined storm/sanitary sewer systems, and other problems can all cause water and sewer systems to experience problems under certain circumstances.

Fortunately, many important flood mitigation activities have taken place in recent decades, including the widespread separation of combined sewer systems, the installation of backflow preventers in houses, and the dredging, expansion, and re-design of drainage systems. Numerous activities have demonstrated that many municipalities and their utility providers have been able to learn from the hard lessons of the past. Nevertheless, a consideration of the types of flood events that have occurred in the past will help to keep such events from recurring in the future. From the urban floods of September 2000 and August 2014, the basement flooding near Lake St. Clair in the early 1970s, or the channel changes and ice jams that caused flood problems to emerge in various other areas (such as Robinson Township, Ottawa County) over the past few decades, Michigan and its communities have learned lessons and taken many steps to mitigate flood impacts in the future. More importance is now placed on the preventive role of planners in coordinating their land development plans with the existing knowledge of local floodplains, wetlands, sewer capacity, upstream development, and hydrology. There has been an increased use of stormwater detention and retention areas, and a great deal of progress in the separation of combined sewer systems. However, drainage systems will always need to be maintained—to dredge out the sediment that would otherwise reduce stream capacities, to upgrade components of the infrastructure that have become worn or had their capacity exceeded, to identify and upgrade bridges that act as barriers to water flows, to remove dams that no longer provide a net benefit to nearby lands, to clear away clogging debris such as leaves and branches and logs, and to efficiently clear away log jams or ice jams that would similarly block and divert draining waters away from their intended, safe course. Additional work is needed to identify system components that are vulnerable during power failures, and to prevent floods by providing back-up electricity to those components, either in the form of permanent changes or readily-available back-up generators and the fuel they require.

Information is now readily available to identify and help prioritize areas that are in need of flood mitigation activities. The set of available NFIP floodplain maps is available to view, download, or order from http://msc.fema.gov/portal/home. A system of stream gauges exists across Michigan and is linked with a real-time remote monitoring system through the internet (http://waterwatch.usgs.gov/), allowing the assessment of risks and responses to both local flooding and regional drought conditions. A database of natural hazard events has been online and accumulating information for several years now (http://www.ncdc.noaa.gov/stormevents/). Detailed aerial images are available at various sites on the internet, potentially allowing a comparison between the identified at-risk areas and the actual structures and infrastructure that exist there. However, it will take many years, plus adequate funding and staffing, for all of this new information to be adequately processed and incorporated into state and local plans.

Overlap Between Hydrological Hazards and Other Sections of the Hazard Analysis

Hydrological hazards stem from precipitation patterns. Thunderstorms, snowstorms, and ice/sleet storms produce precipitation that can cause or exacerbate flooding—either immediately or when the frozen precipitation melts. Ice can build up and block critical parts of drainage-ways and thus cause flooding. Similarly, woody debris from severe winds, wildfires, or invasive species can cause trees, utility poles, etc., to build up and jam streams or drains. Extreme cold has caused freeze events in which pipes and water mains have broken and caused floods. Heat waves often worsen the impacts of a drought. Floods can also cause landslides and subsidence problems.

Technological Hazards that inhibit the smooth functioning of drainage or water supply infrastructure may cause or exacerbate either the flooding or drought hazards. For example, sewer pumping and lift stations can go out of operation during a power failure (unless supplied with power by a back-up system or generators), and cause floods or water shortages—especially in heavily developed urban areas. Transportation accidents also have the potential to cause power failures or even water main breaks, and thus produce flooding or exacerbate drought impacts.

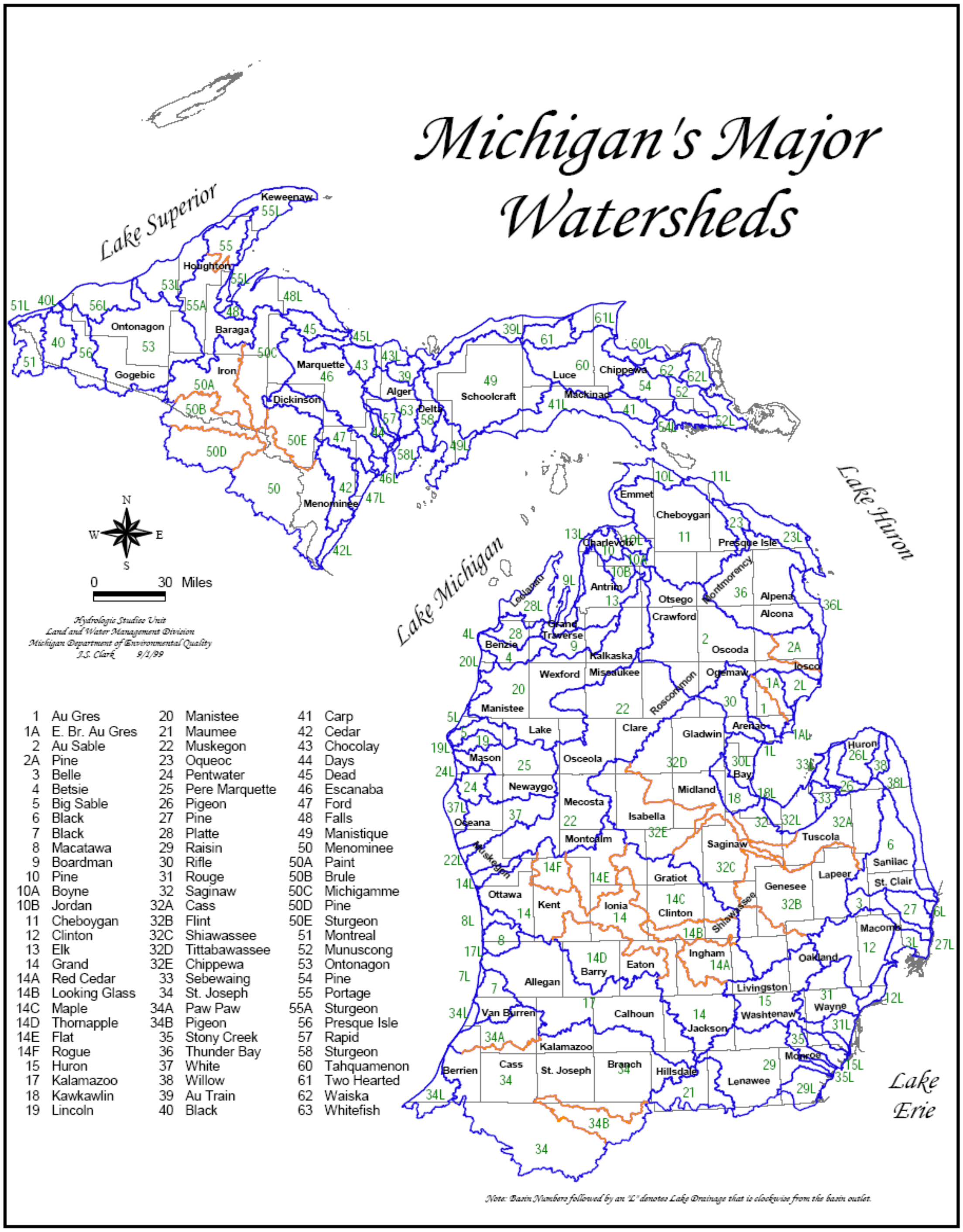
Human-Related Hazards such as terrorism, sabotage, or civil disturbances, may cause water-related infrastructure to be disabled and thus cause or worsen flood or drought events. Public health emergencies may involve the contamination of already-limited water supplies during a drought and thus compound the human impacts of that hazard.

Examining the issue from a different direction, in terms of the effects that can be produced by flood or drought hazards, it can be seen that both flood and drought may, in their own different ways, reduce the quality of an area's water supply—possibly to the point of creating the risk of a public health emergency. Civil disturbances might result from a drought that involves a very limited supply of water for human consumption, or may arise from some form of mismanagement, negligence, or culpability (real or imagined) on the part of some specific agency or actor. An example might be a damaging flood caused by a city's public works department, which might result in hostile protests and the destruction or sabotage of property.

Floods can also cause hazardous materials incidents and transportation accidents, when chemicals, pollutants, facilities, and transportation infrastructure is in the flooded area. Flood waters in urban or polluted areas tend to be contaminated with chemicals, debris from roadways and cars, and industrial residues. Flood waters can also carry the bodies of animals and humans, and exacerbate insect, snake, rodent, mold, and mildew problems that affect the public health of the area. Floods may hinder the response to emergency events (such as fires, accidents, or utility failures). Floodwaters may cause infrastructure failures, either due to physical impacts and erosion of roads and facilities, or by interfering with the functioning of equipment, electrical supply, etc. in the flooded area. **Combined sewer systems** (in which stormwater and sanitary sewers both rely upon the same pipes to simultaneously remove unwanted water from the area) can involve the release of untreated sewage from nearby outlets into the area's rivers and lakes, because the system doesn't have the capacity to handle both sewage functions simultaneously. Droughts increase the likelihood of wildfire events, and may also cause land subsidence.

Flood Hazards

Flood hazards in Michigan include fluvial and pluvial floods, dam and levee failures, infrastructure failures, and lakeshore floods. Floods cause extensive property damage each year, reduced quality of life, and even injuries and deaths. The National Flood Insurance Program offers one form of security to communities that have flood-prone areas. As of June 30, 2018, Michigan had 20,378 flood insurance policies in place. This number has recently been declining, but every year, Michigan flood disasters cause an average of more than $100 million in property damage. In a high-risk ("Special Flood Hazard") area, a home has at least a 26% chance of being damaged by a flood during the course of a 30-year mortgage, compared to a 9% chance of being damaged by fire. The map below shows the major rivers in Michigan and their **watersheds** (the area in which water runs off into the river and is then carried to one of the Great Lakes).


Michigan's Major Watersheds
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
N
W
E
S
0 30 Miles
Hydrologic Studies Unit
Land and Water Management Division
Michigan Department of Environmental Quality
J.S. Clark 9/1/99
1 Au Gres
1A E. Br. Au Gres
2 Au Sable
2A Pine
3 Belle
4 Betsie
5 Big Sable
6 Black
7 Black
8 Macatawa
9 Boardman
10 Pine
10A Boyne
10B Jordan
11 Cheboygan
12 Clinton
13 Elk
14 Grand
14A Red Cedar
14B Looking Glass
14C Maple
14D Thornapple
14E Flat
14F Rogue
15 Huron
17 Kalamazoo
18 Kawkawlin
19 Lincoln
20 Manistee
21 Maumee
22 Muskegon
23 Oqueoc
24 Pentwater
25 Pere Marquette
26 Pigeon
27 Pine
28 Platte
29 Raisin
30 Rifle
31 Rouge
32 Saginaw
32A Cass
32B Flint
32C Shiawassee
32D Tittabawassee
32E Chippewa
33 Sebewaing
34 St. Joseph
34A Paw Paw
34B Pigeon
35 Stony Creek
36 Thunder Bay
37 White
38 Willow
39 Au Train
40 Black
41 Carp
42 Cedar
43 Chocolay
44 Days
45 Dead
46 Escanaba
47 Ford
48 Falls
49 Manistique
50 Menominee
50A Paint
50B Brule
50C Michigamme
50D Pine
50E Sturgeon
51 Montreal
52 Munuscong
53 Ontonagon
54 Pine
55 Portage
55A Sturgeon
56 Presque Isle
57 Rapid
58 Sturgeon
60 Tahquamenon
61 Two Hearted
62 Waiska
63 Whitefish
Note: Basin Numbers followed by an "L" denotes Lake Drainage that is clockwise from the basin outlet.

Flood History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Flood Events	Days with (the start of) Flood Events	Tot. property damage	Tot. crop damage	Injuries	Deaths
Washtenaw	33	31	$1,545,000			
Wayne	65	54	$1,123,800,000			
.Livingston	18	18	$1,504,000			
Oakland	26	26	$403,206,000			1
Macomb	40	35	$402,380,000			
5 Co Metro region	**36.4 avg.**	**32.8 avg.**	**$1,932,435,000**			**1**
Berrien	22	19	$7,010,000	$100,000		
Cass	11	11	$700,000			
St. Joseph	6	6	$700,000			
Branch	1	1	$200,000			
Hillsdale	7	6	$350,000			
Lenawee	34	28	$950,000			
Monroe	17	17	$3,980,000			3
.Van Buren	11	11	$4,693,000	$250,000		
Kalamazoo	14	14	$18,060,000	$260,000		
Calhoun	14	13	$6,835,000	$335,000		
Jackson	12	12	$5,160,000	$305,000		
.Allegan	21	20	$15,190,000	$7,325,000	4	2
Barry	16	14	$7,310,000	$700,000		
Eaton	12	12	$6,085,000	$725,000		
Ingham	13	12	$11,560,000	$375,000		
.Ottawa	21	19	$48,365,000	$1,905,000	3	2
Kent	25	24	$4,670,000	$510,000		
Ionia	8	8	$8,360,000	$250,000		
Clinton	13	12	$6,535,000	$375,000		
Shiawassee	14	14	$1,371,000			
Genesee	28	24	$8,050,000			
Lapeer	15	15	$9,820,000	$1,000,000		
St. Clair	11	11	$3,620,000			
.Muskegon	15	13	$6,995,000	$535,000		
Montcalm	11	10	$4,485,000	$375,000		
Gratiot	13	12	$4,485,000	$375,000		
Saginaw	36	34	$2,877,000	$1,000,000		
Tuscola	19	17	$8,170,000			
Sanilac	8	8	$2,285,000			
.Mecosta	14	13	$10,255,000	$345,000		
Isabella	14	13	$8,490,000	$375,000		
Midland	13	13	$2,870,000			
Bay	13	13	$3,060,000	$25,000		1
Huron	10	10	$359,000			
34 Co S Lower Peninsula	**15.1 avg.**	**14.1 avg.**	**$233,905,000**	**$17,445,000**	**7**	**8**

Continued on next page…

Part 2 of Flood History for Michigan Counties – arranged by geography

.Oceana	10	9	$4,860,000	$450,000		
Newaygo	12	10	$10,560,000	$350,000		
.Mason	14	12	$7,555,000	$850,000		
Lake	9	9	$6,390,000	$700,000		
Osceola	13	12	$8,450,000	$575,000		
Clare	9	9	$4,375,000	$275,000		
Gladwin	9	8	$383,000			
Arenac	14	14	$298,000			
.Manistee	9	8	$1,720,000			
Wexford	12	12	$1,182,000			
Missaukee	4	4	$360,000			
Roscommon	3	3	$264,000			
Ogemaw	4	4	$350,000			
Iosco	4	4	$203,000			
.Benzie	2	2	$200,000			
Grand Traverse	8	8	$2,089,000			
Kalkaska	3	3	$220,000			
Crawford	2	2	$206,000			
Oscoda	4	4	$203,000			
Alcona	5	5	$310,000			
.Leelanau	3	3	$250,000			
Antrim	2	2	$200,000			
Otsego	1	1	$203,000			
Montmorency	2	2	$200,000			
Alpena	2	2	$200,000			
.Charlevoix	2	2	$202,000			
Emmet	2	2	$218,000			
Cheboygan	4	4	$228,000			
Presque Isle	1	1	$200,000			
29 Co N. Lower Penin.	**5.8 avg.**	**5.6 avg.**	**$52,079,000**	**$3,200,000**		
Gogebic	19	19	$24,213,000			
Iron	15	15	$945,000			
Ontonagon	15	15	$1,017,000			
Houghton	25	23	$3,102,000			
Keweenaw	10	10	$334,000			
Baraga	19	18	$2,245,000			
.Marquette	41	30	$14,990,000			
Dickinson	21	17	$481,000			
Menominee	11	10	$1,050,000			
Delta	31	25	$1,090,000			
Schoolcraft	9	9	$200,000			
Alger	11	10	$200,000			
.Luce	7	7	$200,000			
Mackinac	6	5	$258,000			
Chippewa	7	7	$325,000			
15 Co Upp.Pen	**16.5 avg.**	**14.7 avg.**	**$50,650,000**			
MI. TOTAL	**1029**	**384**	**$2,252,907,000**	**$20,645,000**	**7**	**9**
Annual avg.	**48.2**	**18.0**	**$105,618,570**	**$967,859**	**0.3**	**0.4**

Source: NCEI site. (Includes NCEI categories for “Flash Flood,” “Flood,” “Heavy Rain,” and “Lakeshore Flood.”)
NOTE: Due to some double counting of multi-county events, state totals are less than the sum of the counties.

Disaster-level flood damages have been noted in many parts of the state, but on average are more of a problem in the Detroit Metropolitan area of the Southeastern Lower Peninsula, due to the much larger amount of development that exists there. The Upper Peninsula often sees an elevated risk of flash flooding from dam and levee failures (see later chapter), while the sprawling developments around the major cities in the southern part of the state have often caused water runoff patterns that severely strain or overwhelm aging drainage infrastructure downstream. The areas that appear to be significantly less at-risk are those on high ground and in headwater locations—also at a relatively high elevation—where waters tend to simply drain to lower-lying areas outside of the community, rather than building up into a local flood problem. The northern Lower Peninsula contains many counties with flood risks that are notably lower than the state average, but <u>every county in the state</u> has documented flood damages.

Impact on the Public, Property, Facilities, and Infrastructure

Riverine flooding has caused displacement, property damage, and impacts on the health of residents. In some cases, utility providers have had facilities located in floodplain areas, and these facilities have been negatively impacted by flooding. Floodwaters can also prevent normal access to structures and facilities. Flooding is a hazard whose risks are routinely underestimated by the public, who may be inclined to attempt to walk or drive through shallow waters, or to allow their children and pets to play in the water as if it were part of a beach or swimming pool. Public education is vital so that there is widespread knowledge of the contaminants and germs that floodwaters contain, and a greater awareness of the risks that floodwaters pose to drivers and pedestrians. Drivers need to know that roads and bridges are often weakened and degraded by flood impacts, and that the road they assume is still there under shallow waters may no longer be intact. Less than a foot of flowing water can cause travelers to end up in a ditch or sinkhole, where persons may find that it is impossible to escape from a submerged vehicle under the pressures exerted by flowing water. Those who are tempted to walk through floodwaters should be informed that the waters tend to conceal the presence of open manholes and dangerous debris, such as rusty nails and metal, or live electrical wires that can cause harmful shocks. Critical facilities within sewage and pumping systems may not be operating if electricity systems go down. The same storm system that brings heavy precipitation may also have strong winds that bring down utility lines, causing a cascading set of problems. The Metropolitan Detroit flood disaster of August 2014 included serious and widespread shutdowns in the area's interstate highway system, as pumps failed to clear waters and many hundreds of stranded cars blocked roadways in the midst of impassable depths of accumulating flood waters. In the City of Houghton, the flash flood disaster of June 2018 caused city streets to crumble under landslide-like effects, making safe response activities more difficult throughout the event.

Impact on the Economic Condition of the State

Although unfortunate weather events and disasters must to some degree be accepted and anticipated by businesses and residents, ordinary business and insurance plans haven't necessarily always factored in a pattern in which Michigan's precipitation levels have slowly been increasing, including a higher proportion that is concentrated in extreme events (see the paragraph that follows, called "Climate Change Considerations"). At the same time that problematic precipitation threatens to periodically overwhelm the capacity of existing drainage infrastructure, Michigan and many of its communities also face the simultaneous problems with the effects of aging upon important segments of this infrastructure.

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

"Ordinary" flood waters in known floodplain areas and riparian lands often contain "hidden" hazards that may not be evident at first. Roads and bridges are often weakened and degraded by flood impacts, and a previously intact roadway area may have been eroded away under a seemingly shallow water surface. Floodwaters tend to conceal the presence of open manholes, dangerous debris (such as rusty nails and metal), and live electrical wires that can cause harmful shocks. Responders and residents in a large flood event therefore deal with numerous hidden hazards as well as floodwaters that are often unclean (containing carcasses, garbage, and filth) and contaminated with chemicals (from area roads, cars, industrial sites, storage facilities, etc.). Infrastructure impacts may cause delays in service delivery. Transportation problems can hinder continuity of operations, when workers and staff have trouble traveling where needed.

Impact on the Environment
Flooding is generally part of a natural cycle that has many important and beneficial functions for the environment. Flooding raises the water table in wetlands, maintains biodiversity, and replenishes nutrients back into the soil. Additionally, higher water tables allow fish and water plants to recolonize and may also help to control some invasive species. Flooding, however, becomes a particular problem in the built environment (especially including old brownfield and Superfund sites with known contaminants). Drainage systems and city sewers can become overwhelmed, causing raw sewage from combined (sanitary and stormwater) sewer systems to back up in basements and onto roadways. Flooding in urban areas can also cause increased runoff, which may carry pollutants through storm sewers into rivers and lakes. Urban runoff can be toxic, as it may contain garbage, fertilizers, oil and other residues from city streets and industrial sites.

Impact on Public Confidence in State Governance
In cases where any type of flood impact causes negative effects on structures, major businesses, public services, roads, utilities, critical facilities, or the ability to access them, doubts can arise about the appropriateness of the planning and development mechanisms that may have allowed these flood impacts to occur. Doubts may also arise about the adequacy of the area’s drainage infrastructure, whether in the form of channels/drains at the surface or storm sewer systems underneath the ground. Especially controversial are cases in which sewer systems are perceived to have caused basement flooding, and when the original designs of some sewer systems have had their capacities exceeded because of subsequent urban development trends, or when outmoded designs have caused waters to be contaminated with sewage. Public health issues in these cases can thus compound the problems caused by flooding itself, in ways that can seem to be attributable to government at one or more levels.

Climate Change Considerations
One of the Michigan trends connected with climate change is to experience increasing amounts of precipitation. Moreover, this precipitation is considered more likely to take the form of acute (and severe) weather events. As mentioned in the winter weather sections, a larger proportion of snow precipitation occurring in snowstorm events can cause more extensive snow accumulation which, under unlucky temperature patterns, may add to the drainage burdens of the normal melting and rainfall patterns of the spring season. In short, spring flood risks are likely to worsen, as are ice jam related winter flood risks.

Assessments in Local Hazard Mitigation Plans
Flood hazards were identified as some of the most significant hazards in local hazard mitigation plans for the following counties: Allegan, Antrim, Baraga, Bay, Benzie, Berrien, Calhoun, Charlevoix, Clare, Clinton, Eaton, Emmet, Genesee, Gladwin, Gogebic, Grand Traverse, Gratiot, Houghton, Ingham, Ionia, Iosco, Isabella, Kalkaska, Kent, Leelanau, Macomb, Manistee, Marquette, Mecosta, Menominee, Midland, Missaukee, Monroe, Montcalm, Newaygo, Oakland, Osceola, Ottawa, Roscommon, Saginaw, St. Clair, Shiawassee, St. Joseph, Tuscola, Wayne, and Wexford (45 counties, an increase from 2014). Some plans, such as those for Allegan and Oakland Counties, specifically identified urban flooding as a primary concern.

Fluvial (Riverine) and Similar Floods

The periodic overflowing of rivers, streams, and channels—due to inadequate drainage capacity, drainage system failures, ice or log jams, accumulated sediments, erosion, or meandering—that results in nearby property damage, safety issues, disruption of infrastructure function and services, and/or decreased quality of life.

Hazard Description

Flooding of land adjoining the normal course of a stream or river has been a natural occurrence since prehistoric times. If these floodplain areas were left free of human structures, floods would not cause significant damage. Development has increased the potential for serious flooding because rainfall that used to soak into the ground or take several days to reach a river or stream via a natural drainage basin now quickly runs off streets, parking lots, and rooftops, and through constructed channels and pipes. Some developments have also encroached into floodplain areas and thus impeded the carrying capacity of the drainage area. Floods can also result when vital drainage channels become clogged with ice, logs, or debris.

Hazard Analysis

Floods can damage or destroy public and private property, disable utilities, make roads and bridges impassable, destroy crops and agricultural lands, cause disruption to emergency services, and result in fatalities. People may be stranded in their homes for several days without power or heat, or they may be unable to reach their homes at all. Long-term collateral dangers include the outbreak of disease, widespread animal death, broken sewer lines causing water supply pollution, downed power lines, broken gas lines, fires, and the release of hazardous materials.

Flood-prone areas are found throughout the state. The type of development that exists within a floodplain will determine whether or not flooding will cause damage. The Michigan Department of Environmental Quality (MDEQ) estimates that about 6% of Michigan's land—roughly the size of the southeast Michigan counties of Wayne, Oakland, Macomb, Washtenaw, and Monroe combined—is flood-prone, including about 200,000 buildings. The southern half of the Lower Peninsula contains the areas with the most flood damage potential.

The primary fluvial flood sources include the connecting waters between the Great Lakes (Detroit River, St. Clair River, and St. Marys River), thousands of miles of rivers and streams, and hundreds of inland lakes. Michigan can be divided into 63 major watersheds (including 23 component watersheds for various important branches and tributaries) and lakeshed areas along the shoreline, as shown in the map at the beginning of the flood hazards section. All of these watersheds experience flooding, usually with fewer problems in the higher-elevation headwater areas and greater problems in downstream urban areas. Flooding can occur on various branches of rivers, creeks, and other water channels. At the end of this chapter, a collection of maps displays all of the official floodplains which have currently been digitized through National Flood Insurance Program-related studies, but these only show a portion of the floodplain areas identified statewide. (The counties that have no flood information displayed in those maps are ones that have not yet had digital flood boundaries made available in GIS format.) More comprehensive (but sometimes outdated) floodplain maps can be viewed or obtained through FEMA's Map Service Center at https://msc.fema.gov/. The next page contains a list of these major watershed areas and sub-areas.

Most riverine flooding occurs in early spring and is the result of heavy rainfall or the combination of rainfall and snowmelt. Ice jams are also a cause of flooding in winter and early spring. Log jams can also cause streams and rivers to be clogged up, and the backed-up waters to overflow the stream's banks. Either ice jams or log jams can cause dangerous **flash flooding** to occur if the makeshift dam created by the ice or logs suddenly gives way. (Please refer also to the chapter on **dam and levee failures**.) Severe thunderstorms often cause flooding during the summer or fall.

The following table lists major watersheds within the state. All of these areas are susceptible to flooding. Although the flood hazard areas are spread throughout the state, the risks from fluvial flooding are greatest where populated areas are situated close to water bodies and channels, on lands whose elevations are not very much higher than those of the nearby river or lake. High-risk areas can also include places located too close to wetlands, or other types of hydric soils. Monetary losses continue to rise, accompanied by infrastructure problems and even some loss of life. Michigan's annual flood-related damages are now estimated at more than $100 million, as documented in the two-page NCEI table at the start of the flood section, which only counts events that were significant enough to be reported on a community-wide level. Many individual households suffer isolated damages, in addition to these major events, which are reported only to their insurance companies and have not been included within these estimates.

NOTE: Lakeshed areas are not included in the table (and their geographic area has not been included here). Most of them are relatively small. Some watersheds in this table feed into others, and this information is included in parenthetical notes within the central column ("Counties involved"). A watershed with a note such as "see Au Gres East Branch" means that another watershed drains into it. With reference to the Michigan watershed map, readers might then choose to treat these as combined watershed areas, and may sum the area of all contributing upstream watersheds.

Watershed area	**Counties involved**	**Area (sq mi)**
Au Gres	Arenac, Iosco, Ogemaw (see Au Gres East Branch)	243.4
Au Gres East Branch	Arenac, Iosco (feeds into Au Gres)	146.8
Au Sable	Alcona, Crawford, Iosco, Montmorency, Ogemaw, Oscoda, Otsego, Roscommon (see Pine-1)	1767.6
Au Train	Alger	119.1
Belle	Lapeer, Macomb, St. Clair	226.9
Betsie	Benzie, Grand Traverse, Manistee	242.3
Big Sable	Lake, Mason	178.7
Black-1	Lapeer, St. Clair, Sanilac	710.3
Black-2	Allegan, Van Buren	287.1
Black-3	Gogebic	255.2
Boardman	Grand Traverse, Kalkaska	283.6
Boyne	Charlevoix, Otsego (feeds into Pine-2)	71.7
Brule	Iron (feeds into Menominee)	400.5
Carp	Chippewa, Mackinac	171.9
Cass	Saginaw, Sanilac, Tuscola (feeds into Saginaw)	904.8
Cedar	Menominee	377.2
Cheboygan	Charlevoix, Cheboygan, Emmet, Montmorency, Otsego, Presque Isle	1493.3
Chippewa	Clare, Gratiot, Isabella, Mecosta, Midland, Montcalm, Osceola (feeds into Saginaw)	1024.8
Chocolay	Marquette	158.6
Clinton	Macomb, Oakland	797.5
Days	Delta	63.3
Dead	Marquette	163.1
Elk	Antrim, Charlevoix, Grand Traverse, Kalkaska	501.6
Escanaba	Delta, Dickinson, Marquette	927.8
Falls	Baraga	46.9
Flat	Ionia, Kent, Mecosta, Montcalm (feeds into Grand)	562.9
Flint	Genesee, Lapeer, Oakland, Saginaw, Shiawassee (feeds into Saginaw)	1331.1
Ford	Delta, Dickinson, Marquette, Menominee	461.6
Grand	Eaton, Ingham, Ionia, Jackson, Kent, Montcalm, Muskegon, Ottawa (see Flat, Looking Glass, Maple, Red Cedar, Rogue, and Thornapple)	2174.8
Huron	Livingston, Oakland, Washtenaw, Wayne	917.0
Jordan	Antrim, Charlevoix (feeds into Pine-2)	128.7
Kalamazoo	Allegan, Barry, Calhoun, Eaton, Hillsdale, Jackson, Kalamazoo, Ottawa, Van Buren	2033.0
Kawkawlin	Bay, Gladwin, Midland	225.4
Lincoln	Mason	100.9
Looking Glass	Clinton, Ionia, Shiawassee (feeds into Grand)	311.7
Macatawa	Allegan, Ottawa	174.6
Manistee	Antrim, Crawford, Grand Traverse, Kalkaska, Lake, Manistee, Mason, Missaukee, Osceola, Otsego, Wexford	1946.8
Manistique	Alger, Delta, Luce, Mackinac, Schoolcraft	1464.1
Maple	Clinton, Gratiot, Ionia, Montcalm, Shiawassee (feeds into Grand)	946.2
Maumee	Hillsdale, Lenawee (flows into the State of Ohio)	(6554.4)
Menominee	Dickinson, Menominee (see Brule, Michigamme, Paint, and Sturgeon-1; also fed from Wisconsin's Pine watershed [550.2 mi^2])	1296.0
Michigamme	Baraga, Dickinson, Iron, Marquette (feeds into Menominee)	723.6

Montreal	Gogebic	269.6
Munuscong	Chippewa, Mackinac	187.3
Muskegon	Clare, Mecosta, Missaukee, Montcalm, Muskegon, Newaygo, Osceola, Roscommon, Wexford	2723.9
Ontonagon	Gogebic, Houghton, Iron, Ontonagon	1383.9
Ocqueoc	Presque Isle	147.2
Paint	Baraga, Iron (feeds into Menominee)	653.3
Paw Paw	Berrien, Van Buren (feeds into St. Joseph)	445.4
Pentwater	Mason, Oceana	170.7
Pere Marquette	Lake, Mason, Newaygo, Oceana	754.6
Pigeon-1	Huron	145.9
Pigeon-2	St. Joseph (feeds into St. Joseph)	395.7
Pine-1	Alcona, Iosco (feeds into Au Sable)	282.3
Pine-2	Charlevoix (see Boyne and Jordan)	131.6
Pine-3	St. Clair	194.6
Pine-4	Chippewa, Mackinac	276.8
Platte	Benzie, Grand Traverse, Leelanau	192.4
Portage	Houghton, Keweenaw (see Sturgeon-2)	262.1
Presque Isle	Gogebic, Ontonagon	363.1
Raisin	Hillsdale, Jackson, Lenawee, Monroe, Washtenaw	1070.5
Rapid	Delta, Marquette	138.5
Red Cedar	Ingham, Livingston (feeds into Grand)	459.1
Rifle	Arenac, Ogemaw	380.0
Rogue	Kent, Newaygo (feeds into Grand)	261.3
Rouge	Oakland, Wayne	465.0
Saginaw	Saginaw, Tuscola (see Cass, Chippewa, Flint, Shiawassee, Tittabawassee)	251.2
Saint Joseph	Berrien, Branch, Calhoun, Cass, Hillsdale, Kalamazoo, St. Joseph, Van Buren (see Paw Paw and Pigeon, also fed from Indiana's Elkhart watershed [700.4 mi^2])	3867.7
Sebewaing	Huron, Tuscola	104.0
Shiawassee	Genesee, Gratiot, Livingston, Midland, Oakland, Saginaw, Shiawassee (feeds into Saginaw)	1265.6
Stony Creek	Monroe, Washtenaw	124.0
Sturgeon-1	Dickinson, Menominee (feeds into Menominee)	430.6
Sturgeon-2	Baraga, Houghton, Iron, Ontonagon (feeds into Portage)	730.4
Sturgeon-3	Alger, Delta	219.0
Tahquamenon	Chippewa, Luce, Mackinac	809.3
Thornapple	Barry, Eaton, Ionia, Kent (feeds into Grand)	847.9
Thunder Bay	Alcona, Alpena, Montmorency, Oscoda, Presque Isle	1250.3
Tittabawassee	Clare, Gladwin, Isabella, Midland, Ogemaw, Roscommon (feeds into Saginaw)	1446.1
Two Hearted	Luce	207.0
Waiska	Chippewa	148.4
White	Muskegon, Newaygo, Oceana	537.8
Whitefish	Alger, Delta, Marquette	313.7
Willow	Huron	94.7
Lakeshed (Erie, Detroit River)	Monroe, Wayne	(varies)
Lakeshed (St. Clair)	Macomb, St. Clair, Wayne	(varies)
Lakeshed (Huron)	Alcona, Alpena, Arenac, Bay, Cheboygan, Huron, Iosco, Mackinac, Presque Isle, St. Clair, Sanilac, Saginaw, Tuscola	(varies)
Lakeshed (Michigan)	Allegan, Antrim, Benzie, Berrien, Charlevoix, Delta, Emmet, Grand Traverse, Leelanau, Mackinac, Manistee, Mason, Menominee, Muskegon, Oceana, Ottawa, Schoolcraft, Van Buren	(varies)
Lakeshed (St. Marys R.)	Chippewa, Mackinac	(varies)
Lakeshed (Superior)	Alger, Baraga, Chippewa, Gogebic, Houghton, Keweenaw, Luce, Marquette, Ontonagon	(varies)
NOTE: Some counties were not listed here if their involved watershed areas were small and located near headwaters.		

Michigan's Largest Watersheds (over 150 square miles in area)

Watershed (includes major tributaries)	**Consolidated Area**	**Major riparian <u>urban areas</u>** (out of the list from the Introduction)
Saginaw	6223.6 mi^2	Flint, Saginaw, Bay City, Midland, Mt. Pleasant, Owosso, Alma-St. Louis, Clare, Harrison, Caro, Frankenmuth, Vassar
Grand	5563.9 mi^2	Grand Rapids, Lansing, Muskegon, Jackson, Ionia, Greenville, Hastings, Belding, Eaton Rapids, Portland, Middleville
St. Joseph	5409.2 mi^2	Benton Harbor, Hillsdale, Paw Paw Lake-Hartford, Three Rivers, Berrien Springs, Dowagiac, Constantine
Menominee	4054.2 mi^2	Menominee, Iron Mountain-Kingsford, Iron River
Muskegon	2723.9 mi^2	Muskegon, Newaygo, Big Rapids
Au Sable	2049.9 mi^2	Au Sable-Oscoda, Grayling
Kalamazoo	2033.0 mi^2	Kalamazoo, Battle Creek, Albion, Marshall, Allegan, Douglas-Saugatuck
Manistee	1946.8 mi^2	Manistee
Cheboygan	1493.3 mi^2	Gaylord, Cheboygan
Manistique	1464.1 mi^2	Manistique
Ontonagon	1383.9 mi^2	
Thunder Bay	1250.3 mi^2	Alpena
Raisin	1070.5 mi^2	Monroe, Adrian, Dundee, Blissfield
Portage	992.5 mi^2	Houghton, Laurium-Calumet-Lake Linden-Hubbell
Escanaba	927.8 mi^2	Escanaba, K.I. Sawyer
Huron	917.0 mi^2	Metro Detroit, Ann Arbor-Ypsilanti
Tahquamenon	809.3 mi^2	
Clinton	797.5 mi^2	Metro Detroit
Pere Marquette	754.6 mi^2	Ludington
Black (#1)	710.3 mi^2	Port Huron
White	537.8 mi^2	
Elk	501.6 mi^2	
Rouge	465.0 mi^2	
Ford	461.6 mi^2	
Au Gres	390.2 mi^2	
Rifle	380.0 mi^2	
Cedar	377.2 mi^2	
Presque Isle	363.1 mi^2	
Pine (#2)	332.0 mi^2	
Whitefish	313.7 mi^2	
Black (#2)	287.1 mi^2	South Haven
Boardman	283.6 mi^2	Traverse City, Kalkaska
Pine (#4)	276.8 mi^2	
Montreal	269.6 mi^2	Ironwood
Black (#3)	255.2 mi^2	
Betsie	242.3 mi^2	
Belle	226.9 mi^2	
Kawkawlin	225.4 mi^2	Bay City
Sturgeon (#3)	219.0 mi^2	
Two Hearted	207.0 mi^2	
Pine (#3)	194.6 mi^2	
Platte	192.4 mi^2	
Munuscong	187.3 mi^2	
Big Sable	178.7 mi^2	
Macatawa	174.6 mi^2	Holland
Carp	171.9 mi^2	
Pentwater	170.7 mi^2	Hart
Dead	163.1 mi^2	Marquette, Ishpeming
Chocolay	158.6 mi^2	

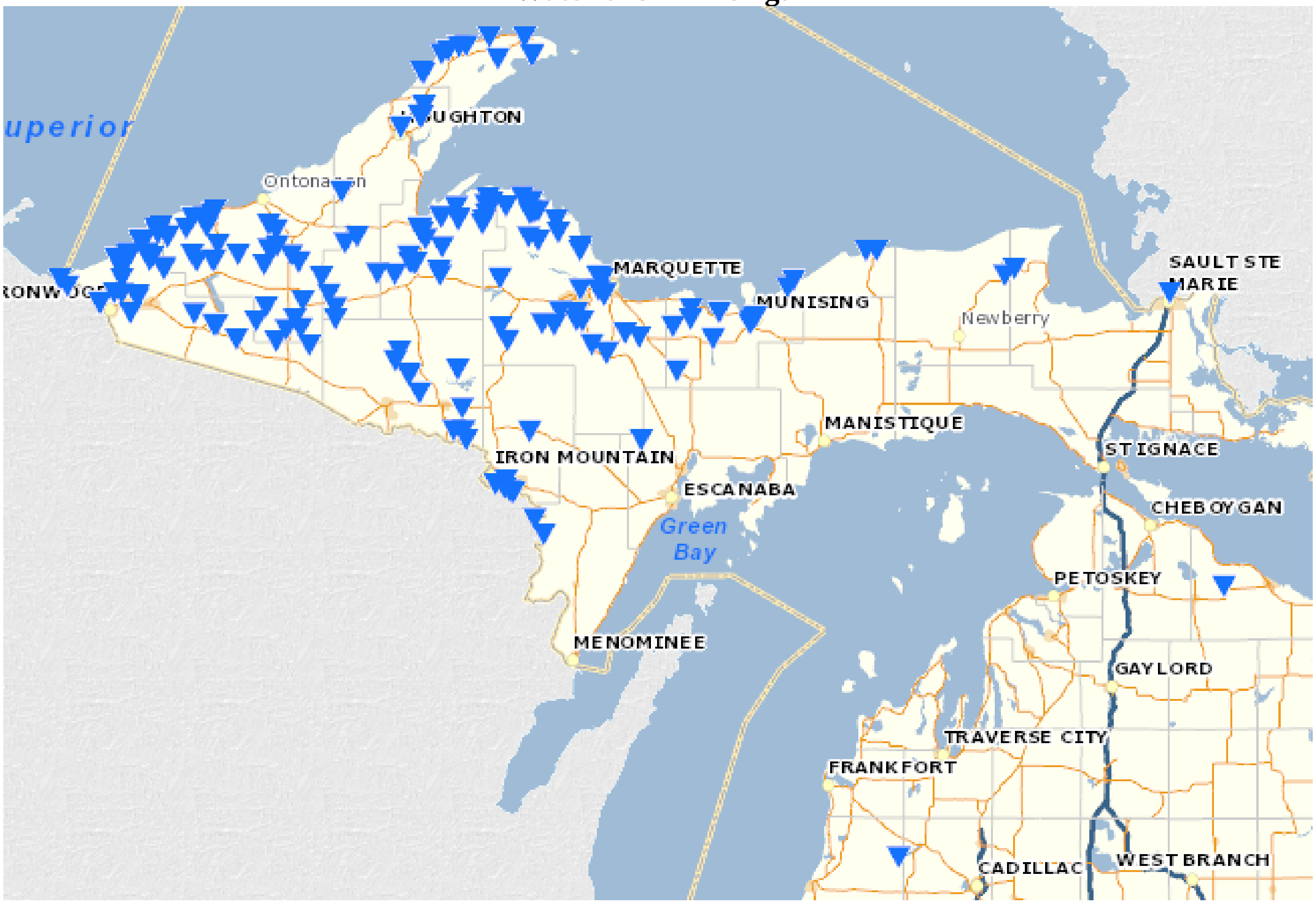
Note: This list is not meant to imply that serious flooding is limited to these areas. Floods occur throughout Michigan.

Watershed areas can be characterized in various ways that suggest how much water runoff each handles, and how quickly. These general indicators are no substitute for the specific detail provided in floodplain maps, but since many areas in Michigan do not have updated digital floodplain maps, a consideration of watershed hydrology principles may be useful. One general principle is that larger watershed areas tend to handle greater quantities of water runoff.

Although the provided table lists the approximate geographic area for each watershed, but some of the largest watersheds have been subdivided, and those who are located at the base of multiple watersheds may want to consider the full combined area, for comparison purposes. Although areas of severe flooding must be identified through a more detailed process, the following list of Michigan's largest consolidated watershed areas:

Within each watershed, greater surface slopes such as hilly topography will increase the average runoff rate for water, often causing the inundation of low areas. One indicator of sloped surfaces and rapid waters is found in the location of Michigan's waterfalls, as shown in the following map.

Waterfalls in Michigan



Source: MDEQ GeoWebFace http://www.deq.state.mi.us/geowebface/

The vast majority of waterfalls are located in the Upper Peninsula, especially its Western half, although a couple are found within the northern part of the Lower Peninsula. These hillier areas of the state can involve flash flood risks, plus the potential for landslide or mudslide effects. In addition to hills and other steep slopes, another type of flood risk involves **confluence** areas where streams come together. There are cases in which the combined runoff involves much more risk than a single stream would normally present. The climatological trend toward increasing precipitation, more of which is concentrated in severe events, is expected to further exacerbate Michigan's flood risks. Snowmelt runoff, combined with heavy rains, is one of the most common causes of Michigan floods during the winter and spring season.

More detailed assessments must occur on a local level. For example, the topographic image at right (from MDEQ GeoWebFace) shows that the Houghton area must deal with runoff that accelerates through an elevation difference of some 500-feet when rainwaters run down from the nearby hills during heavy precipitation events.

Within past editions of this document, **landslides** and **mudslides** had not been identified as a significant hazard within Michigan. Although it was well-known that hilly areas existed within the state, such topics were primarily associated with Great Lakes shoreline areas, and their known risks of erosion. However, the Houghton flood disaster has now made it clear that record-setting rainfall events in particular locations can include damaging landslide and mudslide effects. Research will proceed to further assess this hazard and to include the results of that analysis within the next update of this document. At this time, the Houghton example should be seriously considered by any community with similar topography, to assess (e.g. within its local hazard mitigation plan) whether that area is also at risk from landslide or mudslide effects.

It is now widely known that controlling floodplain development is an important component of flood mitigation. Although there are state and local programs to regulate new development or substantial improvements in flood-prone areas, extra care must still be taken so that floodplain development does not continue to increase and result in flood damages and risks. The opportunity to mitigate flood hazards rests primarily with local government, which regulates land development and enforces building codes. Coordinated land use policies and water management practices would ideally extend to the level of an entire watershed, since upstream developments tend to increase downstream flood risks, and many political jurisdictions may be unaware of how their decisions can affect each other. However, a great amount of work still needs to be done on watershed management, to achieve appropriate levels of flood risk reduction.

In Michigan, significant flooding tends to occur each year, although the locations of flood events tend to vary with precipitation patterns. (Please refer to the table of flood damages by county, in the introductory section on Flooding, and to the specific event descriptions later in this chapter.) Some of Michigan's largest disaster declarations have involved flooding, although widespread urban/pluvial floods have recently caused more damage than fluvial floods. Occasional deaths and injuries are reported in connection with these events—about one death every two years (not counting shoreline and Great Lakes deaths, which are covered in chapters that follow) and a slightly smaller number of injuries. Property damage is extensive, averaging at least $100 million per year from major events.

An additional consideration is the erosion of soil and other land that may eventually cause damage to the roads, structures, and infrastructure that relies on it for stability and support. For example, occasional reports have been received of a house near a river, whose foundation has become at-risk after decades of supporting Earth that has been cut away and moved downstream by the flowing water. Stabilization measures are required in order to keep the house's foundation from becoming destabilized, or even the entire slope of the hillside from eventually giving way in a landslide event. Such things are well-known on Michigan's Great Lakes shores, where the extensive forces of the lake waters cause erosion to occur far more rapidly and dramatically than most of Michigan's rivers (please refer to the chapter on Great Lakes Shoreline Hazards in this document, for more information). Although riverine erosion does not normally result in a community-level disaster or emergency event, structures and infrastructure that are at-risk from erosion may nevertheless benefit from the application of hazard mitigation funds for their protection. There can actually be cases in which erosion eventually makes infrastructure exposed and vulnerable, and leads to local emergency events if a road or bridge collapse eventually occurs. The most common events of this type involve the erosion of the land surrounding an undersized culvert or pipe, eventually causing the water to completely break down the integrity of the land that supports a roadway or bridge, making an important transportation route impassable and sometimes causing deaths during its collapse. There are other cases in which a water main, gas line, or underground utility cables can eventually become exposed and vulnerable to freezing weather, breakage and leaks, or the inflow of water, causing an infrastructure breakdown.

Impact on the Public, Property, Facilities, and Infrastructure

Settlements have traditionally been located alongside rivers and lakes. This means that older areas often include portions of their development that had originally been located within areas that are now known to be floodplains. The MDEQ estimate of 200,000 at-risk structures includes permanent residences, and suggests that thousands of residents will experience damaging flood events while living in these areas of Michigan. In addition to the direct impacts upon property, the public is also affected by even the temporary closure of businesses, streets, downtown areas, and critical facilities. Many facilities (such as local hospitals) are located in downtown areas that are at-risk during severe flood events. Sewer infrastructure can be overwhelmed by heavy rainfall events, and the resultant floods can lead to power failures, road closures, and problems with water supply and quality. For example, during the 2018 flood disaster in Houghton, Michigan Technological University had to be temporarily closed because of flood impacts upon the university's electrical power equipment.

Impact on the Economic Condition of the State

Since many important businesses, facilities, government offices, and infrastructure are located in downtown areas that are near rivers, many floods result in negative economic impacts, although most of these are temporary and involve just the local areas that experience flooding. Fortunately, there has been an increased awareness of flood risks, the value of insurance coverage, the consideration of hazards within business plans, facility plans, and government continuity plans. Although floods still cause many small businesses to suffer and eventually close, it can be difficult to determine how many of these might have stayed open if more consideration had been given to flood risks as an element of contingency planning and location selection processes. Michigan continues to promote an awareness of natural hazards and to encourage planning and hazard mitigation to reduce these risks to businesses and the infrastructure that supports them. One of the current challenges involves the budgeting of needed improvements in drainage and stormwater sewer systems. For example, flood risks can be reduced by dredging projects that clear away sediments and debris that had gradually reduced the speed or volume of water flowing through an area, but which can be expensive for local budgets to handle. (Even though these activities are important flood-prevention activities, FEMA considers dredging and debris clearance to be normal maintenance expenses, and excludes them from its hazard mitigation grants.)

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

Many downtown and floodplain areas include bridges and roadway segments that may become impassable, slowing response times and even requiring boats to be used to provide emergency services to some areas. As suggested in the preceding description of the economic impacts of flooding, major flood events often do cause interrupted services and operations among local businesses, facilities, government offices, and related agencies. Fortunately, these disruptions still tend to be infrequent and temporary, but continued planning, infrastructure improvements, and other flood mitigation activities are needed to help alleviate these problems. Key facilities, supplies, and routes should be evaluated with respect to known floodplain locations and potential drainage system breakdowns. Alternative locations or facilities may be available to help reduce the risk or extent of interruptions.

Impact on the Environment

The main problem involves floodplains that spread unhealthy or contaminated waters, potentially including substances that are spread from hazardous materials sites. In addition to the substances that are picked up by water as it runs off of streets and other surfaces, a flooded area may inundate current or old industrial sites, possibly even including heavily contaminated Superfund sites, transporting harmful substances into other areas.

Impact on Public Confidence in State Governance

When floodplains have been clearly identified through governmental processes such as Flood Insurance Rate Maps and the FEMA RiskMap process, future floods within these areas may prompt some of the public to raise questions about the difficulties of flood mitigation efforts, especially involving prominent central places or events that involved strong impacts upon residents. It is important to seek and implement opportunities for flood mitigation through a combination of investments, specialized grants, and more general support of emergency preparedness, resilient land use policies, coordinated partnerships, and public education.

Significant Riverine Floods

Michigan has experienced 14 flood disasters since 1975 which resulted in both a Presidential Major Disaster Declaration and a Governor's Disaster Declaration (opening up the full range of federal and state supplemental disaster assistance). That averages about one major disaster every three years, but the average during the 21st Century has increased to about one every two years. A slightly lower number of additional events have resulted only in a Governor's Disaster Declaration (activating state supplemental and limited federal disaster assistance). Combined, these flood disasters have caused billions of dollars in damage to homes, businesses, personal property, and agriculture. These disasters include all types of floods. This chapter will focus upon fluvial (riverine) flooding, and the following chapter will emphasize pluvial/urban flooding, but the same events can involve both types of flood at the same time.

The following brief synopses describe Michigan flood events in the past few decades in which flood impacts predominantly occurred in or near identified floodplains that surround rivers, other drainage channels, and inland lakes (or as a result of jams or failures in watershed drainage channels). Events which were predominantly pluvial or urban in nature (involving excessive runoff, ponding, and failures of urban storm sewer systems) will be emphasized within the next chapter. Many other damaging flood events have occurred at the local level, without qualifying for a governor's disaster declaration, and some of these are included in the following descriptions, where they had readily been identified and described within the NCEI online database of NOAA.

Significant Flood Events in Michigan

NOTE: Many of these events could also have been listed in the chapter on Pluvial/Urban Flooding, and many of the events in that chapter could also have been listed here. Please refer to both chapters for a more complete sense of Michigan's flood history.

March 24-27, 1904 – Central and Southern Lower Michigan

One of the most disastrous and extensive floods ever to occur in Michigan struck the central and southern Lower Peninsula during March 24-27, 1904. The flooding was caused by runoff resulting from intense rainfall, compounded by heavy snowpack and frozen soils, which swelled rivers so that they spilled over their banks. The flooding was most prevalent in the Grand, Kalamazoo, Saginaw and River Raisin basins, and to a lesser extent in the Huron and St. Joseph River basins. (The flood peaks from this flood are still the highest associated with spring flooding in the southern Lower Peninsula since recordkeeping began.) Damage was widespread and severe. In Grand Rapids, the flooding caused 14,000 persons to be homeless and damaged 2,500 homes and 30 businesses. Damage was estimated at $2 million. In Lansing, the flood was the most extensive in 135 years of local history. One fatality was reported, and damage was $200,000. In Bay City, numerous dams were undermined or washed away, and highway and railroad bridges were damaged—forcing a halt to railroad traffic. In Kalamazoo, an area of two square miles was inundated, with damages estimated at $50,000. **NOTE: Historical figures have not been adjusted for inflation.**

April 4-11, 1947 – Central and Eastern Lower Michigan

The flood of April 4-11, 1947 was caused by a combination of snow and rainfall that began in late March of that year. In early April, two frontal systems dumped several inches of rain in many localities across central and eastern Lower Michigan. The areas primarily affected by the April 1947 flood included the Clinton, Detroit, Grand, Kalamazoo, Saginaw and St. Clair Rivers, and the River Rouge. The city of Flint was particularly hard hit, with damage totaling $4 million. Damage was also significant in Northville, where floodwaters filled basements and inundated first floors of numerous residences.

April 24-26 and May 7-12, 1960 – Upper Peninsula

Record floods were widespread in the Upper Peninsula on April 24-26 and May 7-12, 1960. The April flood affected primarily the Montreal, Black and Presque Isle River basins in the western Upper Peninsula. The May flood affected the Manistique River basin in the central and eastern Upper Peninsula. Intense rainfall contributed to both flood events. Rainfall was 3-5 inches during April 24-26 and 4-6 inches during May 6-12. The size of the area covered by flooding was significant, but the damage was limited because the affected area was not densely developed. Flood losses to residences, businesses, and public roadways and bridges were limited to $575,000.

July 1992 – Gogebic County

On July 2 and 3, 1992 severe storms struck Gogebic County, dumping over six inches of rain in a 24-hour period. The stormwater runoff caused creeks and rivers to overflow, causing severe damage to the road system throughout the county. Culverts were washed out, roads washed away, bridges were clogged with debris, and numerous residents were stranded because they could not use the road systems. Several road washouts were particularly severe – as much as 16-20 feet deep. The conditions were determined to be a serious threat to life safety and essential services. A Governor's Disaster Declaration was granted to provide assistance to the county in repairing the road washouts and clearing debris.

April 1996 – Western/Southern Upper Peninsula

The melting of a heavy snow pack combined with rain during the second half of April and caused many streams and rivers to flood—especially in Menominee, Iron, and Delta Counties. The flooding inundated and washed out several roads and bridges, flooded many yards and basements, and caused nearly $2 million in public damages. Up to 24 roads were closed off at the height of the flood event.

June 1997 – West Michigan

On June 20-21, 1997, a series of intense thunderstorms passed through West Michigan, spawning heavy rainfall that flooded many areas in Allegan, Ottawa, Barry, and Van Buren counties. Flood and wind damage was particularly severe in Allegan County, which reported four injuries, five homes destroyed and 234 damaged, and 37 businesses damaged. Damage to public facilities, roads and bridges, and culverts and drainage channels totaled nearly $1.5 million. Ottawa County officials reported damage to 111 homes and five businesses, in addition to nearly $700,000 in public damages. On June 27, 1997, a Governor's Disaster Declaration was granted to Allegan and Ottawa counties to provide supplemental state assistance for the public damage. The SBA provided low-interest disaster loans to those home and business owners that suffered uninsured damage from the flooding or wind.

July 1997 – Southeastern Michigan (Federal Disaster #1181 – 6 counties)

On July 2, 1997, a series of intense thunderstorms struck central and southeast Michigan, causing extensive wind damage. A Presidential Major Disaster Declaration was granted for five counties, primarily for the wind-related damage. However, the heavy rainfall produced by these storms caused flooding in Wayne and Macomb counties. Flood-related damage to the public water and sewer systems in those two counties totaled nearly $300,000. It should be noted that these flooding problems occurred at the same time the two counties were also faced with flooding problems associated with high water levels on the Great Lakes.

April 1998 – Alpena County

Rapid snowmelt, combined with intense rainfall that began on March 30, 1998 and continued through April 2, resulted in severe flooding in the northeast portion of Alpena County. The flooding forced residents of 80 homes in one subdivision 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 $700,000. A Governor's Emergency Declaration was granted to provide supplemental state assistance to the county. In addition, a Small Business Administration (SBA) Declaration was also granted that provided low-interest disaster loans to the home and business owners impacted by the flooding.

April 2002 – Western Upper Peninsula (Federal Disaster #1413 – 6 counties)

In 2002, record-setting snowfall in February and March set the stage for flooding in April. During February and March of 2002, the north-central and western parts of Upper Michigan received over 100 inches of snowfall. The snow pack held over 11 inches of water. The snow quickly melted during a six-day period (April 11-17), releasing all that water into creeks, streams, rivers and lakes. To heighten the situation, over two inches of rainfall occurred between April 10-12 over much of Upper Michigan, and record high temperatures in the 70s and 80s were recorded on the 15th and 16th. During those two days, a dramatic snow melt occurred with nearly two feet of snow melting away. To complicate matters further, moderate rain during the morning of the 18th and severe thunderstorms in the afternoon and evening dumped up to an additional 1½ inches of water over an already saturated and flooded Upper Peninsula. Following the rain and warm temperatures, streams and rivers began to rise and overflow. Many local and county roads were closed due to high water and several dams were in jeopardy of failing. Localized flooding of low-lying areas was common across the western and central Upper Peninsula. Major flooding on rivers and lakes occurred in eight Upper Michigan counties. Approximately 160 homes and businesses were affected by the rising waters. Major highways US-2, M-28, and M-64 were closed and 25 local and county roads were also closed due to high water. The Black, Montreal and Ontonagon Rivers all went above flood stage. A partial failure of the Presque Isle Wildlife Dam occurred on the Presque Isle River. Heavy rains and rapid melting of the snow pack contributed to the collapse of a 10 feet wide section of the earthen portion of the dam. The total cost of the flooding was estimated at $18.5 million. A Presidential Major Disaster Declaration was granted to six counties in the Upper Peninsula.

May 2003 – Marquette and Baraga Counties

When the Mother's Day storm runoff from the Huron Mountains overwhelmed a dike holding back Silver Lake in northwest Marquette County, a wave of water inundated the Dead River basin all the way to Lake Superior in Marquette. A number of roads and bridges were washed out by the flood waters. An evacuation order was issued for about 1,800 people. The Presque Isle Power Plant at the Upper Harbor in Marquette was flooded and shut down for a number of days, resulting in shortages of electricity across western and central Upper Michigan. A Governor's Emergency Declaration was issued for Marquette County, where $14 million in property damage was reported. In neighboring Baraga County, and additional $2 million in flood damages occurred.

May-June 2004 – Southern Lower Michigan (Federal Disaster #1527 – 23 counties)

In May 2004, a stationary front over Iowa, Wisconsin, and Michigan brought severe thunderstorms and heavy rains, which caused widespread flooding over Southern Lower Michigan. Much of the rainfall occurred in saturated areas that had experienced well-above average precipitation for the month of May. Over a 36-hour period (12 am May 22nd to 8 am May 23rd), 2 to 6 inches of rain fell across Southeast Michigan. Backyards were submerged under several feet of water. About 100 homes in Macomb County had damage of about $100,000 each. Road and bridge damage was expected to cost $10 million to repair. Total rainfall over the Grand River basin from May 20th through June 3rd varied from four to as much as seven inches. It was the biggest and longest duration flooding event in the past ten to twenty years across southwestern and south central Lower Michigan. It was the wettest May on record in Lansing and Muskegon and the third wettest May on record in Grand Rapids. A Presidential Major Disaster Declaration was granted to 23 counties in the southern Lower Peninsula. Macomb County damages were estimated at $100 million, and damages of about $1 million each were reported for the counties of Clare, Gratiot, Isabella, Lake, Mason, Mecosta, Montcalm, Newaygo, Oceana, and Osceola.

January 30, 2013 – Mecosta County

An ice jam occurred along the Muskegon River and caused floods that resulted in about $4.6 million in property damage at the town of Paris (just north of Big Rapids). Over a dozen flooded homes were evacuated in the middle of winter, near Rogers Heights. The area of Riverside Drive and 183rd Avenue (12th Mile Road) especially experienced problematic flooding.

April 12, 2014 – Newaygo and Osceola Counties

About 400 homes along the Muskegon River were impacted by flooding as snowfall and rainfall caused the river levels to rise greatly. About $4 million in property damage was estimated in Newaygo County, and $3 million in Osceola County. Significant road damage also resulted. A governor's disaster declaration was proclaimed for floods in these two counties, although the storm event also involved a great deal of wind damage in and around these areas.

July 12, 2016 – Gogebic County

Rainfall amounts from 3 to 6 inches fell across portions of Gogebic County starting on the evening of July 11, resulting in flash floods in the early morning hours of July 12. Many areas of road were washed out an impassable. Many persons were stranded at Little Girls Point, and a county patrol car was swept up in flood waters at the Montreal River, near the Wisconsin border. Property damages were estimated at $6.15 million.

June 22-27, 2017 – Central Lower Peninsula (Federal Disaster #4326 – 4 counties)
Five to eight inches of rain fell and resulted in widespread major flooding. A state and federal disaster declaration ensued, involving the counties of Bay, Gladwin, Isabella, and Midland. In Midland County, more than 1900 homes were damaged and 57 were destroyed, and public infrastructure impacts involved 193 roads and bridges that were damaged or destroyed ($116.4 million in damage). In Bay County, 145 homes were damaged, and 50 roads and bridges damaged or destroyed ($3 million in damage). Isabella County calculated over 100 roads closed at the same time, plus at least $70 million in property damage to area homes, roads, and bridges. In Gladwin County, water entered a few homes that were located near creeks and streams, especially near Wixom Lake, and some roads were flooded and washed out near Dale. Total property damages were estimated at $189.5 million across all four counties, and $21 million in crop damage occurred within Isabella County. Numerous trees and power lines had also been knocked down in the initial storm event, in an area south of M-59.

It is important to remember that only a selection of the most impactful flood events have been described here. Smaller areas are known to suffer repeated flooding, such as an area on the Grand River in Robinson Township (Ottawa County), which is subject to floods from ice jams and sedimentation. After multiple evacuations between the mid-1990s and the mid-2000s, a multi-million-dollar PDMP grant funded flood mitigation projects that helped to reduce the future impacts of flooding in that area. The floods caused by ice jams were especially harmful because their occurrence in the middle of winter inhibited the ability of homeowners to drain waters and clean up afterward. The flood persisted for days during a January 2005 winter cold spell, while the Grand River peaked at 4.3 feet above flood stage. A state of emergency was declared in the township, but since the impacted area was limited to just two neighborhoods, it was calculated that the criteria for a federal disaster declaration could not be met. Assistance was limited to the Small Business Administration's low interest disaster loans.

A few years later, $11 million in flood damages were estimated from a September 2008 event around Comstock, in Kalamazoo County. An additional $5.25 million in flood damages were estimated in various statewide locations from the same September 2008 weather event. Part of the heavy rain was due to the remnants of Hurricane Ike. In December of 2008, about $3.6 million in flood damages occurred in Ottawa County. These events resulted in county emergency declarations. In March 2009, about $3 million in flood damages occurred along the River Raisin, in Monroe County. In June 2009, about $34 million in flood damages occurred to some 2,000 homes in Ottawa County, and $4 million in flood damages occurred in neighboring Allegan County. Both counties declared local states of emergency. August 2009, flooding took place in the southeastern part of Lapeer County, resulting in about $3 million in damage and the closure of M-53 for about 10 days, due to the highway being washed out. In August 2010, Mt. Pleasant experienced significant flooding and about $4 million in damages, including the partial flooding of the Central Michigan Community Hospital.

It is estimated that flood damages in Michigan now average more than $100 million per year. Only some of those costs are covered under the flood insurance policies of the National Flood Insurance Program (although that is now more than $2.2 million per year), and most of the rest seems to be absorbed out-of-pocket by individuals and communities. Although digital flood map coverage has been gradually expanding, there are still areas of Michigan without this convenient source of flood information. NOAA's online NCEI database lists about $2.27 billion in Michigan flood damages between 1996 and 2017 (an average of over $106 million per year), but it is known (from local planning efforts, project applications, and Michigan disaster declarations) that there are a great many local events that are not reported in that database. Much more study is needed to build a comprehensive understanding of all vulnerable areas within Michigan, as many Flood Insurance Rate Maps have not yet been digitized or updated, and the USGS rapidly continues to build its hydrologic models through its network of stream gauges. These extensive flood mapping efforts are focused upon the best-known fluvial and shoreline flood risks, but do not yet cover all the possibilities that could arise from blocked drains, ice jams, low-lying areas, and failures of municipal stormwater systems.

Programs and Initiatives

Michigan Silver Jackets
Silver Jackets is a program originated by the U.S. Army Corps of Engineers to create, maintain, and integrate comprehensive partnerships with state and federal agencies, and to seek sustainable solutions to reduce risk associated with flooding and other natural hazards. The Michigan Silver Jackets Team is an interagency team dedicated to creating a collaborative environment to bring together federal, state, local, and other stakeholders to develop and implement natural hazard mitigation projects by combining available agency resources, which include funding, programs, and technical expertise. The Team has worked together on projects focused on flood risk reduction in the Lansing Metropolitan Area, Newaygo County, the City of Kalamazoo, and the Townships of Green Oak and Hamburg.

The Michigan Silver Jackets Team has been functioning for years, but a team charter was formalized in 2016. It has been meeting at least 6 times per year, in Lansing.

USGS Water Watch
This web-based service provides real-time monitoring of stream gauge stations across the state. The icon for each station can be clicked on to obtain historical and statistical records. The web address is http://waterwatch.usgs.gov/new/.

The USGS "Water Alert" program
This service started in August of 2010 and is publicly available, with a website located at http://water.usgs.gov/wateralert/. The program enables users to elect to receive text messages and/or e-mails for any USGS stream gauge stations, when certain flow and water-quality conditions are observed. Each user may set his or her own criteria for notification. They can be alerted about the onset of a flood, or about a pre-flood stage that will allow them to take advance actions to prepare for and respond to a flood. It also offers some users the capacity to make inferences about stream locations beyond those in the existing list of official NWS flood forecast locations.

National Weather Service Doppler Radar
National Weather Service Doppler Radar can now more easily detect severe weather events that threaten life and property—including weather events that can lead to riverine flooding. Most significantly, the lead-time and specificity of warnings for severe weather have greatly improved since the early 2000s. The National Weather Service (NWS) Doppler Weather Radar Network (WS-88D) has undergone many upgrades since 2010 in the Service Life Extension Program that will keep the system operational well into the 2030s. Upgrades include additional technology to detect atmospheric particle size and movement (dual polarization) that aids the NWS in detecting severe winds, large hail, and tornado structure. Doppler technology calculates both the speed and the direction of wind motion inside of severe storms. The system allows forecasters to identify conditions leading to severe weather, as well as information on the direction and speed of storms once they form.

National Weather Service Watches/Warnings
The National Weather Service issues a **watch** for an area when the meteorological conditions are conducive to the development of severe weather there. People in the watch area are instructed to stay tuned to National Oceanic and Atmospheric Administration (NOAA) weather radio and other media for weather updates, and to watch for developing storms.

Once radar or a trained Skywarn spotter detects the existence of severe weather, the National Weather Service will issue a specific **warning**, such as a "severe thunderstorm warning," that identifies where the weather system was observed, the direction in which it is moving, and the time frame during which the storm is expected to affect an area. Persons in the warning area are instructed to seek shelter immediately, postpone outdoor events, or to take other actions.

The State and local government agencies are warned via the Law Enforcement Information Network (LEIN), NOAA weather radio, and the Emergency Managers Weather Information Network (EMWIN). Public warning is provided through the Emergency Alert System (EAS). The National Weather Service stations in Michigan transmit information directly to radio and television stations, which in turn pass the warning on to the public. The National Weather Service also provides detailed warning information on the Internet at www.weather.gov, where interactive maps are available. State and local government agencies also receive weather warnings through a variety of modern technologies such as private weather mobile applications and internet services. These applications and services allow local and state governments to send notifications of National Weather Service warnings to the public. There are multiple web and mobile applications available for individuals to sign up for, that will provide them with alerts when the National Weather Service issues weather warnings.

Severe Weather Awareness Week
Each spring, the Emergency Management and Homeland Security Division of the Michigan Department of State Police, in conjunction with the Michigan Committee for Severe Weather Awareness, sponsors Severe Weather Awareness Week. This annual public information and education campaign focuses on such severe weather hazards as

tornadoes, thunderstorms, lightning, high winds, flooding, and hail. Informational materials on floods and other hazards are disseminated to schools, hospitals, nursing homes, other interested community groups and facilities, and the general public.

All Hazards Resources for Rural Communities
The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Flood Inundation Mapping
The Flood Inundation Mapping (FIM) Program of the U.S. Geological Survey (USGS) helps communities protect lives and property by providing tools and information to help them understand their local flood risks and make cost-effective mitigation decisions. The USGS works with the National Weather Service, the U.S. Army Corps of Engineers, and the Federal Emergency Management Agency to connect communities with federal flood-related science thereby ensuring the quality and consistency of flood inundation maps across the country.

The USGS Flood Inundation Mapping Program has two main functions: (1) Partner with local communities to assist with the development and validation of flood inundation map libraries. A flood inundation map library is a set of maps that shows where flooding may occur over a range of water levels in the community's local stream or river. The USGS works with communities to identify an appropriate stream section, gather the necessary data to model where flooding will likely occur, and verify that the maps produced are scientifically sound. (2) Provide online access to flood inundation maps along with real-time streamflow data, flood forecasts, and potential loss estimates.

Once a community's map library is complete, it is uploaded to the USGS Flood Inundation Mapper, an online public mapping application at https://fim.wim.usgs.gov/fim/. The Mapper allows users to explore the full set of inundation maps that shows where flooding would occur given a selected stream condition. Users can also access historical flood information and potential loss estimates based on the severity of the flood. The Mapper helps communities visualize potential flooding scenarios, identify areas and resources that may be at risk, and enhance their local response effort during a flooding event.

RiskMAP
This program's name stands for risk mapping, assessment, and planning. It is a federal-led partnership to coordinate all levels of government with area partners, including Native American agencies, to reduce risks in a process that updates and provides new maps and plan development processes. Several types of products are made available as a result of these activities, including maps, documents, and digital information. RiskMAP is currently extremely active in Michigan. FEMA is in the process of updating the Great Lakes' coastal flooding area for most of the state. There are currently more than 20 counties at various stages in the RiskMAP process.

Michigan Flood Hazard Regulatory Authorities:
Land Division Act, 1996 PA 591, as amended by 1997 PA 87 – The Land Division Act governs the subdivision of land in Michigan. The Act requires review at local, county and state levels to ensure that the land being subdivided is suitable for development. From a flood-hazard viewpoint, a proposed subdivision is reviewed for proper drainage by the County Drain Commissioner, and for floodplain impacts by the MDEQ, Water Resources Division.

Provisions of the Act and its Administrative Rules require that the floodplain limits be defined and prescribe minimum standards for new residential developments in areas within or affected by a floodplain. Restrictive deed covenants, filed with the final plat, stipulate that any building used or capable of being used for residential purposes in areas within or affected by a floodplain shall meet the following conditions:

- Be located on a lot having a buildable site of 3,000 square feet of area with its natural elevation above the floodplain limit. (Lots with less than 3,000 square feet of buildable area above the floodplain may be filled to achieve that area.)
- Be served by streets within the proposed subdivision that have surfaces no lower than one foot below the elevation defining the floodplain limits.

- Have lower floors, excluding engineered basements, that are not lower than the elevation defining the floodplain limits. (The Michigan Building Code requires the lowest floor to be at least one foot above the 1% annual chance flood elevation level, and this requirement includes regular basements.)
- Have openings into the basement that are not lower than the elevation defining the floodplain limits.
- Have basement walls and floors that are below the elevation defining the floodplain limits made watertight and designed to withstand hydrostatic pressures.
- Be equipped with a positive means of preventing backup from sewer lines and drains serving the building.
- Be properly anchored to prevent flotation.

Floodplain Regulatory Authority, found in Water Resources, Part 31 of the Natural Resources and Environmental Act, 1994 PA 451, as amended – The floodplain regulatory portion of Act 451 regulates residential occupation of high-risk flood hazard areas and ensures that other uses do not obstruct flood flows. A permit is required from the MDEQ 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. (Floodways are the channel of a river or stream and those portions of the floodplain adjoining the channel that are reasonably required to carry and discharge a 100-year flood. These are areas of moving water during floods.) New residential construction is specifically prohibited in the floodway. Non-residential construction may be permitted in the floodway, although a hydraulic analysis may be required to demonstrate that the proposed construction will not harmfully affect the stage-discharge characteristics of the watercourse.

The Act does not apply to watersheds that have a drainage area of less than two square miles. (Those small watersheds are considered to be local drainage systems, and do not fall under the Floodplain Regulatory Authority.)

Soil Erosion and Sedimentation Control, Part 91 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – This portion of the Act seeks to control soil erosion and protect the waters of the state from sedimentation. A permit is required for all earth changes that disturb one or more acres of land, as well as those earth changes that are within 500 feet of a lake or stream. The Act itself does not address flood hazards, per se. However, if sedimentation is not controlled, it can clog streams, block culverts, and result in continual flooding and drain maintenance problems.

Inland Lakes and Streams, Part 301 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – This portion of the Act 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. Though reduction of flooding is not a specific goal of this Act, minimizing restrictions on a stream can help to reduce flooding conditions.

Wetlands Protection, Part 303 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – This portion of the Act requires a permit from the Department of Environmental Quality 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 storm water runoff control. The hydrologic absorption and storage capacity of wetlands allows them to serve as natural floodwater and sedimentation storage areas. The Act recognizes that the elimination of wetland areas can result in increased downstream flood discharges and an increase in flood damage. Permits for wetland alterations are generally not issued unless there is no feasible alternative and the applicant can demonstrate that the proposal would not have a detrimental impact upon the wetland's functions.

Natural Rivers Program, Part 305 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – The Natural Rivers Act was originally passed in 1970, and has been incorporated as Part 305 of the Natural Resources and Environmental Protection Act. The purpose of this program is to establish and maintain a system of outstanding rivers in Michigan, and to preserve, protect, and enhance their multi-faceted values. Through the natural rivers designation process, a Natural River District is established (typically 400 feet 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. Not all of the zoning ordinances on the natural rivers have the same requirements, but they all have building setback and vegetative strip requirements. Although the purpose is not specifically to reduce flood losses, by requiring building setbacks (in many cases prohibiting construction in the 100-year floodplain), flood hazard mitigation benefits can be realized.

Dam Safety, Part 315 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – The Dam Safety Unit within the Land and Water Management Division of MDEQ has the primary responsibility to ensure dam safety within the state. Following the September, 1986 flood in central Lower Michigan (see the description in the Significant Riverine Floods section), the current Dam Safety Act was passed to ensure that dams are built and maintained with necessary engineering and inspections for safety of the public and the environment. The Department of Environmental Quality is required to review applications involving construction, reconstruction, enlargement, alteration, abandonment and removal for dams that impound more than five acres of water and have a height of six feet or more.

Refer to the Dam Failures section for more information on this regulatory authority and hazard.

Manufactured Housing Commission Act, 1987 PA 96, as amended – The Michigan Manufactured Housing Commission Act and its implementing Administrative Rules provide regulation on the placement of manufactured homes, and establish construction criteria. Manufactured homes are prohibited from being placed within a floodway, as determined by the Department of Environmental Quality. In addition, manufactured homes sited within a floodplain must install an approved anchoring system to prevent the home from being moved from the site by floodwaters (or high winds), and be elevated above the 100 year flood elevation.

Local River Management Act, 1964 PA 253 – Enacted in 1964, the Local River Management Act provides for the coordination of planning between local units of government in order to carry out a coordinated water management program. Implementation of the water management program occurs through the establishment of watershed councils. These councils conduct studies on watershed problems, water quality, and the types of land uses occurring within the watershed. Watershed councils have the authority to develop River Management Districts for the purpose of acquisition, construction, operation, and financing water storage and other river control facilities necessary for river management. 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.

State Flood Hazard Mitigation Plan

Michigan's governors have long recognized the need for flood mitigation activities. Executive orders and directives have been issued to create a State Flood Hazard Mitigation Plan. This responsibility has been shared by the Michigan Department of Environmental Quality, the Michigan State Police, and other governmental departments, in coordination with the MHMCC (now the MCCERCC). Thus, those parts of the Michigan Hazard Mitigation Plan that deal with flooding have also served the function of providing the most recently updated detail for the State Flood Hazard Mitigation Plan, which (starting in 1977) mandated (1) the consideration of flood risks in the construction of buildings and roads, (2) the identification and mitigation of flooding at such facilities, where practical and economically feasible, (3) the attachment of appropriate restrictions upon flood prone lands that may be sold or given to non-state entities, and (4) the inclusion of flood hazard considerations by all state agencies involved in land use planning activities. Details regarding flood regulations, land use development efforts, coordination, and educational activities appear in this plan, including its list of hazard mitigation strategies.

Road Infrastructure Flood Mitigation Committee

Following the September 1986 floods, the Michigan Department of Transportation (MDOT) formed a flood mitigation committee to determine ways to lessen damage to road infrastructure caused by riverine flooding. The committee consisted of representatives from the County Road Association of Michigan, the Federal Highway Administration, the MDEQ, and MDOT. One of the primary purposes of the committee was to identify reasons for failed stream crossings and damaged roads during a flood event, and make recommendations for achieving more flood-resistant stream crossings. The committee published its findings and recommendations in a report that is used today as a reference guide for officials involved in road infrastructure design and maintenance.

As a result of one of the committee's recommendations, the MDEQ regularly sponsors workshops and seminars on stream crossing design and erosion control practices. These workshops are geared toward design engineers at the state, county and local levels, in addition to private consultants and county drain commissioners.

1980s Voluntary Community-Initiated Acquisition and Relocation Projects

With the understanding that acquisition and relocation is one of the best ways to guarantee that homes and businesses will not continue to be repeatedly damaged by cyclical flooding, in the 1980s the cities of Owosso and Midland initiated voluntary acquisition and relocation programs using various community and privately-generated funds.

The **city of Owosso, Shiawassee County,** used Small Cities Block Grants and private investment to relocate 40 homes out of the floodplain, revitalize downtown development, and develop a park along the Shiawassee River.

The **city of Midland, Midland County,** rejected U.S. Army Corps of Engineer's proposals for dikes and channel improvements as too expensive and visually unfavorable. Instead, the City used Dow Foundation Grants and matching general revenue funds to purchase flood-prone structures and return the property back to its natural state. The ongoing purchase of properties has been entirely voluntary. Over 120 structures were purchased and removed from the floodplain.

Floodplain Service Program

The need to identify a flood hazard area before construction is essential to the goal of flood mitigation. The MDEQ regularly provides floodplain information to public and private interests as part of its Floodplain Service Program under the Water Resources Division. The goal of the program is to provide 100-year floodplain information to interested parties so that informed purchase or development decisions can be made. In addition to providing floodplain information, the MDEQ will provide information on land and water "interface" permit requirements and on building requirements relating to construction in flood hazard areas.

National Flood Insurance Program

For many years, the strategy for reducing flood damages followed a structural approach of building dams and levees and making channel modifications. However, this approach did not slow the rising cost of flood damage, and did not provide an affordable opportunity for individuals to purchase insurance to protect themselves from flood damage. It became apparent that a different approach was needed.

The National Flood Insurance Program (NFIP) was instituted in 1968 to make flood insurance available in communities that have agreed to regulate future floodplain development. As a participant in the NFIP, a community must adopt regulations that: 1) require any new residential construction 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 (the floodproofing must be certified by a registered professional engineer or architect); 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. In return for adopting floodplain management regulations, the federal government makes flood insurance available to the citizens of the community. In 1973, the NFIP was amended to mandate the purchase of flood insurance, as a condition of any loan that is federally regulated, supervised or insured, for construction activities within the 100-year floodplain.

As of September 2018, there were 20,302 active flood insurance policies in Michigan. This figure reveals a 20% decline since 2010, yet officials from FEMA and the MDEQ had already estimated that only 15% of all flood-prone structures in Michigan eligible to purchase flood insurance actually had flood insurance around that time. Furthermore, since only about half of all local communities in Michigan have chosen to participate in the NFIP, there are thousands of structures that are flood-prone, but are not eligible to purchase flood insurance through this program. (There were 881 participating communities as of September 17, 2018, although this does mark an increase from 867 communities at the end of 2010.)

Top 10 Michigan Counties – Number of Flood Insurance Policies

County	Number of Policies
Wayne	3,322
Macomb	1,579
St. Clair	1,513
Oakland	1,363
Saginaw	1,254
Monroe	1,169
Bay	1,125
Washtenaw	625
Kent	615
Clinton	614

As of 9/17/2018; Source: Federal Emergency Management Agency

The counties with the most flood insurance policies include the most urbanized areas of the state, and include counties located along the eastern shoreline of Michigan, along Lake Huron, Lake Erie, Lake St. Clair, and/or a connecting waterway such as the Detroit River or the St. Clair River. Unfortunately, coverage within most of these counties has shrunk considerably during the decade.

Since 1978, about $88.4 million in claims have been paid due to flooding in Michigan. It should be remembered that officially claimed flood losses are only a small percentage of the total losses that are occurring from flood events. The flood insurance losses provide a good indication of where flooding problems currently exist, but they do not necessarily provide the best estimate of the total losses that are actually occurring. Since the Great Lakes experience periodic high lake levels and associated flooding, it is not surprising that seven of the ten communities showing the highest amount of flood insurance payouts occurred on the Great Lakes and their connecting waterways.

Communities that are members of the NFIP probably have floodplain maps (called Flood Insurance Rate Maps, or FIRMs) that show where the floodplain areas are in the community and provide Base Flood Elevation (BFE) measurements. These calculations are based on surveying the topographical, hydrological, pedological, and land cover characteristics of the area's watershed. The result is a statistical model—a “100-year” floodplain area has a 1% chance of flooding in a given year, and the BFE is the water depth associated with an event of that probability. Some areas may flood less frequently, such as a 500-year floodplain which has a 1-in-500 chance of flooding in a given year. The names "100-year" and "500-year" can be very misleading. A "100-year" level flood may occur several times in a century, just as it is possible to flip a coin and get tails many times in a row. For detailed analysis of flooding, the basic principle of risk is that there is a 1% chance per year of flooding that is at the BFE level. For example, if BFE is 365' and the elevation of a structure's first floor is 363' above sea level, then the result would be floodwaters that are two feet over the ground floor of that structure. Lesser flooding is likely to occur with even greater frequency—if two feet of floodwaters hit that structure with 1% probability, the likelihood of getting just a few inches of floodwaters is even greater in any given year. Conversely, the likelihood of flooding that has three or four-foot depths would be less than a 1% annual chance. FEMA models for flooding divide 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. Within the same floodplain area, a structure's elevation (and whether it has a vulnerable basement) may make all the difference between suffering severe damages, and experiencing no damages. Ideally, flood risk information can be combined with structural information (such as might be available through a building department or assessor's office) and a Geographic Information System (GIS) could make the analysis of such information easier. It must also be noted that for some communities, these flood studies have become rather old and have not yet been verified or updated. Therefore, those who refer to these maps for hazard mitigation planning purposes are advised to review the original study’s data, model assumptions, and conclusions, to make sure that they are still representative of current conditions. Official floodplain maps that have been digitized are included in general form (smaller scale, less detail) at the end of this chapter.

The Community Rating System (CRS) allows participating communities to earn discounts for their residents' flood insurance premiums. The following communities (as of October 2018) are all CRS participants in Michigan that have earned discounts of between 5% and 25% on the policy premiums for their NFIP-insured properties:

CRS Class 5 (25% discounts earned): Midland City (Midland County)
CRS Class 6 (20% discounts earned): Ann Arbor City (Washtenaw County), Vassar City (Tuscola County)
CRS Class 7 (15% discounts earned): Dearborn Heights City (Wayne County), Novi City (Wayne County), Saginaw Township (Saginaw County), Shelby Township (Macomb County), Sterling Heights City (Macomb County)
CRS Class 8 (10% discounts earned): Brooks Township (Newaygo County), Detroit City (Wayne County), Gibraltar City (Wayne County), Grand Haven Township (Ottawa County), Hamburg Township (Livingston County), Luna Pier City (Monroe County), Portage City (Kalamazoo County), Rockwood City (Wayne County), Taymouth Township (Saginaw County), Zilwaukee City (Saginaw County)
CRS Class 9 (5% discounts earned on NFIP policy premiums): Bedford Township (Monroe County), Commerce Township (Oakland County), Fraser Township (Bay County), Plainfield Township (Kent County), Richfield Township (Genesee County), Saugatuck City (Allegan County), Taylor City (Wayne County)

(Counties have been listed here in parentheses only to help readers geographically locate the communities in this list. Communities participate in the CRS at the level of a township, city, or village, rather than at a county level.)

In addition, the following communities are in Class 10, and do not currently receive any discount:
CRS Class 10 (Rescinded) City of Farmington Hills (Oakland County), Park Township (Ottawa County), Sumpter Township (Wayne County)

This two-page table lists of all counties in Michigan that have flood insurance statistics associated with them. The table provides some indicators of the areas in Michigan that have the greatest concerns about flood damage:

National Flood Insurance Statistics by County

County	Total premium	Policies	A-Zone Policies	Total coverage	Claims since 1978	Total Paid Since 1978
Alcona	$24,945	32	21	$5,470,300	10	$16,161
Alger	$14,159	13	9	$2,192,900	5	$39,012
Allegan	$97,785	177	109	$37,367,500	82	$641,247
Alpena	$75,285	78	39	$14,818,800	10	$15,228
Antrim	$17,732	24	7	$6,863,700	4	$920
Arenac	$164,727	182	134	$24,438,100	83	$564,806
Baraga	$6,152	4	3	$385,900	6	$14,324
Barry	$255,499	210	162	$32,174,200	262	$2,536,598
Bay	$1,006,701	1,125	875	$161,146,900	757	$8,435,559
Benzie	$48,653	34	22	$7,862,600	7	$54,860
Berrien	$282,758	398	232	$84,259,600	326	$4,571,298
Branch	$125,010	103	81	$15,156,700	31	$589,692
Calhoun	$175,945	168	69	$37,862,400	64	$297,510
Cass	$41,496	48	22	$10,297,300	8	$60,130
Charlevoix	$9,704	21	2	$6,045,000	3	$41,356
Cheboygan	$52,711	53	41	$9,783,800	5	$6,156
Chippewa	$59,607	67	32	$12,758,700	4	$122,643
Clare	$37,225	31	25	$4,489,500	3	$24,021
Clinton	$1,158,612	614	444	$139,020,800	234	$998,994
Crawford	$24,048	20	13	$3,237,800	0	$0
Delta	$36,972	57	33	$8,492,800	21	$60,364
Dickinson	$18,545	22	12	$3,316,400	5	$12,714
Eaton	$203,510	215	98	$43,144,900	123	$620,061
Emmet	$12,677	19	4	$6,170,900	2	$13,560
Genesee	$430,786	440	178	$95,707,800	426	$2,573,194
Gladwin	$19,843	18	13	$2,194,400	21	$365,535
Gogebic	$4,066	8	2	$1,179,000	10	$68,943
Grand Traverse	$49,648	69	19	$16,765,300	31	$244,818
Gratiot	$82,464	77	63	$9,921,500	23	$107,682
Hillsdale	$41,720	40	30	$4,173,500	11	$157,590
Houghton	$7,900	13	5	$1,944,800	6	$110,167
Huron	$225,656	232	177	$30,761,400	84	$254,431
Ingham	$491,044	405	221	$91,456,300	166	$1,621,355
Ionia	$119,166	127	98	$18,435,500	24	$121,216
Iosco	$152,736	217	133	$29,639,500	40	$198,677
Iron	$0	0	0	$0	3	$0
Isabella	$88,117	120	48	$21,982,700	31	$508,477
Jackson	$257,551	182	127	$40,252,300	35	$156,005
Kalamazoo	$342,961	227	112	$56,518,300	237	$3,189,009
Kalkaska	$3,057	6	5	$255,200	0	$0
Kent	$1,096,829	615	400	$160,325,900	594	$9,324,123
Lake	$11,467	16	4	$2,835,600	38	$532,832
Lapeer	$60,845	63	40	$11,906,000	28	$176,783
Leelanau	$78,534	69	43	$18,236,300	12	$20,104
Lenawee	$89,580	66	50	$10,957,700	57	$338,266
Livingston	$288,020	256	185	$58,242,800	107	$907,123
Mackinac	$52,322	46	29	$9,018,200	4	$8,898
Macomb	$1,644,073	1,579	945	$347,223,800	1,226	$6,784,918
Manistee	$37,059	35	22	$7,082,100	22	$165,160
Marquette	$32,877	43	16	$10,015,500	15	$175,003
Mason	$39,211	38	11	$9,233,300	9	$51,635

National Flood Insurance Statistics by County (continued)

County	Total premium	Policies	A-Zone Policies	Total coverage	Claims since 1978	Total Paid Since 1978
Mecosta	$44,085	68	25	$11,538,200	56	$1,337,318
Menominee	$57,018	77	42	$14,748,800	24	$55,496
Midland	$71,910	78	42	$12,557,300	33	$1,467,914
Monroe	$1,572,607	1,669	1,416	$273,047,000	1,640	$8,457,308
Montcalm	$9,442	11	7	$1,828,500	6	$26,174
Muskegon	$143,351	235	181	$40,846,500	92	$350,593
Newaygo	$89,225	91	58	$16,413,500	125	$2,823,203
Oakland	$1,275,132	1,363	560	$331,411,800	452	$3,231,807
Oceana	$50,429	72	44	$13,278,900	25	$82,914
Ontonagon	$21,865	22	14	$3,251,700	9	$4,653
Osceola	$43,569	52	36	$7,407,200	49	$1,175,695
Ottawa	$452,653	485	236	$108,200,600	269	$2,798,948
Roscommon	$3,117	10	1	$1,745,000	0	$0
Saginaw	$1,142,879	1,254	1,132	$138,115,500	560	$4,314,478
Sanilac	$18,062	27	4	$6,521,000	14	$122,607
Schoolcraft	$369	1	1	$30,000	1	$8,009
Shiawassee	$245,358	230	187	$26,776,900	58	$96,557
St. Clair	$1,261,469	1,513	1,157	$298,894,700	867	$2,995,848
St. Joseph	$97,693	96	62	$13,103,900	103	$1,530,289
Tuscola	$115,674	139	114	$15,802,500	122	$880,842
Van Buren	$103,385	101	60	$21,524,600	27	$136,456
Washtenaw	$555,809	625	334	$157,099,800	106	$770,448
Wayne	$3,206,045	3,322	2,129	$570,164,400	2,253	$7,775,943
Wexford	$38,792	39	22	$7,372,300	7	$20,098
STATE TOTAL		20,302	13,329	$3,834,702,800	12,213	$88,362,756

Flood Management and Mitigation Education

The Water Resources Division of MDEQ has developed several guidance documents aimed at local officials involved in floodplain management and flood mitigation. These guidebooks are used as textbooks in training workshops and as a reference for day-to-day activities.

The Emergency Management and Homeland Security Division, Department of State Police, has developed a local hazard mitigation planning handbook for local officials. This guidance document provides an overview of a planning process that communities can follow to help reduce their vulnerability to a wide array of natural, technological and human-made hazards – including riverine flooding.

The Water Resources Division and the Emergency Management and Homeland Security Division periodically conduct floodplain management and flood hazard mitigation training courses and workshops for state and local officials. The Water Resources Division also conducts regular community assistance contacts and visits as part of its administrative duties under the National Flood Insurance Program. Such contacts/visits are a form of training aimed at improving a community's implementation of floodplain management practices. In addition, the Water Resources Division continuously conducts flood hazard workshops for lenders, realtors, building officials, engineers, citizens and any other interested parties.

Flood Mitigation Assistance Program (see also the other state-administered federal grants listed next)

With the passage of the National Flood Insurance Reform Act of 1994, Congress authorized the establishment of a federal grant program to provide financial assistance to states and local communities for flood mitigation planning and activities. The Federal Emergency Management Agency (FEMA) has designated this the Flood Mitigation Assistance Program (FMAP). The FMAP funds can be used to fund activities that reduce the risk of flood damage to structures insurable under the National Flood Insurance Program. The FMAP is state-administered (by the Emergency Management and Homeland Security Division of the Michigan State Police). Cost share for the program ranges from 100% federal to 75% federal, 25% local, depending upon the specific project.

Three types of FMAP grants are available: 1) **planning grants** to assist local communities in developing the flood hazard portion of their mitigation plans; 2) **project grants** to fund eligible flood mitigation projects, with an emphasis on repetitively or substantially-damaged structures insured under the NFIP; and 3) **technical assistance grants** to assist the state in providing technical assistance to applicants in applying for the program or implementing approved projects.

State and Federally-Assisted Relocation of Floodprone Properties
The State of Michigan has been very pro-active in its initiation and participation in the acquisition and relocation of floodprone properties, in both pre- and post-disaster situations, using federal Hazard Mitigation Grant Program (HMGP) and Flood Mitigation Assistance Program funds. For extensive lists of these projects, and related information, please refer to the newest edition of the Michigan Hazard Mitigation Plan.

U.S. Army Corps of Engineers (USACE)
The U.S. Army Corps of Engineers has multiple programs that can assist with flood risk reduction. These include the Flood Plain Management Services (FPMS) program, which is 100% federally funded, the Planning Assistance to States (PAS) program, which involves a 50/50 cost-share, and Section 205 Flood Risk Management, which is a flood program that includes construction funding along with feasibility analysis and alternatives-development processes. More information on these programs can be found on the web page located at the following internet address:
https://www.lre.usace.army.mil/Missions/Planning/Technical-Planning-Assistance/

Other State and Federally-Assisted Flood Hazard Mitigation Projects
The State of Michigan has used a variety of other federal funding sources to assist in the implementation of flood mitigation projects. Those funding sources have included (1) the Hazard Mitigation Grant Program (HMGP), (2) the Pre-Disaster Mitigation Program (PDMP), (3) the Public Assistance Grant Program (PAGP), (4) the Presidentially Declared Disaster Assistance to Individuals and Households program, (5) Section 1362 of the National Flood Insurance Program (no longer in existence), (6) Community Development Block Grants (CDBG), and (7) Farmers Home Administration (FmHA) loans. State and local funds have been used to match the federal sources of funding. Please refer to Attachment C in the Michigan Hazard Mitigation Plan (Hazard Mitigation Funding Sources and Projects) for more information.

Flood Guidance for Local Hazard Mitigation Planning
Riverine flooding is a hazard that has been modeled for many decades now, and has some of the clearest methods of detailed analysis. Many guidance documents and publications are available to use in local assessments of this hazard, and local assessments are very important because of the much more detailed knowledge and more relevant authorities possessed at the local level. Much flooding affects small locations that do not show up well in a statewide analysis. Once risk categories from floodplain maps have been established for vulnerable structures, the amount of damage from flood events can be estimated using FEMA techniques. The basic technique is to find the replacement value of the structure, and to estimate damages by equating different flood depths with appropriate percentages of that replacement value. The following table estimates damages to structures, in terms of the percentage of a building's replacement value, for different flood depths and structure types. (This table was adapted from Flood Insurance Administration guidance, based on historical averages from observed flood damages.)

NOTE: The replacement value of a residential structure can be estimated, where information is not readily available. For example, online construction cost estimation tools, RS Means, the Residential Building Replacement Values of the International Code Council, or various other methods could be used. Supposing that a typical price of $101 per square foot of a residential structure was found using some authoritative source of this kind. In such a case, this price per area can then be multiplied by the calculated square footage of the structure that matches the kind of use for which the costs were provided (in this case, residential). For example, a 1000 square-foot house with 100% of that area dedicated to residential uses would have an estimated replacement cost of $101,000. A commercial facility would have its own distinct costs per square foot determined and then multiplies by the area dedicated to that use. Multi-use structures could have multiple components calculated separately and then added together for each unit. In this way, replacement values can be obtained.

FLOOD DAMAGE ESTIMATION TABLE
(Numbers given are damages as a percentage of the structure's replacement value)

	Type of structure					
Flood depths (depth of flooding in feet)	1 story, no basement	2 story, no basement	Split-level, no basement	1 or 2 story with basement	Split level with basement	Mobile home
Under ½ foot, in basement only	0	0	0	4	3	0
About 1 foot, in basement only	0	0	0	8	5	0
2+ feet in basement, <½' surface	9	5	3	11	6	8
About 1 foot flooding at surface	14	9	9	15	16	44
About 2' flooding on ground floor	22	13	13	20	19	63
About 3' flooding	27	18	25	23	22	73
About 4' flooding	29	20	27	28	27	78
About 5' flooding	30	22	28	33	32	80
About 6' flooding	40	24	33	38	35	81
About 7' flooding	43	26	34	44	36	82

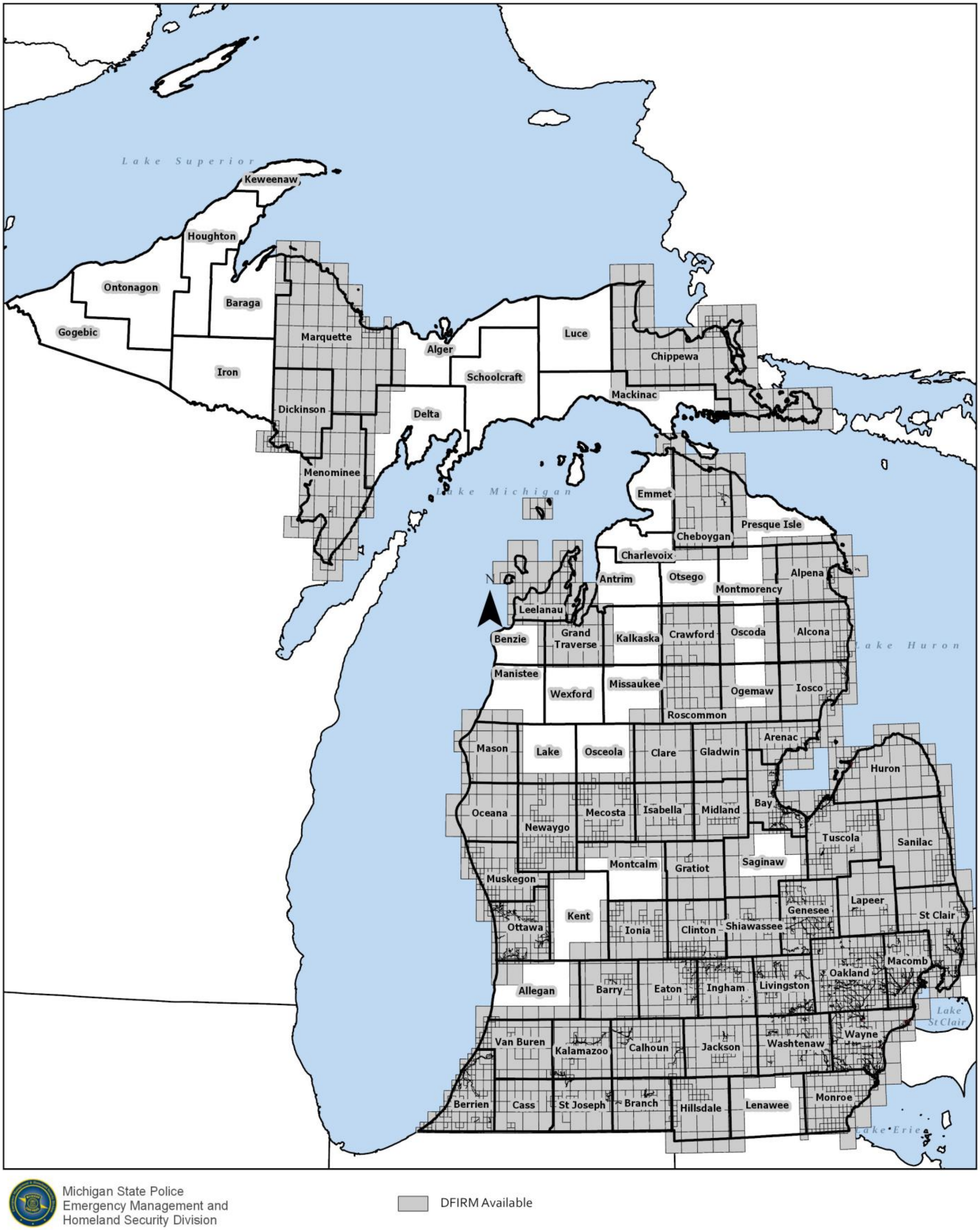
NOTE: Since replacement value may exceed the current market value of a structure, damages greater than 50% of replacement value can be considered a total loss of the structure, unless special historic or service functions require that additional expenses be undertaken to repair and preserve it.

In addition, damages to the contents of structures can be estimated, by assuming that their value is 30% of the replacement value of the home, and then assuming that damages to those contents will be 1.5 times the percentages listed in the table above. This formula should be adequate for estimating residential losses. (The structural and contents formulas combine as follows: Total damages = 1.45 times the percentage listed in the table times the replacement cost of the structure.) Loss of contents in commercial facilities can be assessed more accurately by business owners or organizations participating in the development of a local plan. Other damages and costs could be those involving public facilities and infrastructure, road closures, diverted traffic, loss of rental income, and so on.

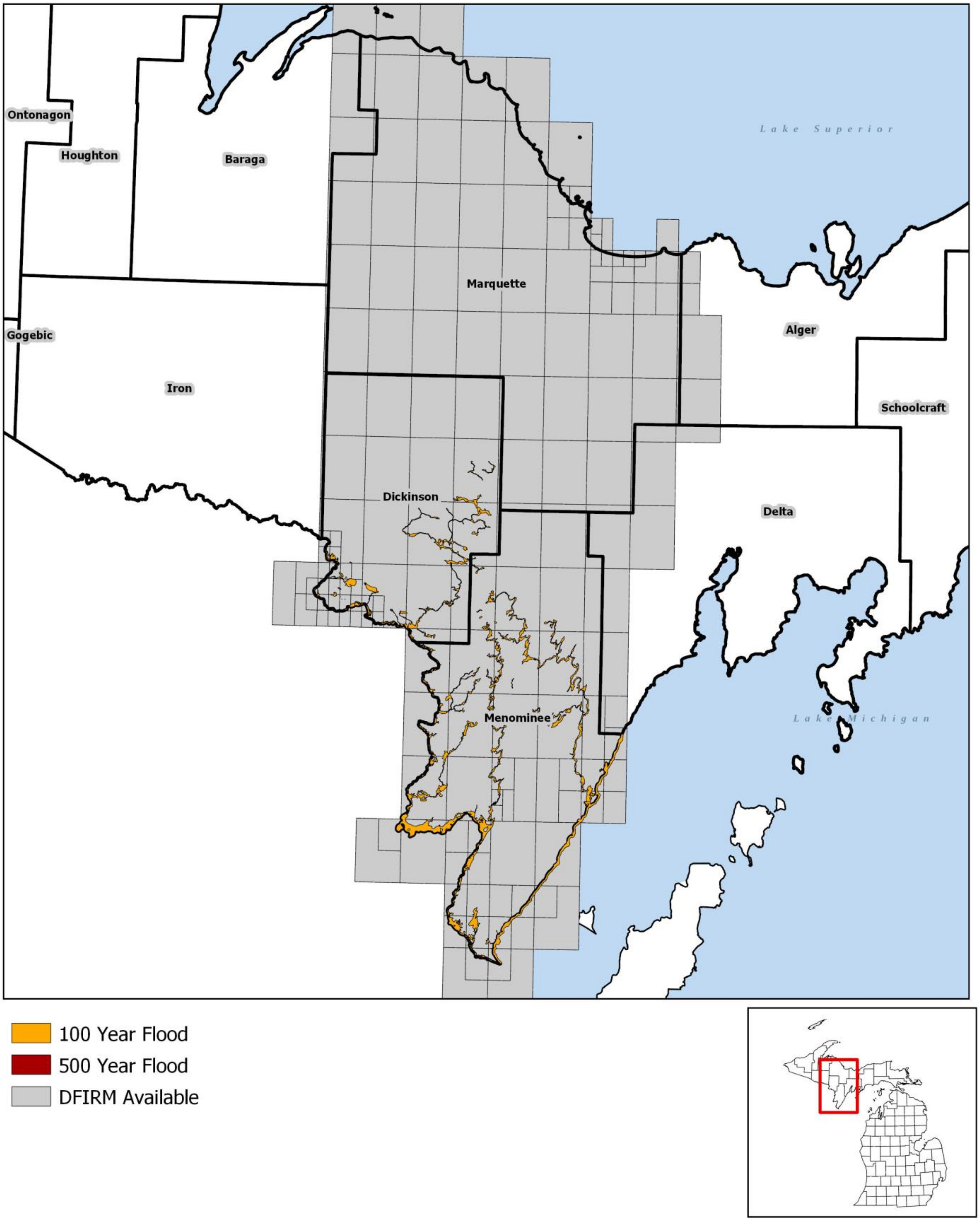
Hazard Mitigation Strategies for Fluvial (Riverine) Flooding

- Floodplain management—planning acceptable uses for areas prone to flooding (through comprehensive planning, code enforcement, zoning, open space requirements, subdivision regulations, land use and capital improvements planning) and involving drain commissioners, hydrologic studies, etc. in these analyses and decisions.
- Acceptable land use densities, coverage and planning for particular soil types and topography (decreasing amount of impermeable ground coverage in upland and drainage areas, zoning and open space requirements suited to the capacity of soils and drainage systems to absorb rainwater runoff, appropriate land use and capital improvements planning) and involving drain commissioners, hydrologic studies, etc. in these analyses and decisions.
- Dry floodproofing of structures within known flood areas (strengthening walls, sealing openings, use of waterproof compounds or plastic sheeting on walls).
- Wet floodproofing of structures (controlled flooding of structures to balance water forces and discourage structural collapse during floods).
- Elevation of flood-prone structures above the 100-year flood level.
- Purchase or transfer of development rights – to discourage development in floodplain areas.
- “Floating” architectural designs for structures in flood-prone areas.
- Construction of elevated or alternative roads that are unaffected by flooding, or making roads more flood-resistant through better drainage and/or stabilization/armoring of vulnerable shoulders and embankments.
- Government acquisition, relocation, or condemnation of structures within floodplain or floodway areas.
- Employing techniques of erosion control within the watershed area (proper bank stabilization, techniques such as planting of vegetation on slopes, creation of terraces on hillsides, use of riprap boulders and geotextile fabric, etc.).
- Protection (or restoration) of wetlands and natural water retention areas.
- Higher engineering standards for drain and sewer capacity, or the expansion of infrastructure to higher capacity.
- Joining the National Flood Insurance Program (NFIP).
- Obtaining flood insurance. (Requires community participation in the NFIP.)
- Participation in the Community Rating System (CRS).

Michigan Digital Flood Insurance Rate Map (DFIRM) Availability



Michigan Digital Flood Insurance Rate Map (DFIRM) Area 1



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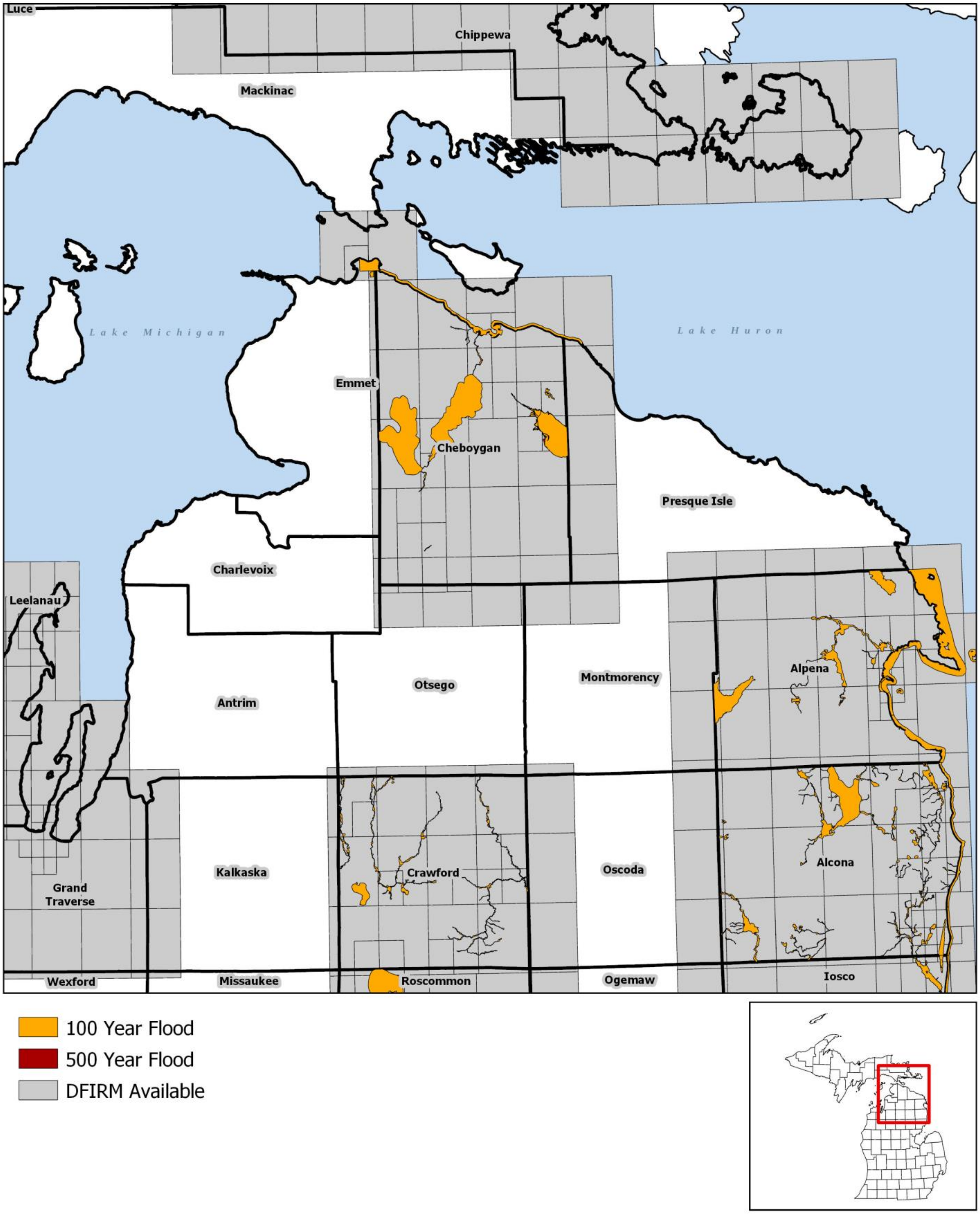

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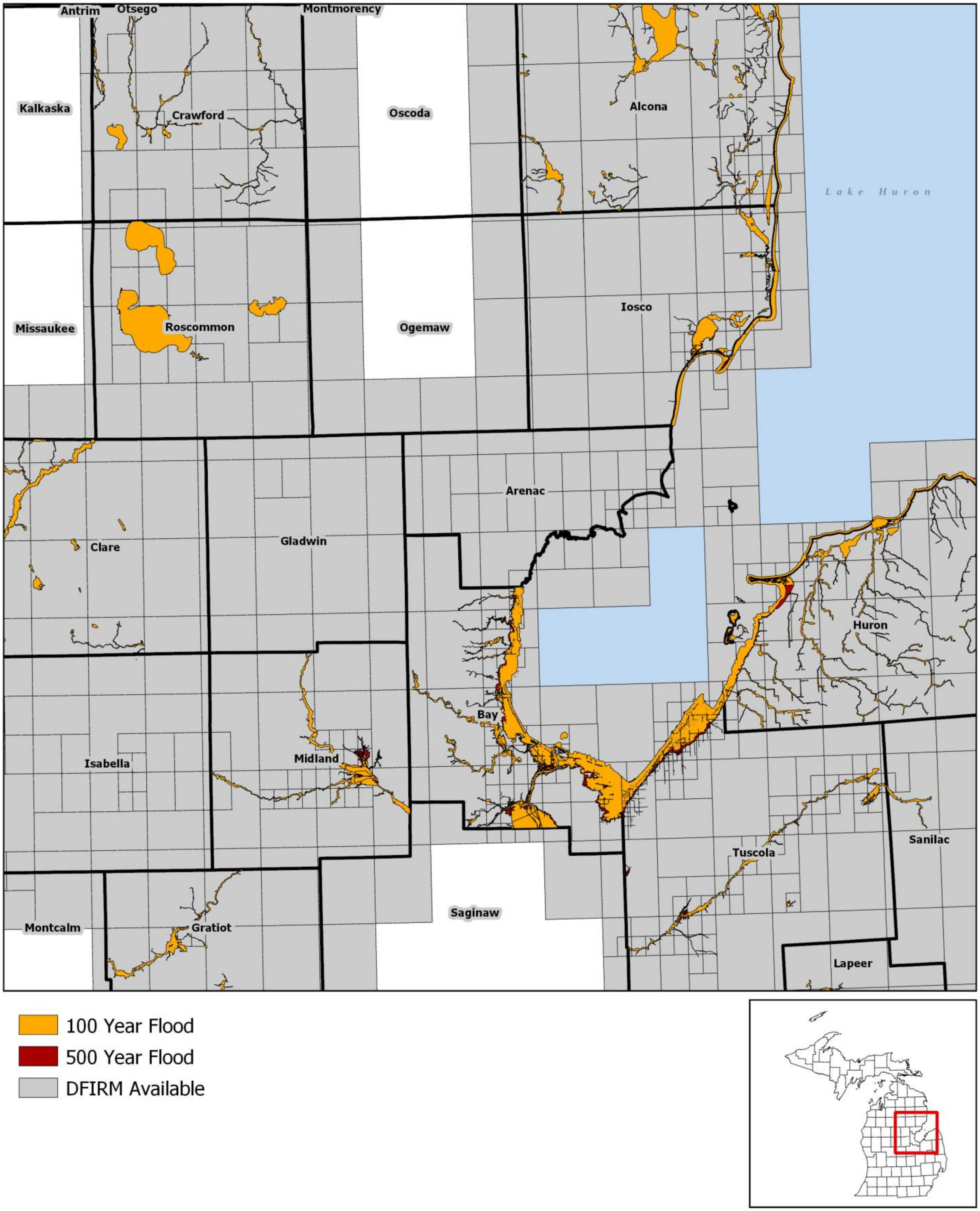

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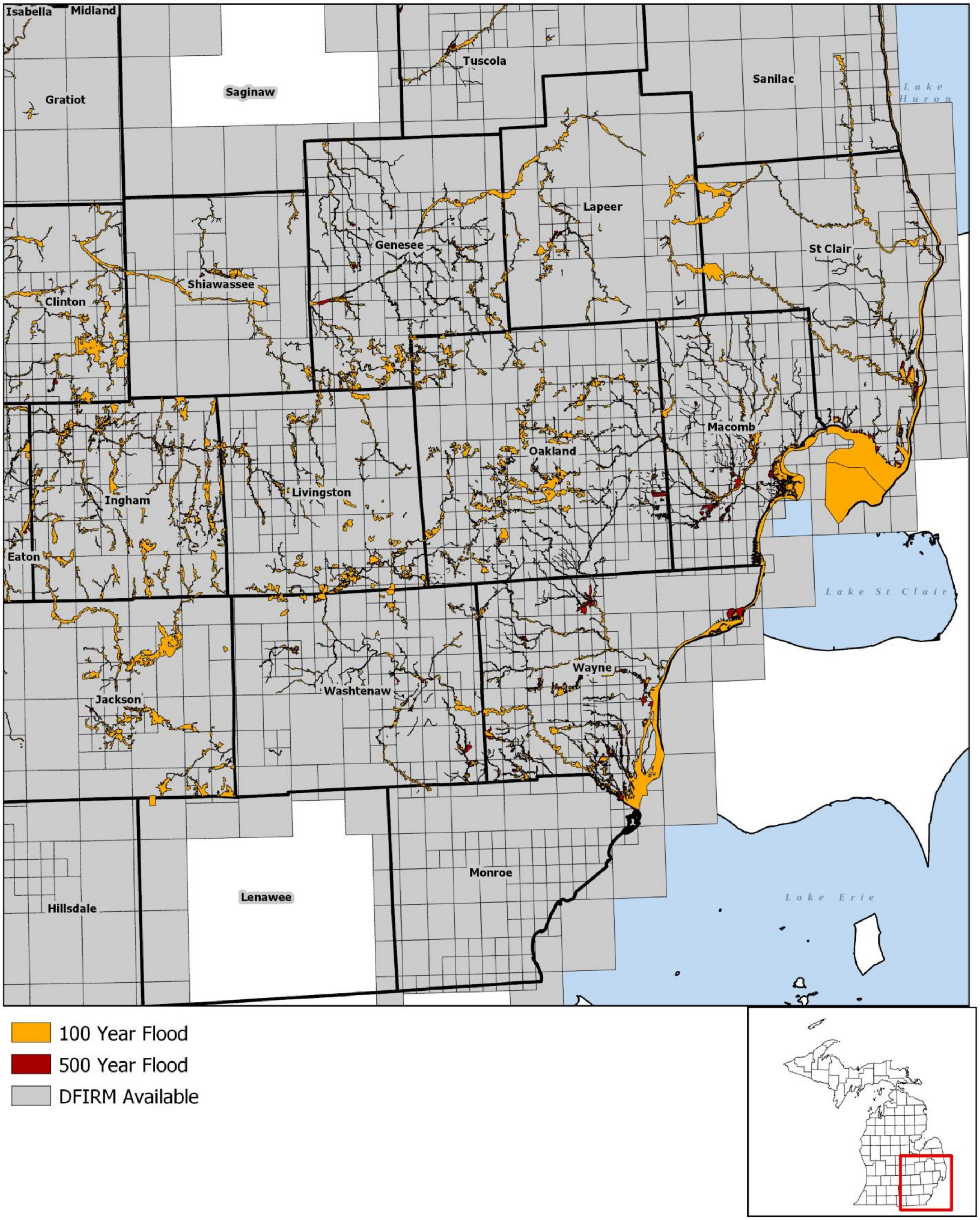
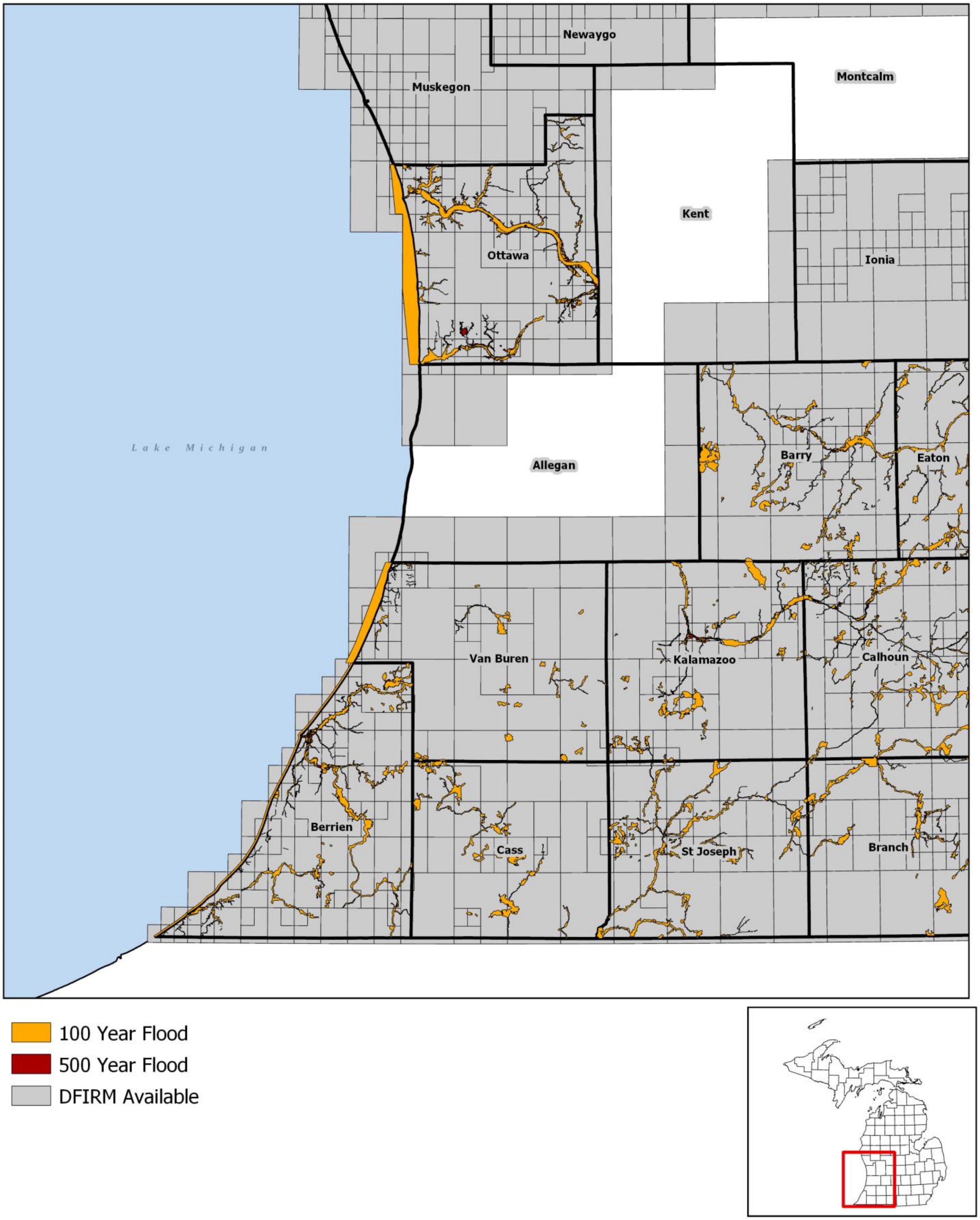
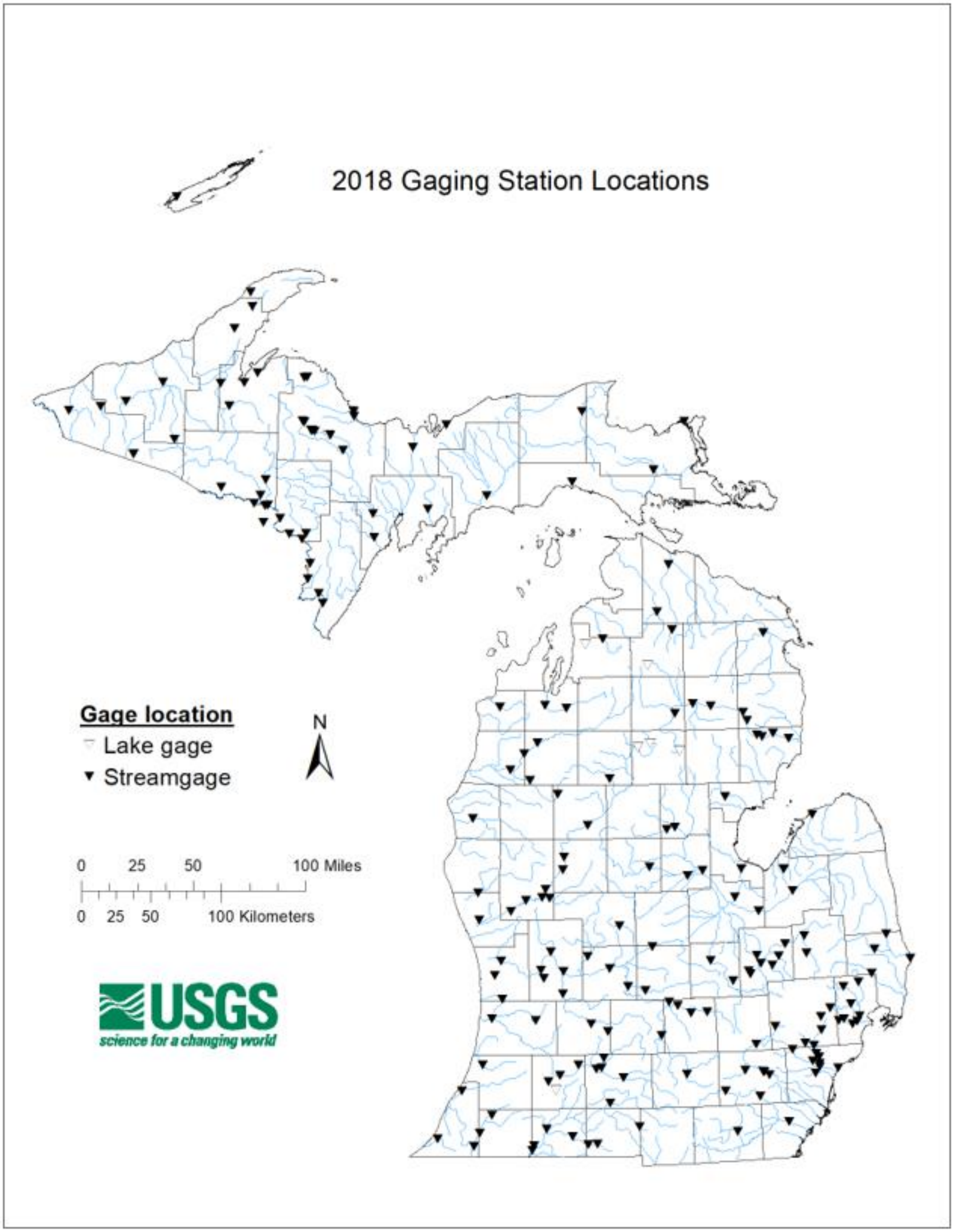


Michigan Digital Flood Insurance Rate Map (DFIRM) Area 5



USGS Stream Gauge Locations in Michigan



Pluvial and Urban Floods

The accumulation of water in low-lying and inadequately drained areas, following heavy precipitation events, including structural or power failures in municipal sewage systems, causing waters to flood or back-up into houses, other structures, and infrastructure.

Hazard Description

In addition to the flooding of land that is adjacent to streams and lakes, rainfall and snowmelt generates huge quantities of water that run downhill and collect within low-lying areas within cities and other areas. The drainage systems within every Michigan county, plus most of its municipalities, are limited in the amount of water that they can successfully handle within a particular time-frame. Although much water eventually soaks into the ground and is delayed by natural plant growth as it falls, the increasing amount of paved and built-up land surfaces in Michigan tends to instead cause waters to quickly drain downhill at a rate that can overwhelm the existing drain systems in many areas. Some areas never had much drainage, but as long as these low-lying areas do not contain structures or important infrastructure, they can flood or act as wetlands and thus provide a natural benefit to detain and cleanse natural water runoff. The real problem exists where waters collect across roads, in basements, and even throughout the downtown areas within cities. In some cases, this occurs at the same time as riverine and lake flooding, but there are many flood impacts that occur outside of recognized floodplain areas. Water that normally might take several days to reach a river or stream under natural drainage conditions now quickly runs off of streets, parking lots, and rooftops, and through man-made channels and pipes that in some cases are under-sized. Some developments have also encroached into flood-plain areas and have therefore impeded the water storage and carrying capacity in part of the natural drainage area. This hazard also includes inadequacies or failures in the constructed components of drainage systems, which can cause water or sewer back-ups into basements, or sewer overflows of untreated waters into the environment.

Hazard Analysis

Floods can damage or destroy public and private property, disable utilities, make roads and bridges impassable, disrupt emergency services, and result in fatalities. Related dangers include the growth of molds and mildew, associated health problems, the spread of contaminated flood waters, animal carcasses, damaged utility facilities, broken sewer lines that cause water supply pollution, areas with electrified water, debris and tripping hazards, open manholes, combined sewer overflows and the associated releases of untreated sewage from sanitary sewer systems.

A combination of excessive rainfall and/or snowmelt, saturated ground, and inadequate drainage can easily result in water with no safe place to go. The water will flow downhill to find the lowest elevations available—areas that are often not in an officially recognized floodplain but that flood regularly because of this runoff. This type of flooding is increasingly common in Michigan, as development outstrips the ability of the drainage infrastructure to properly carry and disperse the water flow. Flooding also occurs due to combined storm and sanitary sewers that cannot handle the tremendous flow of water that often accompanies storm events. Typically, the result is water backing into basements, which damages mechanical systems and can create serious public health and safety concerns. Other cases involve the ponding of waters across roads or in other low-lying areas. These additional types of flooding have now been given a separate chapter within this document.

"Urban flooding" may involve low-lying areas that collect runoff waters even though they are not adjacent to drains or bodies of water. This risk varies with the topography, soil types, runoff rates, drainage basin size, drainage channel sizes, and impervious ground surfaces in each area. Other kinds of urban flooding stem from flaws or shortcomings in existing sewer infrastructure. Some flood events may come from undersized or poorly designed sewer systems that cannot always process the amounts of precipitation and runoff that affects an area. Other events may have less to do with system design than with the collective effects of land use and development trends, illegal diversion of water, or actions that plug storm drains or otherwise interfere with system function. In some cases, flooding may result from power failures that temporarily shut down needed pumps and other facilities. (Backup power systems can be a vital flood mitigation strategy in such cases.) Many communities have been upgrading their drainage systems, separating combined sewer systems (in which storm and sanitary sewer systems share many of the same components), and enforcing local codes, but they vary in the amount of long-term benefits so far realized from these actions.

Some forms of flood damage even come from the decisions of individual homeowners and must be addressed on that level. Proper landscaping and downspout placement can prevent rainwaters from pooling around a structure and seeping into a basement. The use of sump pumps and sewer backflow preventers can prevent a great deal of the damages that are reported each year. Property developers and purchasers should be aware of the possibility of flooding in many areas, and should either locate their homes outside of risk areas, or engineer them to be unaffected by such events. This is an especially important concern in areas that are scenic and desirable because of their riparian locations. Some of these individual-level decisions and risks can be difficult to assess, but should be discussed in the flood analysis section of a plan, to increase public awareness and encourage individuals to be proactive and responsible.

Each component of constructed sewer systems may either help to prevent flooding, or be a source of risk where such components are undersized or subject to unexpected failure. One problem involves the historical use of **combined sewer systems** (CSS). In such a system, the same pipes that carry away stormwater are also tasked with carrying away water from a sanitary sewer system. A **stormwater sewer system** handles relatively clean rainwater after it accumulates on the ground, but a **sanitary sewer system** handles a whole array of unhealthy wastes that have been flushed down toilets (officially termed **black water**), or have come out of washing machines, washtubs, dirty bath water, dirty dish water, and anything else that has been rinsed down indoor sinks and drains (officially termed **gray water**). Ideally, all the wastewater that flows into a sanitary sewer system would undergo extensive processing to clean it, before being released back into the larger environment as part of an area's water cycle. At the same time, a separate stormwater system would handle rain, snowmelt, and surface water runoff that flows into many outdoor storm drains, thus preventing pluvial flooding in that area. However, a combined sewer system usually means that with any heavy rain, water from the storm and from the city's wastewater will quickly fills the available underground pipes with an amount of water that overwhelms the system.

To avoid the back-up of contaminated waters into people's basements, a combined sewer system usually allows **combined sewer overflow** (CSO) to occur, which means that the pressure of these waters pushes open **tide gates** (or pushes over the top of **weirs)** that then allow the excess water to flow out directly into nearby streams, rivers, and lakes, without first being treated at an area treatment plant. The release of raw sewage often results in **elevated bacteria levels** within those local water bodies, **oxygen depletion** within those nearby waters, and the sickening and death of fish and animals in that areas (or their unsuitability to be eaten by humans as a result of fishing, hunting, and trapping activities). Many drinking water systems try to make use of nearby water sources, and a heavy contamination level in those water sources makes it more difficult and expensive to ensure that the local supply of water maintains a high level of **water quality.** Even with combined sewer overflows, basement back-ups still do occur in sewer systems that are sufficiently overwhelmed. The result is that **basement flooding** can include not just dirty water (which has picked up chemicals and grime from roads during the runoff process), but water that is heavily contaminated with unhealthy bacteria, which is then able to proliferate in people's basements, cause horrible odors throughout their homes, and the respiratory and other health problems that result.

A detailed local assessment of urban flood hazards can, if resources allow, include an assessment of each source of risk and each element of the drainage and sewer infrastructure. Many older communities have found the expense of **sewer separation** projects to be worthwhile, since it can allow the capacity of both the **storm drainage** and the **wastewater treatment** systems to be markedly improved. Inadequacies in a sanitary sewer system have historically been associated with outbreaks of cholera and other forms of serious **public health emergencies**.

A sanitary sewer system tends to operate primarily through gravity, so that water flows gradually downward through increasingly large pipes to end up in a **wastewater treatment plant**. However, treatment plants are very expensive, and only large cities will have many of these plants. Therefore, in order to serve the entire urban area adequately, the gravity-based sewer pipe network is usually supplemented with various pumps that lift wastewaters from low-lying structures up to a level where they can then flow readily through the gravity-based pipes. This system works very well except when there are **mechanical breakdowns** or electrical **power failures** that prevent pumps and lift stations from doing their job. An important hazard mitigation strategy is to identify the system's locations and components where flooding, CSO, or basement back-ups would be caused by either a power failure or a mechanical breakdown.

An individual homeowner can reduce their basement flooding risks by having a **backflow preventer** installed. This device is designed to prevent waters from flowing "backward" from the sewer system into a structure, instead of from the structure into the sewers. There are some areas in which local regulations prohibit the installation of backflow preventers, out of concern for the additional pressures that would be imposed upon the sewer system if all of the opportunities for pressure and storage relief are blocked by these devices. Ideally, an area's infrastructure would ideally have the capacity to handle the waters that it needs to, but in cases where one person's backflow prevention appears to make the backflow problem slightly worse for all of their neighbors, or might collectively cause an even more serious breakdown in the area's infrastructure, such regulations may exist as an effort to keep system pressures manageable and more evenly distributed until the system can be effectively upgraded within that entire at-risk area.

The following list describes some important <u>sewer system components</u> that should be evaluated and considered for potential vulnerabilities and improvements:

1. Drain designs – Stormwater flows along streets that are designed to have a slight tilt (or crowned center). Water will naturally flow downhill to the lowest available point, and a system with a good design and level of maintenance has drains located at various low points so that runoff can flow efficiently off of these surfaces, dropping into the sewer pipes where it continues to drain away underground, until it is carried far away and therefore doesn't keep collecting in one place. Some drain openings are subject to becoming clogged with debris such as leaves, sticks, litter, and grass clippings. Area residents can sometimes prevent local floods by noticing when a local sewer opening has become clogged with such debris, and going out to clear it away themselves before the water ponds too high and creates a local flood problem. In many cases, an unclogged opening will quickly allow the waters to drain into the sewer system, harmlessly. Residents should also take care not to block the stormwater's sewer access carelessly, by not parking vehicles on top of these drain openings, by not covering the openings with boards, or anything else that would inhibit the speedy flow of rainwater through the opening. Lawn care activities should not result in the accumulation of yard waste (grass, leaves, weeds, etc.) along the sides of streets, especially in low-lying areas where storm drains openings are located. Similarly, these areas should be kept clear of litter such as newspapers, bottles, cups, packaging, and so on. The sewer system will only do its job when stormwaters have a chance to flow into that system.
2. Catch basin designs – Beneath a street drain is usually found a **catch basin**, which holds a certain amount of water and only drains into the sewer system after it fills up to a level where the top of the water reaches the level of a pipe opening in the side of the basin's wall. Clogged pipes (see #4, below) can result if littered cans or other items collect and plug up the sewer pipes, so catch basins can have a **hooding** (covering) installed over that side pipe to help prevent large items from entering it
3. Pipe and channel capacities – An area's drain system may be assessed at a scale that may involve an entire watershed (or set of watersheds). In Michigan, it is standard for each county to oversee its drainage capacity, to identify problems, and arrange for maintenance and improvements. The county **drain commissioner** is the top official that oversees these matters, locally. At a smaller level, municipal **public works** departments may oversee their own portions of an integrated county system, or these responsibilities may be distributed differently so that some clear agency has the capacity to oversee and maintain or improve the drainage system in their area of jurisdiction. For example, the responsibilities that smaller cities might collectively call "public works" will usually have their own separate, dedicated departments within larger cities (e.g. The Detroit Water and Sewerage Department). Alternatively, a **special district** may be defined that covers multiple local jurisdictions (e.g. a sewer authority centered around a single treatment plant whose service area crosses over various local political boundaries). Channels and pipes located high-up (e.g. at the tops of hills) usually do not need to handle as much water capacity as those located at the lowest elevations, so drainage systems usually have many small channels or pipes that feed into gradually larger ones, as the waters flow from every stretch of a large watershed area toward some low-lying destination such as a large lake. Each channel (which can be above ground) or pipe (usually located below ground) should have sufficient capacity to handle the amount of water that needs to be drained off to prevent flooding.
4. Drainage system maintenance – Various kinds of maintenance are needed within any drainage system. Flowing water naturally tends to cause multiple geological effects simultaneously: the **weathering** (or wearing down) of materials that the waters flow against, the **erosion** (or carrying away) of materials away from a location, and the **deposition** (or accumulation) of those carried materials somewhere else, downstream. Natural streams change their shape gradually (or **meander**) as a result of these activities. One form of deposition is called **sedimentation**, as the amount of space that used to be available to carry water downstream

gets gradually filled in by the accumulation of sand, small rocks, detritus, etc. <u>NOTE: This description is just as applicable to traditional floodplain risks as it is to urban drainage systems.</u> Normal maintenance activities for any drainage system will include (1) the reinforcement of materials that might otherwise crumble as a result of weathering, (2) the protection of material against erosion (i.e. against its unproductive transport to another locations), and (3) the clearance (or **dredging**) of unwanted materials that naturally accumulate and block space that is needed for the efficient passage of flowing waters. That last category includes the accumulation of weeds, trees, litter, and other material that is taking space away from a drainage channel and therefore interfering with its function. Finally, (4) the expansion of a channel's **capacity** to handle water, in some cases by replacing slower (high-friction) natural drains with faster (low-friction) pipes, in other cases by upgrading pipes to a larger size, and in still other cases by replacing covered pipes (crossing beneath roads) with actual bridge structures that provide far more open space for waters to flow smoothly underneath. Pipes can also get clogged up with various materials underground (which range from wet papers to animal carcasses to so-called "fatbergs.") Catch basins may also need periodic cleaning to restore their holding capacity and prevent solid objects from plugging up sewer system pipes.

5. Managing illicit (or unanticipated) input – Some additional sources of water can add up to levels that exceed a system's capacity, and become a matter for **regulation and enforcement**. Sometimes, the dumping of fluids into the drainage system is deliberate (and is usually only a problem in urban areas that have limited system capacity), but in other cases, additional waters can come from structural breakdowns that allow additional waters to leak into a system, beyond its intended design capacity. (A related problem involves leaks that cause waters to flow out of a system in places they were not intended to, often leading to sinkholes or other ground **subsidence** problems.)
6. Pumping/lift stations and treatment plant capacities – Even if waters are flowing efficiently through all the channels and pipes, as intended, there may be chokepoints created by power failures or mechanical breakdowns at these facilities. **Back-up power** should be prepared and used wherever such facilities' operations are considered critical to the community's safety.
7. Areas of potential backflow – Tide gates can help to prevent lake currents and tidal pressures from forcing waters uphill into a municipal system (and then into residential basements). At the level of individual structures, backflow preventers (where permitted) can be installed into basements to reduce that type of flood risk. Homeowners can often obtain additional coverage on their **insurance** policies, to reimburse them from losses due to sewer back-ups, even if they do not have full flood insurance coverage.
8. Retention and detention areas – When thinking of drainage infrastructure as a system, in which some components can help or hinder the function of other components, it can become clear that capacity is defined not just in terms of the quantity of water that can be handled, but also in terms of the rates at which it can be processed effectively. The overall quantity of water that enters the sewer system can be reduced if it is **retained** in natural or artificial ponds, deliberately designed for that purpose. Some volume of space gets dedicated for the purpose of collecting and holding rainwater, where it can then naturally evaporate while seeping gradually into the soils, where it eventually becomes part of the area's groundwater. In other cases, the main effect is not to permanently retain or divert water from the drain and sewer system, but merely to **detain** it so that the rate at which water enters the system is less likely to exceed the system's capacity. The term retention and detention might sound similar, but a detention area is designed to drain off so that it is normally dry (between storms), while a retention area often just appears to be a pond that has been built into the design of a particular area. These are especially important in (or downstream from) rapidly developing areas, whose **impermeable surfaces** (concrete parking lots, tar roofs, blacktopped roads, etc.) would otherwise cause much more rapid water flows downhill, or to downstream communities, than is normally the case with wooded or grass-covered natural lands. A natural spot to store water would be in existing floodplain and wetland areas, where possible by clearing away structures that are already being repeatedly flood-damaged.
9. Permeable pavement, pervious surfaces, rain gardens, bio-swales, green roofs, rain barrels – These can have benefits similar to that of retention and detention areas, but can even collectively prevent large quantities of water from needing to go into the constructed storm sewer at all, instead encouraging rain water to seep into the ground, to be taken up by plants, to stand in designated pooling areas until it evaporates, or to be collected for convenient and free re-use for such purposes as watering lawns or hosing off pavement. These options are rapidly growing in popularity because they are often have very pleasant, landscaped designs, they serve as environmentally friendly "green infrastructure," they help to improve local air quality, they help to reduce the owner's water utility bills, and they help to reduce the impacts of urban heat islands.

10. Structural flood risk reduction measures – In some cases, especially when space is limited and dense or unique urban developments need to be preserved, the most useful flood mitigation strategy may be to construct floodwalls or levees or new artificial drainage channels that block floodwaters from directly going past the obstruction. This is also common along the shores of the Great Lakes, where floods may be accompanied by forceful wave pressures, if they are not blocked by seawalls, dikes, or berms. Unfortunately, it is apparent that there are widespread gaps in public understanding of the need for this protection, and many such structures have been damaged or destroyed by persons who are more concerned with an unobstructed view of lake waters than for the safety and protection of their homes and those of their neighbors.

The old saying that "a chain is only as strong as its weakest link" seems relevant here. A drainage and sewer system can be nearly perfect, except for one chokepoint or vulnerability, and that can be all it takes to result in serious risks, damages, and loss of life.

Within past editions of this document, **landslides** and **mudslides** had not been identified as a significant hazard within Michigan. Although it was well-known that hilly areas existed within the state, such topics were primarily associated with Great Lakes shoreline areas, and their known risks of erosion. However, the Houghton flood disaster has now made it clear that record-setting rainfall events in particular locations can include damaging landslide and mudslide effects. Research will proceed to further assess this hazard and to include the results of that analysis within the next update of this document. At this time, the Houghton example should be seriously considered by any community with similar topography, to assess (e.g. within its local hazard mitigation plan) whether that area is also at risk from landslide or mudslide effects. (Each contour line in the map below represents a height difference of about 33 feet.)

The Houghton County aspects of the 2018 Western Upper Peninsula flood disaster perfectly illustrate the dangers of pluvial flooding that causes flash floods and mudslides. In that event, runoff waters had accelerated through an elevation difference of some 500-feet from the surrounding hilly lands. Following an extreme level of precipitation, the flow of waters, and the materials they swept downhill with them, had become devastatingly dangerous, destroying streets and homes and fatally injuring a child caught in a collapsing basement. The key damages in and around Houghton did not occur from the nearby river overflowing its banks, nor from back-ups or failures within the city's own sewer system. The problem was fundamentally a pluvial one—excessive rainfall flowing rapidly downhill into low-lying areas, with eroded materials then scouring away downstream surfaces such as roads and culverts.

Impact on the Public, Property, Facilities, and Infrastructure

Two of Michigan's largest declared disasters have now involved this type of flooding—the Metropolitan Detroit flood events of 2000 and 2014. Similar problems occur in many other urban areas, as well as less severe impacts within rural areas of the state. These events have caused billions of dollars of damage within recent decades, sometimes in conjunction with riverine and lake floods. Rather than traditional overland flood impacts, urban flooding usually involves basement flooding, sewer back-ups, and inundated roads, including multiple interstate highways simultaneously made impassable throughout Michigan's largest urban area.

Impact on the Economic Condition of the State

Although the most severe urban floods do not happen every year in the same locations, some of the worst events are focused upon the most central infrastructure within Michigan's largest urban areas being overwhelmed. Michigan's cities act as vital hubs in transportation, trade, communication, and other key economic functions, but large cities have historically been built adjacent to rivers and coasts, in relatively low-lying locations toward which water tends to flow during its downhill journey toward the Great Lakes. Therefore, urban floods are often inundating the very areas that serve as our most important economic hubs. Fortunately, the value of specific locations is less critical during today's "information economy" compared to a century ago, but the shipment of agricultural and manufactured products is still a very large and fundamental part of Michigan's economy, and is vulnerable to disruption when flood problems shut down key roadways and downtown areas in our cities. Even a small city can cause large-scale shutdowns in huge industries such as the automotive sector, because many manufacturing processes rely upon the timely supply of key industrial parts from plants located in small cities. (An example of this can be found in the chapter on structural fires, involving an Eaton Rapids plant where a fire caused automobile production to stall. Similar vulnerabilities probably exist with respect to floods.)

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

Where floods have caused roadways, bridges, or facilities to become impassable or inoperable, even just temporarily, serious obstacles can result that affect life safety. Floods have been known to affect hospitals, infrastructure facilities, and even local emergency operations centers (although this is uncommon). Improvements have been occurring to relocate such at-risk emergency facilities into less vulnerable areas, but some structures such as hospitals are too massive to affordably be relocated in the near future, and other forms of flood mitigation must be attempted in order to preserve the vital functions provided by these facilities. In some cases, pumping and electric power facilities are located near rivers, and their failure from riverine flooding can cause infrastructure breakdowns that result in more widespread urban/pluvial flooding as well. Among other impacts, floods can disrupt the supply of electricity and therefore disrupt the operations and service delivery in important agencies. For example, the recent flood disaster in Houghton included basement-level flooding that affected the power supply at Michigan Technological University and caused the entire campus to be temporarily shut down.

Impact on the Environment

Urban flooding is more likely to inundate paved surfaces and industrial sites that include hazardous materials or pollutants, and thus exacerbate environmental challenges within the area. Although specific sites may already be well-known and designated for clean-up (e.g. superfund sites), these locations are not necessarily fully separable from their surrounding lands during times of flooding. One of the best-known impacts of urban flooding is upon local water quality, as areas that are still covered by old "combined" sanitary and stormwater sewer systems will have "combined sewer overflow" events in which large quantities of untreated water and sanitary sewage gets dumped along with the outflow of the area's stormwater system. This has resulted in high bacterial counts within the receiving and downstream waters. Lake quality can also be degraded, through the formation of harmful algal blooms and the expansion of areas in which fish cannot survive.

Impact on Public Confidence in State Governance

Although floodplain and shoreline floods tend to be accepted as natural events that relate more to private decisions about property purchase and building construction locations, urban flooding is more clearly connected with the capacity of infrastructure, and its break-downs, and is therefore more closely associated with government management and funding processes. The public expects publicly funded infrastructure to be correctly sized and well-maintained enough to prevent disasters, but may not always be aware of the complex connections between gradual development decisions by private property owners and the collective public interest (and expense) involved in regulating development to prevent drainage systems from becoming overwhelmed over time. Although some locations and systems are well-financed at a local level and are able to handle current needs, there are other locations whose local budgets have become increasingly strained over time, as various industries have declined and population shifts have occurred. One of the problematic patterns that has not yet been fully resolved is the large trend involving "greenfield" suburban developments that cause more water to flow toward historic central city systems. However, as noted before (several paragraphs ago), not all flood events should be blamed upon inadequacies of local infrastructure. Conditions do change over time, and realistically it takes time for everyone to recognize these changes and to implement changes that expand the capacity of our infrastructure to handle these changes. For example, much drainage infrastructure has been calculated to handle historical patterns of rainfall, but only within recent decades has the evidence shown that precipitation within Michigan has been increasing (as explained within this document's new chapter called "Climate Trends"). As the evidence of risks become well-known among all stakeholders, citizens become willing to fund the improvements in infrastructure that are necessary to better handle these risks. For example, the 2014 flood disaster in Metropolitan Detroit resulted in an interjurisdictional agreement toward collectively funding the central sewer infrastructure, offsetting some of the jurisdictional, land use, and budgetary mismatches problems that had developed during the preceding half-century.

Significant Pluvial/Urban Floods in Michigan

<u>NOTE</u>: Many of these events could also have been listed in the chapter on Riverine Flooding, and many of the events in that chapter could also have been listed here. Please refer to both chapters for a more complete sense of Michigan's flood history.

December 1972 – Lower Peninsula (Federal Disaster #363 – 9 counties)

A series of severe storms produced a great deal of precipitation during the Spring thaw season. The resulting floods resulted in a federal disaster declaration for a set of counties in the southeastern two-thirds of the Lower Peninsula, stretching from Iosco County, at the northeastern extreme, down to Berrien County at the southwestern state boundary, with Arenac and Bay Counties in between. Another affected area was the "thumb" and metropolitan area of Wayne, Monroe, and Macomb Counties, on the south, and Tuscola and St. Clair Counties, farther north. Every one of these nine counties would soon face another flood disaster merely four months later, as the Spring season arrived with its snow thaws (see below).

April 1973 – Lower Peninsula (Federal Disaster #371 – 14 counties)

A series of severe storms produced a great deal of precipitation during the Spring thaw season. The resulting floods resulted in a major disaster declaration for 14 counties across much of the Lower Peninsula—from Iosco to Berrien, and from Huron County down to Wayne County. Arenac, Bay, Macomb, Monroe, Saginaw, St. Clair, Tuscola, Sanilac, and St. Clair Counties were part of the disaster area. The Detroit Metropolitan region was heavily affected, as was the Upper Peninsula county of Menominee and the southeastern county of Van Buren. Many of these same southeastern and Saginaw Bay area counties had been affected by the December 1972 event just a few months before.

April 1975 – Southern Lower Michigan (Federal Disaster #465 – 21 counties)

A series of intense thunderstorms struck southern Lower Michigan in the last two weeks of April 1975, spawning several tornadoes and causing widespread flooding over a 21-county area. Total public and private damage was nearly $58 million. A Presidential Major Disaster Declaration was granted for the 21 affected counties: Allegan, Barry, Berrien, Calhoun, Clinton, Crawford, Eaton, Genesee, Ingham, Ionia, Kalamazoo, Kent, Lapeer, Livingston, Macomb, Oakland, Ottawa, Saginaw, St. Clair, Shiawassee, and Van Buren.

September 1975 – West Central / Central Lower Michigan (Federal Disaster #486 – 16 counties)

During the last week of August and first week of September 1975, intense thunderstorms and severe winds pounded a 16-county area in west-central and central Lower Michigan. Intense rainfall accompanying these storms caused widespread flooding, resulting in nearly $3 million in public and private damage. A Presidential Major Disaster Declaration was granted for the 16 affected counties: Allegan, Clare, Genesee, Gratiot, Ingham, Isabella, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, and Shiawassee.

October 1, 1981 – Southern Lower Peninsula

News articles reported a large event that did not show up in official disaster-declaration records. Heavy rains on October 1 reportedly caused floods that resulted in more than $250 million in damages across 28 counties in southern Michigan. Floods were noted at 22 forecast points. During that morning, all freeways in the Detroit Metropolitan area were closed for several hours. Approximately 300 washed-out sections of rural roads and 30 damaged bridges were noted. One fatality was also reported during this event. 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)

In March 1982, a combination of heavy rainfall and melting snow resulted in a flood disaster in Berrien and Monroe counties. Damage from that event was estimated at $12 million. One death was directly attributed to the flood conditions. A Presidential Major Disaster Declaration was granted for the two affected counties.

September 1985 – East Central Michigan (Federal Disaster #744 – 6 counties)

A year earlier, on September 5, 1985 severe thunderstorms struck east central Michigan, resulting in flooding in a six-county area. As much as 7.45 inches of rain fell in Genesee County, which was hardest hit. The heavy rainfall caused flash flooding in many areas. Damage occurred primarily from overbank flooding on major rivers and streams. In addition, widespread flooding occurred in residential areas due to overburdened stormwater drainage systems. Over 2,500 homes were damaged, many roads were washed out and bridges damaged, and extensive agricultural damage occurred. Total public and private damage was estimated at $63 million. A Presidential Major Disaster Declaration was granted for the six counties of Alcona, Genesee, Iosco, Lapeer, Saginaw, and Shiawassee.

September 1986 – Central Lower Michigan (Federal Disaster #774 – 30 counties)

Beginning on September 10, 1986 a slow moving low-pressure system moved across the middle of the Lower Peninsula. In a 24-hour period, the intense rainstorm produced rainfall ranging from 8 to 17 inches over an area 60 miles wide and 180 miles long. In Big Rapids, 19" of rain fell from September 9 to 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.) About 30,000 homes suffered basement and structural damage and 3,600 miles of roadways were impassable as a result of the failure of four primary bridges and hundreds of secondary road bridges and culverts. The heavy rainfall resulted in 11 dam failures, and 19 others threatened with failure. Over $300 million in damage resulted from the flood. This was the worst flood in Michigan in 50 years. Thirty (30) counties were included in the Presidential Major Disaster Declaration granted for this flood.

June 1989 – Branch, St. Joseph, and Kalamazoo Counties

Heavy rainfall from May 31 to June 4, 1989 caused widespread flooding in Branch, St. Joseph and Kalamazoo counties. Over 400 homes incurred flood damage and many local roads washed out. (The storms also caused significant wind damage in some areas, particularly in the village of Manchester in Washtenaw County.) A Governor's Disaster Declaration was granted to provide assistance to the counties. In addition, SBA low-interest disaster loans were made available to home and business owners in the affected counties to help repair flood and wind-related damages.

April 1993 – Shiawassee County

Flash flooding caused by heavy rains occurred in Rush and Hazelton Townships in Shiawassee County on April 21, 1993. The flooding caused widespread and severe washouts and structural damage to roads and bridges, greatly hampering the ability of emergency vehicles to provide timely emergency response to many parts of the county. As a result, the Governor granted a Disaster Declaration to the county to provide supplemental state assistance in repairing the damage and opening up the roads.

July 1994 – Lapeer, Sanilac, and Tuscola Counties

Heavy rains caused flash flooding in the counties of Lapeer, Sanilac and Tuscola on July 7-8, 1994. The flooding was widespread and caused severe damage to roads, drainage systems, and several homes. Saginaw County also suffered some storm-related damage, but to a lesser extent than the other three counties. Total public damage in Lapeer, Sanilac and Tuscola counties exceeded $1 million. Ninety-three homes incurred some level of damage. A Governor's Disaster Declaration was granted on July 8, 1994 to provide supplemental state assistance in the recovery.

May 1996 – Berrien County

On May 10, 1996, heavy rain in southern Berrien County caused widespread flash flooding that damaged nearly 100 miles of roadway (20 miles incurred severe damage) and numerous culverts, caused bridge washouts, collapsed basements, and undermined a railroad track. In addition, a dam in danger of overflowing had to be systematically drained by the Michigan Department of Environmental Quality and the U.S. Army Corps of Engineers. Public damage was estimated at $250,000. A Governor's Disaster Declaration was granted on May 22, 1996 to provide supplemental state assistance with the road, bridge, culvert and dam repairs. In addition, SBA low-interest disaster loans were made available to home and business owners that suffered uninsured damage from the flooding.

June 1996 – Thumb Area (Federal Disaster #1128 – 7 counties)

From June 21-23, 1996, intense thunderstorms producing heavy rainfall caused widespread and severe flooding in east central Michigan (the Thumb area). Some areas received over five inches of rain in a four to five-hour period, which quickly outstripped the ability of the public drainage and sewer systems to handle the massive amounts of water runoff. The result was widespread flash flooding that caused numerous road and bridge washouts, culvert failures, damage to drainage channels, and damage to over 2,700 homes and 40 businesses. These storms also spawned a tornado that struck the city of Frankenmuth in Saginaw County, destroying six homes and one business, and damaging another 108 homes and nine businesses. The total public and private damage exceeded $25 million, most of which was flood-related. A Presidential Major Disaster Declaration was granted for the seven counties most heavily impacted by the storms and flooding.

February 1998 – Southeast Michigan

Heavy rain, averaging almost 3 inches across many locations, caused flooding to occur in Wayne and Monroe Counties. (Three inches of rain is more than Detroit's average for the entire month of February.) The hardest-hit locations were in eastern Monroe County, where lakeshore flooding exacerbated the area's water runoff problems. East winds gusted to as high as 45mph, causing the Lake Erie water level to rise 3.5 feet above normal at Luna Pier and flooding many roads along the lakeshore. This event was topped by six-foot waves during the night of February 17th. The high water and pounding surf destroyed two private docks and prevented effective runoff further inland. Reports of basement and road flooding came in from all over Monroe County. Urban flooding was also significant in parts of Wayne County—hundreds of basements and many streets were flooded in cities around Detroit (especially Taylor, Dearborn Heights, Westland, and Grosse Ile), and a state of emergency was declared for much of the county. High water briefly closed the Southfield Freeway just north of Interstate 94 (in Dearborn). In Macomb County, the communities of Warren, St. Clair Shores, and Clinton Township also experienced urban and lowland flooding. Total damage exceeded $1 million.

September 2000 – Wayne and Oakland Counties (Federal Disaster #1346)

A Presidential Major Disaster Declaration was granted to Wayne and Oakland Counties for urban flooding and sewer backups caused by intense rainfall on September 10 and 11, 2000. Although much damage took the form of basement flooding, which is not the type of flooding that is normally easy to see and broadcast through the mass media, this was one of the largest Michigan disasters ever to occur, in terms of the sheer amounts of documented damages to homes in Detroit and its surrounding cities. The event was denoted as federal disaster number 1346, and hazard mitigation funds made available to Michigan as a result of this disaster were instrumental in allowing local hazard mitigation plans to be developed in most areas of the state.

September 22-23, 2000 – Southeast Michigan

When heavy rainfall caused the flooding of Thread Creek and inundated the city of Grand Blanc's storm and sanitary sewer systems as well as Genesee County's secondary sewer system, the resulting floods damaged nearly 50 homes and businesses. The Governor requested, and received, an SBA Disaster Declaration for this event, making low-interest disaster loans available to affected residents in Genesee County and the contiguous counties of Lapeer, Livingston, Oakland, Saginaw, Shiawassee, and Tuscola.

February 2001 – Genesee County

Heavy rainfall and melting snow in parts of Southern Lower Michigan on February 9-10, 2001 caused flooding in many areas, but particularly in Genesee County. The worst flooding occurred in the southern half of Genesee County, where damage to roads, drains and other public facilities was extensive. Two major pumping stations were damaged by the flooding, resulting in estimated repair costs in excess of $7 million. Repair and flood-fighting costs for the County Drain Commission totaled nearly $600,000, and the County Road Commission incurred an additional $1.8 million in flood-related damages and costs. The flooding also caused damage to dozens of homes and forced the evacuation of a 200-resident mobile home park. A Governor's Disaster Declaration was granted to provide supplemental state assistance to the county for public facility damages and costs. In addition, a Small Business Administration (SBA) Declaration was also granted that provided low-interest disaster loans to the home owners impacted by the flooding. (In addition to the damage in Genesee County, this flood event also caused damage to several hundred homes in Lansing and threatened to overtop the Shiawassee town Dam in Shiawassee County and the Peninsular Paper Dam in Ypsilanti. Fortunately, local and state officials were able to take steps to stabilize both dams and mitigate the threat of collapse.)

February 10-13, 2001 – Monroe County

Although Monroe County flood damage estimates were fairly low (mostly from flooded basements) during this event involving the cresting of the River Raisin, the incident is noteworthy because it was fatal to three young persons who drowned when their pickup truck attempted to cross a flooded road (near the Saline River) and ended up in a ditch filled with 10 feet of water. A fourth person in the truck was the only one able to escape, by squeezing out of a rear passenger window and swimming to safety.

August 2-3, 2006 – Sanilac and Lapeer Counties

Thunderstorms dumped rain at a rate of nearly 2 inches per hour, soon totaling about 5 inches in Sanilac County and as much as 10 inches in and around the Brown City area. Flash flooding began at 11pm on August 2, heavily damaging many homes throughout Brown City. 220 damage claims were filed, and total damages were estimated at $1.55 million. A few homes each reported nearly $100,000 in damage. Flood water levels reached 3 feet deep in a mobile home park within the city. After about 3 hours, flood waters stopped rising, and began to recede by noon on August 12. An additional $1 million in crop damages was also reported in Lapeer County's North Branch area, where nearly a dozen roads were washed out and closed. Several homes were heavily damaged on the east side of Burnside Township, adding up to a total of about $300,000 in Lapeer County property damage.

June 2008 – Lower Peninsula (Federal Disaster #1777 – 12 counties)

Beginning on June 6, severe weather impacted twelve counties and two major population centers in the southwest and central Lower Peninsula. The National Weather Service reported two flash floods that exceeded the "100-year" threshold, confirmed three EF1 tornadoes, and also noted severe thunderstorms with winds exceeding 100 mph. Rainfall totals were estimated between 7 and 12 inches, exceeding the "100-year" rainfall values of 3.5 inches in less than 6 hours. Flash flooding washed out roads, flooded crops, and caused moderate flooding of rivers and streams. A large severe thunderstorm squall line affected Southwest Michigan on June 8, with four counties experiencing winds of 75 to 100 mph. Disaster declarations were requested and received in July, for 11 full counties. Some of the worst damages were noted in Allegan County ($2 million in property damage and $2 million in crop damage), Mason County ($3 million in property damage, $0.5 million in crop damage), Lake County ($2 million in property damage, $0.5 million in crop damage), Ottawa County ($1 million in property damage, $1.5 million in crop damage), Osceola County ($1 million in property damage, $0.25 million in crop damage), Manistee County (nearly $1 million in property damage), and Wexford County (about $¾ million in property damage). Three persons died in this event—two at Castle Park (Allegan County) when a car plunged down a 50-foot ravine along a washed-out road, and one in Holland (Ottawa County) as a farmer tried to remove boards from the Worley Drain Dan during the event.

September 2008 – Southern Lower Peninsula

Excessive rainfall which started on September 13th resulted in extensive flooding over many days following. Many roads in the city of Kalamazoo were closed for several days, and damage to public infrastructure (mostly roads and bridges) was estimated at $11 million. At Augusta, the total rainfall was reported as 10.5 inches. A state of emergency was declared in Kalamazoo County—466 homes in the City of Kalamazoo were flooded, along with ten businesses. Surrounding counties were less extensively damaged, with Berrien County suffering about $750,000 in damage, and $½ million estimated for each of the counties of St. Joseph, Cass, and Oakland, and lesser amounts for the counties of St. Clair, Lapeer, Saginaw, Washtenaw, Wayne, Livingston, and Macomb.

June 2009 – Southwest Michigan (Ottawa and Allegan Counties)

After thunderstorms with heavy rainfall moved in from Lake Michigan, already saturated ground resulted in flooding that damaged numerous homes and streets, estimated at more than 2,000 homes damaged in some way, and 57 damaged or washed-out roads. A local state of emergency was declared in Ottawa County, where total damages were estimated at $34 million. In neighboring Allegan County, about $4 million in damage was estimated.

August 11-13, 2010 – Isabella County

Downtown Mt. Pleasant suffered from flash flood impacts as at least four inches of rain fell during a time period of no more than three hours. $4 million in property damage was calculated, $3 million of which involved 39 buildings on the campus of Central Michigan University. The damages required repairs to ceilings, floors, walls, insulation, equipment, mechanical systems, and storm sewers on the campus. Street flooding occurred in downtown Mt. Pleasant, and the intersection of Isabella and Baseline Roads was washed out. Some roads had over a foot of water across them, including High and Bellows Streets. The flood affected portions of the Central Michigan Community Hospital.

July 27-29, 2011 – Central Lower Peninsula (especially Ingham County)

Several heavy rainstorms moved across the southwest Lower Peninsula during these three days, flooding roadways, intersections, and residential areas within Lansing (Ingham County). Road closures and damages also occurred within Eaton, Jackson, and Barry Counties. Total property damages were estimated at $6.75 million (plus $400,000 in crop damage). About $5 million of the property damage involved a Lansing neighborhood (Burchfield Drive) where boat rescue operations were necessary. The affected Lansing neighborhood is not located next to a river. Many homes had 4 to 5 feet of water in their basements, and an apartment building was evacuated after sewage backed up into the building with an inflow of rainwater. The American Red Cross opened a shelter for evacuees at a nearby high school. Twenty additional homes suffered significant flood damage in Ingham County.

May 2012 – Heavy Rains and Flash Flood (Genesee and Shiawassee Counties)

Half a foot of rain fell on the Flint area during May 4, causing cars to be stranded on roadways, evacuation of some residents by boat, numerous roads shut down (including sections of Interstates 75 and 69), and some bridges to be washed out. In Genesee County, property damage totaled $7.1 million and the City of Swartz Creek and Township of Flint were particularly hard-hit. An apartment building, near Hill Road in Grand Blanc Township, saw $1.7 million in damage and had to be evacuated as electric power was taken out and 30 cars were nearly submerged. In neighboring Shiawassee County, about $1.1 million in property damage occurred.

April-May 2013 – Western Lower and Upper Peninsulas (Federal Disaster #4121 – 16 counties)

Record flooding occurred during the month of April, most directly caused by an accumulation of heavy rains and resulting in disaster declarations for numerous counties across the western portions of the state (plus the cities of Grand Rapids and Ionia, which were both specifically named in the Governor's disaster declaration). Hundreds of homes were flooded, more than 300 roads were closed, and the preliminary damage assessments totaled more than 32 million dollars. The flooding was exacerbated by the melting of significant snowpack—especially in the Western and Central Upper Peninsula. According to the NCDC website in 2014, the following damage amounts were sustained by each of the following counties: $5 million in Allegan, $5 million in Barry, $5 million in Calhoun, $3 million in Clare, $5 million in Clinton, $3 million in Eaton, $1 million in Gogebic, $3 million in Gratiot, $2.9 million in Houghton, $5 million in Ingham, $7 million in Ionia, $3 million in Isabella, $3 million in Jackson, $5 million in Kalamazoo, $3 million in Lake, $625,000 in Marquette, $3 million in Mason, $3 million in Mecosta, $1.4 million in Midland, $3 million in Montcalm, $5 million in Muskegon, $5 million in Newaygo, $3 million in Oceana, $550,000 in Ontonagon, $3 million in Osceola, $5 million in Ottawa, $1.3 million in Saginaw, and $3 million in Van Buren.

August 11 to 13, 2014 – Metropolitan Detroit (Federal Disaster #4121 – 3 counties)

Excessive rainfall occurred from a storm that was concentrated over the metropolitan area and thus had severe impacts upon the most densely populated areas within Wayne, Oakland, and Macomb Counties, where a disaster was then declared. Four to six inches of rain fell during a 4-hour period, an amount that overwhelmed storm sewer systems and expressway pumps. All the major expressways serving the central urban area were affected, and their closures caused huge transportation issues during the Monday afternoon rush hour. It was estimated that 1,000 cars were stalled and abandoned within flooded areas, while rescues had to be performed. About 75,000 homes and businesses were damaged, more than 3,000 of which involved major damage. Road and bridge damages also occurred, with total losses calculated at $1.8 billion across the metropolitan area. This event was very similar to the major disaster of September 2000, but with severe transportation impacts added on top of the widespread basement flooding, plus 2 deaths. Official FEMA damage estimates calculated the damages in 2014 as less severe than in the 2000 event by using changed standards that discounted huge amounts of damage to basements with unfinished areas. Despite this downgraded estimate of qualifying flood impacts, the event inspired new metropolitan coordination efforts around shared funding of regional stormwater systems. This event also had impacts beyond the central metropolitan area, based upon reports from Bay, Genesee, and Saginaw counties of roads that were flooded to depths up to 3 feet.

June 16 to July, 2018 – Western Upper Peninsula (Federal Disaster #4381 – 3 counties)

Starting on June 16, a storm system produced historically heavy rainfalls of nearly seven inches in parts of Gogebic, Houghton, and Menominee Counties, and most of that rainfall occurred within a 6-hour overnight period in the early morning of June 17. An official with the National Weather Service estimated that this level of precipitation can be described as a “1000-year event,” using the current probability estimation methods. The three-day totals were recorded as potentially as high as 8.4 inches in Houghton County, 7.82 inches in Gogebic County, and 5.63 inches in Menominee County. The most severe problems resulted from the area’s hilly topography, especially in Houghton County, in which unusual amounts of debris were carried by the rapid runoff waters. Sediment and rocks were loosened and washed down hills, resulting in damaged buildings and infrastructure through direct forces plus scouring effects. A 12-year old boy in Houghton died after the basement wall of his Canal Road home collapsed under these flood impacts. Entire city blocks in Houghton saw their paved street surfaces crumble and become impassable under the impacts of the flash flood. Numerous additional roads and homes were also damaged in diverse locations throughout the three counties. A Governor’s disaster declaration in June was followed up by a subsequent second declaration on July 12, and then by a federal disaster declaration. The FEMA Preliminary Damage Assessment process identified 172 homes with minor damage, 50 with major damage, and 3 considered destroyed. Over 200 roads were closed during the disaster, some of which seriously inhibited emergency response capabilities. Road damages were estimated at $40 million. Houghton County also had to deal with serious damages to approximately 50 miles of off-road trails that formed an important part of the area’s winter tourist economy as well as alternative transportation routes for snow vehicles during conditions in which excessive snows inhibit or prevent normal road travel. The damaged trails were important for recreational as well as functional transportation needs in an area that receives much more snow than most of the state does. Many homes, yards, basements, stream beds, streets, and roads were filled with material from areas washed out by rain runoff and flood waters. The trail system damage involved 151 washed-out areas, involving additional damages estimated at more than $20 million. Unfortunately, only 1% of the affected households were covered by flood insurance that would have provided compensation for the kinds of damages sustained in this event. The federal disaster declaration had been approved to provide Public Assistance, but not Individual Assistance of the type that these households would have wanted. An unsuccessful appeal was attempted to try to have the declaration include Individual Assistance. Total damages were estimated to be at least $100 million.

Hazard Mitigation Strategies for Urban Flooding

- Stormwater management—Adequate design, installation, maintenance, and monitoring of municipal storm sewer systems. Ordinances or amendments to assist in stormwater management (e.g. forbidding illicit discharges). Planning for and regulating areas prone to flooding (acceptable uses and development restrictions through comprehensive planning, code enforcement, zoning, open space requirements, subdivision regulations, purchased or transferred development rights, land use and capital improvements planning) and involving drain commissioners, hydrologic studies, etc. in these analyses and decisions.
- Homeowner’s and rental insurance that includes coverage of damages and cleanup of sewer backflow impacts.
- Structural projects to channel water away from people and property (dikes, levees, floodwalls) or to increase drainage or absorption capacities (spillways, water detention and retention basins, relief drains, drain widening/dredging or rerouting, debris detention basins, logjam and debris removal, extra culverts, bridge modification, dike setbacks, flood gates and pumps, wetlands protection and restoration).
- Higher engineering standards for drain and sewer capacity, or the expansion of infrastructure to higher capacity.
- Drainage easements (allowing the planned and regulated public use of privately owned land for temporary water retention and drainage).
- Installing (or re-routing or increasing the capacity of) storm drainage systems, including the separation of storm and sanitary sewage systems.
- Farmland and open space preservation.
- Elevating mechanical and utility devices above expected flood levels.
- Flood warning systems and the monitoring of water levels with stream gauges and trained monitors.
- Increased coverage and use of NOAA Weather Radio.
- Anchoring of manufactured homes to a permanent foundation in flood areas, but preferably these structures would be readily movable if necessary or else permanently relocated outside of flood-prone areas and erosion areas.
- Control and securing of debris, yard items, or stored objects (including oil, gasoline, and propane tanks, and paint and chemical barrels) in floodplains that may be swept away, damaged, or pose a hazard when flooding occurs.
- Back-up generators for pumping and lift stations in sanitary sewer systems, and other measures (alarms, meters, remote controls, switchgear upgrades) to ensure that drainage infrastructure is not impeded.

- Detection and prevention/discouragement of illegal discharges into storm-water sewer systems, from home footing drains, downspouts and sump pumps.
- Employing techniques of erosion control in the area (bank stabilization, planting of vegetation on slopes, creation of terraces on hillsides).
- Increasing the function and capacity of sewage lift stations and treatment plants (installation, expansion, and maintenance), including possible separation of combined storm/sanitary sewer systems, if appropriate.
- Wetlands protection regulations and policies.
- Use of check valves, sump pumps and backflow preventers in homes and buildings.
- Acceptable land use densities, coverage and planning for particular soil types and topography (decreasing amount of impermeable ground coverage in upland and drainage areas, zoning and open space requirements suited to the capacity of soils and drainage systems to absorb rainwater runoff, appropriate land use and capital improvements planning) and involving drain commissioners, hydrologic studies, etc. in these analyses and decisions.
- Employing techniques of erosion control within the watershed area (proper bank stabilization, techniques such as planting of vegetation on slopes, creation of terraces on hillsides, use of riprap boulders and geotextile fabric, etc.).
- Protection (or restoration) of wetlands and natural water retention areas.
- Landslide mitigation ideas: Do not build houses, buildings, parks, or playgrounds close to steep slopes; install flexible pipe fittings to avoid gas and water line breakage.

Programs and Initiatives

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

Great Lakes Shoreline Hazards

Water-level fluctuations, current and wave actions, and other conditions in the Great Lakes that cause flooding or erosion, or otherwise threaten life, health, and property in shoreline areas, including harmful algal blooms, ice surges, storm surges, meteotsunamis, rip currents, shoreline erosion and recession.

Hazard Description

Michigan has over 3,200 miles of coastline, the longest freshwater coastline in the world. About 4.7 million persons live in the state's 41 shoreline counties. Wind, waves, water levels, and human activities constantly affect the communities along the shores of the Great Lakes. Shoreline **flooding** and **erosion** are natural processes, occurring at high, average, and even low Great Lakes water levels. However, during periods of high water, flooding and erosion are more obvious, causing serious damage to homes and businesses, roads, water and wastewater treatment facilities, and other structures in coastal communities. **Low lake levels** can also pose a hazard, as cargo ships are more prone to running aground and the shorelines may also become more polluted from lake bottom debris. Long-term and seasonal variations in precipitation and evaporation rates primarily control the Great Lakes water levels and their fluctuations. The extent of ice cover affects the rate of evaporation during the winter. Greater ice cover results in less evaporation during winter and leads to higher water levels in the spring.

The Great Lakes occupy an area of 95,000 square miles and drain an amount of land twice that size. They hold nearly one-fifth of the world's fresh surface water. Because the land draining into the Great Lakes is so vast, changes in the amount of water running into the lakes from precipitation within the basin has an enormous effect on water levels. Following long periods of above-average yearly precipitation, there is an accompanying rise in water levels. This rise is not immediately evident because of the delay between the time precipitation falls within the drainage basin and the time that runoff waters enter the lakes. The same holds true for below-average yearly precipitation. The reduced flow of runoff water eventually results in lower Great Lakes water levels.

Much of Michigan's character is defined by the Great Lakes. The beaches provide numerous recreational opportunities and add great value in real estate markets. Unfortunately, the hazards inherent in coastal areas are not always apparent. Development activities along the shoreline significantly alter the natural ebb and flow of coastal dynamics. Continuing development of coastal areas threatens to exacerbate the shoreline flooding and erosion problem. In addition, meteorological conditions can cause damaging wave impacts (**seiches** and **meteotsunamis**), winter lake patterns can cause damaging **ice surges** (also known as ice shoves), **rip currents** cause multiple deaths and injuries each year, and **harmful algal blooms** (HAB) have led to serious reductions in water quality, as well as degrading the stock of healthy lake fish.

Hazard Analysis

Great Lake water levels go through complicated cycles that are not easy to predict. The time between periods of high and low water levels can vary widely. Records indicate the maximum differences in levels have varied from nearly four feet on Lake Superior to over six and one-half feet on Lakes Michigan and Huron. Seasonal fluctuations caused by more water runoff can cause lake level fluctuations averaging about one foot on Lakes Superior, Michigan and Huron, and one and one-half feet on Lake Erie. The graphs toward the end of this chapter show the long-term annual average water levels of the Great Lakes since 1918. More current information can be found at the Great Lakes Water Dashboard, at https://www.glerl.noaa.gov/data/dashboard/GLWLD.html, and the NOAA Lake Level Viewer at https://coast.noaa.gov/llv/.

In addition to natural causes of water level fluctuation, there are four human-caused factors that can also affect water levels to a limited degree: (1) diversion of water for power generation, municipal water supply, and navigation, (2) regulation of water levels via dams and other control structures, (3) dredging of connecting waterways for navigation purposes, and (4) covering land surfaces with impervious materials that cause storm runoff to be delivered to water bodies more quickly than the pre-development runoff rates. Even though these human-caused factors do affect water levels, natural factors such as precipitation, evaporation and winds have a far greater overall impact. The majority of shoreline flooding and erosion that occurs along the Great Lakes is caused by natural factors. It should be remembered that it is humans who place themselves in harm's way by building structures in dynamic coastal areas. If that did not occur, the natural processes of flooding and erosion would not be viewed as problems. In fact, the sand for the recreational beaches we enjoy is formed from coastal erosion processes that are problematic in other areas.

Flooding and High-Water Levels

Generally, low-lying lands along the coastline are prone to shoreline flooding during both high and low lake water periods. The Michigan Department of Environmental Quality (MDEQ) has designated 41 communities on Michigan's shoreline as flood risk areas, meaning that they have floodplain-like areas with at least a 1% annual chance of a designated flood level being exceeded. These designations allow the mapping of flood-prone areas in a manner similar to riverine flooding, but these shoreline areas may suffer from additional damages caused by the added effects of wave action and seiche activities on the Great Lakes. The MDEQ estimates that approximately 10% of Michigan's Great Lakes shoreline is flood-prone, involving lands encompassing more than 45,000 acres and located in 30 counties.

Low-Water Levels

Low water levels are also cyclical and can have notable economic impacts. The Lake Superior basin, which is the headwaters for the Great Lakes, is an important factor in lake levels. In the past, low snow pack in the Lake Superior basin has disrupted the other lakes' seasonal replenishment cycle, driving water levels down. Among those most affected by the low water levels are the shipping companies that operate massive, 1,000-foot-long iron ore and coal carriers on the Great Lakes. Low water levels can force these cargo ships to lighten their loads by as much as 6,000 tons to reduce their drafts and avoid running aground in channels and ports. Also, in recent years, ferry services that transport people to and from islands have been forced to shut down because of low water depths. Significant drops in water levels can also result in an increase in demand for dredging projects, which can be very expensive. In addition to the high cost of the dredging itself, homeowners and marina operators are faced with the cost of safely disposing of sediments that have been contaminated with heavy metals, pesticides, diesel fuel, and other toxic substances. Under state environmental laws, dredged material must be appropriately disposed of. (For more details, please refer to the new dredge procedure described at https://www.michigan.gov/documents/deq/wrd-policy-048-sediment-testing_620980_7.pdf .)

Erosion

Shoreline erosion hazards involve the loss of property as the supporting sand or soil is removed by wind and wave action. Worst-case scenarios tend to involve inhabited structures that, over the years, have had adjacent lands eroded away and now stand perilously close to lake waters or shoreline cliffs. The foundation of a structure, or underground utility pipes in the area, may become fully exposed and vulnerable to weather, extreme temperatures, water damage, or other sources of risk. Roads and structures may be just one storm away from falling into the lake when the shoreline is significantly eroded to the extent that it reaches a structure's foundation and the area's important infrastructure. Another frequent situation in Michigan involves shoreline roadways whose banks erode and cause the road surface to crack, become unstable, or more prone to deposits of sand, snow, water and ice from nearby beaches and water bodies. The costs of delayed traffic and detours can be counted as harmful shoreline effects. Travel on shoreline highways can also be made treacherous by sand, mists, and snow blown in by wind gusts.

A high-risk erosion area (HREA) is defined by the Great Lakes Shorelands Administrative Rules (promulgated pursuant to Part 323, Shorelands Protection and Management, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended). An HREA is an area of shoreline where erosion studies have indicated that the landward edge of active erosion is receding at an average of one foot or more per year, over a minimum 15-year period. The MDEQ has identified 125 municipalities along the Great Lakes coast that have shorelines containing HREAs. Property owners within an HREA are notified of the erosion rates of their shoreline. The highest average annual erosion rate in Michigan is currently 17.1 feet (2012), in Burt Township (Alger County).

Within those erosion areas, any new permanent structure, including septic systems, must comply with building setback regulations that require a minimum distance between the existing erosion hazard line and proposed structures. Additions to existing structures must also adhere to setback regulations. The intent of these and other applicable building restrictions is to minimize the extent and magnitude of shoreline flooding and serious erosion problems along the Great Lakes coast. Although shoreline flooding and erosion are inevitable, severe damage can be avoided if prudent shoreland management practices are followed and adequate emergency procedures are implemented. Coordination of federal, state and local shoreland management and emergency preparedness efforts is vital to keeping Michigan's shoreline areas as safe and undamaged as possible. The recession of the Great Lakes water levels is cyclical, but there is not much, other than dredging, that can be done to combat the negative effects. Therefore, it is important for those involved in water transportation to be prepared for all types of water fluctuations.

A map toward the end of this chapter indicates the townships that contain high-risk erosion areas as determined by the MDEQ under Part 323, Shorelands Protection and Management. (Erosion also occurs along rivers, and that topic is included in the chapter on Riverine Floods.)

The MDEQ administers programs to balance the impact of shoreline flooding and erosion with the development pressures facing the Great Lakes shoreline, by implementing coastal construction standards, such as lowest-floor elevation requirements and construction setbacks. These types of approaches do not interfere with the natural processes of flooding and erosion, but instead use what is known about coastal hazards to develop construction standards to protect property.

Under Part 323, the regulatory programs for high-risk erosion and flood risk areas may be administered by local units of government. 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. Presently, just two communities have added the regulatory responsibility of the erosion program to their building and zoning departments. As with many regulatory programs that address private property development rights, the potential for conflict in these areas is high. This is especially true in the realm of expensive shoreline real estate, where a view of the water conflicts with the threat of property loss from future flood and erosion events. Political pressure can also be exerted in some situations. Compliance with these regulations has best been achieved through cooperation between state and local governments. Public understanding and support of these programs can be increased by improved communication with property owners regarding the natural hazards associated with the Great Lakes shoreline. About 10 major periods of flooding/erosion have occurred on the Great Lakes since 1918—about every 8.3 years.

Coastal hazard management is most effective when responsibility is shared among multiple levels of government and property owners. Local plans and ordinances can fill management gaps and be tailored to local site characteristics and community needs.

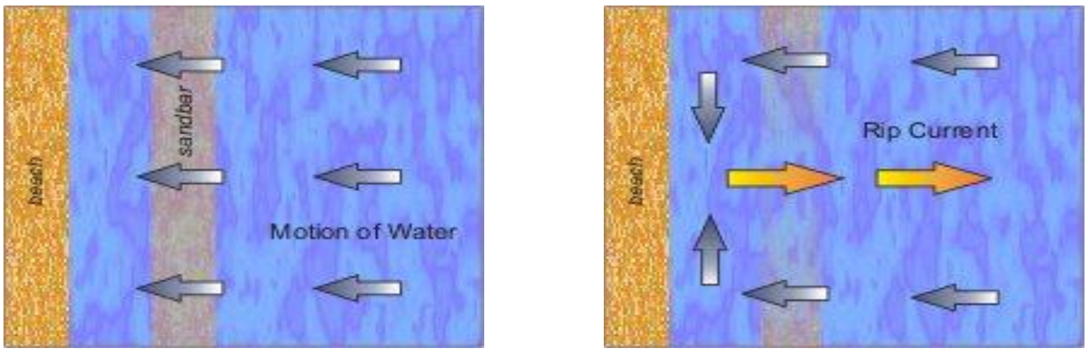
<u>Seiches and Meteotsunamis</u>
Weather-related events can also cause lake fluctuations that can last from several hours to several days. For example, windstorms combined with differences in barometric pressure can temporarily tilt the surface of a lake so it is higher at one end and lower at the other end. The water levels oscillate back and forth, with levels changing by as much as eight feet. This phenomenon is called a **seiche** (typically pronounced as saysh) and can drive lake waters inland over large areas, cause the weakening of existing structures and erosion of shoreline areas, make water travel hazardous, and cause flood damages, deaths, and injuries to occur.

Meteotsunamis are similar to earthquake-generated tsunamis (and to wind-dominated seiche events), but are generally smaller and originate in meteorological events in the which rapid changes and differences in barometric pressure (often associated with fast moving weather systems) are the predominant source of the different water levels. Large meteotsunamis can have devastating coastal impacts (damaging waves, flooding, strong currents) that cause significant damage, injury and death. Meteotsunamis are frequently observed in the Great Lakes, averaging 106 events per year (most of which are fortunately too small to be damaging). Although difficult for an ordinary observer to distinguish, a seiche and a meteotsunami can occur at the same time. They are technically distinct in that a seiche involves the presence of standing waves in which water levels usually take between three and seven hours to shift between their lowest and highest levels, while a meteotsunami involves a progressive wave moving onto shore, with a period is under two hours (sometimes as low as two minutes). Lake Erie is well-known for seiche events, and from a Michigan perspective, this means that the shoreline of Monroe County would be the main recipient of their impacts. Meteotsunamis can cause and exacerbate rip currents, and are believed to have played a role in some of the historic high-fatality rip current incidents that had previously been attributed to seiche events.

When lake levels are tipped away from Michigan, problems can arise from the dry intakes that are exposed by the unexpectedly low water levels, potentially affecting the water supply for critical facilities, including those used for nuclear power plant safety. (All three of Michigan's nuclear plants are located on a Great Lakes shoreline.)

Rip Currents (and Other Dangerous Near-Shore Currents)
A rip current is a strong, narrow flow of water moving away from the shore, and can be life-threatening to swimmers. On sandy beaches, when wind drives waves toward the shore, the water accumulates near the shoreline, "piling up" landward of a sand bar. This water moves along the shoreline, as a longshore current, until it finds or creates an exit (**rip channel**) back to the lake. The current is strongest at the surface, and can dampen incoming waves, leading to the illusion of a particularly calm area. Rip current speeds are typically 1-2 feet per second. However, speeds as high as 8 feet per second have been measured. Rip currents cause approximately 100 deaths annually in the United States. In the Great Lakes alone, the average over the last sixteen years is 11 drownings per year caused by rip currents. About 80% of rescues by surf beach lifeguards are due to rip currents. A picture showing how rip currents are formed is shown below.

Rip Current Formation



Structural rip currents—those that form adjacent to human-made structures such as piers—cause more incidents than traditional rip currents. These currents form as the longshore current turns lakeward as it interacts with the structure. Structural currents pose increased dangers due to the deep trough that occurs along the structure, rocks and other hazards along the structure itself, and the fact that escape from this type of current is more difficult than a traditional rip current. Jumping and swimming from piers is popular in many Great Lakes coastal locations, but these actions should be discouraged as they directly expose persons to the dangers posed by structural rip currents.

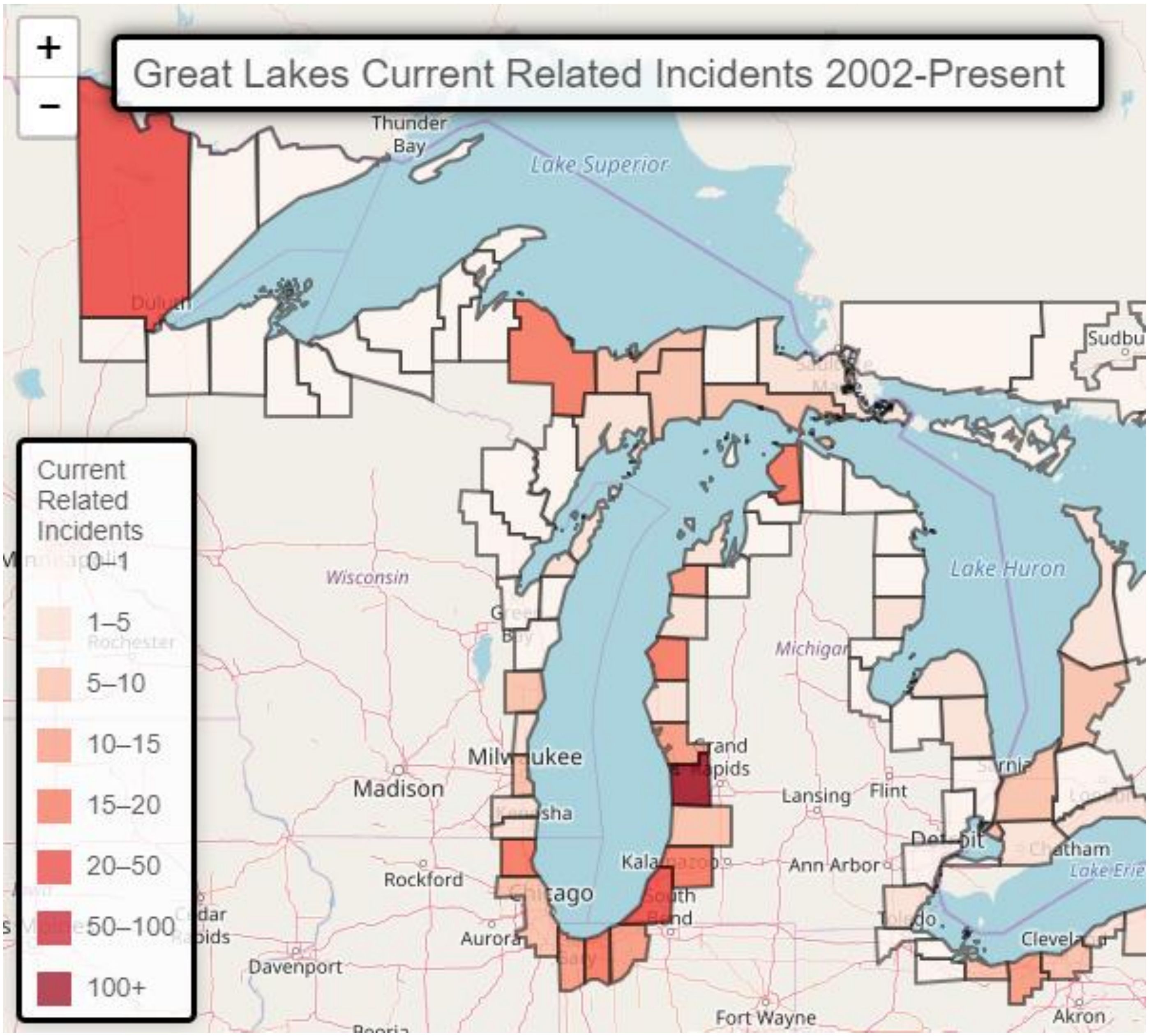
River outlet currents occur where streams and rivers flow into the Great Lakes, combining with lake currents to create a strong offshore flow that is dangerous to swimmers. The river typically cuts a deep trough into the lakebed, and these deep areas may cause swimmers additional difficulties. Swimmers should avoid river outlet areas.

Channel currents form between the mainland and islands or rock outcrops that are close to shore. The current speed intensifies as it passes through the restricted channel, making these areas hazardous for swimmers as well.

In recent years, rip current advisories have been announced by the National Weather Service, as a part of their weather warning information system. These warnings advise about dangerous swimming conditions, and that rip currents are more likely to exist near break walls, sandbars, jetties, and piers. The National Weather Service hosts a Great Lakes Beach Forecast web map, showing expected beach conditions with color-coded swim-risk information, at https://www.weather.gov/greatlakes/beachhazards.

Persons who are caught in a rip current should wade or swim sideways (parallel to the beach) so as to leave the rip current area before it pulls them too far away from shore. The most important action is to conserve one's strength so as to stay afloat (rather than expending one's strength in an over-desperate struggle to "fight the current"). Once out of the rip current's pull, head back to shore at a pace that is appropriate to one's strength. In some circumstances, a swimmer may have been observed by beach lifeguards while being pulled by the current, and in such a case, if waves and weather are not too severe to allow a rescue, a swimmer may simply need to stay afloat until the lifeguards can bring aid.

According to the National Climatic Data Center, Michigan has experienced at least 30 deaths and 9 injuries caused by rip currents or other shoreline hazards since 1996. A two-page table from that source summarizes these shoreline hazard events and casualties and appears toward the end of this chapter. A more specifically dedicated resource can be found in the Great Lakes Current-Event Database. Below is a map representing a larger number of current-related incidents (i.e. not just fatalities) that more clearly shows the coastal areas that present greater risks.



Source: https://www.weather.gov/greatlakes/beachhazards_stats

Harmful Algal Blooms (HAB)

Cyanobacteria has been a periodic problem, especially in Lake Erie. When conditions are right, huge amounts of algae bloom within lake waters, and have a harmful effect upon water quality and the aquatic ecosystem. Harmful algal blooms (HABs) are associated with the runoff of nutrients from inland agricultural activities, but residential landscaping can also be a contributor. The primary human impact involves public health concerns—recreational uses of a lake and its shoreline can be brought to a halt, and the usefulness of the lake water as a source for municipal water systems can also be threatened. A NOAA-affiliated agency in Ann Arbor, the Great Lakes Environmental Research Laboratory (GLERL), offers information and technical expertise on the health and ecosystem effects of cyanobacteria, HABs, and hypoxia. For more information, please refer to that agency's web site on this topic (at http://www.glerl.noaa.gov/res/HABs_and_Hypoxia/) and to the appropriate state-level agency office of the MDEQ, at https://www.michigan.gov/deq/0,4561,7-135-3313_3681_3686_3728-383630--,00.html.

Ice Surges (aka Ice Shoves)
Not all shoreline areas have reported problems with ice surges, but selected locations appear to have recurrent problems with these events. The key location with the worst documented impacts found in media reports is on the western shoreline of Saginaw Bay, north of Bay City, where houses are at-risk along the shoreline and incidents have been reported in 2009, 2013, and 2014 (at a minimum). This hazard has not yet been fully analyzed, but research is currently in progress, especially involving NOAA and the Great Lakes Research Center that is a component of Michigan Technological University (described more fully in the Programs and Initiatives section in this chapter). Additional shoreline counties that may have experienced these risks include those in the Keweenaw Bay and Green Bay areas on Lakes Superior and Michigan. NOAA reports that it is currently working to add ice predictions to its Great Lakes Coastal Forecast System (GLCFS).

Lake Weather
Another Great Lakes hazard is the potential effect of severe winds upon marine activities. Although some description of marine accidents can be found in the Transportation Accidents section, it must be noted here that severe winds tend to be felt more strongly on open waters (winds from an approaching storm front often strike in advance of the storm itself, by 5 minutes or even more). Waterspouts (which are like a tornado, but involve contact with water instead of land) are a common occurrence posing a great threat to marine traffic. Seventeen Michigan waterspouts have been noted by NCDC between 1993 and 2001, including one that caused $200,000 in damage to a boat house and storage building at Drummond Island on July 3, 1999. Many additional events have occurred since, which NCDC has classified according to the corresponding lake location rather than as part of Michigan itself. Waterspouts are less frequent on Lake Superior (8 events since 2001) than on Lakes Huron (23 events) or Michigan (51 events).

Impact on the Public, Property, Facilities, and Infrastructure
Great Lakes shoreline flooding is similar to inland (riverine) flooding in some ways (such as having a probabilistically definable flood risk area), but the shoreline tends to have a much greater risk of allowing strong wave action as part of a flood's impacts. Storm seiches can make the magnitude of shoreline flooding much greater than what is possible in most inland areas. In addition, patterns of Great Lakes shoreline erosion tend to be a larger issue than the erosion associated with Michigan's rivers, since the water effects are greater, and the topographic relief in Michigan's shoreline areas is sometimes considerable. For example, the erosion resulting from a single severe thunderstorm has caused large sections of shoreline roadway to crumble and disappear into the crashing waters, involving a drop of dozens of feet on the southern coasts of Lake Michigan, and has encroached upon structures located nearby. One of the impacts upon property and recreation stems from efforts to armor some shoreline segments against erosion, only to find that this has exacerbated erosion in other locations, or prevented sediments from replenishing beaches with new sand. Some critical facilities, such as nuclear power plants, require access to water but are also subject to some of the shoreline risks described in this chapter. Water systems have recently proven vulnerable to harmful algal blooms. Many casualties have occurred as a result of rip currents, meteotsunamis, and seiches. Various roadways and structures have been identified as damaged by, and still vulnerable to, coastal erosion and wave impacts.

Impact on the Economic Condition of the State
There are some coastal locations in which roadways have been rendered unsafe as a result of erosion and their proximity to wave effects from the Great Lakes, especially during severe weather when waves can set new records. Overall, this does not currently have an exceptionally large economic impact on the state as a whole, but there are local economies that have indeed been severely affected by challenges to their recreational provisions and infrastructure, such as the harmful algal blooms on Lake Erie which degraded the quality of lake waters and interfered with recreation and water supplies in parts of the Monroe County.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Compared to riverine flood events, the main additional risks posed by shoreline flooding and erosion hazards involve the generally greater topographic relief along certain shoreline areas, and the greater potential impact likely to be seen from a single event such as a storm or seiche that involves substantial wave action. The event may cause roadways and property to crumble and tumble dozens of feet into the waters of one of the Great Lakes. Thus, weakened shoreline roads may cause personnel, vehicles, or equipment to plummet down a steep incline, if erosion has been severe enough to cause such a collapse. Shoreline events may also require more extensive use of boats and marine

equipment during response activities, with an associated increase in the variety of risks to responders. Safe access will be particularly problematic for any structures that may fall into water as a result of erosion. Responder safety has been a clear concern when any rescue and search efforts are required during severe weather on the Great Lakes. The closure of shoreline roads (either temporarily or permanently) as a result of shoreline hazards has already raised questions and local discussions about emergency response delays that may result. Most services remain intact, except during the severe incidents themselves.

Impact on the Environment

Environmental impacts can result from structural efforts to try to control Great Lakes shoreline flooding and erosion. The construction of hard shore-protection can exacerbate erosion on nearby properties, as wave energy flanks the hardened structure. The installation of a seawall or revetment (for local erosion protection) also causes sand supply to be cut off from shoreline beaches. This deepens the nearshore and allows larger waves to impact the coast with an even greater energy over time. As explained previously, shoreline floods and erosion are natural processes, and part of a normal and healthy environment as long as human construction is not built in areas that are at-risk from and in opposition to these natural shoreline processes.

Impact on Public Confidence in State Governance

Great Lakes shoreline flooding and erosion impacts are probably similar to those of riverine flooding, except that shoreline impacts may seem to be less controllable than riparian impacts. Erosion severity is likely to be far greater along the shoreline, especially when involving substantial elevations in which the roads and homes are located along bluffs or cliffs and are thus clearly imperiled by any degradation in the solidity of the supporting land structure that is subjected to erosion and weakening. Thus, part of the public may be prone to question why structures were allowed to be built in an area at-risk from erosion effects, or whether some government-funded mitigation action may be undertaken to preserve the condition and value of such property, once it is recognized as being at-risk.

Significant Shoreline Hazard Events in Michigan

July 4, 1929 – Grand Haven (Ottawa County)

After an early-morning storm had passed, tens of thousands of persons gathered for an Independence Day celebration in the Grand Haven State Park. Later in the day, a 6-meter wave surged over the Grand Haven pier, sweeping persons into the Lake as the water retreated. Strong rip currents near the shore carried away several more persons, and a total of 10 were killed that day.

July 13, 1938 – Holland (Allegan County)

During an otherwise calm day, a 3-meter wave struck the Holland State Park, causing five swimmers to drown.

November 11, 1940 – Lake Michigan Seiche

Enormous waves were generated by a huge storm system, with winds blowing in from the southwest and reaching speeds of up to 75 mph. The northern shore of Lake Michigan was reported to have sustained considerable damage from the push of water during the resulting seiche. Five vessels and 66 lives were lost (including 57 deaths from the sinking of two freighters that are also listed in the Transportation Incidents section of this document). A car ferry was damaged and driven ashore at Ludington.

1972-1973 – High Lake Levels and Shoreline Floods

During 1972-73, high water levels caused flooding in over 30 counties, resulting in more than $50 million 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 to shoreline communities.

1985-1986 – High Lake Levels and Shoreline Floods

Record-high lake levels in 1985-86 culminated in a Governor's disaster declaration for 17 shoreline counties. The USACE implemented its Advance Measures Program, and the State of Michigan implemented three unique shoreline flooding and erosion mitigation programs aimed at reducing future flood impacts on shoreline communities and homeowners. (See Programs and Initiatives section.) After a mid-1980s storm event and high waves along the shore of Lake Michigan, Saugatuck Township residents found that a large section of Lakeshore Drive had crumbled away, southwest of Douglas. At least a couple hundred feet of paved road was missing, causing access problems for some area homes, and a very long detour for those used to driving into town along that route. The road has not been rebuilt, but some erosion-control methods were later installed to help waters drain into the lake without carrying much of the shoreline with it. See also the 2008 event listed below.

1997-1998 – High Lake Levels and Shoreline Floods

The high-water period in 1997-98 resulted in the Great Lakes being at or near the record levels set in the mid-1980s. In response to the threat of severe shoreline flooding and erosion, the U.S. Army Corps of Engineers (USACE), at the request of the Governor, implemented its Advance Measures Program to assist Michigan shoreline communities in their flood and erosion mitigation efforts. (See Programs and Initiatives section for more details.) More than 20 Michigan jurisdictions took advantage of this program. Storms in 1998 reportedly caused shoreline erosion damage in New Buffalo (Berrien County), and subsequent years' events have added to the concerns at that location.

May 31, 1998 – Lake Michigan Seiche (Berrien County)

A derecho produced widespread wind gusts of 60 to 90 miles per hour and moved across Lake Michigan, causing the sinking of a tugboat north of Muskegon (in White Lake Channel north of Wabaningo). Repairs for the boat were estimated at $20,000. Consumers Energy reported more than 600,000 customers without power, marking the most destructive weather event in the company's history. It took up to 10 days to restore power to all areas. Although most of the damages, deaths, and injuries in this storm system were caused by other storm effects, one component was the wave action that took its toll just north of Muskegon.

July 4, 2003 – Sawyer (Berrien County)

Seven persons drowned in an incident that had initially been described as rip currents, but was later classified as a meteotsunami on the basis of data in water level records around the time of the incident.

July 4, 2006 – Berrien County Rip Current

Wave on Lake Michigan ranged from 2 to 6 feet and allowed for several rip current occurrences near Berrien County shores. County officials conducted at least 6 rescues, despite numerous warnings and advisories having been announced. 4 persons were treated at beaches, but 1 rescued woman died several days later.

October 28-29, 2006 – Lake Erie Seiche

After two days of wind blowing at speeds of 30 to 40 mph, the difference in water levels between one end of Lake Erie and the other reached 8 feet. Fortunately, the seiche caused a drop rather than a rise of waters along Michigan's coastline, but this can still cause a weakening and erosion of shoreline areas. The waters at Monroe were 4 feet below the level they had been at merely two days before, on October 27.

2000s – Low Lake Levels

Low water levels existed in Lakes Michigan, Huron, and Erie, after the fastest decline in water levels in the Great Lakes in nearly a century and a half. Between the summer of 1997 and the spring of 2003, the middle Great Lakes (Michigan, Huron, and Erie) each dropped by almost five feet. Water levels in Lakes Michigan and Huron remained below their long-term annual average until 2014, and have again risen above that long-term average since that time.

August to September 2007 – Muskegon County Water Level Recession

Local reports described drought-related effects upon marine traffic in the Muskegon area. A super-freighter became stuck in the mouth of Muskegon Harbor and was reported as the second large ship to run aground within the space of a month, in the same location. Shipping officials stated that additional dredging was needed in Great Lakes ports because of low water levels.

June 8, 2008 – Lakeshore Drive (Allegan and Berrien Counties)

On the morning of June 8, 2008, two persons died after their car was submerged while delivering newspapers along their Lakeshore Road route, 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 previous night, causing the car to fall at least 50 feet into the ravine below. Local debates, discussions, and a lawsuit have been reported concerning this road, including issues such as potential delays in emergency response times when providing services to residents there, compared to the costs, risks, and increased traffic of replacing the road where it had collapsed during the high lake-level period of 1985-1986 (please refer to the listing for that event for more information). Concerns have also been reported involving "Old Lake Shore Drive" in the City of St. Joseph (Berrien County), and its adjacent railroad tracks near the Lake Michigan shoreline.

August 15, 2009 – Mackinac County Rip Current

Onshore winds and significant wave action resulted in rip currents on the far northern beaches of Lake Michigan. Two persons died near the Pointe Aux Chemes sand dunes (about 10 miles northwest of St. Ignace), when a 16-year-old teen was carried into deeper water by currents, and his 66-year-old grandfather attempted to rescue him. Both were overcome by waves and currents, and revival attempts were unsuccessful when the two were finally retrieved.

August 5, 2010 – Rip Currents (Marquette and Alger Counties)

Two teenaged swimmers drowned in high waves and rip currents near Presque Isle (Marquette County), where winds gusted to over 30mph at times. In Grand Marais Harbor (Alger County), a father and son both drowned in similar high waves, winds, and rip currents.

September 3, 2010 – Berrien County Rip Current

Strong winds created dangerous conditions on far southeastern Lake Michigan, where waves as high as 16 feet caused extremely strong rip currents. A man from Chicago drowned after he became separated from a rubber raft (which saved his two companions), and was swept out into deeper waters. Numerous agencies attempted to find and rescue the man, but lake conditions caused a rescue craft to capsize, injuring four rescue workers and causing the search mission to be called off.

October 15, 2011 – Berrien County High Surf

One person died when a kayak capsized inside a New Buffalo break-wall, amidst waves of 8 to 10 feet (cresting to 14 feet at the shoreline). Strong winds had caused these rough waters to arise. Two teenaged kayakers were rescued, but the third was lost underwater.

May 13, 2013 – Linwood (Bay County)

An ice surge damaged homes along the shoreline near Linwood. News coverage documented giant hills of ice estimated at up to 20 feet tall near these homes. This is a regular event in this area of Saginaw Bay, but not all damaging incidents have yet been collected for these events.

August 2014 – Lake Erie Algal Bloom (Monroe County)

On August 2, 2014, the City of Toledo, Ohio detected higher levels of Microcystin than deemed safe in its water supply due to harmful algal blooms (HABs) in Lake Erie. Monroe County also had this same issue. The National Oceanic and Atmospheric Administration released a satellite image showing a small but concentrated algae bloom centered right where Toledo draws its water supply. Researchers largely blamed the algae's resurgence on manure and chemical fertilizer from farms that wash into the lake along with sewage treatment plants. Leaky septic tanks and storm-water drains have contributed, too. Combined, they flush huge amounts of phosphorus into the lake. Both Toledo and Monroe County officials issued a "Do not drink or boil" water advisory to residents. 500,000 customers in Toledo and 30,000 customers in Monroe County were affected by the toxic contamination. The ban forced residents to scramble for water for drinking, cooking, and bathing. Drinking the water could cause vomiting, cramps, and rashes. The water ban was lifted on August 4, 2014.

October 31, 2014 – Halloween Storm on Lake Michigan (Berrien County)

Severe weather caused enormous waves to appear in the Great Lakes. Lake Superior reported 7.9-foot waves, and a buoy at the southern end of Lake Huron recorded 15.4-foot waves, but it was Lake Michigan that reached an extreme level, with a buoy near Holland recording a wave that was 21.7 feet, the second-tallest ever recorded at that location. Wind speeds were around 60 mph at the time. Many of the reported impacts were felt in Indiana, just south of the Michigan border, but New Buffalo (Berrien County) saw a retaining wall destroyed, which exposed a home's foundation on the edge of the lake, and led to its demolition.

2014 to 2016 – F.J. McLain State Park (Houghton County)

Park facilities were notably impaired after severe Lake Superior storms in 2014 and 2015 resulted in erosion that damages park roadways, utilities, and embankments related to a dozen lakefront campsites. Continued erosion reportedly threatened an additional 18 campsites at the park, which were closed for safety reasons.

October 24, 2017 – Lake Superior Seiche (Marquette County)

As winter was arriving, heavy winds resulted in a seiche on Lake Superior. Although the main impacts were felt in Duluth, Minnesota, the Granite Island buoy north of Marquette measured a wave that was 28.8 feet in size. This was the tallest wave ever recorded with modern instruments on Lake Superior. Two persons were reportedly swept off the Black Rocks at the Presque Isle Park (Marquette County), and believed to be victims of this event.

April 15, 2018 – Monroe and Bay County Shoreline Flooding

In addition to heavy precipitation that mixed rain, snow, sleet, and freezing rain, strong and persistent winds blew from the northeast and caused lake shore flooding around Saginaw Bay and the western shores of Lake Erie. Wind gusts at or above 50 mph were reported in Bay County on April 14. Some homes in Luna Pier (Monroe County) were evacuated, and along with flooded shoreline roads (especially in LaSalle Township), the total property damage was estimated at $5 million within Monroe County. Grand Beach and North Shores also had evacuations occur, as homes were impacted. In Bay County, property damages were estimated at $2 million, as water reached some homes in Bangor Township. Power outages also took place in many areas, as a result of this weather system's strong winds and freezing rain impacts.

Programs and Initiatives

Michigan Technological University's Great Lakes Research Center

The Great Lakes Research Center (GLRC) provides state-of-the-art laboratories to support research on a broad array of topics. These topics contain information relevant to hazards such as erosion, floods, and invasive species. Faculty members from many departments across Michigan Technological University's campus collaborate on interdisciplinary research, ranging from air–water interactions to biogeochemistry to food web relationships. There is also a location in Ann Arbor. One of the GLRC's most important functions is to educate the scientists, engineers, technologists, policymakers, and stakeholders of tomorrow about the Great Lakes basin. The Center for Science and Environmental Outreach provides K–12 student, teacher, and community education/outreach programs, taking advantage of the Center's many teaching labs. The GLRC also contains a lake-level marine facility and convenient deep-water docking, providing a year-round home for Michigan Technological University's surface and sub-surface fleet of marine vehicles.

The MDEQ High-Risk Erosion Area Program

The High-Risk Erosion Area program of the Michigan Department of Environmental Quality was created to prevent structural property loss in areas of the Great Lakes shore-land as determined by the department, based on studies and surveys, to be subject to erosion as required by Part 323 of the Natural Resources and Environmental Protect Act (1994 PA 451 as amended, aka NREPA, and its corresponding Administrative Rules). Lake levels may fluctuate dramatically in response to weather and climate. Wave action, storms, wind, ground water seepage, surface water runoff, and frost are contributing factors to changing and reshaping the shoreline. During periods of low water, property owners are often lulled into believing homes may be safely built closer to the water's edge. Yet longtime residents have many stories about high water levels, the subsequent erosion of the Great Lakes shoreline, and the homes that have fallen into the lake as their foundations have been compromised. This destruction has resulted in severe financial loss to property owners. Public losses to recreation facilities, roads, and other public works have also occurred. Structures threatened by erosion may be moved landward, protected by costly shoreline projects, or lost. High risk erosion areas are those shore-lands of the Great Lakes where recession of the landward edge of active erosion has been occurring at a long-term average rate of one foot or more per year, over a minimum period of 15 years. MDEQ staff conducted the initial recession rate research of coastal counties between 1980 and 1986, during which time they identified high-risk erosion areas in 36 of Michigan's 41 coastal counties. Recession rates change over time as water levels fluctuate and coastal conditions change. Recession rate research is ongoing and often results in changes to the locations of high-risk erosion areas along the shoreline. The high-risk erosion area program increases consumer awareness of the danger of shore erosion and provides advice and technical assistance to many citizens living with the dynamic Great Lakes shorelines. Presently, about 7,500 individual property owners are affected by shoreline setback requirements. All citizens benefit from the program's efforts to reduce the need for public disaster assistance, promote consumer protection, and reduce the loss of natural resources.

Algal Bloom Monitoring System

The NOAA National Centers for Coastal Ocean Science (NCCOS) developed the Algal Bloom Monitoring System to routinely deliver near-real-time products for use in locating, monitoring, and quantifying algal blooms in coastal and lake regions of the US. This application delivers a suite of bloom-detection products in the form of geographic based images. At this time, products are available for selected regions. New products are being evaluated, and new regions are being considered, and will be made available through this system as they are proven useful. Harmful algal blooms (HABs), sometimes known as "red tide," occur when certain kinds of algae grow very quickly, forming patches or "blooms" in the water. These blooms can emit powerful toxins that endanger human and animal health. Reported in every coastal state, HABs have caused an estimated $1 billion in losses over the last several decades to coastal economies that rely on recreation, tourism, and seafood harvesting. Blooms can lead to odors that require more costly treatment for public water supplies. NCCOS conducts and funds research that helps communities protect the public and combat blooms in cost-effective ways, and therefore works toward the goal of stopping blooms before they occur.

Great Lakes Current Incident Database

The "dangerous currents" web-site describes issues pertaining to rip currents and similar phenomena. Dangerous currents and breaking waves are common in the Great Lakes region. Rip currents and other currents found near piers are extremely dangerous for swimmers. The "dangerous currents" website provides information for swimmers, educators, first responders and the media. Although many persons refer to rip tides, undertows, and similar expressions, these terms can provide misleading impressions about the nature of the risks, and are better referred to as dangerous currents. (There are no tides in the Great Lakes, and therefore no rip tides, and lake currents don't pull a person down under the water, therefore not correctly termed as undertow.) Although many persons know that ocean and river currents can be dangerous, many don't realize that there are similarly dangerous currents found in the Great Lakes. http://www.miseagrant.umich.edu/dcd/dcdsearch.php

Meteotsunami Forecasting and Warning System

A Meteotsunami Forecasting and Warning System for the Laurentian Great Lakes is planned with the goal to construct a framework for developing a real-time meteotsunami warning system that can meet weather forecast requirements, thus reducing risks due to coastal flooding, preventing swimmer drowning, and increasing the safety of nuclear power plant operations. The system is sponsored by NOAA's Great Lakes Environmental Research Laboratory (GLERL) and the Cooperative Institute for Great Lakes Research (CIGLR):
https://ciglr.seas.umich.edu/opportunities/summits-working-groups/meteotsunami-forecasting-and-warning-system-summit/ .

Michigan Shoreline Flood and Erosion Hazard Regulatory Authority

Shorelands Protection and Management, Part 323 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended – Part 323 is designed to provide protection to Michigan's Great Lakes shoreline. While these fragile and dynamic shorelines are desirable vacation and recreational areas, they also present inherent hazards to development and are vulnerable to the effects that development often brings. Part 323 gives the MDEQ responsibility to identify hazardous and fragile coastal areas, to establish regulations designed to minimize the impact of development on these areas, and to minimize risks facing new developments. Part 323 identifies three coastal areas: 1) high-risk erosion areas – those shorelines identified as receding at an average long-term rate of at least one foot per year; 2) flood risk areas – those coastal areas that are vulnerable to Great Lakes flooding; and 3) environmental areas – those coastal areas necessary for the preservation and maintenance of fish and wildlife. Regulations have been developed for the unique management issues facing each area.

Mechanisms provided in the law to accomplish this protection are state-developed zoning ordinances, special studies, plans, and remedies for violation of rules. The Act gives the MDEQ the authority to identify and regulate high-risk erosion, flood risk, and environmental areas using setbacks, zoning, and building code standards. Permits are required for construction in high-risk erosion or flood areas, or for alterations in an environmental area. If a local ordinance has been approved by the MDEQ, the regulation will be done at the local level. In the absence of a local ordinance, permits must be obtained from the MDEQ.

In high-risk erosion areas, the Administrative Rules for the Act require: 1) a 30-year setback for small, readily moveable permanent structures having a foundation size of 3,500 square feet or less; 2) a 60-year setback for all other permanent structures, including waste treatment systems; and 3) all proposed structures of 3,500 square feet or less located within the 60-year setback must be readily moveable. The readily-moveable provision allows the structure to be moved landward if the home is ever threatened with erosion damage. High-risk erosion areas can be identified through the lists and maps available at www.mi.gov/shorelands.

In flood-risk areas, the Administrative Rules require that (1) residential structures must have the lowest portion of all floor joists located at or above the 100-year flood elevation and (2) any additions to existing structures must be elevated above the 100-year flood elevation.

Environmental areas are portions of the Great Lakes shorelands that have been determined to be necessary for the preservation and maintenance of fish and wildlife. Within environmental areas, permits are required for any dredging, filling, grading, other alteration of soil, vegetation, construction of permanent structures, and natural drainage.

National Flood Insurance Program

For many years, the strategy for reducing flood damages followed a structural approach of building dams and levees and making channel modifications. However, this approach did not slow the rising cost of flood damage, and did not allow individuals to purchase insurance to protect themselves from flood damage. It became apparent that a different approach was needed.

The National Flood Insurance Program (NFIP) was instituted in 1968 to make flood insurance available in communities that have agreed to regulate future floodplain development. As a participant in the NFIP, a community must adopt regulations that: 1) require any new residential construction within the 100-year floodplain to have the lowest floor, including the basement, elevated above the 100-year flood elevation; 2) allow non-residential structures to be elevated or dry floodproofed (the floodproofing must be certified by a registered professional engineer or architect); and 3) require anchoring of manufactured homes in floodprone 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. In return for adopting floodplain management regulations, the federal government makes flood insurance available to the citizens of the community. In 1973, the NFIP was amended to mandate the purchase of flood insurance, as a condition of any loan that is federally regulated, supervised or insured, for construction activities within the 100-year floodplain.

As of September 2018, there were 20,302 active flood insurance policies in force in Michigan. This figure reveals a 20% decline since 2010, yet officials from FEMA and the MDEQ had already estimated that only 15% of all flood-prone structures in Michigan eligible to purchase flood insurance actually had bought flood insurance around that time. Furthermore, since only about half of all local communities in Michigan have chosen to participate in the NFIP, there are thousands of structures that are flood-prone, but are not eligible to purchase flood insurance through this program. (There were 881 participating communities as of September 17, 2018, although this does mark an increase from 867 communities at the end of 2010.)

For more information about the participation of Michigan communities in the NFIP and its associated Community Rating System (CRS), please refer to the preceding chapter about Riverine Flooding.

Community Education

The MDEQ periodically holds workshops for lenders, realtors, insurance agencies, citizens and any other interested parties. The workshops provide a wide variety of information tailored to the specific group(s). Topics typically include building code requirements, other state and federal regulations, floodplain management programs, and the responsibilities of involved parties such as local governments, lending institutions, citizens, etc. Staff from the MDEQ will also meet with property owners onsite to discuss shoreline flooding and erosion problems and possible solutions based on the specifics of the property.

National Weather Service Watches/Warnings

In 2005, The National Weather Service announced that it would start issuing Coastal Flood Warnings for the Lower Peninsula shorelines of Lake Michigan and Lake Huron using a model that calculates such factors as wind speed, wave height, and time between waves. Advisories that warn when conditions present an increased risk of rip currents will be posted on the agency's web site and shared with weather broadcasters.

State-Administered Shoreline Hazard Mitigation Programs

In 1986, in response to the Great Lakes shoreline flooding and erosion problems, the State of Michigan established three unique shoreline hazard mitigation programs designed to prevent or minimize damage and impact caused by shoreline flooding and erosion. (Note: These temporary programs were established only for the 1985-86 high water period. They have since been closed out and are no longer available.)

The **Shoreline Community Protection Program** provided grants for community shoreline damage prevention efforts. From 1986 through 1988, the program provided support for flood and erosion mitigation projects undertaken by local governments in the form of grants which would cover 85% of the cost of projects. Four hundred seventy one (471) grants were awarded, totaling approximately $4.2 million.

Two interest-rate buy-down programs, the **Emergency Home Moving Program** and **Emergency Flood Protection Program**, were established on a temporary basis to encourage a non-structural approach to erosion and flood hazards during the 1985-86 high water levels on the Great Lakes. The programs provided a lump sum payment equaling 3% of the interest rate of the secured loan amount for projects to move houses away from the eroding bluff line or elevate homes in floodprone areas. From 1986 through 1988, a total of $2 million was made available to interested homeowners. A total of 72 structures were relocated under the program, and 43 were elevated.

USACE Advance Measures Program

The USACE Advance Measures Program can be implemented to assist a state or local government in mitigating the potential damage and impact caused by flooding. Under the Advance Measures Program, the Army Corps of Engineers may provide "self-help" materials (i.e., sandbags, sand, and plastic sheeting), at 100% federal cost, to participating units of government for use in direct pre-flood mitigation activities. An example of a self-help project would be the construction of temporary sandbag dikes. The Advance Measures Program also has a construction component under which the Corps 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 Corps 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. Examples of construction projects that could potentially be funded under this component of the program include earthen levees, rock and/or sand-filled cribs, and concrete and/or steel sheetpile seawalls.

The Advance Measures Program and its predecessor, Operation Foresight, has been implemented during the last three high water periods on the Great Lakes. Over 100 flood mitigation projects have been funded under these programs in Michigan and other Great Lakes states over the last three decades. In response to the high lake levels in 1972-73, the Corp's Operation Foresight program provided over $13.5 million in funds for self-help and flood mitigation construction projects. During the 1985-86 high water period, total project costs for self-help and construction projects under the Advance Measures Program exceeded $12.5 million. In the most recent high-water period (1997-98), in response to request by the Governor, the USACE provided approximately one million self-help sandbags, and worked with seven communities to complete eight Advance Measures construction projects. Those projects are located on or adjacent to Lake Erie, Lake St. Clair, and Saginaw Bay.

Great Lakes Shoreline and Wetlands Task Force Report

A special task force was assembled to study state and federal regulations on wetlands and to develop recommendations for the regulatory agencies to allow shoreline property owners access to their waterfront while maintaining the ecological value of the areas. The report identified areas of inconsistency in existing Army Corps of Engineers and Michigan Department of Environmental Quality (MDEQ) permitting processes and recommended that the agencies work together to alleviate the inconsistencies. The report identified and listed the activities that shoreline property owners can undertake without requiring a permit from either the state or federal regulatory agency. The report is available at www.lre.usace.army.mil.

The Great Lakes Beach and Pier Safety Campaign

The Great Lakes Beach and Pier Safety Campaign is a collaborative effort between multiple agencies and organizations from Michigan, Illinois, Pennsylvania, and Ohio. It is a comprehensive approach to addressing the lack of education and understanding of rip currents and the dangers they present during storms on the Great Lakes. The campaign was developed by The Great Lakes Beach and Pier Safety Task Force, which has produced an educational video on rip currents entitled "Respect the Power." The task force, along with assistance from State Farm Insurance, has mailed out 3,000 copies to all of the middle schools, high schools, and public libraries in Michigan.

Other State and Federally-Assisted Flood Mitigation Projects

The State of Michigan has used a variety of federal funding sources to assist in the implementation of flood mitigation projects. Those funding sources have included: 1) the Hazard Mitigation Grant Program (HMGP); 2) the Flood Mitigation Assistance Program (FMAP); 3) the Pre-Disaster Mitigation Program (PDMP); 4) the Public Assistance Grant Program (PAGP); 5) the Individual and Family Grant Program (IFGP) – no longer in existence; 6) the National Flood Insurance Program, Section 1362 (no longer in existence); 7) Community Development Block Grants (CDBG);

and 8) Farmers Home Administration (FmHA) loans. State and local funds have been used to match the federal sources of funding.

Coastal Management Program

The Coastal Zone Management Act (CZMA), originally passed in 1972, enables coastal states, including Great Lakes states, to develop a coastal management program to improve protection of sensitive shoreline resources, to identify coastal areas appropriate for development, to designate areas hazardous to development, and to improve public access to the coastline. Michigan was among the first states to have its coastal program approved in 1978. The program is administered by the Office of the Great Lakes, in the Michigan Department of Natural Resources. The program includes local pass-through grants and administration of coastal related sections of Michigan's Natural Resource and Environmental Protection Act, 1994 PA 451, as amended. Review of federal agency activities, for consistency with Michigan's approved program, is performed by the Great Lakes Shorelands Unit in the Water Resources Division (WRD) of the MDEQ.

Hazard Mitigation Alternatives for Shoreline Flooding and Erosion

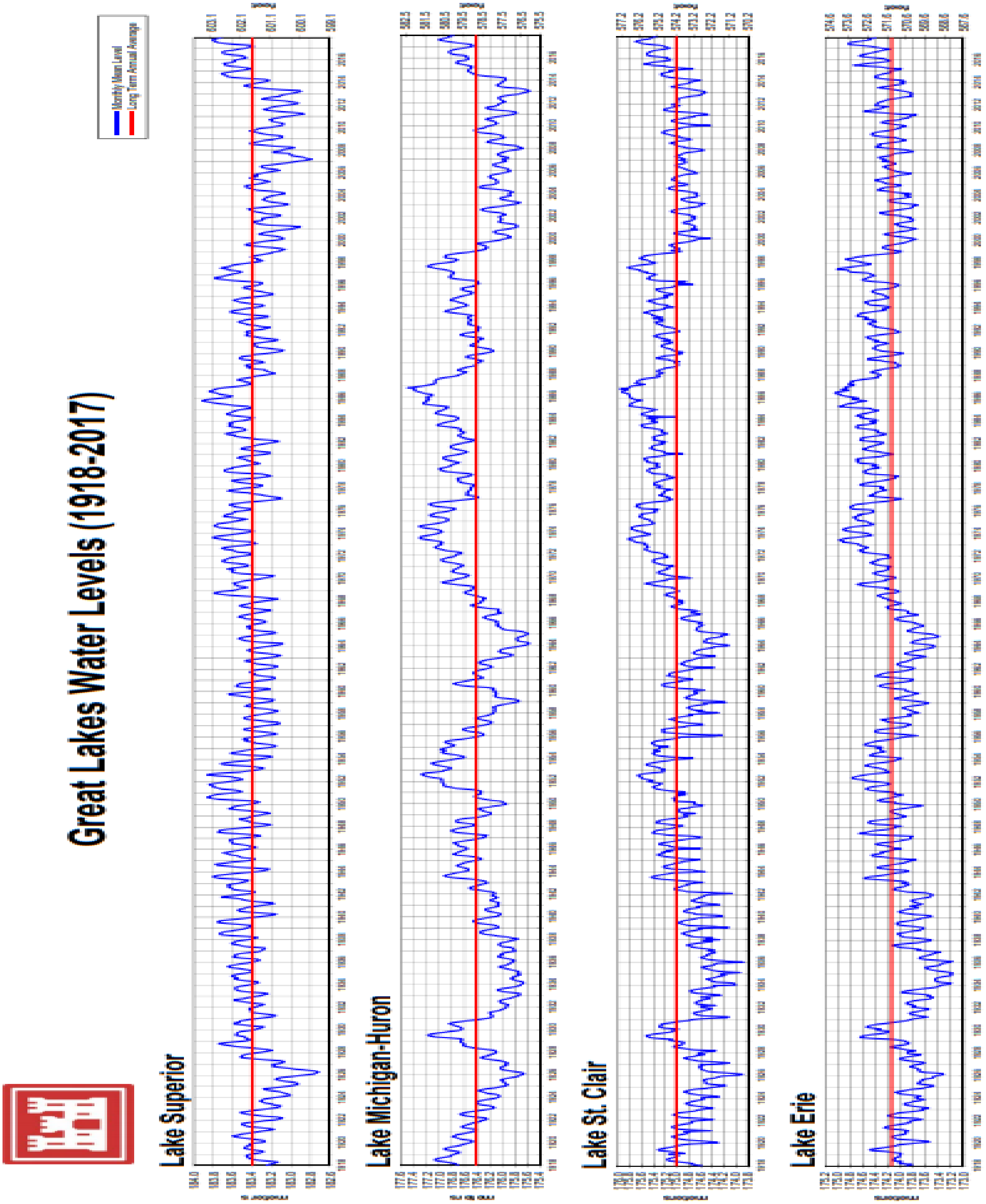
- Floodplain/coastal zone management – planning acceptable uses for areas prone to flooding (comprehensive planning, zoning, open space requirements, subdivision regulations, land use and capital improvements planning).
- Dry floodproofing of structures within known flood areas (strengthening walls, sealing openings, use of waterproof compounds or plastic sheeting on walls).
- Wet floodproofing of structures (controlled flooding of structures to balance water forces and discourage structural collapse during floods).
- Elevation of flood-prone structures above the 100-year flood level.
- Construction of elevated or alternative roads that are unaffected by flooding, or making roads more flood-resistant through better drainage and/or stabilization/armoring of vulnerable shoulders and embankments.
- Government acquisition, relocation, or condemnation of structures within floodplain or floodway areas.
- Employing techniques of erosion control in the area (bank stabilization, planting of vegetation on slopes, creation of terraces on hillsides).
- Enforcement of basic building code requirements related to flood mitigation.
- Joining the National Flood Insurance Program, obtaining insurance, and participating in the Community Rating System (CRS).
- Structural projects to channel water away from people and property (dikes, levees, floodwalls) or to increase drainage or absorption capacities (spillways, water detention and retention basins, relief drains, drain widening/dredging or rerouting, debris detention basins, logjam and debris removal, extra culverts, bridge modification, dike setbacks, flood gates and pumps, wetlands protection and restoration).
- Elevating mechanical and utility devices above expected flood levels.
- Flood warning systems.
- Monitoring of water levels with stream gauges and trained monitors.
- Anchoring of manufactured homes to a permanent foundation in flood areas, but preferably these structures would be permanently relocated outside of flood-prone areas and erosion areas.
- Control and securing of debris, yard items, or stored objects in floodplains that may be swept away, damaged, or pose a hazard when flooding occurs.
- Increased coverage and use of NOAA Weather Radio.
- Locating structures and infrastructure landward of the established setbacks.

Assessments in Local Hazard Mitigation Plans

Shoreline hazards were identified as some of the most significant hazards in local hazard mitigation plans for the following counties: Antrim, Baraga, Bay, Benzie, Emmet, Grand Traverse, Houghton, Keweenaw, Leelanau, Luce, Macomb, Manistee, and Marquette.

Great Lakes Water Levels: 1918-2017

Measurements are in meters



Source: USACE, https://www.lre.usace.army.mil/Portals/69/docs/GreatLakesInfo/docs/WaterLevels/LTA-GLWL-Graph_2017.pdf?ver=2018-02-16-161313-577

Shoreline Hazard History for Michigan Counties – arranged by geography – 1-1-1996 to 4-30-2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions
NOTE: N/A means not applicable (not a coastal county)

COUNTY or area	Shoreline Events	Days with Shoreline Hazards	Tot. property damage	Injuries	Deaths
Washtenaw	N/A				
Wayne					
.Livingston	N/A				
Oakland	N/A				
Macomb					
5 Co Metro region					
Berrien	18	17		8	16
Cass	N/A				
St. Joseph	N/A				
Branch	N/A				
Hillsdale	N/A				
Lenawee	N/A				
Monroe	2	2			
.Van Buren	1	1			
Kalamazoo	N/A				
Calhoun	N/A				
Jackson	N/A				
.Allegan	1	1			
Barry	N/A				
Eaton	N/A				
Ingham	N/A				
.Ottawa					
Kent	N/A				
Ionia	N/A				
Clinton	N/A				
Shiawassee	N/A				
Genesee	N/A				
Lapeer	N/A				
St. Clair					
.Muskegon	2	2	$20,000		
Montcalm	N/A				
Gratiot	N/A				
Saginaw					
Tuscola					
Sanilac	1	1			
.Mecosta	N/A				
Isabella	N/A				
Midland	N/A				
Bay					
Huron	3	3			
34 Co S Lower Pen	**0.8 avg.**	**0.8 avg.**	**$20,000**	**8**	**16**

Continued on next page…

Part 2 of Shoreline Hazard History for Michigan Counties – arranged by geography

.Oceana					
Newaygo	N/A				
.Mason	N/A				
Lake	N/A				
Osceola	N/A				
Clare	N/A				
Gladwin	N/A				
Arenac					
.Manistee	1	1			1
Wexford	N/A				
Missaukee	N/A				
Roscommon	N/A				
Ogemaw	N/A				
Iosco					
.Benzie	2	2		1	1
Grand Traverse					
Kalkaska	N/A				
Crawford	N/A				
Oscoda	N/A				
Alcona					
.Leelanau	1	1			1
Antrim					
Otsego	N/A				
Montmorency	N/A				
Alpena	1	1			
.Charlevoix					
Emmet	2	2			1
Cheboygan					
Presque Isle					
29 Co N Lower Pn	**0.2 avg.**	**0.2 avg.**		**1**	**4**
Gogebic					
Iron	N/A				
Ontonagon					
Houghton	1	1			
Keweenaw	1	1			
Baraga	1	1			
.Marquette	5	5			5
Dickinson	N/A				
Menominee					
Delta	1	1			1
Schoolcraft					
Alger	4	4	$2,000		2
.Luce	1	1			
Mackinac	1	1			2
Chippewa	1	1	$200,000		
15 Co Upp.Pen	**1.1 avg.**	**1.1 avg.**	**$202,000**		**10**
MICHIGAN TOTAL	**51**	**44**	**$222,000**	**9**	**30**
Annual average	**2.4**	**2.1**	**$10,408**	**0.4**	**1.4**

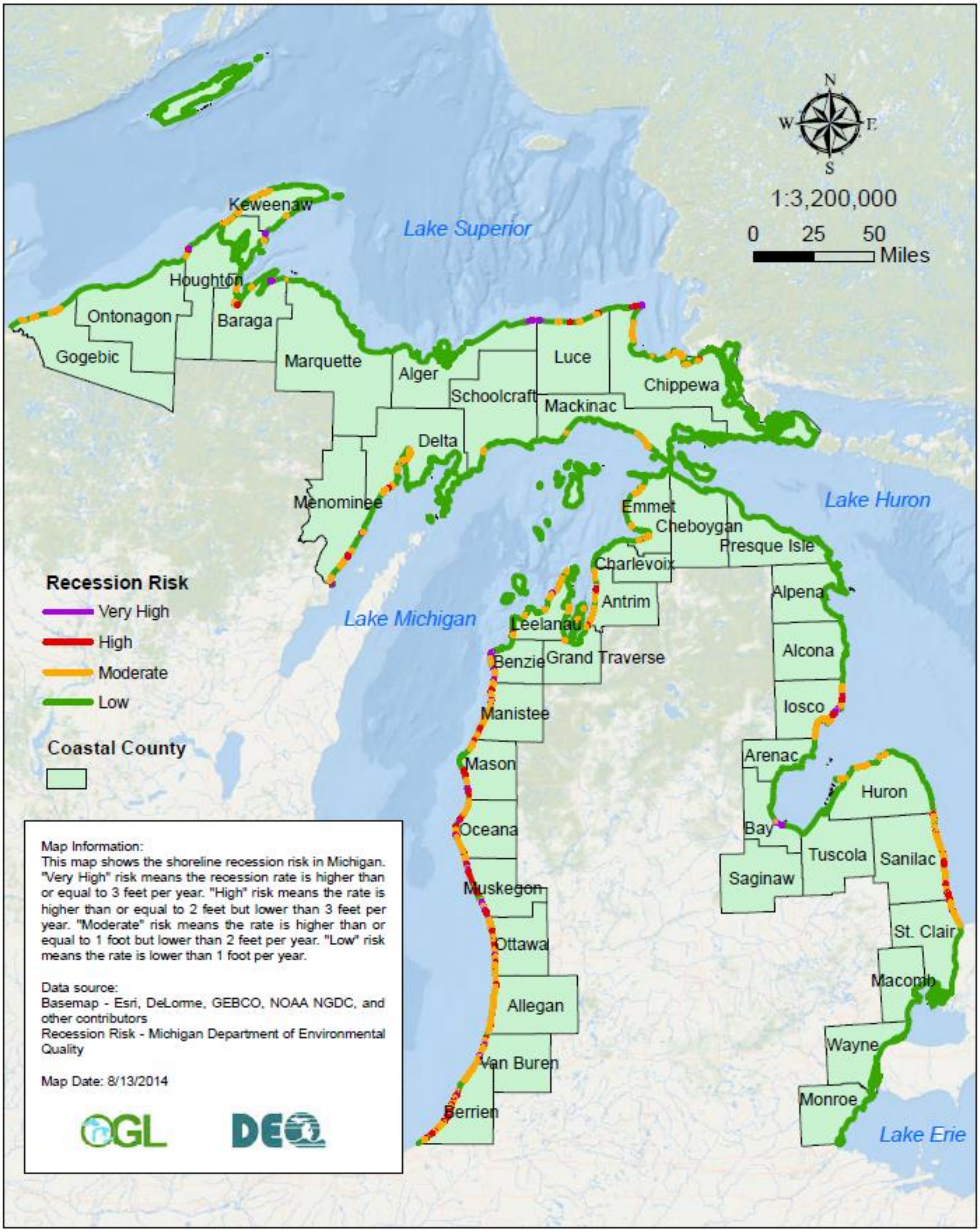
NOTE: Includes the NCDC categories of "High Surf," "Rip Current," "Seiche," and "Waterspout."

NOTE: Some qualifying shoreline events have been classified by NCDC under other hazards, such as flooding. This table does not fully represent the impacts of the shoreline erosion hazard.

Michigan Great Lakes Shoreline Erosion Hazard Areas

Source: Michigan Department of Environmental Quality

Shoreline Recession Risk in Michigan



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 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.

Flood control structures such as levees, berms, and floodwalls may also fail. A **levee** (or dike) is usually a compacted earthen structure, made up of soil types impervious to water (especially at their core). Their sides tend to be sloped and require ongoing maintenance to prevent seepage. A **berm** is merely 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. Although more expensive to build, floodwalls may be chosen over levees as their non-sloped walls take up less space in crowded urban areas and can provide section gates that open and close.

Hazard Analysis

Many of Michigan's first dams were relatively small efforts related to gristmills and older industry, the remnants of which may still exist. The late 19th Century also saw private hydroelectric efforts upon waterways. As many dams aged, changing economics created challenges for continued maintenance. In some cases structures were simply 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 useful life of an earth embankment dam is 50 years according to the United States Bureau of Reclamation. While there are many variables, the Association of State Dam Safety Officials has projected an average age of 57 years for roughly 90,000 existing dams nationwide. The majority of these dams are "low hazard" (see below), but about 17% are "high hazard". The Michigan Department of Environment, Great Lakes, and Energy (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 Natural Resources and Environmental Protection Act (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.

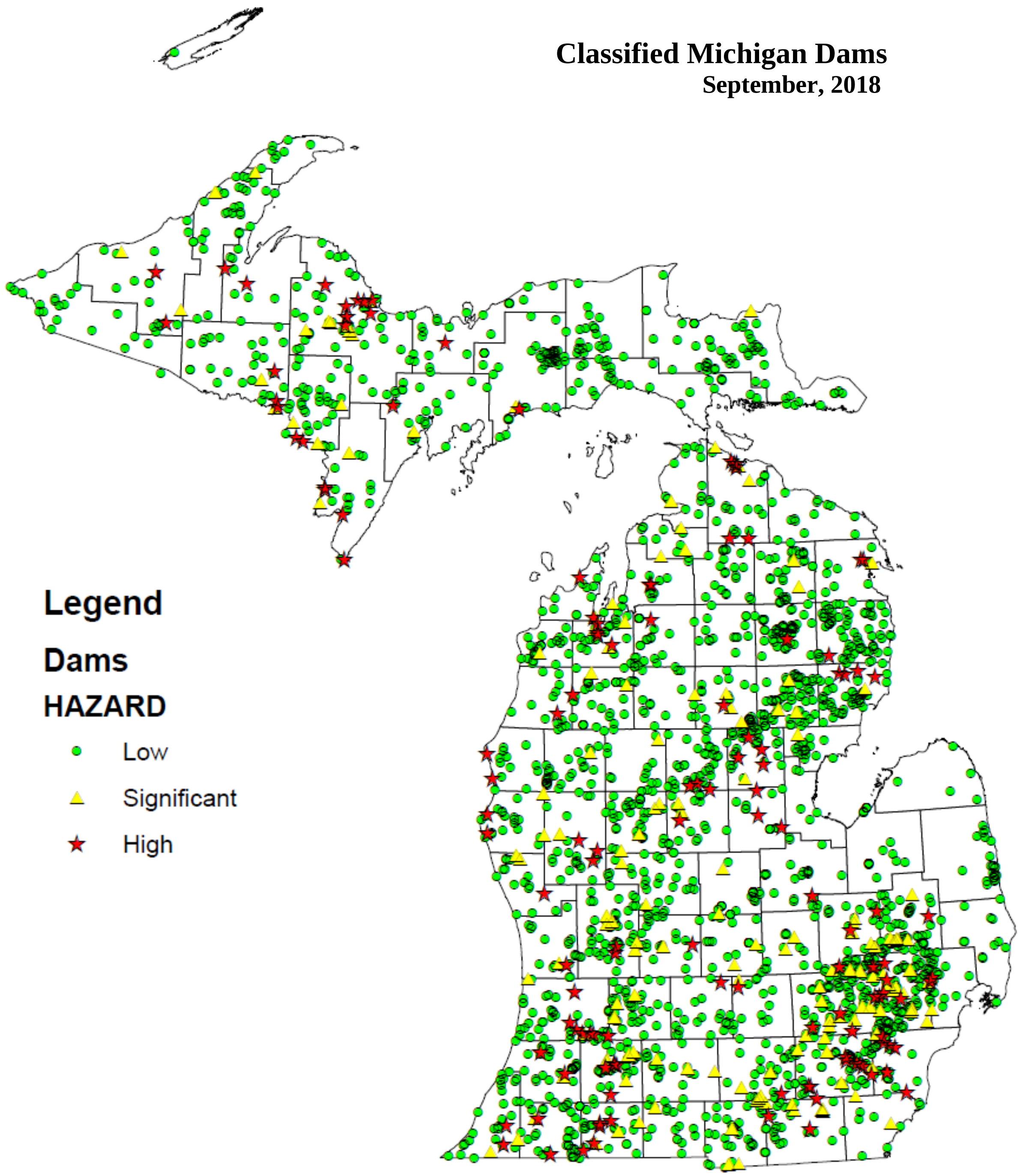
- A Significant Hazard Potential Dam means a dam where failure may cause damage limited to isolated inhabited homes, agricultural buildings, structures, secondary highways, short line railroads, or public utilities, where environmental degradation may be significant, or where danger to individuals exists.

- 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.

The Federal Emergency Management Agency's (FEMA) pocket guide 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

As of 2019, 135 Michigan dams were classified under state law as being High Hazard Potential Dams, with 156 and 840 dams classified as being Significant or Low Hazard Potential Dams, respectively. High Hazard Potential Dams are listed by county towards the end of this chapter. An interactive web map can be accessed by clicking HERE.



(source: Michigan State Police)

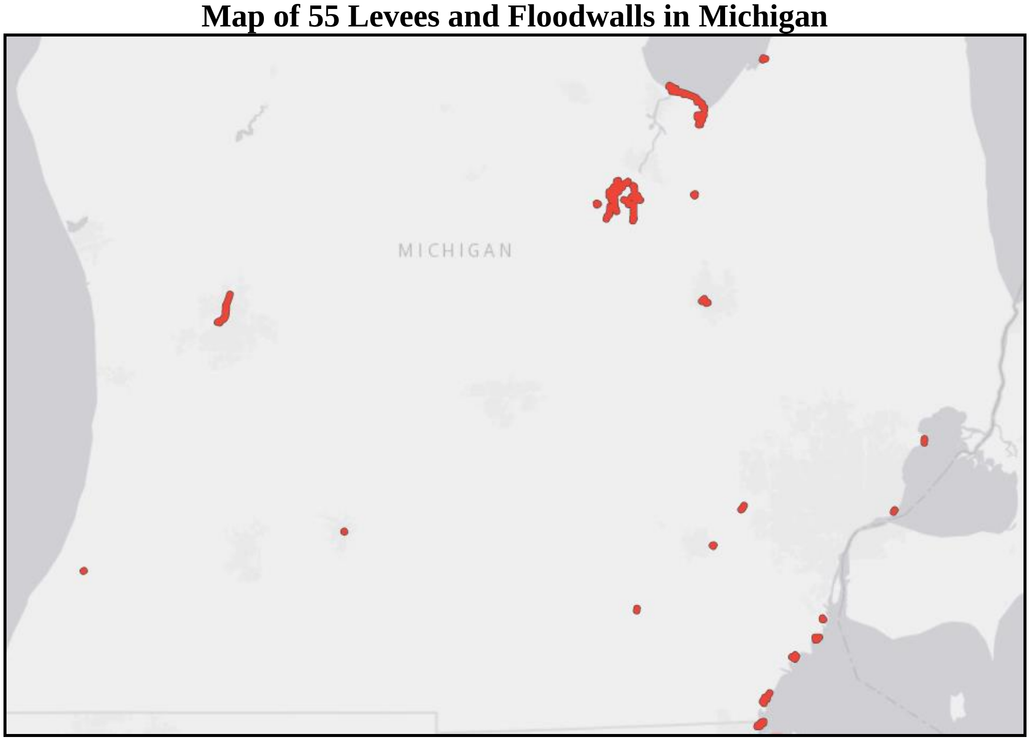
Effects from dam failures can be more severe than those from riverine flooding due to the potential size of a sudden flash flood and wave action from a catastrophic failure. It should be noted however that a "high" hazard status does not always indicate the kind of deadly flood risk that some laypersons 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 upon the integrity of important roads. Just one potential impact type being identified as sufficiently elevated will raise the category level for an entire dam.

Upstream dam failures that occur in other counties may still have catastrophic consequences for far away downstream communities. 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 means 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 upon scope and outcome. A community with no history of dam failure may wish to examine the histories of similar dams (based on size, construction, ownership, and maintenance schedules), 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 about 2.3 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. In the 2018 Michigan Infrastructure Report Card, the American Society of Civil Engineers assigned Michigan's dams a C- grade, citing more than $225 million necessary to address the state's aging dams. Michigan has 271 dams that are over 100 years old, and 12% of Michigan dams have a High or Significant Hazard Potential Dam rating. Roughly 67% of its dams are over 50 years old. An inventory of older dams suggests an actual risk for failures higher than the recent history of events alone may indicate.

Thirteen counties also have floodwalls or levees (not counting small berms): Bay (8), Berrien (1), Calhoun (2), Genesee (3½), Huron (1), Kent (3), Lenawee (½), Macomb (1), Monroe (4½), Saginaw (22), Tuscola (½), Washtenaw (1½), and Wayne (6). The ½ refers to dams located on political borders.

Map of 55 Levees and Floodwalls in Michigan



(source: U.S. Army Corps of Engineers https://levees.sec.usace.army.mil/#/, as listed on August 10, 2020)

Ten of these are levees of the U.S. Army Corps of Engineers (USACE), with the remaining locations indicating non-federal levees locally constructed, operated, and maintained. The National Levee Database continues to be updated, and information should be confirmed when used for local planning purposes. Downtown Grand Rapids has the tallest Michigan floodwall, as well as the largest estimated consequence from failure.

While not the focus of this chapter, it bears mentioning that 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".

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.

Impact on Public Confidence in State Governance

Recorded dam failures in Michigan have threatened some residents' perceptions of the reliability of government standards and policy regarding the engineering, inspection, and maintenance of such structures. The worst such instance involved the 2020 failure of the Edenville Dam, which was a privately owned and difficult to regulate hydroelectric dam which received significant media attention due to lengthy legal proceedings. Public uncertainty over federal versus state roles and regulations may also create levels of discord and confusion.

Select Dam Failures in Michigan

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 on the River Raisin was washed out by flooding in June of 1969 and was later rebuilt. Some older historical dams throughout the state were simply abandoned when they failed or were no longer needed.

September 1986 – Central Lower Michigan (Federal Disaster #774 – 30 counties)

A slow moving low-pressure system produced 8-17” of rainfall over a 60 mile wide/180 mile long area during a 24-hour period. In Big Rapids, 19” 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 $300 million in damages.

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 snow melt, with their water/wastewater treatment and electric plants in danger of inundation and shutdown. The 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 federal Disaster Declaration was issued by the President.

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 11am the next day, accumulated waters had overtopped the Tourist Park Dam, which then failed structurally at 12:30pm, 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 $3.2 million (of which $1,000,000 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 U.S. 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.

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”, 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 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’s impact was estimated at $200,000. Many roads were also inundated or washed out.

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 evaluations 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 $1.8 million.

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 $60,000 in property damage to them. 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 U.S. 127 bridge.

May 19, 2020 – Gladwin, Midland, and Saginaw Counties (Federal Disaster 4547-DR)
A heavy storm began on May 18, delivering up to 6-8" 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 9 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 $320 million in property damage.

Many evacuated persons found shelter with friends, but 280 families were put up in motel or hotel lodging. At least 500 persons made use of temporary shelter facilities, made difficult due to COVID-19 pandemic precautions. Some evacuees chose to sleep in their vehicles to reduce virus exposure. Evacuations also included multiple nursing homes in Saginaw and Midland Counties, involving hundreds of senior citizens. One senior facility in Midland had roof damage and 18 inches of floodwaters. 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 stood up. Power failures occurred as cables were damaged, and there were additional impacts on gas, phone, and internet lines. The area network hub for Sanford TDS was completely lost. Downtown business closures and inundated agricultural lands hurt the economy. The drained lake areas created an erosion risk as the former shorelines threatened to crumble and place properties at risk.

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.

Programs and Initiatives

Michigan Dam Safety Program (DSP)
Part 315 of NREPA, 1994 PA 451, Dam Safety, provides for the rating and inspection of state dams. Dams over 6 feet tall that create impoundment surface areas of 5 acres or more are regulated by Part 315. Regulated dam owners are required to maintain an Emergency Action Plan (EAP) 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 DSP to regulate certain other dams (Part 307 establishes legal lake levels and describes the authority to maintain lakes and operate dams). Additional information can be found on EGLE's Dam Safety Program 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.

Federal Energy Regulatory Commission (FERC) and Federal Programs
Hydroelectric dams are not regulated under Part 315 of NREPA (above) and are instead licensed by the FERC. 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 Dam Safety Program can be found HERE.

National Inventory of Dams
The National Inventory of Dams (NID) is a congressionally authorized database that includes information for all High and Significant Hazard Potential Dams, as well as many Low Hazard Potential Dams. The NID is maintained and published by the U.S. Army Corps of Engineers (USACE).

High Hazard Potential Dam (HHPD) Program
The program provides technical, planning, design, and construction assistance for the rehabilitation of certain High Hazard Potential Dams under the National Dam Safety Program (33 U.S.C. 467f, Sec. 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. In conjunction with FEMA, 9 dams were identified in 2020 as having potentially met federal eligibility requirements. Program related assessment information is available at the end this chapter.

Hazard Mitigation Alternatives for Dam Failures

- Regular inspection and maintenance of dams.
- Funding mechanisms to assist dam owners in the removal or repair of dams in disrepair.
- Moving private dams into public ownership (where necessary for safety).
- Development regulation in dam inundation zones.
- Public warning systems.
- Obtaining insurance.
- Increased coverage and use of NOAA Weather Radio
- Increased funding for dam inspections and enforcement of the Dam Safety Program to ensure that dams meet or exceed design criteria as required by law.
- Constructing emergency access roads to dams, where needed.
- Pump and flood gate installation/automation.

Assessment in Local Hazard Mitigation Plans

Dam failures were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Alpena, Houghton, Iron, Marquette, Midland, and Newaygo (a decrease between 2014 and 2019).

Statewide Dam Listing

EGLE maintains a database of all dams that are: (1) regulated by Michigan's dam safety laws, (2) hydropower dams regulated by the Federal Energy Regulatory Commission (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 following page.

COUNTY	MICHIGAN HIGH HAZARD POTENTIAL DAMS
Alcona	Alcona Dam (54' hydro on Au Sable River)
Alger	Au Train Dam (38' hydro on Au Train River)
Allegan	Allegan City Dam (14' retired hydro on Kalamazoo River), Lake Doster Dam (34' recreational on tributary to Silver Creek), Menasha Dam (22' Otsego hydro recreational on Kalamazoo River), Monterey Lake Dam (20' recreational on Pigeon Creek), Otsego Dam (21' MDNR retired hydro on Kalamazoo River), Trowbridge Dam (25' MDNR retired hydro on Kalamazoo River)
Alpena	Four Mile Dam (35' hydro), Norway Point Dam (62' hydro)—both on Thunder Bay River
Antrim	Bellaire Dam (18' County retired hydro on Intermediate River), Cedar River Dam (25' Bellaire Village retired hydro on Blair Lake/Craven Pond)
Baraga	Ford Dam (26' MTU recreational on Plumbago Creek), Prickett Diversion Dam (61' hydro on Sturgeon River)
Berrien	Buchanan Dam (28' hydro), Berrien Springs Dam (36' hydro)—both on St. Joseph River
Cass	Adamsville Dam (10.7' hydro on Christiana Creek), Upper Mill Dam (14.3' recreational on Dowagiac Creek)
Cheboygan	Cornwall Creek Dam (33' MDNR recreational on Cornwall Creek), Little Black River Structures A-D (21.7', 25', 31.1', 34' Cheboygan flood/stormwater on Little Black River branches and tributaries), Wildwood Lake Dam (23' recreational on Bradley Creek)
Clare	Lake 13 Dam (19' recreational on Runyon Creek), Shamrock Lake Dam (16' County recreational on Elm Creek), Surrey Lake Dam (20' Clare recreational on Tobacco River)
Delta	Escanaba #4 Dam (69' hydro on Escanaba River)
Dickinson	Big Quinnesec Falls Dam (82' hydro), Little Quinnesec Falls Dam (65' hydro—both on Menominee River
Eaton	Carrier Creek Structures A-B (24', 20' County flood/stormwater on Carrier Creek), Myers-Henderson Detention Pond (13' County flood/stormwater on Miller Creek)
Genesee	Hamilton Dam (22' Flint water supply on Flint River), Holloway Dam (38' Flint recreational on Flint River), Linden Mill Dam (17' County retired hydro on Shiawassee River)
Gladwin	Chappel Dam (32' County retired hydro on Cedar River), Edenville Dam (54' hydro on Tittabawassee River), Lake Lancer Dam (36' County recreational on Sugar River), Secord Dam (57' hydro on Tittabawassee River), Smallwood Dam (36' hydro on Tittabawassee River)
Grand Traverse	Boardman Dam (56' County retired hydro), Brown Bridge Dam (46' Traverse City retired hydro), Sabin Dam (34' County retired hydro), Union Street Dam (21' Traverse City recreational)—all on Boardman River
Ingham	Moores Park Dam (21' hydro on Grand River)
Ionia	Webber Dam (33' hydro on Grand River)
Iosco	Cooke Dam (54'), Five Channels Dam (60'), Foote Dam (55'), Loud Dam (55')—all hydro on Au Sable River
Iron	Michigamme Falls Dam (70'), Peavy Falls Dam (75'), Way Dam (50') all hydro on Michigamme Riv.
Isabella	Lake Isabella Dam (41' recreational on Chippewa River)
Isabella	Lake Isabella Dam (41' recreational on Chippewa River)
Jackson	Brooklyn Dam (22' retired hydro on River Raisin)
Kalamazoo	Bryant Mill Dam (16.75' retired hydro on Portage Creek), Lower Comstock Dam (18' Township recreational on Comstock Creek), Middle Comstock Dam (21' Township recreational on Comstock Creek), Morrow Dam (25' hydro on Kalamazoo River), Sunset Lake Dam (11.06' County recreation on Gourdneck Creek)
Kalkaska	Rugg Pond Dam (24' County retired hydro on Rapid River)
Kent	Ada Dam (31'), Cascade Dam (31' Township), LaBarge Dam (32') all hydro on Thornapple Riv.
Lapeer	Mill Creek Structure (28' flood/stormwater on North Branch Mill Creek)
Leelanau	Leland Dam (19' County retired hydro on Lake Michigan tributary), Meeuwenberg (42' recreational on Cedar Lake tributary)
Lenawee	Addison Mill Dam (24.5' Addison retired hydro on Bean Creek), Atles Mill Dam (13' recreational on River Raisin), Lake Adrian Dam (30' Adrian water supply on Wolf Creek)

(cont.)

COUNTY	MICHIGAN HIGH HAZARD DAMS
Livingston	HiLand Lake Dam (19.1’ Washtenaw recreational on Portage River/Hell Creek), Nichwagh Lake Dam (16’ retired hydro on Huron River tributary), Woodland Lake Dam (19’ recreational on South Ore Creek)
Mackinac	Cedarville Operation Tailings Basin Dam (10’ tailings on Lake Huron tributary)
Macomb	Lower Stony Lake Dam (32’), Upper Stony Lake Dam (24’)—both recreational on Stony Creek
Manistee	Hodenpyl Dam (90’), Tippy Dam (80’)—both hydro on Manistee River
Marquette	Carp Intake Dam (57’ retired hydro on Carp River), Carp River Dam (60’ retired hydro on Carp River), Hoist Dam (85’ hydro on Dead River), Lake Sally Dam (15’ on Ely Creek), McClure Dam (64’ hydro on Dead River), Ogden Lake Dam (9’ on Ely Creek), Silver Lake Basin Dam (36’ on Dead River), Tilden Recirculation Basin (95’ water supply on Schweitzer Creek tributary), Upper Dam #2 (62’ Marquette City hydro on Dead River)
Mason	Hamlin Lake Dam (23’ MDNR recreational on Big Sable River), Ludington Pumped Storage (170’ hydro)
Menominee	Chalk Hill Dam (38’), Grand Rapids Dam (32’), Lower Menominee River Dam (29’), White Rapids Dam (52’)—all hydro on Menominee River
Midland	#6 Brine Pond Dam (12’ on Tittabawassee River tributary), Midland Storage Basin (20.5’ Midland City flood/stormwater), Sanford Dam (36’ on Tittabawassee River), Tertiary Pond Dam (14.7’ on Tittabawassee River tributary)
Muskegon	Muskegon Waste Water Lagoons (21’ County on Black and Mosquito Creeks)
Newaygo	Croton Dam (60’ hydro on Muskegon River), Hardy Dam (125’ hydro on Muskegon River), White Cloud Dam (18.9’ City retired hydro on White River)
Oakland	Clarkston Dam (34’ retired hydro on Clinton River), Dawson Millpond Dam (9’ County retired hydro on Clinton River), Heron Dam (26’ MDNR recreational on Thread Creek), Lake Louise Dam (12’ County recreational on Kearsley Creek), Lake Neva Dam (17’ recreational on Cedar Creek), Oxbow Dam (15’ County recreational on Huron River), Pontiac Lake Dam (21’ County on Huron River), Wildwood Lake Dam (22’ MDNR recreational on Thread Creek)
Oceana	Holiday Lake Dam (27’ recreational on Golden Creek), Upper Silver Lake Dam (25’ recreational on Au Sable Creek)
Ontonagon	Bond Falls Dam (46’ hydro on Ontonagon River Middle Branch), Victoria Diversion Dam (120’ hydro on Ontonagon River West Branch)
Oscoda	Mio Dam (50’ hydro on Au Sable River)
Ottawa	Buttermilk Creek Detention Dam (13’ County flood/stormwater on Buttermilk Creek)
Roscommon	Lake James Dam (17.7’ recreational on Denton Creek)
Saginaw	Misteguay Creek 4 (39’ County recreational on Misteguay Creek)
St. Joseph	Constantine Hydro Dam (30’ hydro on St. Joseph River), Mottville Dam (20’ hydro on St. Joseph River), Portage Plant Dam (19’ retired hydro on Portage River), Sturgis Dam (41’ Sturgis City hydro on St. Joseph River), Three Rivers Dam (16’ hydro on St. Joseph River)
Schoolcraft	Manistique Papers Dam (25’ retired hydro on Manistique River)
Van Buren	Maple Lake Dam (27’ Paw Paw Village retired hydro on Paw Paw River South Branch)
Washtenaw	Argo Dam (18’ Ann Arbor City retired hydro on Huron River), Barton Dam (29’ Ann Arbor City hydro on Huron River), Ford Manchester Dam (26.5’ Manchester Village retired hydro on River Raisin), Geddes Dam (28’ Ann Arbor City retired hydro on Huron River), Manchester Mill Dam (18’ retired hydro on River Raisin), Peninsular Paper Dam (21’ Ypsilanti City retired hydro on Huron River), Rawsonville Dam (54’ Ypsilanti Township hydro on Huron River), Superior Dam (32’ Ann Arbor City hydro on Huron River)
Wayne	Detroit Metro Airport Stormwater Pond 6 (17’ flood/stormwater on Frank & Poet Drain), Flat Rock Dam (16.5’ retired hydro on Huron River), French Landing Dam (35’ Van Buren Township hydro on Huron River), Nankin Mill Dam (17’ County retired hydro on River Rouge Middle Branch), Newburgh Dam (29’ County retired hydro on River Rouge Middle Branch), Phoenix Dam (24’ County retired hydro on River Rouge Middle Branch), Waterford Dam (20.5’ retired hydro on River Rouge Middle Branch), Wilcox Dam (27’ retired hydro on River Rouge Middle Branch)

High and Significant Hazard Potential Dams in Michigan*
(as of August 26, 2020)

County	High Hazard	Significant Hazard	Total	County	High Hazard	Significant Hazard	Total
Alcona	1		**74**	Lake		2	**36**
Alger	1		**23**	Lapeer	1	6	**63**
Allegan	6	2	**48**	Leelanau	2	1	**16**
Alpena	2	1	**11**	Lenawee	3	5	**33**
Antrim	2		**15**	Livingston	3	7	**61**
Arenac		1	**19**	Luce			**24**
Baraga	2		**15**	Mackinac	1		**29**
Barry		3	**44**	Macomb	2	1	**28**
Bay			**6**	Manistee	2		**14**
Benzie		1	**28**	Marquette	9	8	**67**
Berrien	2	2	**32**	Mason	2		**14**
Branch		1	**20**	Mecosta		4	**40**
Calhoun		3	**27**	Menominee	4	2	**19**
Cass	2	1	**43**	Midland	4		**14**
Charlevoix		3	**14**	Missaukee		1	**17**
Cheboygan	6	3	**26**	Monroe		2	**11**
Chippewa		1	**60**	Montcalm		2	**33**
Clare	3		**42**	Montmorency		2	**37**
Clinton		2	**21**	Muskegon	1	2	**17**
Crawford			**17**	Newaygo	3	1	**24**
Delta	1	1	**24**	Oakland	8	15	**150**
Dickinson	2	3	**41**	Oceana	2	2	**23**
Eaton	3		**26**	Ogemaw		3	**68**
Emmet		1	**18**	Ontonagon	2	2	**20**
Genesee	3	7	**35**	Osceola		1	**17**
Gladwin	5	1	**35**	Oscoda	1		**54**
Gogebic			**21**	Otsego			**23**
Grand Traverse	4	4	**31**	Ottawa	1	1	**24**
Gratiot		2	**19**	Presque Isle			**15**
Hillsdale		5	**46**	Roscommon	1	3	**36**
Houghton		1	**36**	Saginaw	1		**25**
Huron			**6**	St. Clair			**16**
Ingham	1	1	**14**	St. Joseph	5	3	**34**
Ionia	1	1	**26**	Sanilac			**27**
Iosco	4	1	**49**	Schoolcraft	1	1	**53**
Iron	3	2	**30**	Shiawassee		2	**15**
Isabella	1	3	**22**	Tuscola			**17**
Jackson	1	4	**36**	Van Buren	1	1	**38**
Kalamazoo	5	5	**44**	Washtenaw	8	4	**66**
Kalkaska	1		**23**	Wayne	8	1	**38**
Kent	3	5	**59**	Wexford		2	**30**
Keweenaw			**9**	**TOTAL**	**141**	**158**	**2621**

* Roughly 88% of Michigan's dams are classified as Low Hazard Potential Dams. Their number can be calculated at the county level by subtracting the number of high and significant dams from the provided totals (for example, Wexford County would have 28 low hazard dams). The number of High Hazard Potential Dams in Marquette County and the greater Metropolitan Detroit area is greater than in most areas of the state.

High Hazard Potential Dam Grant Program: Assessment of Eligible Dams

The MSP/EMHSD coordinated with EGLE's DSP, which used information provided by USACE and previous assessment records from their own databases in preparation of this eligible dam assessment summary. Dam owners and local Emergency Managers had prior involvement in the development of referenced EAPs. While the contents of a full risk analysis for each HHPD eligible dam is beyond the scope of this document, primary data and vulnerabilities are presented in the tables below. Further information, including access to each dam's EAP, is available by contacting the EGLE DSP.

In conjunction with FEMA, the initial HHPD assessment and prioritization process involved the identification of all dams that met the following criteria: (1) prior assessment as high hazard potential, (2) an approved EAP on file with EGLE, (3) an assessed dam condition of poor or unsatisfactory, (4) in general, non-hydroelectric dams, (5) not constructed under the Department of the Army or other federal authority, (6) judged as not meeting minimum EGLE dam safety standards, (7) judged as posing an unacceptable risk to the public, (8) calculated population risk for a catastrophic failure, (9) potential for environmental impacts from such a failure, and (10) having a coordinated interest with local stakeholders (including dam owners). Nine dams are potentially eligible as shown below.

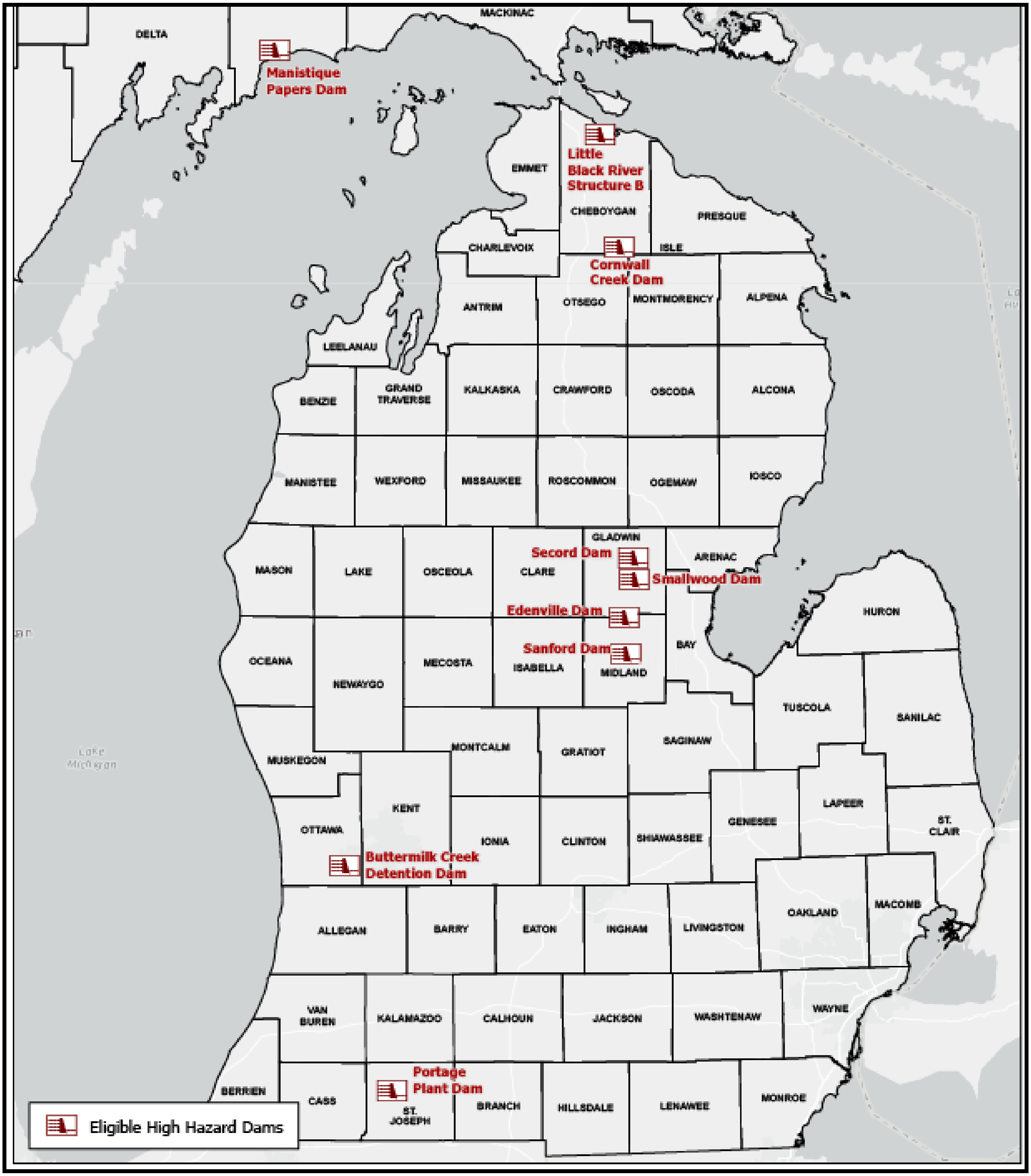
NAME	NID #	CONDITION*	TYPE, BUILT	POPULATION AT RISK (PAR)	COUNTY	OWNER
LITTLE BLACK RIVER, STRUCTURE B	MI00042	POOR	EARTH 1962	100[a]	CHEBOYGAN	CITY OF CHEBOYGAN
CORNWALL CREEK DAM	MI00246	POOR	EARTH 1966	100	CHEBOYGAN	MICHIGAN DEPT. NATURAL RESOURCES
PORTAGE PLANT DAM	MI00374	POOR	EARTH 1922	7,400	SAINT JOSEPH	PORTAGE POWER COMPANY
MANISTIQUE PAPERS DAM	MI00377	POOR	CONCRETE 1919	4,324	SCHOOLCRAFT	MANISTIQUE PAPERS, INC.
SECORD DAM	MI00547	UNSATISFACTORY	EARTH 1925	10,000[b]	GLADWIN	FOUR LAKES TASK FORCE
SMALLWOOD DAM	MI00548	UNSATISFACTORY	EARTH 1925	10,000[b]	GLADWIN	FOUR LAKES TASK FORCE
EDENVILLE DAM	MI00549	UNSATISFACTORY	EARTH 1924	10,000[b]	GLADWIN	FOUR LAKES TASK FORCE
SANFORD DAM	MI00550	UNSATISFACTORY	EARTH 1925	10,000[b]	MIDLAND	FOUR LAKES TASK FORCE
BUTTERMILK CREEK DETENTION DAM	MI04010	POOR	EARTH 2000	7,116	OTTAWA	OTTAWA COUNTY WATER RESOURCES COMMISSION

*Condition ratings: Satisfactory, Fair, Poor, Unsatisfactory. Unsatisfactory means a safety deficiency is recognized that requires immediate or emergency remedial action for problem resolution. Click HERE for National Inventory of Dams terminology.

[a] PAR reported in original USACE hazard classification. [b] PAR estimated on evacuations from May 19, 2020, flood event.

Some notable data limitations included older Population at Risk (PAR) value information and non-digitized inundation mapping processes due to the age of some EAPs. A map showing the locations of the nine potentially eligible dams for HHPD Grant funding in 2020-2021 is provided on the following page. Note that while infrastructure for the Edenville dam is substantially located in Gladwin County, some aspects of the dam are located in Midland County. The most devastating impacts from a severe failure would occur in the downstream Midland area, serving as a reminder that local Emergency Managers must look beyond their own county borders.

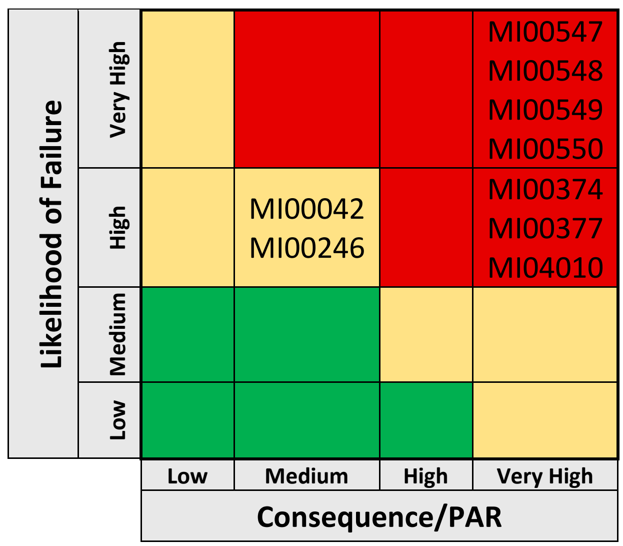
Potentially Eligible Dams Under the HHPD Grant Program, 2020-2021



(source: Michigan State Police)

Dam Name	Vulnerability / Deficiency
Little Black River Structure B	Piping exhibiting embankment loss is adjacent to the outlet pipe on the downstream slope.
Cornwall Creek Dam	Does not meet desirable factors of safety for slope stability due to ineffective clay core and high phreatic surface.
Portage Plant Dam	An engineering inspection is long overdue.
Manistique Papers Dam	Currently there is no legal owner of the dam due to bankruptcy and foreclosure. Significant structural deterioration of all concrete components. Difficulty with managing and operating gates causes concerns regarding flow management.
Secord Dam	Spillway lacks adequate hydraulic capacity and embankments lack desirable factors of safety for potential instability modes.
Smallwood Dam	2020 flood exposed concerns for erosion and embankment loss at auxiliary spillway. Additionally, erosion on downstream slopes around primary spillway identified a need for additional erosion protection.
Edenville Dam	Dam failed on May 20, 2020. Failure mode was identified as static liquefaction induced by elevated water levels. Spillways lacked adequate hydraulic capacity.
Sanford Dam	Dam failed on May 20, 2020. Failure mode was overtopping due to upstream failure of Edenville Dam. The former dam relied on fuse plug spillway for increased capacity.
Buttermilk Creek Detention Dam	It has been found that the auxiliary spillway for the dam was filled in for the development of an adjacent property. Further analysis is required to determine the impact on design flood capacity.

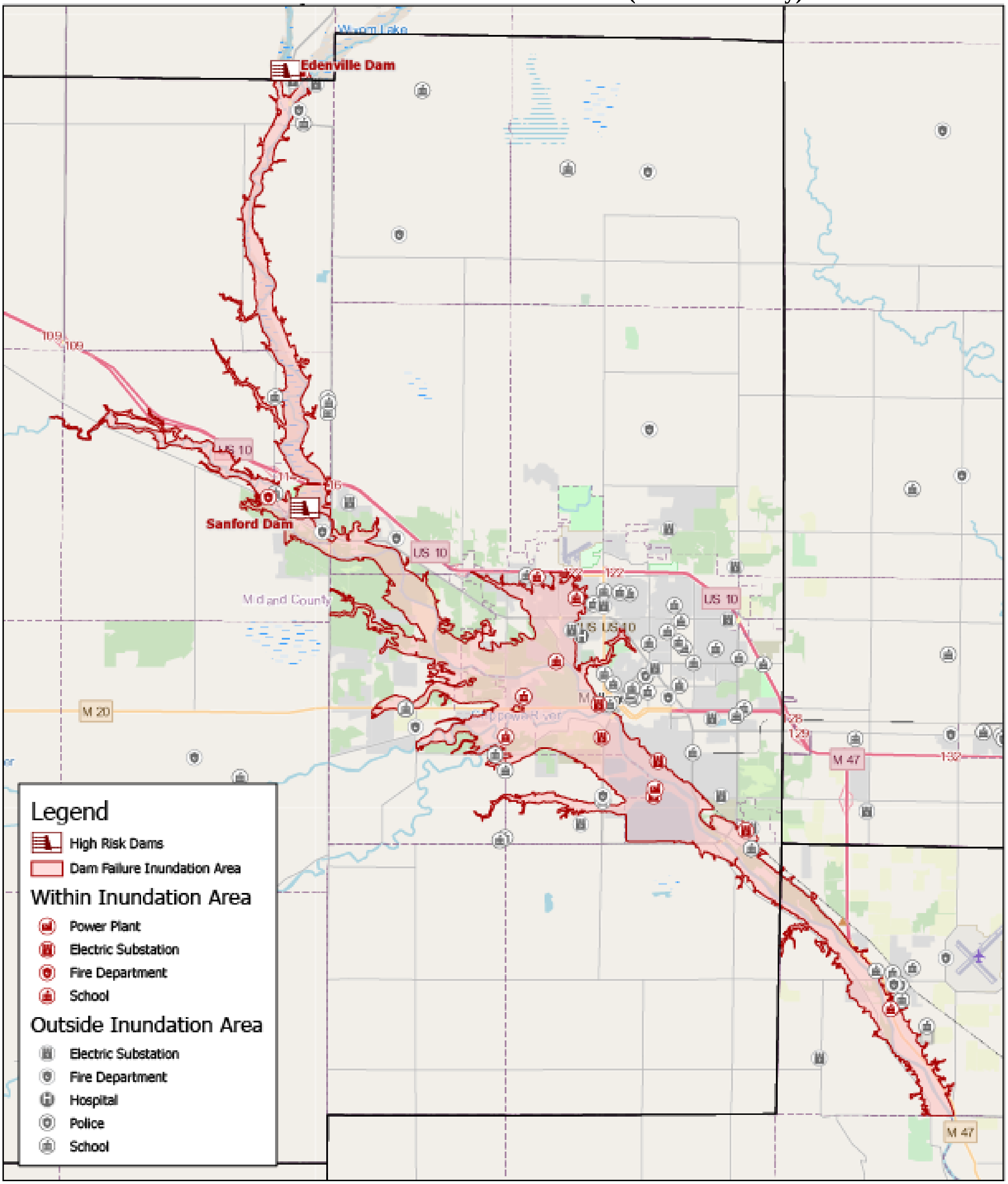
Dams received primary analysis based upon a FEMA recommended Risk Eligibility Matrix that examined both the likelihood of dam failure and the consequence of failure to the affected populations. This generated a subset of the four highest risk dams (MI00547-Secord, MI00548-Smallwood, MI00549-Edenville, and MI00550-Sanford).



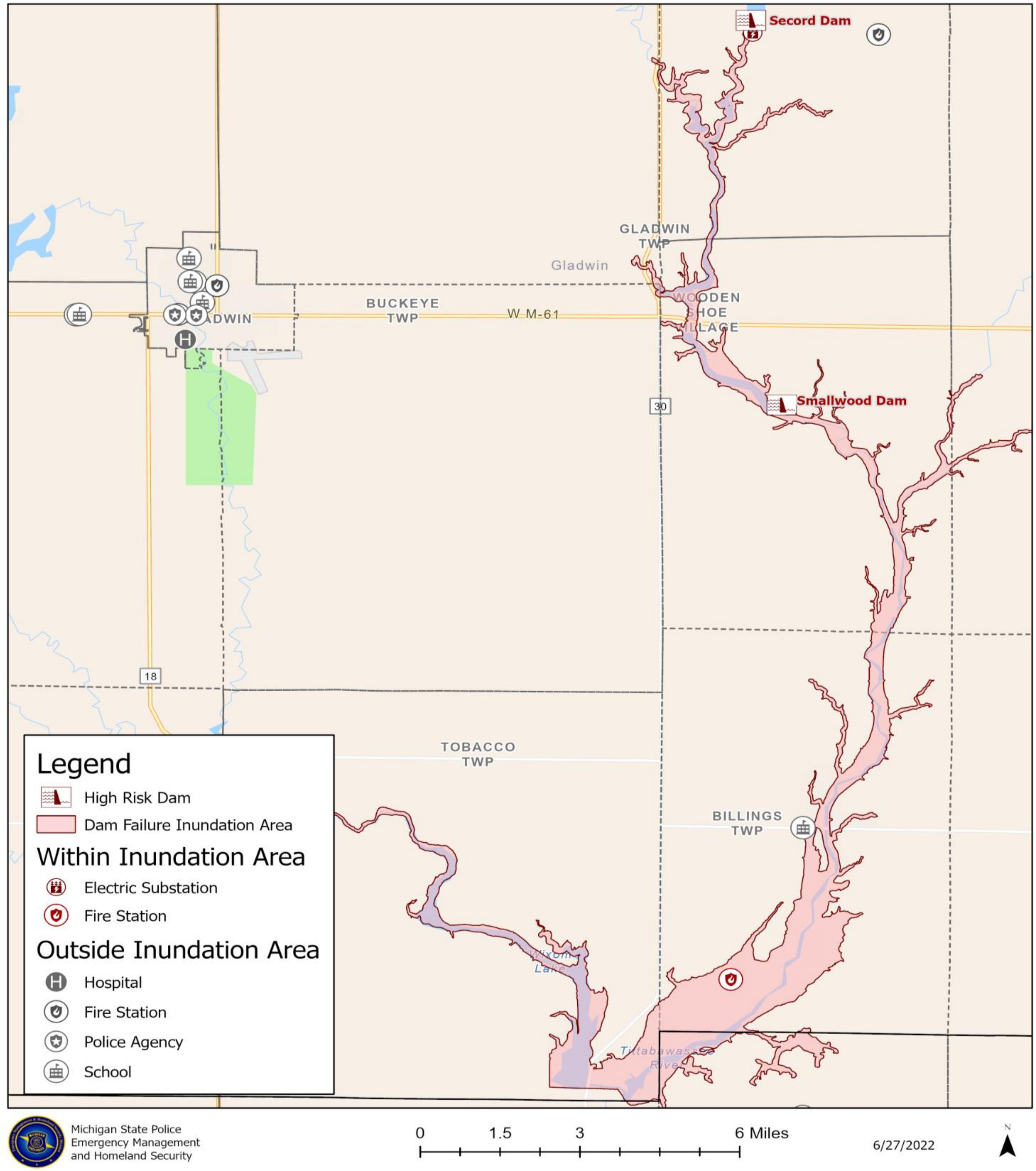
The severe failures of both the Edenville Dam and Sanford Dam in 2020 made them the prioritized focus of an application under the HHPD Grant Program. EGLE received a preliminary award notice for the two dams on Sept. 15, 2021, in the amount of $396,745. Including a necessary 35% state match, total approved project costs were $610,377 (Grant No. EMW-20210GR000167). Additional information on the grant is available by contacting the EGLE DSP.

There were multiple recommendations provided to the Governor and Legislature for consideration to improve dam safety following a review by the Association of State Dam Safety Officials (ASDSO) and the previously mentioned 2021 report by the Michigan Dam Safety Task Force. Within these are recommendations to develop a more thorough risk prioritization for all inventoried dams. The first deficiency identified in this effort was a lack of more refined population at risk (PAR) data, where downstream population figures grossly overrepresented PAR and skewed all dams to a higher risk. Inundation mapping improvements are also needed. Once completed, maps for HHPD eligible dams will be shared with emergency managers for inclusion in local plans. Examples for some completed maps are provided on the following pages. Addressing future HHPD planning has been designated as a new formal mitigation objective for 2021, see the Michigan Hazard Mitigation Plan for additional information.

Edenville and Sanford Dams Inundation Zone (Midland County)



Secord and Smallwood Dams Inundation Zone (Gladwin County)



Drought

A water shortage caused by unusual hydrologic conditions such as a deficiency of rainfall, and generally lasting for an extended period of time.

Hazard Description

Drought originates in a natural reduction in the amount of water available over an extended period of time, usually a season or more in length. Drought is a normal part of an area's climate, including areas that have very high or low average rainfall. A drought involves a level of precipitation or runoff that is substantially below an area's norms. In low-rainfall areas, drought involves a level of aridity that exceeds that which is usual for the climate. The severity of a drought depends not only on its location, duration, and geographical extent, but also on the area's water supply needs for human activities and vegetation. This geographic variation in drought standards can make the hazard difficult to describe to non-specialized audiences, and makes it difficult for them to assess when and where one occurring.

Drought differs from other natural hazards in several ways. First, there is no exact beginning and end point that is obvious for a drought, whose effects may accumulate slowly and linger even after the event is generally thought of as being over. Second, the lack of clearly visible and universal standards to define a drought can make it difficult to confirm in a timely manner whether one actually exists, and its degree of severity. Third, drought impacts are often less obvious than other natural hazards, and they are typically spread over a large geographic area. Fourth, most communities do not have any contingency plans in place for addressing drought. This lack of pre-planning can hinder support for drought mitigation capabilities that would otherwise effectively increase awareness and reduce drought impacts.

Hazard Analysis

Droughts can cause many severe impacts on communities and regions, including: 1) water shortages for human consumption, industrial, business and agricultural uses, power generation, recreation and navigation; 2) a drop in the quantity and quality of agricultural crops; 3) lowered water quality within lakes, streams, and other natural bodies of water; 4) malnourishment of wildlife and livestock; 5) increase in wildfires and wildfire-related losses to timber, homes, and other property; 6) declines in tourism in areas with water-related attractions and amenities; 7) declines in land values due to physical damage from the drought conditions and/or decreased economic or functional use of the property; 8) reduced tax revenue due to income losses in agriculture, retail, tourism and other economic sectors; 9) increases in insect infestations, plant disease, and wind erosion; and 10) possible human impacts due to food shortages, extreme heat, fire, and other health-related problems such as diminished sewage flows and increased pollutant concentrations in surface water.

Although it is difficult to determine when a drought began, once it is recognized then it can be classified within four different categories—meteorological, hydrologic, agricultural, and socioeconomic. 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 soil moisture with respect to the water needs of plant life such as crops. A **socioeconomic** drought is when the effective demand for water exceeds the supply to the extent that costs begin to escalate, sometimes as a result of weather-related shortfalls. As the population increases (both in the U.S. and worldwide), so too does the need for water for drinking, growing food, and running businesses and homes. That increasing need will eventually increase human vulnerability to future droughts.

The U.S. Drought Monitor (https://drought.unl.edu/droughtmonitoring/MonitoringHome.aspx) uses four classifications of severity, from the least intense category (D1) to the most intense (D4), with an additional (D0) category used to designate a "drought watch" area in which long-term conditions such as low reservoir levels are probably present. The Drought Monitor summary map is available online, identifying current drought areas and labeling their intensity. While not the only way to characterize droughts, the U.S. Drought Monitor is convenient and their classification levels have recently been used in various reports and assessments of drought conditions. Short-term indicators are on the level of 1 to 3 months, while long-term indicators focus on durations of 6 to 60 months.

Palmer Drought Classification Categories

Category	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: U.S. Drought Monitor web site https://droughtmonitor.unl.edu/AboutUSDM/AbouttheData/DroughtClassification.aspx

In addition, the U.S. Drought Monitor uses two general drought categories in assessing an event—an A to denote agricultural effects on crops, pastures, and grasslands, and an H to denote hydrologic effects on water supplies such as rivers, groundwater, and reservoirs.

Despite thousands of miles of rivers and streams and its surrounding Great Lakes, Michigan still experiences occasional drought conditions. Most common are agricultural droughts, with severe soil-moisture deficits, which have had serious consequences for crop production, particularly when coupled with extreme summer temperatures. Also, various water bodies, both inland lakes and the Great Lakes themselves, cyclically go through periods of low-water levels. Michigan has emerged from its latest such period and is now experiencing high water levels. (See the chapter on Great Lakes Shoreline Hazards for more information about these trends in water levels.)

Drought can be a "low-profile" hazard that does not get a lot of public attention in Michigan, compared with other parts of the United States. Nevertheless, parts of Michigan have tended to experience significant drought conditions about 20% of the time on average (depending upon how it is measured). Even if the occurrence of drought appears at first to be of lesser concern for a community, it is important to include a consideration of the drought hazard in local hazard mitigation planning, since plans are an excellent way to deal with gradual or longer-term hazards such as drought.

When a drought takes place, there are many impacts that can result from the extended dry period. These impacts can be classified as economic, social, and environmental. Of great significance is the economic loss of crop production through lower yields, poorer crop quality, and reduced productivity of the land. (Michigan's fruit production is especially vulnerable to lesser yields, as was seen in a 2001 drought event that caused the destruction of one-third of the state's fruit and vegetable crop.) Timber production is also reduced, through exacerbated risks from forest fires and tree diseases, and fisheries have lesser amounts of fish as water quality tends to degrade. Lessened production in the agricultural sector leads to income losses for farmers and industries dependent on agricultural products. Lower hydrologic levels lead to water shortages for municipalities and potential production limits or shutdowns in industries and businesses that depend on large volumes of water. Tourism becomes hampered by lower lake and river depths, due to the recreational difficulties and inconveniences that are caused. Severe and prolonged droughts could have catastrophic effects on the economy, in cases when adverse conditions lead to disruptions in the regional and national economy and when widespread economic losses affect the supply and distribution of goods and services.

Droughts can come to threaten to public health and safety, as water shortages and decreased water quality raise threats of illness, wildfires, and land subsidence. Conflicts between water users can arise, especially when a river or lake has competing uses among municipal, agricultural, industrial, and recreational users. Water restrictions and limitations among residents can, in severe cases, change daily lifestyle patterns or even create social unrest. Water is frequently needed for emergency responses to fires—either those occurring in structures, or wildfires in natural areas.

Environmentally, a drought brings the aforementioned lowering of water levels and water quality for surface lakes and rivers, and strains the subterranean aquifers in the state. Various animal and plant populations may decline and be at heightened risk of disease. Air quality is reduced by an increase of dust and pollutants in the air. Soil quality and quantity is also diminished due to enhanced erosion, especially around freshly exposed areas near lowered lakes and streams.

The process of drought monitoring involves having ready access to an ongoing supply of information regarding precipitation, stream flows, lake levels, etc. By examining one or more drought indices, encroaching or existent drought conditions can be monitored and adapted to. Drought-related scales include river and stream flows (expressed either as a percentage of normal or as a percentile), the Standardized Precipitation Index, Crop Moisture Index, Surface Water Supply Index, and the Drought Monitor. Through these, an assessment of present conditions and forecasts are available. Using the indicators given by various agencies, you can monitor drought conditions in your area. A guide to various indicators is available here: http://www.droughtmanagement.info/indices/. Appropriate precautions and water policies might be undertaken when these indicators (and professional recommendations) merit.

Urbanized Areas

The entire state is subject to the impacts of drought. However, some areas are more vulnerable to certain drought-related impacts than others. Large urbanized areas can be more vulnerable to water shortages and business disruptions due to the sheer number of water users that are competing for the limited water resources. In those areas, water management strategies typically have to be implemented to deal with the water shortage problems. Public health and safety concerns are also numerous - everything from maintaining adequate water supply for firefighting to addressing the needs of the elderly, children, ill or impoverished individuals suffering from heat-related stress and illness. The latter is particularly problematic for densely urbanized, inner-city areas, because heat-related deaths occur much more frequently in those areas than in suburban and rural areas. (See the Extreme Temperatures section for more detailed information.)

Rural Areas

In rural agricultural areas and the heavily forested areas of Northern Michigan, drought brings on a host of other problems to address. The agricultural areas of Michigan are vulnerable to drought conditions that impact the quantity or quality of crops, livestock, and other agricultural activities. These areas often depend heavily on agricultural production for their economic needs. A prolonged drought can seriously impact local and regional incomes, and negatively affect the viability of some agricultural operations.

In Northern Michigan's forested regions, drought can adversely impact timber production, agriculture, and some tourism and recreational enterprises. A large problem drought presents here is the increased risk of wildfire. As the 1976 Seney fire proved, a drought-impacted landscape could quickly turn a small fire into a raging, out of control conflagration.

Agricultural Disaster Declarations Involving Drought

2012-2018

Number	Declared	Description	Counties	In Area 1	In Area 2	In Area 3	In Area 4
S3275	7-12-2012	Drought	5	0	0	5	0
S3303	7-25-2012	Drought	10	0	0	10	0
S3332	8-8-2012	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	9-5-2012	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	1-9-2017	Drought	51	5	25	16	5
12 TOTAL EVENTS Declared by the U.S. Secretary of Agriculture:				**3**	**6**	**10**	**2**

NOTE: The four columns on the right refer to the "General Geographic Divisions" in the Michigan Profile Chapter and its accompanying map: Area 1 (Upper Peninsula), Area 2 (Northern Lower Peninsula), Area 3 (Southern Lower Peninsula), Area 4 (Metropolitan Detroit).

Statewide

A substantial portion (one-third) of Michigan's recent agricultural disaster declarations have involved drought impacts, as shown in the preceding table. Michigan tourism industry is also important, with the Great Lakes attracting numerous boaters and vacationers each year. Many of the "nice weather" activities and attractions involve water-related swimming, boating, fishing, and resort activities, and these forms of recreational and tourist attractions can all be negatively impacted by the effects of drought conditions, if water levels or quality are reduced sufficiently. Resort areas and boat docks have physical designs that tend to be based on particular water levels. In recent cases of moderate and severe drought, stream flows can fall below 50% of their normal levels, in many cases reducing the navigability of waterways and altering the relationship between water levels/locations and built facilities for recreational access to that water (boardwalks, docks, fishing sites, et cetera).

Impact on the Public, Property, Facilities, and Infrastructure

Drought impacts may include limited or restricted access to water, and higher prices for water and agricultural goods. There is a threat to public health and safety if water shortages and decreased water quality raise threats of illness, land subsidence, and wildfires. Conflicts between water users can arise, especially when a river or lake has competing uses among municipal, agricultural, industrial, and recreational users. Water restrictions and limitations among residents can also change daily lifestyle patterns and in severe cases can create political unrest. Some municipal systems and infrastructure may find the maintenance of water quality and supply to be more difficult and expensive, under drought conditions.

Impact on the Economic Condition of the State

Substantial economic impacts can affect the agricultural and tourist sectors, which are very important for Michigan's economy, especially its rural areas. Drought may cause the erosion of topsoil (with an associated loss of productivity and land value) and exacerbate other types of erosion, involving associated costs for property owners. An increase in costs for affected products and services might be expected to arise from a severe drought impacts. Some recent drought events have resulted in agricultural disaster declarations involving all or nearly all of Michigan's 83 counties.

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

Droughts may be expected to affect a community's capacity to fight wildfires, and perhaps even major structural fires as well. There may be access issues involving egress into private property. For example, a water shortage may require access to a water pond on private property, to assist with efforts to fight a wildfire in the area. Otherwise, no particular responder issues should arise from a drought event. 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.

Impact on the Environment

A drought can have serious consequences for the environment if the length and severity of the event is great enough. The hydrological effects of drought can include a loss of wetlands and lower water levels in lakes, ponds and rivers that are used for irrigating agricultural crops. Additionally, a deficit in rain for an extended period of time may cause groundwater depletion and a reduction in the water quality. Drought may also impact plant and animal life by a reduction in drinking water and loss of biodiversity. Drought is also the cause of many wildfires, which destroy wildlife habitats and alter an area's ecosystem. Air quality is reduced by an increase of dust and pollutants in the air. Soil quality and quantity is also diminished due to enhanced erosion, especially around freshly exposed areas near lowered lakes and streams.

Impact on Public Confidence in State Governance

In some areas, the government is responsible for infrastructure maintenance and water supply planning and storage, and could be perceived as having failed during a major drought event. Actual responsibility for these issues varies with the specific jurisdiction(s) and agencies involved. Public expectations of government responsibility may be lower in areas with many natural water sources, and areas that make heavy use of individual rather than municipal supply sources. Some interesting cases emerge, however, in areas that have industries that commercially bottle area groundwater for profit. In cases of drought, or of lessened quantity or quality of local groundwater, there is likely to be popular discontent among segments of the public who hold local or state government responsible for “allowing” (or even “favoring”) for-profit water bottling businesses to compete with the claimed interests of the area’s residential water-users.

Climate Change Considerations

Although the effect of climate change on Michigan has involved an overall increase in precipitation, and the severity of Michigan’s droughts has generally been decreasing over the past half-century, nevertheless there will still be drought events and dryer seasonal phases, especially in areas that are locally more susceptible. In particular, shorter-duration seasonal droughts are expected to worsen during the warmer half of the year, even though the overall annual averages have been showing increases in precipitation. With sufficient planning and water infrastructure, the climate change effects upon this hazard may actually be beneficial on the whole in the medium-term, although the hazard will definitely not disappear, and in the longer-term is expected to greatly worsen (after a period of several decades).

Drought Related Monitoring and Measurement

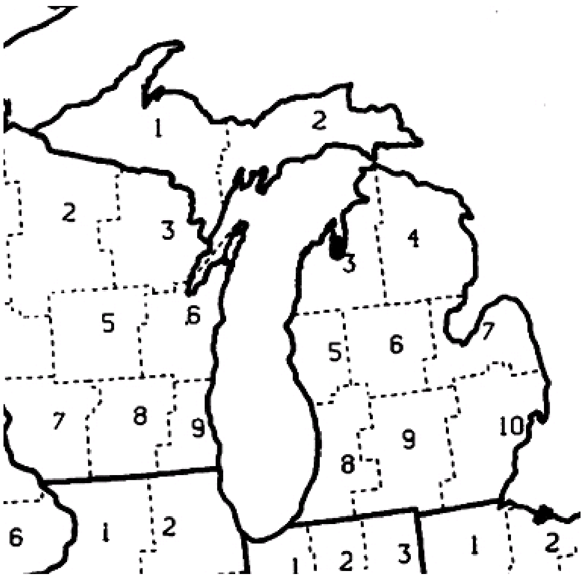
The process of drought monitoring involves having ready access to an ongoing supply of information regarding precipitation, stream flows, lake levels, etc. By examining one or more drought indices, encroaching or existent drought conditions can be monitored and adapted to. Drought-related scales include river and stream flows (expressed either as a percentage of normal or as a percentile), the Standardized Precipitation Index, Crop Moisture Index, Surface Water Supply Index, and the Drought Monitor. This type of information may be found through the National Drought Mitigation Center website, https://drought.unl.edu/Home.aspx, or the USGS Drought Watch web page at http://waterwatch.usgs.gov/?m=dryw&r=mi. Through these, an assessment of present conditions and forecasts are readily available. Using the indicators given by these agencies, you can determine how close or how severe drought conditions may be for your area. Depending on the readings and predictions from the indices, you can estimate how much risk and what kind of potential losses may arise from year to year. Heading into springtime in a given year with above average precipitation lessens the threat of impending drought (and its consequences) while dry fall and winter conditions lead to a heightened awareness of potential summer drought conditions.

Many major droughts have affected the United States during the 20th Century. The 21st Century so far has seen many problems especially in the Western United States, and has also exacerbated the risks and impacts of wildfires. This document is more narrowly focused upon Michigan events, rather than national trends, however, since Michigan has more than a century of historical records to draw upon and analyze.

Michigan’s 10 climate divisions, which have been used for drought monitoring by the National Climatic Data Center, are described below, and some detail will then be provided about the most notable historic drought events as they have affected the State of Michigan, specifically, and each of its internal climate divisions. These climate divisions are considered to be the most appropriate geographic level of analysis, for purposes of this state-level analysis. More detailed assessments are performed by specialized state agencies, federal agencies, and utility providers. Those agencies concerned with agricultural production are especially pertinent in assessing and addressing this hazard.

In August and September 2007, all 83 counties received drought disaster declarations from the U.S. Department of Agriculture due to crop losses from drought. In the Muskegon harbor, two freighters became stuck, with low water levels increasing the need for dredging activities and causing ships to unintentionally run aground on the sandy harbor bottom. At the beginning of August, three counties (Allegan, Kalamazoo, and Van Buren) were judged to be at D2 (severe drought) status. Twelve other counties in Southwest Michigan were evaluated as having D1 (moderate drought) conditions. Several others were considered to have abnormally dry (D0) status. Wildfire dangers were similarly escalated, due to these dry conditions, with fire danger levels in Southern Michigan ranging from “high” to “extreme.” (Usually fire dangers become less significant after a spring “green up,” but this year was an exception due to the drought effects.) Water flows in various rivers and creeks were far below normal—in many cases only about 60% of their usual rates. In addition to various **Red Flag Warnings**, by mid-August the Michigan Department of Natural Resources released a proclamation prohibiting the use of fire on or adjacent to forest lands for 75 counties in Michigan. In late August, drought conditions worsened, with 23 Northern Michigan counties at moderate (D1) drought status and two (Chippewa and Mackinac) at severe (D2) drought status. Although some rainfall in early September allowed the fire restriction proclamation to be rescinded in 23 southern Michigan counties, it remained in effect for 52 of the more northern counties. By late September, drought conditions had been alleviated somewhat by additional rainfall, except for the Upper Peninsula, which still had severe drought (D2) status in seven of its western counties, and moderate (D1) drought status for 5 of its eastern counties. (Source: Law Enforcement Information Network messages)

Michigan's 10 climate divisions (for drought monitoring and analysis)



Information from the National Centers for Environmental Information (NCEI) is available for the current tracking and historical research of drought events in Michigan, but since dry conditions in one region may be balanced (in a statewide average) by wet conditions in another region, it is appropriate to look at specific regions rather than the state as a whole, to assess the presence and severity of drought conditions from the historical data. For this plan, 124 years of data was analyzed (from 1895 to 2018) for each of the 10 climate divisions illustrated in the map.

To assist with local planning efforts, the counties contained within these 10 climate divisions are hereby listed, and although historical data can at this time only be provided for the divisions as a whole, a summary of the most severe events from NCEI records have been included for each of the ten Climate Divisions. Following this is an overarching description of incidents and trends shown in historical drought records for Michigan.

Significant Droughts affecting Michigan

Division 1: Baraga, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Marquette, Menominee, and Ontonagon Counties. The most extreme drought was in January 1977, when the Palmer Drought Severity Index (PDSI) hit a record low of -7.33 (the all-time record for Michigan). Lengthy drought incidents (at least 8 months long) took place in 1895-1896 (10 months), 1908-1909 (10 months), 1910-1911 (16 months), 1921-1922 (8 months), 1925-1926 (11 months), 1930-1931 (12 months), 1933-1934 (9 months), 1948-1949 (12 months), 1963-1964 (9 months), 1976-1977 (8 months), 1986-1987 (12 months), 1989-1990 (13 months), 1998 (9 months), 2006-2008 (22 months), 2008-2009 (12 months), 2011-2012 (12 months).

Division 2: Alger, Chippewa, Delta, Luce, Mackinac, and Schoolcraft Counties. The most extreme drought was in October 1948, when the Palmer index hit a record low of -5.65. Lengthy drought incidents took place in 1895-1896 (12 months), 1909-1911 (24 months), 1914-1915 (8 months), 1925-1926 (13 months), 1930-1931 (13 months), 1933-1934 (8 months), 1947-1948 (13 months), 1955-1956 (11 months), 1962-1964 (17 months), 1989-1990 (8 months), 1997-1999 (20 months), 2005-2007 (23 months).

Division 3: Antrim, Benzie, Charlevoix, Emmet, Grand Traverse, Kalkaska, Leelanau, Manistee, Missaukee, and Wexford Counties. The most extreme drought was in February 1931, when the Palmer index hit a record low of -6.52. Lengthy drought incidents took place in 1895-1896 (15 months), 1910-1911 (8 months), 1913-1914 (11 months), 1914-1915 (8 months), 1921-1922 (8 months), 1925-1926 (9 months), 1930-1931 (13 months), 1935-1936 (20 months), 1955-1956 (9 months), 1963-1964 (10 months), 1976-1977 (11 months), and 1998-1999 (11 months).

Division 4: Alcona, Alpena, Cheboygan, Crawford, Iosco, Montmorency, Ogemaw, Oscoda, Otsego, Presque Isle, and Roscommon Counties. The most extreme drought was in February 1931, when the Palmer index hit a record low of -6.13. Lengthy drought incidents took place in 1895-1896 (15 months), 1908-1911 (37 months), 1913-1915 (21 months), 1925-1926 (10 months), 1930-1931 (12 months), 1948-1949 (17 months), 1955-1956 (12 months), 1963-1964 (8 months), 1976-1977 (11 months), 1989-1990 (8 months), 1998-1999 (11 months), and 1999-2001 (21 months).

Division 5: Lake, Mason, Muskegon, Newaygo, and Oceana Counties. The most extreme drought was in February 1931, when the Palmer drought severity index hit a record low of -6.06. Lengthy drought incidents took place in 1895-1896 (15 months), 1901-1902 (11 months), 1910-1911 (14 months), 1921-1922 (9 months), 1925-1926 (13 months), 1930-1931 (13 months), 1934 (9 months), 1956-1957 (8 months), 1963-1964 (19 months), 1971-1972 (11 months), 1976-1977 (10 months), and 2002-2003 (12 months).

Division 6: Clare, Gladwin, Gratiot, Isabella, Mecosta, Midland, Montcalm, and Osceola Counties. The most extreme drought was in February 1931, when the Palmer index hit a record low of -6.22. Lengthy drought incidents took place in 1895-1896 (15 months), 1910-1911 (18 months), 1930-1931 (14 months), 1934-1935 (9 months), 1936-1937 (13 months), 1963-1964 (15 months), and 1976-1977 (9 months).

Division 7: Arenac, Bay, Huron, Saginaw, Sanilac, and Tuscola Counties. The most extreme drought was in April 1931, when the Palmer index hit a record low of -6.25. Lengthy drought incidents took place in 1930-1931 (17 months), 1934-1935 (16 months), 1936-1937 (11 months), 1963-1965 (18 months), 1976-1977 (8 months), and 1998-1999 (12 months).

Division 8: Allegan, Berrien, Cass, Kalamazoo, Kent, Ottawa, and Van Buren Counties. The most extreme drought was in February 1931, when the Palmer index hit a record low of -6.45. Lengthy drought incidents took place in 1901-1902 (8 months), 1913-1914 (9 months), 1920-1921 (8 months), 1930-1932 (27 months), 1962-1965 (30 months), 1999-2000 (9 months), and 2005 (8 months).

Division 9: Barry, Branch, Calhoun, Clinton, Eaton, Hillsdale, Ingham, Ionia, Jackson, Shiawassee, and St. Joseph Counties. The most extreme drought was in April 1931, when the Palmer index hit a record low of -6.60. Lengthy drought incidents took place in 1913-1914 (10 months), 1922-1923 (10 months), 1930-1931 (18 months), 1934-1935 (13 months), 1962-1965 (31 months), 1976-1977 (8 months), and 2002-2003 (8 months).

Division 10: Genesee, Lapeer, Lenawee, Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties. The most extreme drought was in August 1931, when the Palmer index hit a record low of -6.98. Lengthy drought incidents took place in 1901-1902 (9 months), 1922-1923 (10 months), 1930-1931 (17 months), 1933-1936 (34 months), 1963-1965 (35 months), 1971-1972 (9 months), 1998-1999 (10 months), 1999-2000 (8 months), and 2002-2003 (8 months).

The following two tables summarize 124 years of drought records in all 10 of Michigan's specified climate divisions. There are many possible ways of expressing this data and comparing Michigan's geographic areas. A consideration of the most severe Palmer Drought Severity Index values has already been provided (which found that division number 1 had the most severe drought in Michigan, with a Palmer index of -7.33 for January 1977), along with lists of lengthy drought periods (which numbered from 6 to 16 per division, during the period from 1895 to 2018). The first table below expresses the percentage of years that either had no drought months at all (with the Palmer Index always above a value of -2.0), or had drought months beyond a certain level of severity. Since a Palmer Index of -2.0 is considered to be a moderate drought (U.S. Drought Monitor category D1), this was the base criterion used to establish the presence of drought in the area during a given month. The percentage of years in which Palmer Index values met various thresholds for drought severity are provided in the table. The annual figures suggest that climate divisions 1, 3, and 4 are more drought-prone within Michigan.

Drought Years in Michigan, by Climate Division

(covering the 124 years from 1895 to 2018)

Climate Division	Years without any drought months	With drought ≤ - 2.0 Palmer	With drought ≤ - 3.0 Palmer	With drought ≤ - 4.0 Palmer	With drought ≤ - 5.0 Palmer	With drought ≤ - 6.0 Palmer	With drought ≤ - 7.0 Palmer
1	51%	49%	**33%**	15%	**7%**	**3%**	**1%**
2	49%	51%	30%	14%	4%	0%	0%
3	46%	**54%**	28%	9%	3%	1%	0%
4	51%	49%	30%	**17%**	4%	1%	0%
5	45%	55%	21%	10%	2%	1%	0%
6	53%	47%	20%	10%	2%	1%	0%
7	**54%**	46%	23%	7%	2%	1%	0%
8	52%	48%	28%	10%	2%	1%	0%
9	**54%**	46%	22%	9%	4%	2%	0%
10	**54%**	46%	24%	15%	6%	**3%**	0%

An analysis by year tends to overstate Michigan's drought-susceptibility, because the presence of a single drought month may be counted the same as an entire year of sustained drought (although longer drought periods often will be distinguished by having more severe Palmer Index values). A single month's drought will not necessarily cause severe agricultural impacts, because the timing of the drought with regard to the crop cycle is also important for the extent of drought impact. Therefore, an analysis of the percentage of drought months is also provided here, as a different indicator of drought frequency. These tables suggest that Climate Divisions 1, 3, and 4 are more drought-prone than other areas. The listing (on the previous page) of lengthy drought incidents (lasting 8 months or longer) can also give a kind of indicator regarding the frequency of droughts that likely had a significant agricultural impact, although these are all summary indicators by climate division and may vary considerably from the actual performance of individual farms within a particular area. The differences between Michigan's climate divisions may be significant, but are not enormous. One reason for this is that drought is defined with respect to an area's precipitation norms.

Drought Months in Michigan, by Climate Division

(covering the 1,487 months from January 1895 through November 2018)

Climate Division	Months without any drought (Palmer >-2)	With drought ≤ - 2.0 Palmer	With drought ≤ - 3.0 Palmer	With drought ≤ - 4.0 Palmer	With drought ≤ - 5.0 Palmer	With drought ≤ - 6.0 Palmer	With drought ≤ - 7.0 Palmer
1	80.8%	19.2%	8.4%	3.7%	1.5%	0.4%	0.1%
2	81.2%	18.8%	9.6%	2.6%	0.5%	0.0%	0.0%
3	81.1%	18.9%	6.6%	2.2%	0.6%	0.2%	0.0%
4	80.2%	19.8%	10.1%	4.3%	0.8%	0.1%	0.0%
5	81.4%	18.6%	6.8%	1.8%	0.4%	0.1%	0.0%
6	84.1%	15.9%	6.3%	2.4%	0.9%	0.1%	0.4%
7	85.3%	14.7%	6.3%	2.0%	0.7%	0.2%	0.0%
8	82.9%	17.1%	6.8%	2.3%	0.7%	0.3%	0.0%
9	85.7%	14.3%	6.3%	3.3%	1.2%	0.3%	0.0%
10	83.7%	16.3%	8.4%	4.0%	2.2%	1.0%	0.0%

Note: Many values in this analysis have changed since the previous editions of this document. Differences in data sources (and which specific drought index was used) account for these changes. For this update, all quantitative drought data in these tables have been freshly analyzed from the same NCEI source.

April 1895-June 1896 Statewide

The available NCDC drought records (those that use the Palmer drought index) began with a period of severe to extreme drought throughout Michigan. The state as a whole was in a drought for 15 months, between April 1895 and June 1896. In terms of the Palmer Drought Severity Index, a low point of -4.81 was reached in November 1895. Every one of Michigan's climate divisions registered drought conditions for at least 5 months, and divisions 3 through 6 lasted as long as 15 months. The drought was extremely severe in the Eastern Upper Peninsula and the Traverse Bay area. The Eastern U.P. had Palmer values below -4.0 for two months in a row, between July and August 1895. Recovery was uneven over the different climate divisions, with the droughts in divisions 5 and 6 lasting through August (although the statewide drought had lasted only through June).

November 1901-April 1902 Western, Central, and Southern Lower Peninsula

In statewide terms, a drought stretched from November 1901 to April 1902, reaching a low point of -2.59 in February 1902. The Upper Peninsula was completely spared from this drought, however, as was the far northeast of the Lower Peninsula, but most of the Lower Peninsula had and extremely rough time. Climate division 5 felt the lengthiest droughts, starting back in December 1900 and, except for March 1901, felt this drought stretch through 1901 and last through February 1902. Drought severity was exceptional in climate divisions 5 and 10, reaching Palmer Index values of -5.16 in division 5 in January 1902 and a low value of -4.25 in division 10 in April 1902.

September 1908-August 1911 Statewide

Statewide, a first drought period lasted from September 1908 through November 1909, and was soon followed by a second, from March 1910 through August 1911. Both phases were of similar severity, with the first phase's low point (Palmer Index -4.74) occurring in December 1908 and the second phase's low point of -4.53 occurring exactly two years later. The three months between each statewide drought event saw only partial relief at a regional level within Michigan, as drought continued in climate divisions 2, 4, and 5. The Western Upper Peninsula reached a first low point in January 1909, with a Palmer Index level of -4.97, then reached a greater low of -6.34 in December 1910. The drought was less severe in climate divisions 2, 3, 5, and 8, but similarly long-lasting. Climate division 4 reached its low point in January 1909 with a Palmer Index level of -5.27. Climate division 6 reached its low point in January 1911 with a Palmer Index value of -4.67. The drought was relatively mild within climate division 7, occurring only during the 4 final months of 1908. Climate divisions 9 and 10 were spared nearly as much.

November 1913-May 1915 Statewide

This period saw two phases of overall, state-level drought, the first from November 1913 through May 1914, and the second lasting from November 1914 through May 1915, each of which saw low points within the severe drought level (-3.19 in December of 1913 and -3.87 in April 1915). Much of this drought was concentrated in the northernmost part of the Lower Peninsula (the Detroit region and Western Upper Peninsula were almost entirely spared). Climate division 2 reached an extreme drought (-4.27) in April 1915, climate division 3 nearly matched that (-4.05) in December 1913, and climate division 4 exceeded it for 8 months, starting in October 1914 and ending in May 1915, with a low point in the exceptional range of -5.42.

June 1921-January 1922 Statewide

Michigan endured 8 months of severe drought conditions, with its low point measuring -3.08 on the Palmer Index, in July 1921. Climate divisions 1, 2, 3, 5, 8, and 9 suffered the most, with divisions 1 and 5 reaching extreme drought levels (D3). Climate divisions 6, 7, and 10 had a less deleterious pattern, and climate division 4 was entirely spared.

March-August 1925 Statewide

All parts of Michigan were struck with drought problems in mid-1925. Statewide, 6 months of drought, reaching the severe D2 level, were measured, but the duration of the event was much longer in the Upper Peninsula and Northern Lower Peninsula. Climate divisions 1 through 5 suffered the most, with the low point occurring in climate division 4, which reached a Palmer Index level of -4.32 in January 1926. Climate divisions 6 through 10 saw lesser impacts, although their droughts still reached the moderate D1 level.

1930s Statewide, National

Without a doubt, the "Dust Bowl" series of droughts during the 1930s were the most famous ever to occur in the U.S. The backdrop for John Steinbeck's famous book, The Grapes of Wrath, these events became an ecological and human disaster of huge proportions. In addition to widespread exceptional drought conditions from years without rainfall, problems were caused by poor land management practices. As the land dried up, great clouds of dust and sand, carried by the wind, covered everything and the term "Dust Bowl" was coined. As a result of this drought, millions of acres of farmland became useless, forcing hundreds of thousands of persons to leave their farms and seek an existence elsewhere. Although exact figures were not kept, some researchers estimate that nearly $1 billion (in 1930s dollars) was provided in assistance to victims of the Dust Bowl drought. That event also ushered in a new era of farming and conservation programs and practices aimed at preventing a recurrence of a drought of the magnitude and impact of the Dust Bowl droughts.

In Michigan, this "dust bowl" 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 ever recorded in Michigan occurred in early 1931, when the 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 in climate division 5 to -6.98 in climate division 10 (in the southwestern Lower Peninsula). The all-time low statewide Palmer Index value of -7.73 occurred in February 1931—the same month that 5 of Michigan's climate divisions simultaneously hit their own record lows. Even if only the extreme drought levels (D3) are considered, these conditions were unusually long-lasting. Between 1930 and 1931, all nine of Michigan's most heavily affected climate divisions experienced this most unusual level of drought for at least 6 straight months (in the Western Upper Peninsula) to as many as 15 continuous months (in climate divisions 8 and 9). Unfortunately, those areas that experienced the more prolonged conditions of extreme drought were also the most heavily agricultural areas of the state, in the southern Lower Peninsula. Nevertheless, the entire state was struck very hard—climate division 8 experienced 27 consecutive months of drought between July 1930 and September of 1932.

Except for the southwestern Lower Peninsula, 1932 was a healthy water year. But the years 1933 to 1935 saw drought conditions return throughout the state. Although the southwestern Lower Peninsula was nearly normal, everywhere else saw drought that reached extreme D3 levels during a significant proportion of this time. Statewide, between 1933 and 1935, a low point of -5.45 in the Palmer Index was reached in August of 1934. In southeast Michigan (climate division 10), 34 months of drought lasted from November 1933 to August 1936, ranging from severe to exceptional levels.

The remainder of the decade after 1936 included some droughts that were severe but not severe at the statewide level. Some climate divisions dropped below -3.0 (severe) but generally not below -4.0 (extreme) on the Palmer Index.

October 1944-March 1945 Southern Lower Peninsula

At the statewide level, 6 months of drought occurred, and reached the severe (D2) level, with a low point of -3.60 in January 1945. The drought mainly impacted climate divisions 5 through 10 at this level, with other areas not having a problem. Within the southern Lower Peninsula, most areas reached the extreme D3 drought level, and in March 1945, southeastern Michigan even reached the exceptional D4 level (Palmer Index -5.02).

October 1947-December 1949 Northern Michigan

Although the state as a whole only officially registered a couple of 4-month drought periods from 1947 to 1948 (and none at all in 1949), these statistics conceal a very serious drought felt within the Upper Peninsula and the Northeastern Portion of the Lower Peninsula, which lasted for nearly two years. Climate divisions 1, 2, and 4 experienced lengthy drought conditions during these 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 Palmer Index value 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 Palmer Index value, -5.65. The western Upper Peninsula suffered the longest of any area in this event, with droughts during the entire period from October 1947 to April 1949 with the exception of the single month of April 1948. Within the climate division of the western Upper Peninsula, the Palmer Index got as low as -5.74 in October 1948, and stayed at that exceptional D4 drought level until the end of that year.

July 1955-February 1956 Northeastern Michigan

Statewide, an 8-month drought period was measured with Palmer Index values that reached the severe D2 level, with a low value of -3.37 reached in September of 1955. Climate divisions 2, 3, 4, and 5 all felt this drought for a period of at least 6 consecutive months, with the longest stretch of uninterrupted drought occurring in climate division 4, lasting for an entire year from July 1955 through June 1956 and reaching a low point with exceptional D4 drought severity involving a Palmer Index of -5.00 in February 1956. Climate divisions 2 and 3 reached the extreme D3 drought level, and climate division 5 reached the severe D2 level during this event.

November 1962-December 1964 Statewide

This was the most serious statewide drought event since the 1930s, and there has been a general trend of lessening drought problems within Michigan during the second half of the 20th Century when compared with the first half. In this event, the mildest impacts were in the northeastern Lower Peninsula and the worst impacts were in the entire southern part of the Lower Peninsula. However, no region of the state escaped without at least 8 continuous months of drought. The statewide drought levels lasted for 26 consecutive months, from November 1962 to December 1964. Climate divisions 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 5 months, with the lowest point reached in February 1964 at a Palmer Index value of -5.97. Within the three southernmost climate divisions, southwestern Michigan stayed within the extreme D3 classification level with a low Palmer value of -4.22 in February 1964. The central and eastern portions of the southern Lower Peninsula reached exceptional D4 drought levels, with climate divisions 9 and 10 both reaching their low points in February 1964, with values of -6.15 and -6.40, respectively.

September 1976-July 1977 National (including Michigan)

The 1976-77 drought in the Great Plains, Upper Midwest, and West of the United States also severely impacted Northern Michigan. 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 Palmer Index value of -5.29 (within the D4 exceptional drought classification). Although climate division 1 (the eastern Upper Peninsula) only had 9 months of drought, it set its all-time lowest Palmer Index record during this event, with a value of -7.33 in January 1977. Other northern Michigan climate divisions similarly had shorter but exceptional drought levels, with the eastern Upper Peninsula reaching a Palmer Index value of -5.14 in December 1976, and climate division 6 reaching -5.61 in July 1977. The northern Lower Peninsula approximately matched the state as a whole, in terms of the length and severity of drought it experienced, with climate division 4 reaching a -5.37 Palmer Index low and climate division 3 reaching a value of -5.06 during January 1977.

Extreme drought conditions in the Upper Peninsula contributed heavily to the large wildfire that struck the Seney area in July of 1976, which started from a lightning strike that ignited dry grasslands and eventually burned over 74,000 acres over a 1½ month period, costing $8 million to contain. (The chapter on Wildfires contains more detailed information about this fire.) Drought had involved a significant reduction in rainfall (6-8 inches below normal) in the area, and the water table in the 95,455-acre Seney National Wildlife Refuge had dropped one foot, exposing old vegetation, peat and muck to the drying forces of intense sunlight. Eventually, that material became a tinderbox that helped fuel the destructive fire. Fortunately, injuries and damage to improved property were minimal, although the loss of forest resources was staggering.

1998-2003 National, including Michigan

Droughts and heat waves in recent years have caused considerable damage to agriculture and related industries in several areas of the U.S. The drought and heat wave from Texas to the Carolinas in the summer of 1998 caused an estimated $6-9 billion in damage. The drought and heat wave of the summer of 1999 caused over $1 billion in damage, mainly to agricultural crops in the Eastern U.S. The drought and heat wave in the South-Central and Southeastern U.S. in the summer of 2000 resulted in over $4 billion in damages and costs. The drought and heat wave that struck Michigan during the summer of 2001 damaged or destroyed approximately one-third of the state's fruit, vegetable and field crops, resulting in a U.S. Department of Agriculture 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. In 2002, moderate to extreme drought affected more than 45 percent of the country during the months of June, July, and August. Nationwide, the summer was the third hottest on record, following only 1936 and 1934. The summer of 2002 was also very hot and dry in Michigan. Several record highs were set throughout eastern Michigan during the month of September. During the first half of the month, hundreds of communities across the area were under water restrictions. Hardest hit from the drought was the agricultural industry. September yields across most of the area were estimated at under 50 percent and many counties across eastern Michigan were declared agricultural disaster areas. The severely dry weather was classified as a drought until mid-2003.

In terms of the Palmer Drought Index at a statewide level, these droughts fell into three phases: one from July 1998 through June 1999, a second from November 1999 through April 2000, and a third from December 2002 through April 2003. Technically, each of these phases was shorter and less severe than the one preceding it, but from the description above it can be seen that the impacts had compounded over time, to exceed what the raw hydrological values might otherwise have suggested. Michigan's overall Palmer Index reached a low of -4.78 in December 1998, its low during "phase 2" was -3.21 in December 1999, and its low in “phase 3” was -2.88 in February 2003. Within Michigan’s climate divisions, the most severe problems jumped around from year to year, with different areas suffering from different impacts over time. The start of the problems was actually in northern Michigan at the end of 1997, with drought conditions detected in climate divisions 1, 2, 3, 4, and 6 in November and December of that year. The Upper Peninsula then saw lengthy droughts through most or all of 1998, reaching Palmer Index lows of -5.27 in the west and -4.42 in the east (both in December 1998). As the Upper Peninsula recovered during 1999, drought conditions that had appeared in climate divisions 3, 4, 7, 8, and 10 during the last half of 1998 continued and even worsened during 1999. Although climate division 3 had returned to normal by late 1999, the other 4 divisions saw their droughts persist into 2000. As climate divisions 7, 8, and 10 got back to normal during mid-2000, drought returned to the eastern Upper Peninsula for the rest of that year, and persisted into 2001 in the northeastern Lower Peninsula. In Michigan, the 2002-2003 event was distinct from the previous droughts, but they are described together here. The final drought phase most severely impacted climate divisions 5, 6, 8, and 10, although 7 and 9 were also severe. The following Palmer Index numbers help to describe how different climate divisions were affected during these phases of drought: division 2’s second drought phase hit -4.01 in November 2000, division 3 reached -3.34 in November 1998 and then -4.50 in January 2003, division 4 reached -4.01 in January 2000 and then -4.35 in February 2003, division 5 had only moderate droughts until phase 3 and then reached a low of -4.06 in February 2003, division 6 reached -3.74 in both November and December of 1998 and then went to a comparable low of -3.66 in February 2003, and division 7 hit -4.16 in December 1998 and then -3.43 in February 2003. Division 8 reached -3.88 in December 1998, -4.58 in March 2000, and -3.37 in March 2003. Division 9’s severe drought level bottomed out at -3.38 in March 2000 and then -3.56 in February 2003. Division 10 reached -4.16, -4.15, and -4.38 in December 1998, March 2000, and March 2003, respectively.

2005-2007 Northern Michigan (also Great Lakes and Muskegon County)

The Upper Peninsula suffered heavily from drought conditions that started in mid-2005 and persisted with few interruptions through 2009 in its western half. The state as a whole only registered a long drought from May to December in 2005, and then for several months in the last half of 2007. 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 U.P. was only 50 to 70 percent of normal, and the resulting lack of feed led some farmers to downsize their cattle herds. In the northern tip of the Lower Peninsula, very high utility bills were suffered by the proprietors of farms and golf courses, due to the need for near-constant irrigation. Corn and bean crops were severely impacted. A burning ban was also issued for most of the state (the first such ban since 1998) to reduce the risk of wildfires. The statewide drought level in 2005 reached a low point of -3.53 on the Palmer Index in October, and drought levels remained moderate (D2) during the 2007 event, but internal climate divisions better reveal the true severity of these events. Climate divisions 2, 8, and 9 reported at least 6 consecutive months of drought conditions during 2005, including a division 8 low of -3.78 and a division 9 low of -3.38, both in October. The western Upper Peninsula only saw 4 months of drought in 2005 (reaching a low of -3.25 in September) but then saw a 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. The eastern Upper Peninsula felt an enormous drought period that began in May 2005 and remained until August 2007 (except for one single month in April 2007 which, although technically not in drought, was still abnormally dry.) Climate division 1 reported lows of -3.25 in September 2005, -4.26 in November 2006, -5.45 in August 2007, and -3.63 in November 2008. Climate division 2 reported lows of -3.95 in October 2005, -3.61 in July 2006, and -3.98 in August 2007.

This was also a period of low water levels in the Great Lakes. Local reports described some effects of these lowered lake levels upon marine traffic in the Muskegon area. 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 space of a month, in the same location. Shipping officials stated that additional dredging was needed in Great Lakes ports because of low water levels. (NOTE: Although occurring at the same time as a designated drought event, this author is not certain whether this event had drought as its definitive proximate cause. Please refer to the Great Lakes Shoreline Hazards chapter for more information about varying water levels in the Great Lakes.)

A general trend toward a wetter Michigan climate has been in evidence for decades now. A pattern of fewer sustained and severe droughts is one of the benefits that Michigan has experienced as a result. Studies of climate have suggested that a gradual warming pattern has led to an increase in precipitation, since warmer air is capable of carrying more humidity. Climatological experts have advised, however, that the new pattern of concern in the medium-term is an increasing risk from seasonal droughts that may accompany by heat waves. Within this historical overview, thanks to excellent historical data, we can see that the earliest years show 1 or 2 droughts per decade that reach sustained statewide intensity that is at the severe D2 level, or worse. By the mid-20th Century, the data shows an average of barely 1 major drought event per decade. No recent Michigan events have reached the same level as the severe historical droughts that have been described in this section, and therefore this updated analysis has not added any Michigan events from the past decade. Instead, it has completely reassessed the entire Michigan drought history in light of the comprehensive data set that is currently available from the NCEI online database. The events and statistics presented in previous editions of this document have been thoroughly revised to reflect this new data.

Drought History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	**Drought Events**	**Days with Event**	**Tot. crop damage**
Washtenaw	2	2	
Wayne	2	2	$150,000,000
.Livingston	2	2	
Oakland	2	2	
Macomb	2	2	
5 Co Metro region	**2 avg.**	**2 avg.**	**$150,000,000**
Berrien			
Cass			
St. Joseph			
Branch			
Hillsdale			
Lenawee	2	2	
Monroe	2	2	
.Van Buren			
Kalamazoo			
Calhoun			
Jackson			
.Allegan			
Barry			
Eaton			
Ingham			
.Ottawa			
Kent			
Ionia			
Clinton			
Shiawassee	2	2	
Genesee	2	2	
Lapeer	2	2	
St. Clair	2	2	
.Muskegon			
Montcalm			
Gratiot			
Saginaw	2	2	
Tuscola	2	2	
Sanilac	2	2	
.Mecosta			
Isabella			
Midland	2	2	
Bay	2	2	
Huron	2	2	
34 Co S Lower Pen	**0.7 avg.**	**0.7 avg.**	

Continued on next page…

Part 2 of Drought History for Michigan Counties – arranged by geography

.Oceana			
Newaygo			
.Mason			
Lake			
Osceola			
Clare			
Gladwin			
Arenac			
.Manistee			
Wexford	1	1	
Missaukee	1	1	
Roscommon			
Ogemaw			
Iosco			
.Benzie			
Grand Traverse	1	1	
Kalkaska	1	1	
Crawford			
Oscoda			
Alcona			
.Leelanau	1	1	
Antrim	1	1	
Otsego	1	1	
Montmorency			
Alpena			
.Charlevoix	2	2	
Emmet	2	2	
Cheboygan	2	2	
Presque Isle			
29 Co Nrthrn Lower Pen	**0.4 avg.**	**0.4 avg.**	
Gogebic			
Iron			
Ontonagon			
Houghton			
Keweenaw			
Baraga			
.Marquette			
Dickinson			
Menominee			
Delta			
Schoolcraft			
Alger			
.Luce			
Mackinac	4	4	
Chippewa	3	3	
15 Co Upp.Pen	**0.5 avg.**	**0.5 avg.**	
MICHIGAN TOTAL	**54**	**8**	**$150,000,000**
Annual average	**2.5**	**0.4**	**$7,032,152**

Programs and Initiatives

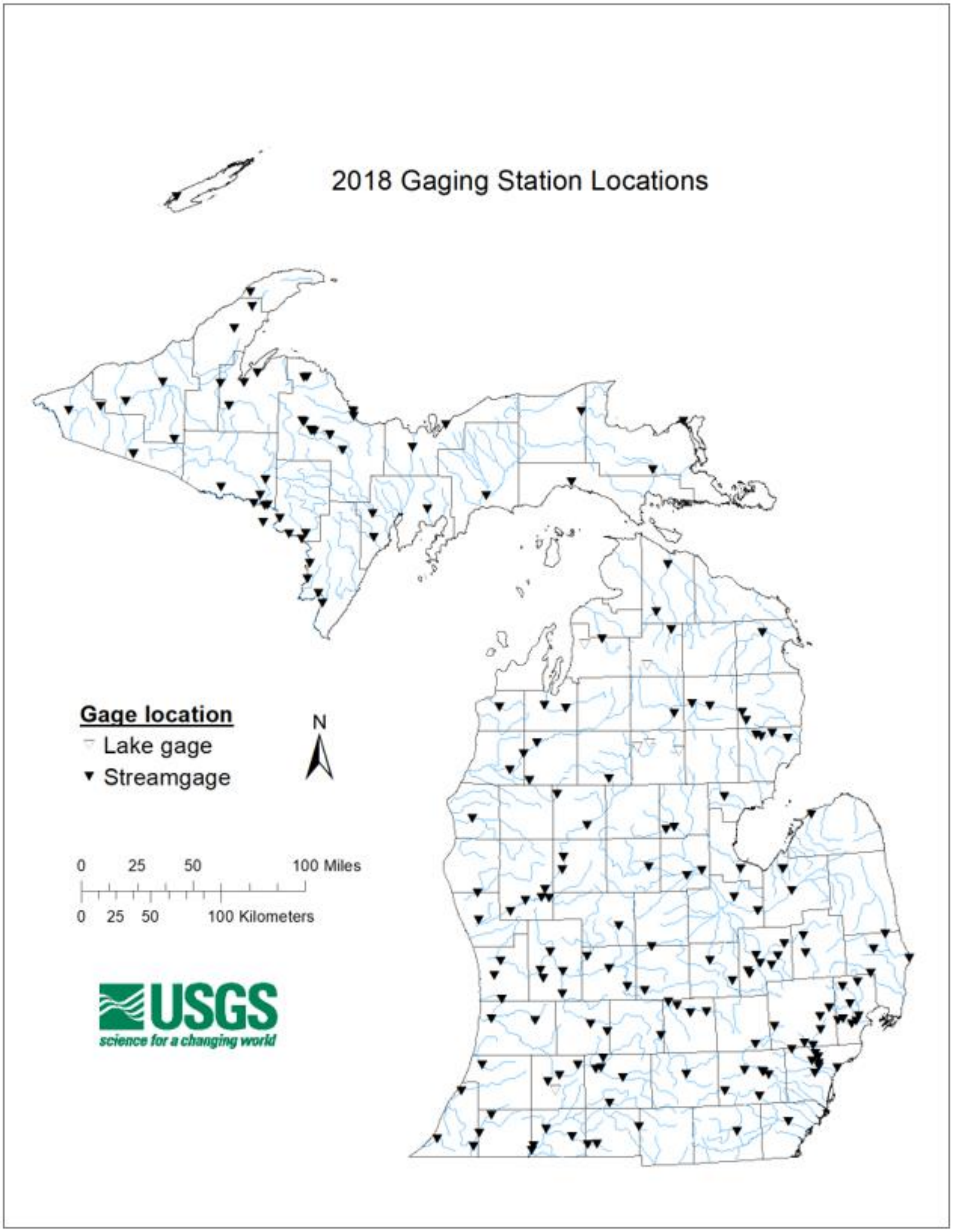
National Drought Policy Act and Commission
Currently, no single federal or state agency monitors drought. Rather, a number of agencies have programs and initiatives in place designed to identify, monitor, analyze, and respond to drought. Recognizing the need for a nationwide, coordinated drought policy designed to prepare for and respond to drought emergencies, Congress enacted in 1998 the National Drought Policy Act (P. L. 105-199), which established the National Drought Policy Commission. The Commission is composed of fifteen members—representative of all levels of government and other drought impacted groups—and is charged by Congress to provide advice and recommendations on the creation of an integrated, coordinated Federal policy for drought emergencies. On May 17, 2000, the Commission provided its findings and recommendations to Congress and published the report "Preparing for Drought in the 21st Century." The Report outlines a national drought policy statement developed by the Commission with preparedness as its foundation. The Report establishes five broad goals and a number of specific recommendations under each. The Commission intends to achieve the goals in the coming years through a combination of legislation, planning, coordination of programs, public/private collaborative partnerships, and public education.

Interim National Drought Council
The creation of the Interim National Drought Council (INDC) was one of the recommendations in the May 2000 report of the National Drought Policy Commission. The United States Department of Agriculture (USDA) immediately moved forward and implemented the council without congressional action. The Interim Council was created to coordinate drought services between the various levels of government until Congress authorizes and funds a permanent council. It was created through a Memorandum of Understanding (MOU) signed by the U.S. Department of Agriculture, U.S. Department of the Interior, Small Business Administration, Federal Emergency Management Agency, U.S. Department of The Army, U.S. Department of Commerce, U.S. Environmental Protection Agency, National Governors' Association, Southern Governors' Association, Western Governors' Association, National Association of Counties, U.S. Conference of Mayors, the National Emergency Management Association, and representatives of urban water interests, rural water interests, the credit community, and tribes. The Consortium of Regional Climate Services, the National Association of Conservation Districts, and the National Drought Mitigation Center were then added by an addendum to the MOU.

U.S. Army Corps of Engineers
The U.S. Army Corps of Engineers (USACE) Institute for Water Resources developed and maintains the National Drought Atlas, which provides information on the magnitude and frequency of minimum precipitation and stream flow in the United States (two important indices of drought). NOTE: Caution should be used when comparing streamflow statistics from the USACE spreadsheet with current, observed conditions at a particular location. This is because the statistics reflect the period of record of the data being analyzed—a longer period makes it harder for an extreme flow condition to be reflected in the value of the statistic. In some cases, it may be tricky to determine the period of time covered by the statistic, since some stations may have been inactive during certain time periods.

U.S. Geological Survey
The U.S. Geological Survey (USGS) is the primary federal agency that collects and analyzes streamflow data, a good index of the relative severity of drought. The agency provides a handy "Water Watch" web site at http://waterwatch.usgs.gov/. The site presents a map that is continually updated through an automated analysis of USGS stream-gauging stations. Additional drought-related links can be accessed from the Michigan-specific web page, http://waterwatch.usgs.gov/new/index.php?m=dryw&r=mi.

Another available resource for historical data (usually the period from 1933 to 1988) is the USGS Hydro-Climatic Data Network, which is composed of 1,659 streamflow stations that have 20 years or more of streamflow records. These stations are present in all 50 states and U.S. territories. The USGS, in cooperation with over 600 other government agencies, operates some 7,300 stream gauges for data collection. In addition to streamflow data, the USGS collects data on water quality, reservoir levels and contents, and groundwater levels for each state. For Michigan, up to the 2005 water year, this data was being published annually in a Water Resources Data for Michigan document. Since the annual report ceased publication, official annual summaries can be obtained on-line, on a site-by-site basis. These data can be accessed by visiting the Annual Water Data Reports site at http://wdr.water.usgs.gov/ or by visiting the web page for a specific stream gauge through http://waterdata.usgs.gov/mi/nwis/rt. The .pdf files present at these sites contain annual information about that stream location, including average daily flow rates that can be used to identify low and high-water flow periods.



USGS Stream Gauge Locations in Michigan

National Weather Service

The National Weather Service (NWS) is the primary Federal agency that collects and publishes precipitation data. The NWS publishes precipitation data from approximately 9,100 non-recording and 2,100 recording stations in the United States. This data is published monthly in reports for each state, titled Climatological Data and Hourly Precipitation Data. Departure from normal precipitation is a commonly used index to determine drought severity.

U.S. Department of Agriculture

The U.S. Department of Agriculture (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 Farm Service Agency (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 (NRCS) 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.
USDA drought products website: https://www.usda.gov/oce/weather/Drought/index.htm

All Hazards Resources for Rural Communities

The internet site at http://www.prep4agthreats.org/ is aimed specifically at rural agricultural communities, presenting information about hazards from the perspective of their agricultural impacts.

National Drought Mitigation Center

The National Drought Mitigation Center (NDMC), located at the University of Nebraska-Lincoln, is a major research and information center whose mission is to help people and institutions in the United States develop and implement measures to reduce societal vulnerability to drought. The NDMC, through its various programs and initiatives, stresses prevention and risk management rather than crisis management. The NDMC builds on the work of the International Drought Information Center (IDIC), also at the University of Nebraska-Lincoln, which takes a worldwide perspective in its research and mitigation work related to the hazard of drought. The NDMC and IDIC are both essentially clearinghouses for drought-related research studies, policy and planning assistance, training and educational initiatives, and information sharing. They are the central coordinating points, worldwide, for drought-related programs and initiatives. https://drought.unl.edu/Home.aspx

State of Michigan

In Michigan, drought identification and monitoring is a multi-agency, collaborative effort that involves the Departments of Agriculture and Rural Development, Environmental Quality, Natural Resources, Health and Human Services, and the Emergency Management and Homeland Security Division of the Michigan State Police. When a drought occurs in Michigan, other agencies, such as the Office of Services to the Aging, may also become involved to monitor the impact of the drought conditions on individuals and families. 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. In extreme cases, the State Emergency Operations Center may be activated and staffed for the duration of the event. A state water strategy was completed in late 2016 and is available online at https://drought.unl.edu/archive/plans/Water/state/MI_2016.pdf.

New laws came into effect on February 28, 2006 to help Michigan better manage water withdrawals to ensure adequate supplies for aquatic life and other users. These laws amended Parts 327 and 328 of the Natural Resources and Environmental Protection Act and the Safe Drinking Water Act. NOTE: This is primarily directed toward ecosystem integrity, and the low-flow conditions considered in these laws are merely representative of low-flow summer months, rather than long-term drought conditions.

Drought Contingency Planning

Because of variations in the drought threat throughout the state, local communities should develop and maintain drought contingency plans (as part of their overall emergency preparedness effort) that address the primary threats that drought presents in their area. For urban jurisdictions, that threat is primarily related to water supply and use management, heat-related illnesses, and continuation of industrial and business operations. For rural jurisdictions, that threat is primarily agricultural and wildfire-related. Such preparedness efforts will not eliminate the negative effects of drought, but they can at least help minimize and manage the consequences of those effects on the population.

Because drought is a low-profile hazard, it does not receive as much attention as it probably should from the emergency management community, governmental agencies, or the public in general. As a result, drought contingency planning is typically a lower priority activity than is planning for other types of natural hazards. Because of the lack of pre-planning, historic responses to drought have been ad hoc and typically involve the creation of special task forces or interagency groups to address drought-related issues as they arise. Once the crisis is over, little is typically done in terms of time or resource commitment in order to ease the impacts of the next drought. Part of the problem stems from the fact that drought contingency planning faces many obstacles, including: 1) lack of a single definition of drought that works in all regions of the country; 2) lack of unified, consistent policies on natural resource management (including water) among states and regions in the U.S.; 3) lack of a lead, coordinating agency for drought mitigation and planning; 4) lack of "dramatic," high-profile impacts (i.e., property damage, casualties, debris, etc.) – which lessens the severity of drought in the minds of community decision-makers and the public; 5) the infrequent nature of drought makes it difficult to garner support for planning and mitigation actions; and 6) the widely-held perception that, because the problem is so enormous in scope and magnitude, there is little that can be done to prevent drought or lessen its impacts.

Having a Drought Contingency Plan for a community is quite important in the event that a severe drought impacts your area. Such a plan should be a separate document detailing what steps need to be taken in the event of a drought. The plan should cover the following questions:

1) Where are primary water sources for the general population?
2) Where are alternative sources for water if the primary sources are inadequate for the community's needs?
3) At what point of lessening water resources do local water restrictions go into place?
4) Are there incrementally strict water regulations related to drought severity?
5) At what point do water restrictions cease?
6) What are the costs of bringing outside water into the community?
7) What is the hierarchy of water distribution to residential, commercial, agricultural and industrial areas?
8) How will children, the elderly, the ill, and other vulnerable citizens be accounted for?

Some additional information can be found here: http://www.prep4agthreats.org/Natural-Disasters/drought

Mitigation Alternatives for the Drought Hazard

- Storage of water for use in drought events (especially for human needs during periods of extreme temperatures, and for responding to structural fire and wildfire events).
- Legislative acts, local ordinances, and other measures to prioritize or control water use.
- Encouragement of water-saving measures by consumers (including landscaping, irrigation, farming, lower-priority lawn maintenance, and non-essential auto washing).
- Anticipation of potential drought conditions, and the preparation of drought contingency plans.
- Designs, for recreational and other water-related structures and land uses, that take into account the full range of water levels (of lakes, streams, and groundwater).
- Designs and plans for water delivery systems that include a consideration of drought events.
- Obtaining agricultural insurance.

Assessments in Local Hazard Mitigation Plans

Drought was identified as one of the most significant hazards in local hazard mitigation plans for the counties of Iosco, Isabella, Luce, Marquette, and Menominee (an increase from 2014).

C. Ecological Hazards

The following outline summarizes the significant ecological hazards covered in this section:

1. Wildfires
2. Invasive species

These types of natural hazards deal with biological ecosystems, and their effects upon the human economy and built environment. The most well-known hazard of this type is that of major wildfires. Although wildfires, like floods, occur naturally, dangers exist because humans live in areas where the disaster event will periodically take place and cause damage and threats to human health and life. Ecological hazards must also be dealt with to maintain Michigan's environmental and recreational quality of life, as well as the important economic sectors that are closely connected with them (such as tourism, recreation, agriculture, and natural resource extraction).

Wildfires

An uncontrolled fire in grasslands, brush lands, or forested areas.

Hazard Description

Forests cover approximately 55% (20.4 million acres) of Michigan's total land area. These vast forests provide Michigan with the largest state-owned forest system in the United States. In addition, Michigan has the fifth largest quantity of timberland acreage, with 19.3 million acres (including hardwoods and softwoods). That vast forest cover is a boon for both industry and recreation, and these areas have been gradually increasing in recent years. However, it also means that many areas of Michigan are vulnerable to wildfires.

Hazard Analysis

Although Michigan's landscape has been shaped by wildfire, the nature and scope of the wildfire threat has changed. Michigan's landscape has changed substantially in recent decades to include developments within wildland areas, so the potential danger from wildfires has probably become more severe. At the same time, a very useful increase in the urban tree cover may have also caused some of these risk areas to include urban areas. Since the 1980s, substantial developments in and around rural areas has increased the potential for loss of life and property from wildfires, except where these developments were distant from forests, and also excluding those cases in which Firewise principles were obeyed. The map at the end of this section shows one estimate of the largest wildland/urban interface (WUI) areas in Michigan. In most rural areas, there are simply not enough fire suppression forces available to protect every structure from a disastrous wildfire.

Contrary to popular belief, lightning strikes are **not** the primary cause of wildfires in Michigan. Recently, only about 4% of all wildfires in Michigan were caused by lightning strikes, and most other causes have been attributed to human activity. Outdoor debris burning is the leading cause of wildfires in Michigan. Most Michigan wildfires occur close to where people live and recreate, which puts both people and property at risk. The immediate danger from wildfires is the destruction of property, timber, wildlife, and injury or loss of life to persons who live in the affected area or who are using recreational facilities in the area.

According to 2017 MDNR information, the leading causes of wildfires from the previous ten years were:

1. Debris burning (32%)
2. Miscellaneous (17%)
3. Powerline (16%)
4. Equipment (11%)
5. Campfires (9%)
6. Arson (6%)
7. Lightning (4%)
8. Fireworks (2%)
9. Structural fires (2%)
10. Smoking (1%)

<u>Areas of Greatest Vulnerability</u>

The maps and tables at the end of this section show a breakdown of wildfires by county for the period since 1981, including both the number of fires and the number of acres burned. The maps indicate that the wildfire threat in Michigan is geographically widespread. The large number of permanent and seasonal homes (especially in the northern Lower Peninsula), coupled with the increase in tourists during the driest (and therefore most vulnerable) times of the year, greatly increase the risk from wildfires.

It should be noted that the figures shown on the maps do not include those wildfires suppressed by local volunteer fire departments or the U.S. Forest Service. If those records were readily available and broken down by county, the statistics would be significantly affected. For example, the 1976 Seney fire burned approximately 74,000 acres, which included federal, state and private lands. In addition, the statistics fail to show the full wildfire problem in the southern Lower Peninsula, due to the small MDNR fire force presence in that area of the state. However, local fire departments in the southern Lower Peninsula respond to hundreds of wildfires per year, and are instrumental in keeping the wildfire threat in the southern Michigan counties in check.

In geographic terms, the percentage of forested land cover is the highest (more than 75% of the total land area) across the entire Upper Peninsula and in the Lower Peninsula counties of Cheboygan, Crawford, Kalkaska, Lake, Montmorency, Oscoda, Otsego, Presque Isle, and Roscommon (based upon a 2004 inventory by the USDA). The Michigan DNR has been involved in approximately 550 wildfire events per year, in recent decades. Although the events in recent decades have not resulted in deaths, major events in the past have done so.

Role of Local Governments

Local governments can take a number of actions to reduce the risk from wildfires. One important action that can be taken at the local level is to adequately address wildfire vulnerability reduction in local zoning ordinances and comprehensive/land-use plans. Most local zoning ordinances lack provisions for wildfire vulnerability reduction, and most comprehensive/land-use plans are not prepared far enough in advance in rural areas to adequately direct development and institute mitigation measures in high-risk fire hazard areas. Communities are not adequately utilizing land use regulations involving fire risk problems and requirements related to vegetation, topography, weather, transportation and access, water supply, and density of development.

Local fire agencies, primarily due to lack of time and/or personnel, only sporadically review proposed lot splits, subdivisions, severances and other developments for fire protection needs. In general, communities are not requiring developers to analyze the fire vulnerability of their large-scale developments. Such analyses are also not required for most variances and special use permits. Builders seeking building permits for additions to homes do not have to retrofit the existing structure to meet wildfire safety and mitigation measures. These measures could include such actions as replacing an existing roof covering with a fire-resistant or non-combustible covering, installing smoke detectors and other fire safety controls, or maintaining a "Firewise" landscape by providing adequate vehicular access, signage streets, roads and buildings, and providing adequate emergency water supplies.

Additional measures that local governments can take to reduce wildfire vulnerability include restricting the open burning of trash and yard debris (which causes nearly one-third of the wildfires in the state), and developing evacuation procedures for wildfires in the jurisdiction's Emergency Operations Plan (EOP) to minimize potential injury and loss of life.

Efforts of the MDNR Forest Resources Division

The MDNR Forest Resources Division is committed to a multi-jurisdictional, coordinated wildfire mitigation effort. The Division is actively working 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.

The MDNR is conducting a detailed statewide assessment to determine communities' risks from wildfire, using Geographic Information System (GIS) technology. This assessment, which is expected to take several years to complete, will identify the areas of greatest concern for wildfires based on existing and projected land uses and population concentrations, as well as topography, hydrology, soils, vegetative cover, and other natural features. The assessment will provide the MDNR and other state agencies, local governments, builders and developers, and private citizens with information needed to make "Firewise" land use and development decisions and to facilitate the creation of community wildfire protection plans (CWPP), thereby reducing the wildfire threat to people and improved property. The risk map at the end of this section was the result of an early approximation using GIS and a basic model, but current mapping will result in products of far greater validity.

Despite these ongoing initiatives of the MDNR Forest Resources Division, wildfire prevention must be emphasized more at the local level if a meaningful reduction in vulnerability is to occur.

Wildfire Suppression

One trend involves wildfires outstripping the ability of firefighters to suppress them. Fire protection in wildland areas cannot be provided at the same level that it is provided in urban areas. Rural fire departments tend to be volunteer forces, the members of which may be widely dispersed, geographically. That dispersion greatly increases the response time in rural and wildland areas. In addition, these forces also tend to be not as well-equipped as their urban counterparts. These factors, coupled with the tremendous increases in development in wildland areas and the lack of readily available water from pressurized underground pipes, contribute to the possibility of wildfire disasters in many rural areas of Michigan.

Wildfire Analysis

FEMA (and others) have created fairly detailed methods for estimating wildfire risks. The information in this subsection summarizes that given in FEMA publication 386-2 ("Understanding Your Risks"), which primarily uses weather, topography, and land cover (fuel) data to estimate wildfire risks. The first analytic activity is to map the "fuel model" categories in the planning area. This process classifies all areas into three "fuel model" categories based on the types of vegetative land cover that could act as fuel in a wildfire event. Here is a summary of the three fuel model categories described by FEMA:

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 6 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 2 or more inches in length, the overstory is not decadent, and there is 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 6 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 the primary ground fuels are duff and litter, branch wood, and tree boles, and pine needles are less than 2 inches long, then the overstory must not be decadent, and there must be 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.)

The United States Department of Agriculture has created a site with wildfire analysis resources, at http://www.fs.fed.us/fire/science/index.html. Since USDA assesses fire risks nationwide, local or state resources will probably be needed to supplement this source in order to accurately assess a community's specific fuel model areas in the local hazard mitigation plan.

FEMA's wildfire model then combines these fuel category areas with assessments of local topography and weather patterns, to identify overall risk categories (called "moderate hazard," "high hazard," and "extreme hazard.") Topographic information provides three land categories, based on the severity of slopes present in an area. Low slope areas have slopes less than or equal to 40%. Moderate slope areas contain slopes measuring from 40% to 60%. Steep slope areas contain slopes greater than 60%.

Weather information can produce estimates of the number of days per year with "critical fire weather" conditions. FEMA has stated that a local or state fire marshal, forestry department, or Department of Natural Resources can help in determining the number of days per year that critical fire weather is experienced in an area.

Overall categories of wildfire risk (moderate, high, and extreme) are given by the following FEMA table:

	Frequency of Critical Fire Weather								
	1 day per year or less			2 to 7 days per year			8 or more days per year		
Fuel Classification	Slope ≤40%	Slope 41%-60%	Slope ≤60%	Slope ≤40%	Slope 41%-60%	Slope ≥60%	Slope ≤40%	Slope 41%-60%	Slope ≤60%
Light Fuel	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High
Medium Fuel	Moderate	Moderate	High	High	High	High	Extreme	Extreme	Extreme
Heavy Fuel	High	High	High	High	Extreme	Extreme	Extreme	Extreme	Extreme

Additional factors that increase fire risk and may be included in a model include lightning and human factors such as the number of persons residing in, camping in, visiting, or traveling through an area. Such persons may increase fire risks through carelessness or ignorance, while other persons (including residents and fire spotters) may reduce the risk of uncontrolled wildfire in an area, through their ongoing fire awareness, prevention, and response activities. It also makes sense to take into account the type of fire-fighting personnel, equipment, expertise, and related resources (such as water) that are available to a community, or lacking in adjacent communities (from which a fire might spread).

Vulnerable structures are those located in or near a potential wildfire area, unless they have taken special steps to become "Firewise." The “Firewise” concept includes the use of non-flammable roof and patio materials, the clearance of vegetation and maintenance of a defensible space around structures, the ability to provide and facilitate site access by emergency responders, other techniques to make a structure potentially able to withstand wildfire events in its vicinity. Structures that are located in a wildland/urban interface area should be evaluated for these sorts of site features that will exacerbate or minimize their vulnerability. Certain design or landscaping features can render an at-risk structure completely vulnerable to any nearby wildfire event, and thus should be prioritized for wildfire mitigation strategies. Although risk-estimation models exist, FEMA has stated that there are no standardized methods for estimating the amount of damages and economic losses that a community will sustain from a wildfire event.

Although risk-estimation models exist, FEMA has stated that there are no standardized methods for estimating the amount of damages and economic losses that a community will sustain from a wildfire event. Hopefully, a study of the risk assessment options described in this section will enable your community to estimate the frequency of its wildfire events, and to identify the most vulnerable structures and locations, based on fuel types, weather patterns, and the characteristics of structures and their surrounding landscape. (To estimate property vulnerability, based on the degree to which wildfire mitigation steps have been used a given site, see the fire protection steps listed at the FIREWISE web pages at http://www.firewise.org/fw_youcanuse/index.htm.) Structures that are not at all Firewise can be considered at-risk for total losses in a serious wildfire event in vulnerable areas. Structures that are partly Firewise should be at significantly lowered risk and thus the chances of a total loss should be lower. To help justify the costs of wildfire mitigation, risk estimates can be converted to dollar values (expected annual losses) by using information about housing values, estimates about the value of house contents, the costs of interrupted services, evacuation, road closures, and displacement. The value of total potential losses for each property in an at-risk area should be reduced in proportion to the extent to which it is Firewise. Overall loss calculations will therefore take the average annual occurrence of a fire event in vulnerable areas and multiply it by the percentage of that vulnerable area that will likely be affected (this will have to be estimated based on available wildfire response capabilities, or can be estimated from analyzing the extent of past wildfire events and how difficult they had been to control). The percentage of the vulnerable area affected might also represent an estimate of the odds of a particular structure in that area being placed at risk. Each at-risk structure can therefore have its value (after being reduced an appropriate percentage that reflects its Firewise characteristics) multiplied by that calculated risk of being involved in a wildfire event. The total of all individual structural losses can then be totaled to estimate an area's annual expected losses from wildfires, and the expected reduction in fire losses can be compared with the estimated annual cost of wildfire mitigation activities. Please note, however, that this comparison has not included the value of protecting human life. Although wildfire casualties are uncommon today, life-safety considerations may tip the balance so that the costs and effort involved in wildfire mitigation activities will be revealed to be justifiable in order to offset an area's risks.

The United States Department of Agriculture has created a site with wildfire analysis resources, at http://www.fs.fed.us/fire/science/index.html. Since the USDA assesses fire risks nationwide, local or state resources will probably be needed to supplement this source in order to accurately assess a community's specific fuel model areas in your local hazard mitigation plan.

Impact on the Public, Property, Facilities, and Infrastructure
Wildfires can cause widespread concerns and disruptions even in cases where physical damages have been prevented. Smoke, closed roadways, and infrastructure impacts may interfere with ordinary life, as well as an area's economy and planned events (including tourism). Wildfires can also directly cause structural fires to occur. Fortunately, many decades have gone by without a catastrophic wildfire that involved the widespread loss of private structures. A couple of recent Luce County wildfires resulted in emergency and disaster declarations, but managed to avoid the kind of widespread, fatal wildfire disasters that used to occur early in Michigan's history. Despite the improved capacity to notify, evacuate, and respond to wildfire areas today, the 2012 disaster did result in more than 100 structures lost. These events also involve the temporary closure of roads that are locally very important for these rural counties. Most critical facilities and infrastructure were not at risk, but a sufficiently long and severe event could easily involve disruptions in such functions, due to potential damage to utility lines and inhibited personnel access to key sites as a result of smoke and fire impacts upon transportation routes.

Impact on the Economic Condition of the State
A major wildfire disaster can be expensive, but fortunately has not been a common event in recent decades. There is some expense involved in monitoring fire risks and keeping watch so that each fire can be responded to before it reaches a disastrous magnitude. This expense has been considered worthwhile to prevent any major outbreaks by reacting quickly to any new fires while they are still as small as possible. Occasionally, fires do grow out of control, particularly in rural areas with fewer roads and local resources, and the primary economic impact involves the costs to local businesses, residents, and jurisdictional budgets. State-level programs and teams help very much to bear these costs at a higher level of government where the distributed costs feel more affordable. Tourism in rural, fire-prone areas is therefore less impacted on the whole, and a boon to residents throughout Michigan. Similarly, key transportation routes in these areas tend to stay open most of the time, thanks to proactive fire preparedness activities.

Impact on Responders, Continuity of Operations, and Continued Delivery of Services
Wildfires involve special training, equipment, and expertise, as well as a large-scale response and different types of risks for responders, including the potential effects of heat and smoke, large areas of challenging wilderness, the risks of extremely rapid wildfire spread, and locations that are often isolated and distant. These tend to present difficulties with responder equipment staging, transport, coordination, and communications. In recent decades, wildfires have only challenged the continuity of operations within the most impacted local jurisdictions, but community service impacts have tended to only be temporary, as a result of road and facility closures during the worst times of fire risk. Normal operations and services can typically continue within a few days.

Impact on the Environment
Wildfire impacts on Michigan's environment can be considerable, due to the fact that Michigan has the largest state-owned forest system in the Eastern United States, as well as the fifth largest timber acreage in the country. Wildfires physically damage natural vegetation, forests, trees, shrubs, grasslands, native animals and insect species, etc, leaving black soot, deposits of peat, smolder, and charcoal-like ground cover that can contaminate the soil and underground water table. Wildfires can also cause dramatic and immediate changes or shock in vegetation, eliminating some species or causing others to appear where they were not present before the fire. Wildfires (depending on their size and

burning time) are a significant source of gases and particulates in the atmosphere, including carbon dioxide, carbon monoxide, methane, non-methane hydrocarbons and oxides of nitrogen. Fire also produces large amounts of small, solid particles (particulate matter) that absorb and scatter solar radiation, exacerbating climate change conditions.

Even though many fires occur close to where human residences are located, they are a normal ecological phenomenon and serve long-term functions for vegetation and the natural environment. Wildfires burn excess brush, maintain large savannah-like openings, and restore wetlands by forcing out various unwanted brush and plants. The natural function of fires within the environment can be considered a renewal or "cleansing process" as long as the fire is not too severe.

Impact on Public Confidence in State Governance

The large scale of wildfires can cause widespread concerns and disruption, smoke, closed roadways, and infrastructure impacts. Since many wildfire locations involve state lands (especially the Michigan Department of Natural Resources), major wildfire events may raise public questions about the effectiveness of governmental policies toward the maintenance and monitoring of conditions on such lands.

Significant Wildfires in Michigan

Michigan has experienced many destructive wildfires. Thousands of homes (during Michigan's first century) and millions of acres of forest have been destroyed by wildfires. According to Michigan Department of Natural Resources (MDNR) and U.S. Forest Service records, over 5.8 million acres of forest in Michigan were burned between 1910 and 1949, an average of 145,000 acres per year. By comparison, it was reported that between 1950 and 1996, the MDNR and U.S. Forest Service were involved in suppressing over 46,100 wildfires that burned 390,000 acres of forest, which averages only 8,300 acres burned per year. This drastic reduction in the acres of timber burned was largely the result of (1) increased use of specialized equipment to suppress the fires, and (2) intensified efforts toward fire prevention. The following list summarizes some of the largest and most severe wildfires that have occurred in Michigan to date.

October 1871 - Lower Peninsula

The State's first recorded catastrophic fire occurred in the fall of 1871, after a prolonged drought over much of the Great Lakes region in the summer of 1871. The drought had left debris from logging and land clearing tinder dry, and as a result numerous fires burned throughout the state. These fires continued to smolder until, on October 8th of that year, gale and hurricane force winds fanned a series of fires across much of the northern Lower Peninsula. Because this tremendously destructive wildfire occurred at the same time as the great wildfires that struck Peshtigo, Wisconsin (which killed 1,300 people in a single night, and also affected Menominee County in the Upper Peninsula) and the Great Chicago Fire (which destroyed much of central Chicago), the Michigan wildfire received little publicity. However, the 1871 Michigan wildfire killed 200 people and burned 1.2 million acres. When the winds finally subsided, the fire's swath stretched from Lake Michigan across to Lake Huron. The most heavily affected area, north of Saginaw Bay, had an area 40 miles square that was completely destroyed, with over 50 people killed. The worst of the fire was over by October 19, although the fire wasn't completely extinguished for over a month.

August-September 1881 - Thumb Area

On August 31, 1881, several small fires in the Thumb came together to form a major conflagration (commonly known as the Thumb fire). A massive area of fires moved through the Thumb counties, and six days later, stopped at Lake Huron. This fire was, in many ways, more severe than the 1871 fire, since settlers had moved into the region in large numbers and logging had gotten underway. More than a million acres were burned; property loss exceeded $2 million, and 282 were killed. Like the 1871 fire, the fire of 1881 came at the end of an extremely severe drought and was the result of hundreds of land-clearing fires being brought together into a conflagration by high winds.

Summer 1896 – Ontonagon Fire

A dry summer exacerbated fire conditions and winds also helped to spread a wildland blaze to the town of Ontonagon, which saw heavy destruction as a result. More than 340 buildings were burned, and hundreds of residents were displaced to nearby farms and the nearby town of Rockland. Animals died and humans were injured, but fortunately, only one person was actually killed in the disaster.

October 1908 – Metz Fire (Presque Isle County)

Droughts in northern Michigan exacerbated wildfire conditions and threatened the town of Metz. Some of the evacuating residents tried to flee by train, but the train was wrecked near the station at Hawks by a burned out culvert, killing 14 passengers, plus two persons who lived at a nearby home. Since the train had found its path blocked by flames, it had attempted to proceed backwards toward Metz and Alpena, but had failed in the effort.

July 1911 – Au Sable-Oscoda Fire (Iosco County, and also Cheboygan, Crawford, and Otsego Counties)

Enormous wildfires ravaged the northern Lower Peninsula and caused massive destruction at 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. Fires at Oscoda and Alpena were reported to have started at slab yards. Damages were estimated at $100,000 in Alpena, and $500,000 in Oscoda and Au Sable. The town of Waters suffered $300,000 in damage to property and at least as much to lumber. At least 500 evacuees were sheltered at Tawas City and East Tawas. Total losses across the area were estimated as at least $1.5 million. Several casualties were reported, but the total number actually killed in the disaster was not clear from reports.

May 1968 – Crawford and Kalkaska Counties

The "Fletcher Road Fire" was started at approximately 2:45pm on May 8, 1968, by a pipeline welding crew whose company later paid out more than $90,000 in damages for timber losses. Tree mortality was almost total within an area of 4,216 acres across Kalkaska and Crawford Counties, and the fire crowned (reached the tree tops) in over 75% of that area. Crown fires like this allow the fire to advance and spread rapidly. The fire was able to "jump" across Fletcher Road and burned at a rate of approximately 2 miles per hour, which is considered to be a fast-moving fire. Smoke could be seen from as far as 20 miles away. A million-dollar gas refinement facility was placed at-risk by the fire, but protected by responder efforts.

August-September 1976 - Seney (Schoolcraft County)

In the late summer months of August and September 1976, a fire near Seney burned approximately 74,000 acres. At least part of the fire was started by lightning and quickly became uncontrollable due to an abundance of flammable material brought on by drought conditions. However, there were also problems involving prescribed, controlled burns and smoldering areas that later reignited and thus created unusual problems. The fire started on federal land and spread to state and privately owned lands. Fire suppression and damage costs exceeded $8 million.

May 1980 - Oscoda County

In May 1980, a wildfire in Oscoda County (known as the Mack Lake fire) destroyed 44 homes and buildings, forced the evacuation of 1,500 people, and killed one firefighter. A total of 24,000 acres were burned, resulting in a total property and timber loss of $2 million. The fire has been claimed to have stemmed from a prescribed burn that got out of control when it "jumped" across a highway. It has been claimed that a major wildfire occurs about every 20 to 30 years in the area.

May 1986 - Marquette County

In May 1986, multiple wildfires in Marquette County burned 7,000 acres and forced the evacuation of 4,000 people at K.I. Sawyer Air Force Base when flames spread right up to some of the housing units.

July 1988 – Escanaba (Delta County)

A large fire caused the evacuation of 60 families and the temporary closure of Highway U.S.-2. Two firefighters were injured battling what became known as the "Stockyard Fire," a name given because the fire area included a site that had previously been used as a stockyard. Again, conditions were exacerbated by regional drought effects.

May 1990 - Grayling (Crawford County)

In May 1990, a wildfire near Grayling in Crawford County (known as the Stephan Bridge Road fire) burned 76 homes and 125 other structures, 37 vehicles and boats, and over 5,900 acres of forestland, resulting in property losses of $5.5 million. The timber losses totaled another $700,000. The fire originated from a controlled burning of a pile of brush and timber accumulated from recently cleared land. The burning was initiated while snow covered the ground, and it had been presumed that the fire was completely extinguished. However, the pile rekindled approximately seven weeks later, and on May 8, ignited the Stephan Bridge Road fire. Strong winds and dry conditions helped spread the fire at a rate beyond that which could be controlled by human intervention. At one point in the fire, the rate of spread was an astonishing 277 feet per minute. Fortunately, the combination of human fire suppression and a passing weather front that produced rainfall finally contained the fire before it could do any additional damage. There were no fatalities as a result of this fire, and only one firefighter was injured from smoke inhalation. However, the property losses were significant.

May 2-7, 1999 - Champion (Marquette County), Epoufette (Mackinac County), Oscoda County

In early May 1999, a wildfire near the village of Champion in Marquette County (known as the Tower Lake fire) burned a total of 5,625 acres of forestland, destroyed at least 8 structures (about 7 more were damaged), and forced the evacuation of 450 persons in Champion as well as those in the vicinity of Fish Lake, Perch Lake, Mud Lake, eastern Michigamme, and Van Riper State Park. In addition, the fire forced the closure of US-41 and M-95 in the area of Champion and Michigamme for several days, and 10 bridges were burned. Timber losses were estimated at $12.8 million, with property losses totaling another $960,000. Aerial firefighting assets were brought in from surrounding areas to help prevent the spread of the fire into Champion, thus saving the town from destruction. At the request of the Governor, the Federal/State Forest Fire Suppression Agreement was activated by the Federal Emergency Management Agency (FEMA) to provide financial assistance to the State and eligible local agencies to cover some of the firefighting costs incurred. At about the same time as the Tower Lake fire, major wildfires were also being fought in several other locations across Northern Michigan. In Mackinac County, an 850-acre fire burned for several days near Epoufette, while another 850-acre fire burned in the Huron-Manistee National Forest in Oscoda County. In the Northern Lower Peninsula alone during that first week of May, MDNR forces fought nearly 40 wildfires. All of the wildfires were fueled by the same dry conditions that set the stage for the Tower Lake fire.

May-June 2000 - Mio (Oscoda County), Torch Lake Township / Lake Linden (Houghton County)

A wildfire that began on April 30 near Mio and was fed by extremely dry conditions consumed nearly 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 to suppress the fire. The fire prompted the evacuation of approximately 30 persons for a short time. Fortunately, the fire did not cause any injuries or structural damage. About a month later, on June 6, a brush fire set on a blueberry farm near Rice Lake in Torch Lake Township, Houghton County, got out of control and eventually burned over 350 acres before being contained the next day. Firefighters from the MDNR and 15 local fire departments, plus two aerial water tankers, were called to fight the blaze. The fire forced the evacuation of over 20 homes and cottages, and at one point was one-half mile wide and almost one mile long. Brisk winds pushed the fire to within one-quarter mile of homes along the shoreline of Lake Superior. However, no structures were lost and no injuries were reported.

March-April 2005 – Roscommon County

A long period of warm and dry weather affected northern Michigan from the end of March through mid April. Once the spring snow melt was completed, the fire danger rapidly increased. A number of wildfires developed in northern Lower Michigan in mid-April. The largest occurred in Nester Township in Roscommon County. This fire (of unknown origin) started on the afternoon of the 16th, and burned over 1,500 acres before it was gradually brought under control over the next several days. There was no known structural damage, though sixteen to twenty homes in the area were evacuated.

April 30 to May 1, 2006 – Oscoda County

A wildfire in Hughes Lake began early in the afternoon of April 30th, ignited by an individual burning brush in a fire pit. The fire spread northwest from Hughes Lake, thanks to southeast winds of 10 to 20 mph. The rate of spread reached as high as 2 miles per hour late in the afternoon of the 30th, with flame heights reaching 300 feet tall. Stands of jack pine, which burn very readily, contributed to the intensity of the fire. Containment activities brought the fire under control by late afternoon of May 1st, although mop-up would continue for several days after. Crews were flown in from as far away as New Mexico and Montana to fight the fire. At its height, almost 300 personnel were involved in fighting the fire. Approximately 5,950 acres of timber and brush land burned, south of M-72, east of M-18, and west of M-33. Sixteen structures and seven vehicles were destroyed—most structures were seasonal and not residential, but an American Red Cross shelter in Luzerne hosted seven persons. A number of evacuations were ordered, some as far west as M-18 in southeast Crawford County, although most residents returned to their homes within a few days. Total damage to property was conservatively estimated at $600,000. Note that this does not include costs incurred in fighting the fire, which were in excess of $800,000.

April 27-30, 2007 – Baraga County

A wildfire in Baraga, which started as a controlled burn by the U.S. Forest Service on the 27th, went out of control by the 29th, fueled by low relative humidity and strong winds gusting over 40 mph. The wildfire consumed more than 1,300 acres in western Baraga County between the 27th and 30th. More than 120 firefighters from the U.S. Forest Service and the Michigan DNR battled the blaze and helped authorities evacuate thirty homes in the Covington area. No injuries or structural damages were reported from the fire. Another fire in northwest Marquette County destroyed three structures and burned approximately 60 acres before it was brought under control on the 29th.

August 2007 – Luce County "Sleeper Lake Fire"

On August 2, a lightning strike ignited a fire in central Luce County and grew to disastrous proportions, burning nearly 19,000 acres and resulting in a governor-declared State of Emergency. More than 220 personnel were involved in fire containment and suppression operations, from local, state, and federal agencies. Fortunately, the relatively remote location caused a limited number of properties to be lost. However, residents had to be evacuated three separate times during the substantial event period. Despite the substantial risks to nearby residents and facilities, efforts to obtain a federal disaster declaration were unsuccessful.

April 24, 2008 – Crawford County

Called the "Four Mile Road Fire," the cause may have been some sparks from a passing train. A Red Flag warning had been in effect when the fire started a few miles south-southeast of Grayling. The weather was warm, dry, and windy, and the fire quickly expanded to the northwest, crossing I-75 (which was closed for several hours) and eventually burning 1,300 acres. On the far south side of Grayling, a gas station and motel were threatened, but spared damage. About a half-dozen cabins near Simpson Lakes were lost (about two miles south of downtown Grayling), and $287,000 in damage was sustained by the Grayling Game Club. Total property damages from the event were estimated at $750,000, and MDNR response costs and timber damages were about $619,000. Fifty homes were evacuated, and power was lost in Grayling. By the evening, winds and temperatures went down and several periods of rain during the night helped the fire to be extinguished.

May 20 to 26, 2009 – Marquette and Baraga Counties

Southwest of Ishpeming, the "Black River Falls Wildfire" started on the afternoon of May 20 when a wind-damaged pine tree fell across a power line. The wildfire destroyed 21 homes, 12 other structures, and caused an estimated $4 million in property damage. The fire had burned 811 acres but was contained by the 22nd, and final clean-up took until the 26th. Personnel and equipment costs to fight the fire were estimated at $100,000 in Marquette County. During the same time period, in neighboring Baraga County, a "Pinery Wildfire" started in an area east of L'Anse and burned 685 acres before being contained two days later (with final clean-up also lasting until the 26th). About $50,000 in property damage was caused when flames destroyed a mobile home and damaged the Pinery Ski Lake trails area and a nearby cemetery. Firefighting costs for the Baraga event approached $125,000.

May 18 to 26, 2010 – Crawford and Kalkaska Counties

A debris fire expanded out of control and resulted in the "Meridian Boundary Fire" by about 1:30pm on May 18. A total of 8,800 acres were eventually burned by this fire, which took until May 26 to reach 95% containment. Twelve residences were destroyed, six were damaged, and 36 outbuildings were either destroyed or damaged, resulting in total property damages of about $825,000. Also on May 18, in adjacent Kalkaska County, the "Range 9 Fire" started when a controlled burn on an artillery range became uncontrolled as winds increased through the area. The Range 9 Fire burned 1,100 acres of mostly grassy areas on the Camp Grayling grounds, but also crossed over the boundary line at one point and destroyed 4 seasonal homes in Blue Lake Township, resulting in an estimated $125,000 in property damage. By late evening on the same date, that smaller fire was under control.

May 20 to 31, 2012 – Luce County "Duck Lake Fire"

About $12 million in property damage resulted from the Duck Lake Wildfire in Luce County, which was ignited by lightning strikes from a line of thunderstorms. The fire started 14 miles north of Newberry and the simultaneous Pine Creek North Wildfire seriously affected large parts of the Seney National Wildlife Refuge. Fanned by strong south winds, the fire spread rapidly toward the shoreline of Lake Superior and forced people in the Pike Lake, Bodi Lake, Culhane Lake, and Little Lake Harbor areas to evacuate. Major roads across that area were closed. A total of 136 structures were burned (including one store and one motel) and the wildfire affected 21,069 acres before it was fully contained in mid-June. The Duck Lake event was the third largest in modern Michigan history. About $600,000 in resources were expended to fight the fire. A governor's state of disaster was declared for Luce and Schoolcraft Counties on May 25.

July 30, 2015 – Marquette County

Firefighter crews battled a 100-acre wildfire in Humboldt Township (Marquette County). The fire started in an area where logging had occurred during the winter, in which loggers had begun working to test a newly built road by mid-summer. The fire had been fueled by warm weather and strong winds, but cooler temperatures and some rain helped contain it. Although at least $150,000 worth of cut timber was destroyed, no injuries were reported.

June 29 to July 1, 2016 – Chippewa County

MDNR firefighter crews responded to an 82-acre fire that started on June 29th in Munuscong (Chippewa County). This was the largest of at least three wildfires that crews had responded to that week. Fortunately, no injuries were reported and no structures were threatened. The U.S. Forest Service battled a 35-acre fire in the Hiawatha National Forest in Chippewa County. A smaller fire was sparked by a lightning strike that same day and charred about three-quarters of an acre in Mackinac County.

May 1, 2018 – Crawford, Wexford, and Newaygo Counties

The Michigan Department of Natural Resources sent fire crews to respond to wildfires overnight on May 1st, including three major blazes in Crawford, Wexford, and Newaygo counties. The fire in Crawford County occurred at approximately 4pm along I-75, about 7 miles south of Grayling. The fire was estimated to be just over 44 acres in size, and a stretch of I-75 was shut down for about an hour and a half. The fire in Wexford County occurred at approximately 5pm in Haring Township, about 5 miles north/northwest of Cadillac. Called the "Bond Mill Pond Fire," it was estimated to be about 79 acres, mostly involving state forest lands. The fire caused the evacuation of 79 residents, who were all allowed to return that same evening. The U.S. Forest Service provided helicopter support for the fire-suppression efforts and dumped 1,600 gallons of water before being grounded due to high winds. The fire in Newaygo County occurred at approximately 6:45pm, just over 6 miles east of Newaygo, south of M-82. This "Oak Fire" was located primarily on federal lands and estimated at 105 acres in size. It was contained by around 1am. Two residents were evacuated and 15 structures were threatened, but excellent work by 11 local volunteer fire departments, U.S. Forest Service crews, and MDNR fire crews resulted in all the structures being saved.

July 20, 2018 – Kalkaska County

A nearly 50-acre wildfire ignited in rural Kalkaska County and kept firefighters occupied for several hours before they contained the blaze. The MDNR led the fire response, with assistance from multiple local fire departments and a military fire engine from Camp Grayling. Fortunately, there were no injuries.

Programs and Initiatives

Michigan Department of Natural Resources Forest Resources Division

The MDNR Forest Resources Division directs and coordinates wildfire prevention, containment and suppression activities on all non-federal lands in the state, as well as Indian Reservations (under contract with the U.S. Bureau of Indian Affairs). The MDNR places great emphasis on wildfire prevention and public education, since the vast majority of wildfires in Michigan are caused by human activity. The MNDR Forest Resources Division's philosophy is that preventing fires from starting in the first place, and precautionary measures around rural homes, are the best means of avoiding or minimizing wildfire losses. When conditions of extreme fire hazard exist, the MDNR can request the Governor to issue an outdoor burning ban to mitigate the potential for wildfire in all or part of the state. Such a ban restricts smoking, fireworks, and outdoor burning activities to approved locations.

Michigan Forest Fire Experiment Station

A string of disastrous wildfires in the early 20th century led to the creation of the Michigan Forest Fire Experiment Station in 1929. This Station, established by what was then the Michigan Department of Conservation (now the Department of Natural Resources) and located in Roscommon, is designed to investigate how wildfires behave, how to properly manage forest fuels, and how to use mechanized equipment to fight wildfires. Its research efforts have been invaluable in helping to prevent, contain and suppress wildfires in Michigan and across the country.

Michigan Interagency Wildland Fire Protection Association

Because the vast majority of wildfires are caused by human activity, the Michigan Department of Natural Resources established, in 1981, the Michigan Interagency Wildfire Prevention Group. It was the first such group in the nation (promoting wildfire prevention and awareness) that had the full involvement of the state's fire agencies. In 1993, the Michigan Interagency Wildfire Prevention Group was expanded to form the Michigan Interagency Wildland Fire Protection Association (MIWFPA). The MIWFPA promotes interagency cooperation in fire prevention, training, fire technology, and firefighting operations. Members of the MIWFPA include the: 1) MDNR Forest Resources Division; 2) USDA Forest Service - Huron-Manistee, Hiawatha, and Ottawa National Forests; 3) USDI National Park Service - Pictured Rocks and Sleeping Bear Dunes National Lakeshores; 4) USDI Fish and Wildlife Service - Seney National Wildlife Refuge; 5) USDI Bureau of Indian Affairs; 6) Michigan Department of State Police - fire investigation; 7) Michigan State Firemen's Association; and the 8) Michigan Fire Chief's Association.

Michigan Natural Resources and Environmental Protection Act

The Michigan Natural Resources and Environmental Protection Act (1994 PA 451), Part 515, assigns responsibility for the prevention and suppression of forest fires to the Director of the Michigan Department of Natural Resources. The Act also establishes requirements for burning permits, allows the Governor to issue prohibitions against the use of fire during extreme fire hazard conditions, and allows the MDNR Director to enter into forest fire assistance agreements with other states and the federal government to control forest fires. These measures contribute to forest fire mitigation by preventing forest fires from starting in the first place, or lessening the spread of fires when they do start (and thus preventing further damage from occurring).

Solid Waste Management Act

The Michigan Solid Waste Management Act (1990 PA 264) prohibits the burning of leaves and grass clippings in municipalities with more than 7,500 population, unless a municipality has an ordinance expressly allowing such burning activities. When properly applied and enforced, this law helps prevent some wildfires, since roughly one-quarter of all wildfires are started by small residential waste fires that get out of control.

Great Lakes Forest Fire Compact

In the Great Lakes region, more than one-third of the 6,000 wildfires that occur annually are caused either by careless burning by residents or children playing with matches. The MDNR Forest Resources Division is a member of the Great Lakes Forest Fire Compact in an effort to reduce these fires. The Compact is a partnership between the states of Michigan, Wisconsin and Minnesota, and the Canadian provinces of Ontario and Manitoba. Its purpose is to promote effective prevention, pre-suppression, and control of wildfires in the Great Lakes region through mutual aid and cooperation. Initiatives are implemented by committees composed of members of the Compact. An example of an activity the Compact has undertaken is the development of a fire hazard assessment for the region. Michigan took the lead on this project, and it has proven to be an extremely beneficial educational tool for communities and property owners in assessing their fire hazard potential.

The efforts of the Compact to build coordination and cooperation are based on the understanding that wildfires are multi-jurisdictional, and that suppression of fires usually requires the efforts of many groups and jurisdictions.

"Firewise Communities" Wildfire Protection Program

The MDNR is a participant in the national "Firewise Communities" Program developed by the National Wildland-Urban Interface (WUI) Fire Protection Program. The WUI Fire Protection Program is sponsored by the nation's major wildland fire agencies and the National Fire Protection Association (NFPA). In addition to the NFPA, other sponsors include the: 1) USDA Forest Service; 2) USDI; 3) USDI National Park Service; 4) USDI Bureau of Land

Management; 5) USDI Bureau of Indian Affairs; 6) USDI U.S. Fish and Wildlife Service; and the 7) National Association of State Foresters. These member agencies have been promoting "Firewise" living since 1986.

The Firewise Communities Program is designed to educate governmental officials and professionals in a wide variety of disciplines (e.g. planners, builders, engineers, architects, bankers, insurance representatives, emergency managers, land managers) on ways in which communities can be designed and built to minimize the threat from wildfires. The current focus of that educational effort is a series of Firewise Communities Workshops being held around the country. At the Workshops, participants use computerized mapping and wildfire simulations to learn how to recognize wildland -urban interface fire hazards, design Firewise homes and landscapes, deliver fire education, and integrate Firewise planning into existing and developing areas of communities. The Firewise Communities Program also produces and distributes guidance documents, videos, and software packages on wildland-urban interface fire issues.

Although the MDNR had worked with the City of Grayling in a pilot program during an effort to promote this initiative, there are at the current time no communities officially recognized as Firewise communities in Michigan.

Wildfire Prevention Week

Due to the high risk of wildfires in Michigan, the state observes Wildfire Prevention Week sometime in April every year. Most Michigan wildfires are human-caused, with one-third caused by people burning debris. An increasing number of people moving into rural areas surrounded by fire-prone vegetation makes preventing wildfires in these areas a critical public safety issue for everyone. The economic value that Michigan forests contribute, in the form of travel, eco-tourism, hunting, fishing, camping and other recreational uses, and timber-related products, is an estimated 200,000 jobs and $12 billion annually. Officials throughout Michigan have stressed that thoughtful activity by humans is critical to preventing wildfires.

Hazard Mitigation Alternatives for the Wildfire Hazard

- Proper maintenance of property in or near wildland areas (including short grass; thinned trees and removal of low-hanging branches; selection of fire-resistant vegetation; use of fire resistant roofing and building materials; use of functional shutters on windows; keeping flammables such as curtains securely away from windows or using heavy fire-resistant drapes; creating and maintaining a buffer zone (defensible space) between structures and adjacent wild lands; use of the fire department's home safety inspections; sweeping/cleaning dead or dry leaves, needles, twigs, and combustibles from roofs, decks, eaves, porches, and yards; keeping woodpiles and other combustibles away from structures; use of boxed or enclosed eaves on houses; thorough cleaning-up of spilled flammable fluids; and keeping garage areas protected from blowing embers).
- Safe disposal of yard and house waste rather than through open burning.
- Use of fire spotters, towers, planes.
- Use of structural fire mitigation systems such as interior and exterior sprinklers, smoke detectors, and fire extinguishers.
- Arson prevention activities, including reduction of blight (cleaning up areas of abandoned or collapsed structures, accumulated junk or debris, and lands with a history of flammable substances stored, spilled, or dumped on them).
- Public notification of fire weather and fire warnings.
- Prescribed burns and fuel management (thinning of flammable vegetation, possibly including selective logging to thin out some areas. Fuels cleared can be given away as firewood or made into wood chips for distribution.)
- The creation of fuel breaks (areas where the spread of wildfires will be slowed or stopped due to removal of fuels, or the use of fire-retardant materials/vegetation) in high-risk forest or other areas.
- Keeping roads and driveways accessible to vehicles and fire equipment—driveways should be relatively straight and flat, with at least some open spaces to turn, bridges that can support emergency vehicles, and clearance wide and high enough for two-way traffic and emergency vehicle access (spare keys to gates for properties should be provided to the local fire department, and an address should be visible from the road so homes can be located quickly).
- Enclosing the foundations of homes and buildings rather than leaving them open with their underside exposed to blown embers or materials.

- Safe use and maintenance/cleaning of fireplaces and chimneys (with the use of spark arresters and emphasis on proper storage of flammable items). Residents should be encouraged to inspect chimneys at least twice a year and clean them at least once a year.
- Proper maintenance and storage of motorized equipment that could catch on fire (from blown embers, etc.)
- Proper storage and use of flammables, including the use of flammable substances (such as when fueling machinery). Store gasoline, oily rags and other flammable materials in approved safety cans. Stack firewood at least 100 feet away and uphill from homes.
- Avoid building structures on hilltop locations, where they will be at greater risk from wildfires (in addition, hillsides facing south or west are more vulnerable to increased dryness and heat from sun exposure).
- Use of proper setbacks from slopes (outside of the "convection cone" of intense heat which would be projected up the slope of the hill as a wildfire "climbs" it).
- Have adequate water supplies for emergency fire-fighting (in accordance with NFPA standards).
- Obtaining insurance.

Emphasis in Local Hazard Mitigation Plans

Wildfires were identified as one of the most significant hazards in local hazard mitigation plans for the following counties: Alcona, Alger, Arenac, Benzie, Clare, Crawford, Emmet, Gogebic, Hillsdale, Iosco, Iron, Isabella, Lake, Livingston, Luce, Mackinac, Marquette, Mason, Missaukee, Newaygo, Oceana, Ogemaw, Osceola, Oscoda, Otsego, Roscommon, Sanilac, and Schoolcraft (28 counties, an increase since 2014).

Wildfire History for Michigan Counties – arranged by geography – Jan. 1, 1996 to Apr. 30, 2017
(The Lower Peninsula regions are ordered by "tiers" from south to north, west to east)
Please refer to the Michigan Profile Map section for an explanation of geographic divisions

COUNTY or area	Wildfire Events	Days with Event	Tot. property damage	Tot. crop damage	Injuries
Washtenaw					
Wayne					
.Livingston					
Oakland					
Macomb	2	2	$20,000		
5 Co Metro region	**0.4 avg.**	**0.4 avg.**	**$20,000**		
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	1			
Sanilac					
.Mecosta					
Isabella					
Midland					
Bay					
Huron					
34 Co S Lower Pen	**0.03 avg.**	**0.03 avg.**			

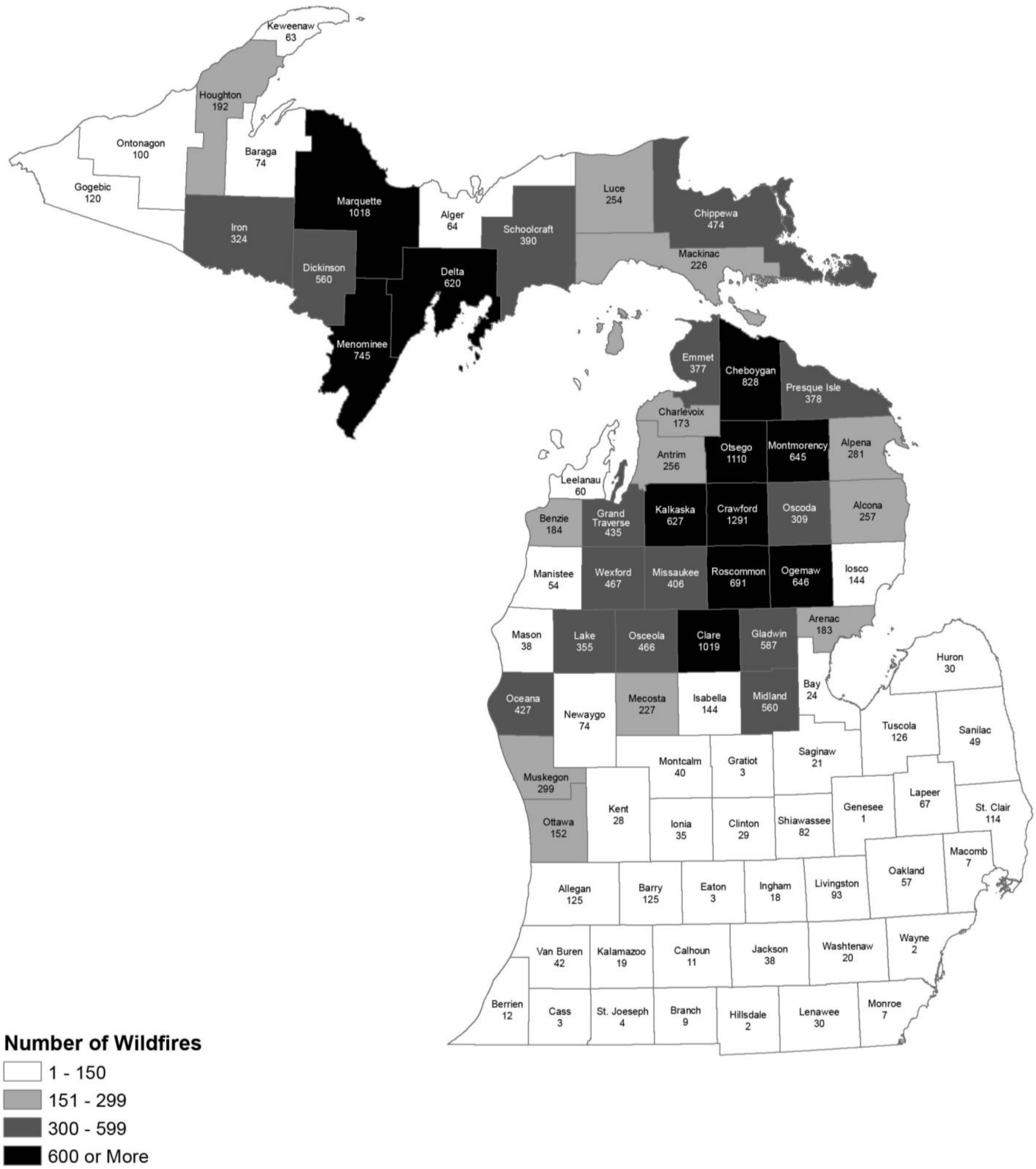
Continued on next page…

Part 2 of Wildfire History for Michigan Counties – arranged by geography

.Oceana					
Newaygo					
.Mason					
Lake					
Osceola					
Clare					
Gladwin					
Arenac					
.Manistee					
Wexford					
Missaukee					
Roscommon	1	1			
Ogemaw					
Iosco	1	1	$40,000		
.Benzie					
Grand Traverse					
Kalkaska	1	1	$125,000		
Crawford	2	2	$1,575,000		
Oscoda	2	2	$600,000		
Alcona					
.Leelanau					
Antrim					
Otsego					
Montmorency					
Alpena					
.Charlevoix					
Emmet					
Cheboygan					
Presque Isle					
29 Co N Lower Pn	**0.2 avg.**	**0.2 avg.**	**$2,340,000**		
Gogebic					
Iron					
Ontonagon	1	1			
Houghton					
Keweenaw					
Baraga	2	2	$50,000		
.Marquette	7	5	$5,006,000	$1,000,000	4
Dickinson					
Menominee					
Delta	1	1	$20,000		
Schoolcraft	1	1			
Alger					
.Luce	2	2	$12,040,000		
Mackinac					
Chippewa					
15 Co Upp.Pen	**0.9 avg.**	**0.8 avg.**	**$17,116,000**	**$1,000,000**	**4**
MICHIGAN TOTAL	**24**	**19**	**$19,476,000**	**$1,000,000**	**4**
Annual average	**1.1**	**0.9**	**$913,055**	**$46,881**	**0.2**

Number of Wildfires, by County, 1981-2018

(On lands under MDNR jurisdiction only)

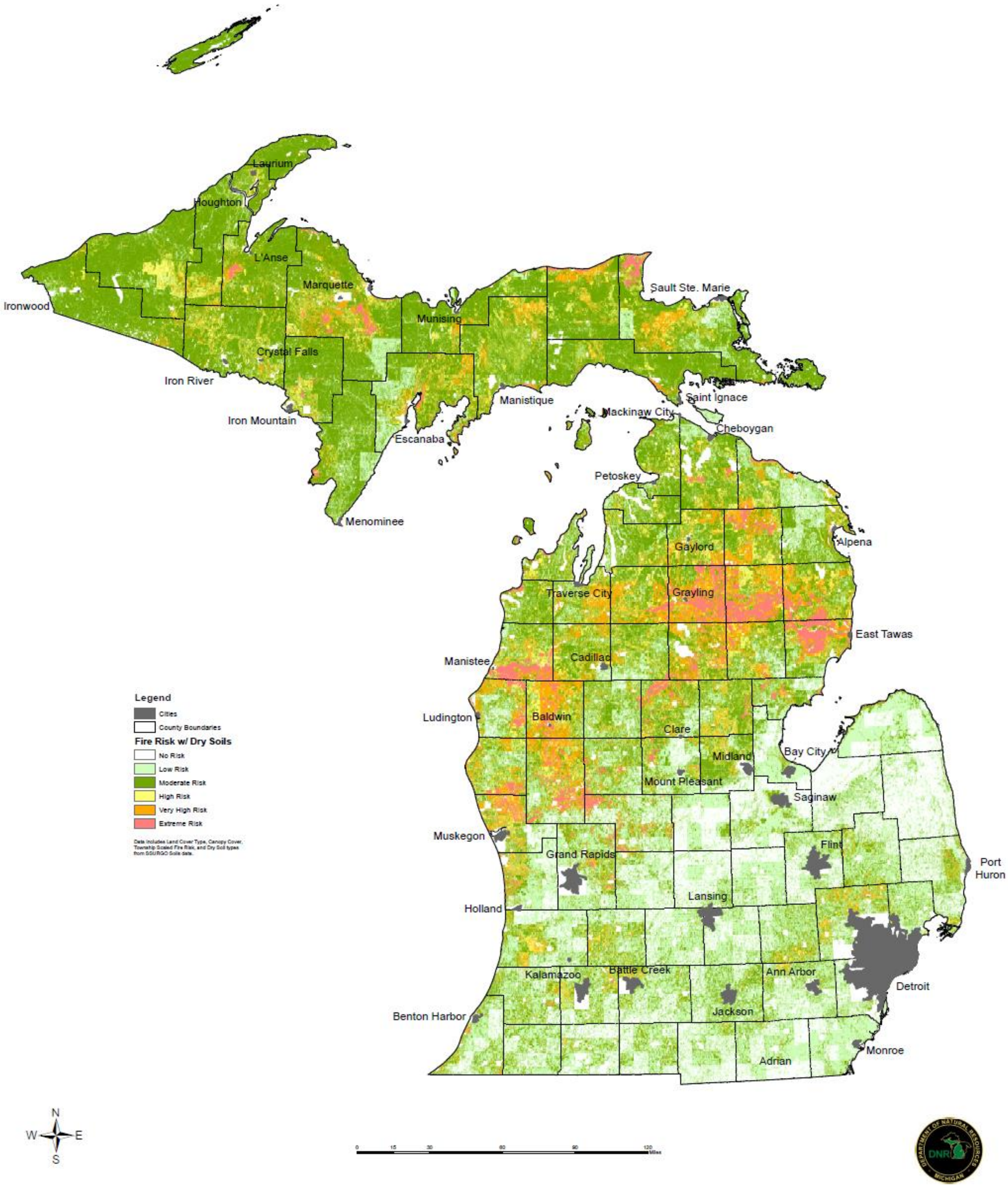


Produced by:
Michigan State Police
Emergency Management and Homeland Security Division
January 2019

Number of Wildfires and Acres Burned, by County: 1981-2018 (MDNR jurisdiction only) Source: MDNR/FRD

County	Number of fires	Number of Wildfires/Year	Number of Acres Burned	Number of Acres Burned/Year
Alcona	257	6.8	1,567.6	41.3
Alger	64	1.7	201.2	5.3
Allegan	125	3.3	594.6	15.6
Alpena	281	7.4	441.6	11.6
Antrim	256	6.7	285.3	7.5
Arenac	183	4.8	703.7	18.5
Baraga	74	1.9	1,936.6	51.0
Barry	125	3.3	613.1	16.1
Bay	24	0.6	180.7	4.8
Benzie	184	4.8	396.8	10.4
Berrien	12	0.3	25.9	0.7
Branch	9	0.2	173.9	4.6
Calhoun	11	0.3	45.3	1.2
Cass	3	0.1	27.0	0.7
Charlevoix	173	4.6	522.2	13.7
Cheboygan	828	21.8	1,571.4	41.4
Chippewa	474	12.5	5,916.4	155.7
Clare	1,019	26.8	2,647.8	69.7
Clinton	29	0.8	142.7	3.8
Crawford	1,291	34.0	32,506.0	855.4
Delta	620	16.3	3,393.7	89.3
Dickinson	560	14.7	2,547.6	67.0
Eaton	3	0.1	0.3	0.0
Emmet	377	9.9	649.6	17.1
Genesee	1	0.0	0.1	0.0
Gladwin	587	15.4	2,161.3	56.9
Gogebic	120	3.2	254.9	6.7
Grand Traverse	435	11.4	1,484.2	39.1
Gratiot	3	0.1	42.7	1.1
Hillsdale	2	0.1	23.0	0.6
Houghton	192	5.1	1,211.9	31.9
Huron	30	0.8	982.5	25.9
Ingham	18	0.5	479.0	12.6
Ionia	35	0.9	765.8	20.2
Iosco	144	3.8	1782.8	46.9
Iron	324	8.5	2,041.2	53.7
Isabella	144	3.8	1,782.8	46.9
Jackson	38	1.0	562.0	14.8
Kalamazoo	19	0.5	125.3	3.3
Kalkaska	627	16.5	3,200.4	84.2
Kent	28	0.7	213.5	5.6
Keweenaw	63	1.7	381.9	10.1
Lake	355	9.3	1,541.8	40.6
Lapeer	67	1.8	629.4	16.6
Leelanau	60	1.6	267.6	7.0
Lenawee	30	0.8	224.2	5.9
Livingston	93	2.4	812.1	21.4
Luce	254	6.7	39,821.3	1,047.9
Mackinac	226	5.9	1,695.9	44.6
Macomb	7	0.2	15.4	0.4
Manistee	54	1.4	1,070.7	28.2
Marquette	1,018	26.8	16,607.2	437.0
Mason	38	1.0	206.2	5.4
Mecosta	227	6.0	1,039.7	27.4
Menominee	745	19.6	2,615.8	68.8
Midland	560	14.7	1,596.3	42.0
Missaukee	406	10.7	1,884.9	49.6
Monroe	7	0.2	658.4	17.3
Montcalm	40	1.1	640.2	16.8
Montmorency	645	17.0	1,371.7	36.1
Muskegon	299	7.9	2,944.9	77.5
Newaygo	74	1.9	548.9	14.4
Oakland	57	1.5	399.9	10.5
Oceana	427	11.2	1,983.6	52.2
Ogemaw	646	17.0	9,480.1	249.5
Ontonagon	100	2.6	1,509.0	39.7
Osceola	466	12.3	1,192.4	31.4
Oscoda	309	8.1	8,872.9	233.5
Otsego	1,110	29.2	2,123.2	55.9
Ottawa	152	4.0	494.3	13.0
Presque Isle	378	9.9	968.6	25.5
Roscommon	691	18.2	4,667.4	122.8
Saginaw	21	0.6	478.6	12.6
Sanilac	49	1.3	453.7	11.9
Schoolcraft	390	10.3	6,770.9	178.2
Shiawassee	82	2.2	618.5	16.3
St. Clair	114	3.0	1,758.1	46.3
St. Joseph	4	0.1	20.3	0.5
Tuscola	126	3.3	1,355.0	35.7
Van Buren	42	1.1	259.4	6.8
Washtenaw	20	0.5	249.1	6.6
Wayne	2	0.1	42.2	1.1
Wexford	467	12.3	1,199.1	31.6
Total DNR fire events	20,650	543.4	194,960.5	5,130.5

Wildfire Risk



Source: Michigan Department of Natural Resources, Forest Resources Division

INVASIVE SPECIES

A species whose introduction to Michigan causes or is likely to cause economic or environmental harm, or harm to human health, to an extent that outweighs the species' known benefits. This chapter includes a consideration of harmful contagious diseases that may have similar impacts.

Hazard Description

An invasive species is defined as a species that is (1) non-native (alien) to the ecosystem under consideration and (2) whose introduction causes or is likely to cause economic or environmental harm, or harm to human health. Invasive species can be plants, animals, and other organisms (e.g., microbes). This chapter includes a consideration of harmful contagious diseases that may have similar levels of impact upon Michigan's ecology or economy. Invasive species typically fall into two broad categories—**terrestrial** (able to live in Michigan's land area) and **aquatic** (able to live within Michigan's water bodies).

Human actions have been an important consideration as a means of invasive species' sudden introduction (thus distinguishing the situation from natural shifts in the distribution of species), but a human-related cause may not be relevant to the extent of impact that results. Nationally, the current environmental, economic, and health costs of invasive species have been estimated as exceeding the costs of all other natural disasters combined, and Michigan's own potential costs have been estimated as extremely serious.

Invasive species can be transported in many ways, such as on animals, vehicles, ships, commercial goods, produce, and clothing. Although non-native species are the foundation of U.S. agriculture, and also are used to prevent erosion, to provide fishing and hunting opportunities, and as ornamental plants and pets, occasionally a non-native organism flourishes too well and causes unwanted economic, ecological, or human health impacts. The terms "invasive" or "nuisance" are used to describe such species. After its arrival, an invasive species becomes capable of establishing a breeding population in its new location and becomes a pest by threatening local biodiversity and causing or threatening human health impacts, significant economic costs, and/or harmful ecological effects to an extent that outweighs its known benefits. New environments may affect rates of reproduction, susceptibility to disease, and other features that affect a species' success. Consequently, a plant or animal that causes little damage to agriculture or natural ecosystems in one area may cause significant problems in another. Certain non-native species are very successful in their new habitats because they out-compete native plants or animals and have no natural controls (predators, diseases, etc.) in the new area. At least 200 well-known, high-impact, non-native species presently occur in the United States. They range from the European gypsy moth and emerald ash borer to crabgrass, dandelions, and German cockroaches, annually costing well over a billion dollars to control. Some even pose human health risks. Others, like the zebra mussel, threaten widespread disruption of ecosystems and the displacement or loss of native plants and animals.

Hazard Analysis

Hundreds of new species from other countries are introduced intentionally or accidentally into the United States each year. These invasive species may arrive on our shores in a variety of ways. Transportation efficiencies that make it possible to travel around the globe in hours rather than weeks make it possible for organisms to survive transportation from one continent to another

As more adaptable and generalized species are introduced to environments already impacted adversely by human activities, native species are often at a disadvantage to survive in what was previously a balanced ecosystem. There are many examples of decreased biodiversity in such areas. One of the primary threats to biodiversity is the spread of humanity into what were once isolated areas, with land clearance and habitation putting significant pressure on local species. Agriculture, livestock, and fishing can also introduce changes to local populations of indigenous species and may result in a previously innocuous native species becoming a pest, due to a reduction of natural predators. This threat intensifies the need for scientists, managers, and stakeholders to cooperate to build better systems to prevent invasion, improve early detection of invaders, track established invaders, and to coordinate containment, control, and effective habitat restoration.

Although invasive species, in most cases, primarily cause environmental damage and degradation, there are situations in which serious threats to public health, safety, and well-being can occur due to animal disease or plant and animal infestations. For example, certain diseases could wipe out large segments of an animal population, creating a potentially serious agricultural disaster and a potential public health emergency (often with a need to properly and rapidly dispose of many animal carcasses).

Similarly, a widespread insect infestation, such as that of the Emerald Ash Borer, has created serious public safety threats (especially in densely populated urban areas) due to dead and dying trees being fire prone (because of their dry, brittle nature) and subject to damaging collapses, especially during high wind events or periods with ice and snow accumulation. Falling trees or limbs can bring down power lines, cause damage to public and private structures, and cause injuries or even death.

Impact on the Public, Property, Facilities, and Infrastructure

The emerald ash borer had caused extensive damage to trees in Michigan, and those weakened trees have often (1) collapsed and caused property damage, including utility line impacts, and (2) required removal, at considerable expense. A disaster declaration request had been sent to FEMA, but the request was not accepted by that agency, leaving state and local budgets, residents, and insurance companies to try to cover the considerable expenses and efforts involved in dealing with the problem. Similar terrestrial species include the Asian Long-Horned Beetle and the Cedar Long-Horned Beetle, although aquatic species and some microbes are also of concern, since they may disrupt or impede forestry, horticulture, and fishing for Michigan residents, tourists, and industries. The most severe potential impact is now estimated to be posed by the invasion of Asian Carp into the Great Lakes. It has been reported that entire summer tourist industries could go into serious decline as a result of such an event, including fishing, swimming, and boating-related activities. Property damage had occurred as a result of the Emerald Ash Borer impacts, and lessened property values may eventually result from a full-scale Asian Carp problem. Some facilities have been affected by Zebra Mussels, but a greater impact has probably now been seen from the return of cyanobacteria problems (i.e. harmful algal blooms) within Lake Erie, which caused a temporary shutdown of the Toledo drinking water supply.

Impact on the Economic Condition of the State

An Asian Carp invasion into the Great Lakes is expected to cause a serious and dramatic decline in Michigan’s major summer tourism sector, to the degree that such an invasive species is expected to interfere with swimming, boating, and water-skiing activities, and to proliferate at the expense of valuable Great Lakes fisheries. The Emerald Ash Borer had caused a regional impact without any of the compensation that had been requested of FEMA. A quarantine area needed to be imposed and enforced, with regard to the transport of firewood and similar lumber that could pose risks of spreading the insect to harm new areas, but this only slowed the spread of infestation, and the quarantine was repealed by the director of MDARD on October 1, 2018.

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

The invasive species hazard is a less familiar one for the general public, generally long-term and insidious in its effects, and rooted in an understanding of the biological sciences. Most emergency management training does not focus on the topic. Emergency management consideration of invasive species is recent and therefore needs to be increased. MSP/EMHSD has recently been strengthening coordination with the U.S. Geological Survey, which has specialized offices dealing with this hazard. An Ann Arbor USGS office deals with Great Lakes aquatic species, and a separate USGS office in Fort Collins, Colorado, deals with terrestrial species. The most damaging Emerald Ash Borer event probably affected some operations and services as a result of damages from falling trees, but such effects were generally minor compared with the direct physical damages.

Impact on the Environment

Terrestrial and aquatic forms of invasive species both pose problems for the ecosystems in which they are introduced. Whether invasive species are brought to an area on purpose or by accident, these non-native life forms can alter the existing ecosystem and decrease an area's biodiversity. Like many hazards that affect Michigan's environment, invasive species have both direct and indirect impacts. The Zebra Mussel, for example, has been invading Michigan's water bodies since the mid 1980's and is responsible for eating the microscopic food supply that is vital to the existing ecosystem. Further, the Zebra Mussel attaches to water intake pipes and screens used for drinking water and industrial plants. Not only do these pests cause environmental problems, but they cause secondary economic impacts to a community as well. Similarly, the Emerald Ash Borer, a non-native insect, is responsible for killing millions of Ash Trees in Michigan, which changes the biodiversity of the forest and diminishes wildlife habitats. Dead trees pose problems for the human-built environment, as well, pulling down nearby wires and damaging structures.

Impact on Public Confidence in State Governance
Terrestrial species are likely to have more general public awareness than aquatic ones, and thus more likely to be a cause for dissatisfaction or loss of public confidence in government. Although there have been well-publicized aquatic species of concern (e.g. zebra mussels, Asian carp), people tend to be more aware of the impacts of terrestrial species, unless their recreational or business activities are more heavily curtailed by aquatic ones. The most recent widespread terrestrial species of concern has been the emerald ash borer insect—trees killed by these insects are prone to collapse, causing property damage, blocked roads, broken utility lines, etc. Citizens and businesses that are more heavily connected with agriculture and tourist industries are more likely to be aware of the impact of invasive species, and thus more likely to express doubts about government policies.

Climate Change Considerations
Different patterns of wildlife have already been concerned as a result of the lengthening average growing season in Michigan. Species that had previously been found only in warmer areas to the south have started to appear in Michigan. Although the definition of invasive species specifically refers to human species introduction, to distinguish these patterns from naturally occurring ones, species transported by human action can be more likely to survive (and thus to become invasive) as climatic changes occur.

NOTE: The following lists and descriptions provide examples of invasive species that pose some threat to Michigan, or have already affected Michigan. For each of these categories, at least several other species could have been included. Some of these species, such as the Gypsy Moth, are already well-established throughout the state, but the text provides information about the kinds of impacts that can result from the invasive species hazard.

Much additional information can be found at https://www.misin.msu.edu/ and http://www.invasive.org/.

A Michigan watch list has been established, and can be found at online at the following web site: https://www.michigan.gov/invasives/0,5664,7-324-68002_74188---,00.html. Species on the watch list have been identified as posing an immediate and significant threat to Michigan's natural resources. The species have either not been confirmed in the wild in Michigan, or have just a limited known distribution. Any occurrence of these species should be reported.

Examples of Potentially Threatening Terrestrial Invasive Species
(Note: These are just a few of the species that are currently on a Michigan watch list.)

Asian Long-Horned Beetle (Anoplophora glabripennis)
Hosts: Several species of hardwood trees found in Michigan. Its favorite host is the Norway maple, although it has been found in other maple species, horse chestnut, elm, box elder, mulberry and poplar trees.
Symptoms: Dark, wet areas on branches and trunks or white foamy sap are often the first symptoms seen in infested trees. The sap often attracts bees, wasps and hornets.
Damage: Trees infested are first weakened, and then die. Damage from these insects and secondary pests will kill a tree within a few years.
Control/Treatment: Prohibited in Michigan. The only known way to eradicate the beetle is to cut down and burn infested trees.

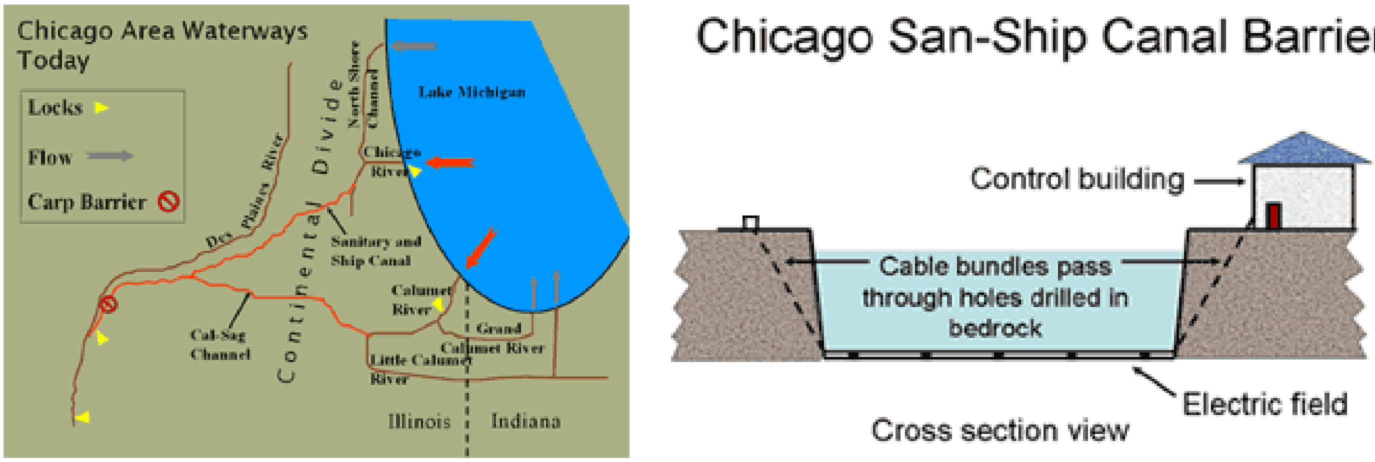
Balsam Woolly Adelgid (Adelges piceae)
Hosts: All true firs.
Symptoms: Small white masses on tree, stunted shoots, formation of galls, tree crown turns red.
Damage: Feeding on the branches of the crown and main stem, causing mortality in 2-6 years.
Control/Treatment: Spraying of individual trees from the ground with lindane has proved effective for control. The spray, prepared by mixing 2.5 pints of 10% emulsifiable concentrate per 100 gallons of water, is applied as a bark drench with a hydraulic sprayer from May through June and September through October to control crawlers. Treatment will reduce populations to below the tree-killing level, and some treated trees may remain generally free from aphids for at least 2 years. Spraying is warranted only in accessible areas supporting relatively high-value trees.

<u>Hemlock Woolly Adelgid</u> (Adelges tsugae)
Hosts: Eastern Hemlocks.
Symptoms: Small white cottony masses at the base of the needles. Needles turn grayish green and drop off. There is a lack of new buds, and low vigor.
Damage: Feeding on twigs by nymphs cause the trees to die within 1-4 years.
Control/Treatment: Horticulture oils that smother the insects have been the best insecticidal treatment. The oils are non-toxic to the trees, as opposed to soap, which is an otherwise effective treatment. However, the least harmful cure may be the introduction of Japanese ladybugs.

<u>Thousand Canker Disease of Walnut</u> **(Pityophthorus juglandis and Geosmithia morbida)**
Hosts: Black walnut and other walnut species.
Symptoms: Infected trees show wilting, curling, and yellowing of leaves on one or more branches in their upper portions, as a fungus from the walnut twig beetles progressively affects the tree's health.
Damage: Causes thousands of small cankers on and under the bark, disrupting the flow of nutrients to the branches. Tree mortality is directly proportional to the number of feeding sites present on the tree.
Control/Treatment: There is no practical treatment, once infected. Landowners should remove affected trees to prevent spread to nearby trees.

Examples of Potentially Threatening Aquatic Invasive Species

<u>Asian Carp</u> **(Ctenopharyngodon Idella Grass Carp, Hypophthalmichthys nobilis Bighead Carp, Mylopharyngodon piceus Black Carp, and Hypophthalmichthys molitrix Silver Carp)**
Hosts: Asian carp made their way into the Mississippi River from Arkansas fish farms in the 1970s as a result of flooding and have steadily swum upstream for years at a pace of 40 to 50 miles a year. Asian carp are currently in the Illinois River and only miles away from entering the Great Lakes.
Symptoms: Decline in native fish species**.** There are four different species of Asian carp that have invaded the Mississippi River: grass (Ctenopharyngodon idella), bighead (Hypophthalmichthys nobilis), black (Mylopharyngodon piceus), and silver (Hypophthalmichthys molitrix). All three species of Asian carp pose a problem to the waterways by devastating habitats and destroying water quality. However, the bighead and silver carp are of the greatest concern, due to their size. These fish can each grow to be 50 to 100 pounds. Although great attention has been focused on these fish recently, dreissenid mussels have already invaded the Great Lakes and caused extensive impacts. (A description of mussels also appears in this section.)
Damage: Researchers expect that Asian carp would disrupt the food chain that supports the native fish of the Great Lakes. Due to their large size, ravenous appetites, and rapid rate of reproduction, these fish could pose a significant risk to the Great Lakes Ecosystem. If bighead or silver carp enter the great lakes, the economic impacts on the fishing industry would be devastating, putting the Midwest's multi-billion dollar-a-year fishing industry at risk. Also, silver carp have been known to cause injuries to boaters, as they jump out of the water.
Control/Treatment: Prohibited in Michigan. To prevent the species from entering the Great Lakes, the U.S. Army Corps of Engineers, U.S. EPA, State of Illinois, International Joint Commission, Great Lakes Fishery Commission, and U.S. Fish and Wildlife Service constructed a temporary electronic dispersal barrier on the Chicago Sanitary and Ship Canal near Romeoville, Illinois, which was activated in April 2002. In late October 2004, construction began on a second, more permanent barrier. The new barrier, completed in February 2005, stretches two rows of electrodes across the canal approximately 220 feet apart. The electrodes pulse DC current into the water, causing fish to turn back rather than pass through the electric current. The electric current poses no threat to humans. A model of the Chicago Canal Barrier can be seen below.
In November 2009, evidence of the presence of Asian carp was detected beyond the electric barrier, which left only a single lock/dam on the Calumet River between the carp's detected location and Lake Michigan. Due to the major ecological threat to Lake Michigan and to recreational boaters, the U.S. Army Corps of Engineers shut down one of the electric barriers for maintenance in December 2009. The Illinois Department of Natural Resources responded to the situation by dumping 2,200 gallons of the toxin rotenone into the canal. Rotenone is deadly for fish but not harmful to humans, animals, or most other aquatic life. The intentional fish kill cost $3 million and produced about 90 total tons of dead fish, but only one carp was found in the Lockport Lock and Dam area. In June 2010, a 19-pound Asian carp was found near the shore of Lake Michigan, in Lake Calumet, about six miles downstream from Lake Michigan, by a commercial fisherman hired by the state of Illinois to do routine fish sampling in the area. The fish confirmed existing DNA evidence suggesting that the Asian carp had indeed breached the electric barrier on the Chicago Sanitary and Ship Canal, which had been considered the last line of defense for Lake Michigan. One type of Asian Carp was recently found within the Great Lakes watershed area, but as grass carp, it was not of the type whose impact is of such widespread concern.



Chicago Sanitary and Ship Canal Dispersal Barrier System (Source: U.S. Geological Survey)

Many other species exist that could become harmfully invasive if they reached Michigan. Although the watch list assesses the most likely risks, any other threatening species must also be identified and reported, so that proper preventive or response activities can occur as quickly as possible.

Significant Invasive Species Incidents and Threats

Example of Risks from a non-Watch List Species

Khapra Beetle (Trogoderma granarium)
Hosts: The beetle prefers hot, dry conditions and can be found in areas where grain and other potential food is stored, such as pantries, malt-houses, grain and fodder processing plants, and stores of used grain sacks or crates.
Symptoms: Destruction of grains and seeds. They can multiply quickly in stored items such as crackers, wheat, flour and baby cereal and rapidly spread to warehouses, storage bins, and mills.
Damage: The beetles can potentially cause severe harm to the agriculture crop industry such as grains and seeds including wheat, soybean, barley, corn and rice.
Control/Treatment: Fumigation with methyl bromide in containers to quarantining shipments until treatment. Powdered neem has been used to control the beetle in wheat stores in India. On November 23, 2018, agricultural specialists found these beetles infesting a bag of seeds that a woman was attempting to bring into the state when traveling by plane from Iraq. There was no indication that the woman was aware of the seed infestation, as she planned to sow her garden with them, but the resulting agricultural damage from such an oversight could have been severe.

Examples of Recent and Active Problems within Michigan

Dreissenid Mussels (including Zebra Mussels and Quagga Mussels) (family Dreissenidae)
Hosts: Freshwater lakes and streams
Symptoms: By firmly attaching to hard surfaces, dreissenid mussels have clogged water-intake pipes and fouled hard-shelled animals such as clams and snails. In addition, zebra mussels have reduced plankton populations, as colonies of mussels filter large volumes of water for food, potentially depleting food resources of larval and planktivorous fishes such as smelt, chub, and alewife. Transfer of suspended material to the lake bottom in mussel waste products also leads to increased water clarity and increased growth of aquatic plants. Although clear water is often considered aesthetically pleasing, this clarity indicates that drastic changes have occurred at the base of the food web and that energy flows through the ecosystem has been altered. The mass media has given a great deal of attention to the zebra mussel, but quagga mussel infestations are actually far more extensive in the Great Lakes. Both zebra and quagga mussels belong to the same genus, dreissenid mussels, but quagga mussels are more tolerant of colder and deeper waters than zebra mussels are. Quagga mussels were first spotted in the Great Lakes around 1990, and have devoured so much plankton that the food web is being altered.
Damage: Communities along the affected lakes and rivers rely on these waters for drinking, industrial water supplies, transportation, commercial fishing and shelling, and recreation. Rapidly expanding populations of dreissenid mussels could ultimately affect many of these activities, in addition to changing the structure of the ecosystem.
Control/Treatment: Restricted in Michigan. Applications of hot water and bleach have been used for control. A new method involving bacteria is being refined.

Dutch Elm Disease
Hosts: Elm trees
Symptoms: Trees infected by elm bark beetles first show wilting, curling, and yellowing of leaves on one or more branches in the upper portion of the tree, as a fungus from the beetles progressively affects the tree's health.

Damage: Large trees may survive and show progressively more symptoms for one or more years. Trees infected through root grafts wilt and die rapidly; this frequently occurs in the spring, soon after the trees have leafed out, and progresses from the base of the tree upward. **Control/Treatment:** Dutch elm disease control has involved two different but related programs: (1) community-wide sanitation programs designed to reduce the level of elm bark beetles (principal carriers of the Dutch elm disease fungus); and (2) prevention of the spread of the disease through natural root grafts from infected trees to adjacent healthy trees. There are probably no community-wide programs being used any more, with a shift toward disease management involving the planting of different species of trees. There is no way to eliminate Dutch elm disease once it begins, but different species such as Siberian elms are resistant to the disease. This disease is still active in Michigan Elm Trees.

Emerald Ash Borer (EAB) (Agrilus planipennis)
Hosts: White, black, and green ash trees.
Symptoms: Typically the upper third of a tree will die back first, followed by the rest during the next year. This is often followed by a large number of shoots or sprouts arising below the dead portions of the trunk. The adult beetles typically make a D-shaped exit hole when they emerge. Tissue produced by the tree in response to larval feeding may also cause vertical splits to occur in the bark. Distinct S-shaped tunnels may also be apparent under the bark. Adults are dark metallic green in color, 1/2 inch in length and 1/16 to 1/8 of an inch wide and are only present from mid-May until late July. Larvae are creamy white in color and are found under the bark.
Damage: The adult beetles feed on ash foliage but cause little damage. The larvae feed on the inner bark of ash trees, disrupting the tree's ability to transport water and nutrients. Many trees appear to lose about 30 to 50 percent of their canopy in one year and the tree is often killed after 2-3 years of infestation. Most of the devastation in Michigan has occurred in the southeastern Lower Peninsula, where about 20 million trees have been killed. Fallen trees have caused extensive property damage. A quarantine area had been imposed by state government in 2002, in an effort to slow the spread of this pest, but by 2018, EAB had spread to 79 of Michigan's 83 counties, and suspected to be present to some degree in the remaining four. Therefore, the quarantine was lifted by Governor Snyder on October 1, 2018.
Control/Treatment: Treatment options for controlling infected or at-risk trees include systemic insecticides applied as soil injections, systemic insecticides applied as trunk injections, noninvasive systemic sprays, and protective cover sprays. If properly applied, these treatment options can prevent EAB larvae from taking over the ash tree about 70% of the time. Treatment also proves to be successful when managing at-risk trees in areas where EAB has been identified. More information on the EAB can be found on the MDARD's website: www.michigan.gov/eab.

Gypsy Moth (Lymantria dispar)
Hosts: Tree foliage.
Symptoms: The egg mass is usually laid within a few feet of the female pupa casing. They are covered by a dense coating of hairs.
Damage: During high population levels, total defoliation can occur. During the months of June and July, defoliating populations cover sidewalks, homes, children's play equipment and other objects, making outdoor activity in residential and recreational areas almost impossible. For Michigan's nursery industry, additional expense and pesticide use are required. For the forest products industry, high gypsy moth populations mean the potential loss of wood fiber from reduced production (due to tree stress or mortality).
Control/Treatment: Counties may get involved in the Michigan Cooperative Suppression Program. The only pesticide used in the Cooperative Suppression Program is Bacillus thuringiensis, most commonly referred to as Bt.

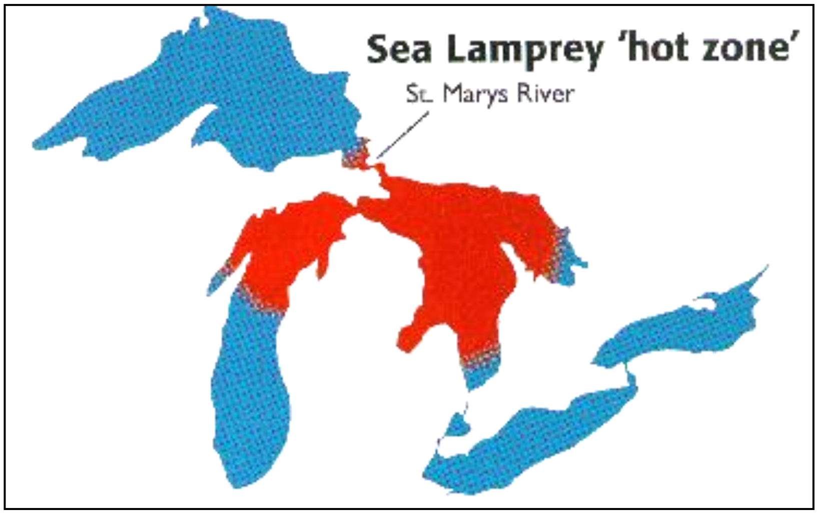
Plum Pox Virus (PPV)
Hosts: Peach, plum, nectarine, apricot, almond, cherry.
Symptoms: Discolored viral rings on leaves and fruit.
Damage: Smaller deformed fruit and reduced fruit production.
Control/Treatment: Control and prevention measures include field surveys, use of certified nursery materials, use of virus-resistant plants (when available), control of aphids, and the elimination of infected trees in nurseries and orchards. A team of scientists from the United States and France has genetically engineered a PPV-resistant plum (known as C5), and this resistance can be transferred through hybridization to other plum trees. This provides a source of germplasm for future breeding programs worldwide. Similar success has not yet occurred in attempts to genetically modify other Prunus species. First found in North America in 1999 (in Pennsylvania), this was confirmed in Michigan for the first time in July 2006, in a Berrien County location, resulting in a large-scale survey and eradication effort. A PPV quarantine was issued by the Michigan Department of Agriculture on March 12, 2007. As of a decade later, the problem seems to have been resolved with that eradication effort and quarantine.

From left to right: Dutch Elm disease, emerald ash borer, gypsy moth, the plum pox virus

Sea Lamprey (Petromyzon marinus)
Hosts: Found in both fresh water and salt water habitats, they breed in freshwater streams and lakes and were first discovered in the Great Lakes in the 1800s.
Symptoms: Sea lampreys prey on a wide variety of fish. The lamprey uses its suction-cup like mouth to attach itself to the skin of a fish (possibly for days) and rasps away tissue with its sharp probing tongue and many hooked teeth, arranged in numerous rows. Secretions in the lamprey's mouth prevent the victim's blood from clotting, and the lamprey sucks the victim's blood. Victims (usually smaller ones) typically die from excessive blood loss or infection. Mature sea lampreys average 2 to 2½ feet long, up to a maximum of about 3 feet. Sea lampreys are

considered a pest in the Great Lakes region and were introduced as an invasive species in the 1800s, originating from the inland Finger Lakes and Lake Champlain in New York and Vermont. Sea lampreys created a problem for key predator fish species including lake trout, lake white fish, and lake herring. The elimination of these key predator fish allowed the alewife, another invasive species, to explode in population, having adverse effects on many native fish species.



Damage: The introduction of the sea lamprey to Lake Superior caused serious declines in fish populations, and an alteration of the ecosystem. The lake trout played a vital role in the Lake Superior ecosystem because it is considered an apex predator, which means that the entire system relies on its presence to be diverse and healthy. As an apex predator was removed from the system, the entire system felt the effects all the way down the food chain. The sea lamprey is an aggressive predator by its nature, which gives it a competitive advantage in a lake system where it has no predators and its prey lack defenses against it. The sea lamprey played a large role in the drastic decline of the Lake Superior lake trout population. One sea lamprey can upset an ecosystem and food chain by eating an estimated 40 pounds of fish or more in its lifetime. This resulted in an unbalanced relationship between predators and prey in the Great Lakes' Ecosystem.

Control/Treatment: Control efforts to mitigate the destructive effects of the sea lamprey have included the use of electric currents, chemicals, and barriers. In 1958, scientists found a chemical (still used today) that selectively killed sea lamprey larvae in their spawning streams, and brought the lamprey under control. In 1986, DNR fish managers, technicians and engineers designed a new lamprey barrier which let fish migrate through to spawn, but captured the lamprey. The new barrier was expected to reduce the number of lamprey beyond it to nearly zero. Lamprey numbers in Lake Michigan are currently only about 10 percent of their peak numbers in the 1950s. Today, biologists and researchers are still looking for new ways to stop the spread of lampreys in lakes, streams, and rivers. It is the hope of the Great Lakes Fishery Commission that at least some of this scientific work on the sea lamprey, including genetic and pheromone studies, will result in a more effective management technique that could one day drastically reduce the need for chemical treatments of spawning grounds. Several million dollars are spent each year on environmentally friendly control methods. Native predatory fish, like the whitefish and lake trout, have been restocked by fisheries professionals to help maintain a healthy level of these species.

A couple of invasive aquatic species: Asian carp and zebra mussel.

Wild Hogs or Boar (Sus scrofa)

Feral swine are defined as free-ranging pigs and are considered to be an aggressive public nuisance. They have been known to attack and chase humans. They can become infected with, and may transmit, diseases that affect human health, domestic livestock, and wildlife, such as brucellosis, tuberculosis, bubonic plague, tularemia, anthrax, and trichinosis. In Michigan, pseudorabies-positive feral swine were removed from private land in 2008. Feral swine have the potential to cause great economic harm to the domestic swine industry, if they were to transmit such disease to commercial swine.

The appearance of feral swine may vary greatly, as they can originate from several subspecies, including the Russian Boar, the wild Eurasian boar, escaped domestic swine, and quite often a mix of domestic and wild-type breeds. These animals can weigh up to 400 pounds, may be covered in coarse hair, may have tusks, and are known to travel in groups. Females in warm states produce two large litters of 8 to 10 piglets per year. In Michigan, feral swine are known to survive the harsh winters. Feral swine tend to follow creeks and drains between food sources. They favor agricultural crops, but when the crops are harvested in the fall, they turn to wildlife food plots, acorns, and other mast foods. Feral swine are known to eat ground nesting birds, small mammals, and grubs.

Damage: Feral swine can tear up the landscape, killing wildlife and pets, damaging farm crops and wildlife habitats, and scavenging uncovered garbage. Their devastating effect on crops accounts for up to $1.5 billion in annual damages nationally. Unlike most animals, feral swine don't stop at just eating crops. They also root holes in the ground as deep as a foot, destroying the crops. Wild hogs can damage as much as 10 percent of a farmer's crop.

To date, the Department of Natural Resources has logged 288 unofficial feral swine sightings by residents in almost every county in Michigan. Since 1999, national experts have estimated that, if unchecked, the feral swine population could become established statewide and cause economic hardship for farmers, and for businesses that cater to wildlife enthusiasts.

Control: On May 13, 2010, the Michigan Legislature amended Public Act 328 of 1976 (Domestic Animals Running at Large) by allowing people to pursue and harvest feral swine at any time. The law does the following: (1) declares swine running at large on public or private property to be a public nuisance, (2) permits a local animal control officer or a law enforcement officer to kill swine running at large on public or private property, (3) permits a person with a concealed weapon permit or a valid hunting license to kill swine running at large on public property, and (4) permits a property owner or other authorized person to kill swine running at large on private property. In the last case, the landowner does not need a hunting license.

Michigan residents who see or shoot a feral pig are asked to report it to the Michigan Department of Natural Resources at (517) 336-5030. USDA Wildlife Services (517-336-1928) and the Wildlife Conservancy (517-641-7677) have feral swine traps available for the use of landowners who are experiencing feral swine damage. The animals will be trapped, removed, and tested for disease, then euthanized and disposed of.

In December 2010, the Michigan Department of Natural Resources classified feral swine as an invasive, exotic or prohibited species under Public Act 451, the state's Natural Resources and Environmental Protection Act of 1994, but the Director's order does not go into effect until April of 2011.

Partners: The Feral Swine Working Group is an interagency team of veterinarians, biologists, and policy personnel within the state and federal governments, Michigan State University, and from numerous stakeholder groups, including the Michigan Animal Control Association, Michigan Farm Bureau, Michigan Pork Producers Association, Michigan United Conservation Clubs, Michigan Corn Growers Association, the Nature Conservancy, United Deer Farmers of Michigan, the Michigan Hunting Dog Federation, and the Michigan Wildlife Conservancy.

Invasive Plant Species in Michigan

Numerous online resources provide more information about plants, such as the NRCS database at http://plants.usda.gov/java/. Please refer to the information in the MDNR publication "Meeting the Challenge of Invasive Plants: A Framework for Action," which can be found at the following website:
http://www.michigan.gov/documents/dnr/Invasives_strategy_final_289799_7.pdf.

Animal Diseases

There are many animal diseases that have the potential to impact Michigan. Diseases from outside Michigan or the United States have the potential to cause widespread mortality in livestock, wildlife, and companion animals. They could result in huge economic losses (primarily through trade restrictions), require significant resources to be allocated for response, and in some cases could also threaten public health. For more information, please refer to the Reportable Animal Diseases documents of the Department of Agriculture and Rural Development. (One introductory link is: https://www.michigan.gov/mdard/0,4610,7-125-48096_48097---,00.html.) Chronic Wasting Disease is an example of a wildlife disease that requires a heightened response, when detected. Foot and Mouth Disease is an example of a livestock disease that would also require a heightened response from Michigan agencies.

Chronic Wasting Disease (CWD)

This is a prion disease of the brain. The infectious agent contaminates the environment and is transmitted from one animal to another.

Hosts: Deer and elk are affected by this brain disease that is present in several western states and in Minnesota and Wisconsin. It was also detected in one Michigan location in 2008 (at an enclosed deer breeding facility in Kent County). Mule deer, white-tailed deer, and Rocky Mountain Elk are the only three species of the family Cervidae that are known to be naturally susceptible to CWD. However, it is very likely that other subspecies of C. elaphus are susceptible to the disease. Although no other deer in Michigan have tested positive for CWD (outside of the isolated Kent County case), it remains a major concern due to the large wild population of deer in the state.

Symptoms: Emaciation, wide stance, lowered head, droopy ears and excessive salivation.

Damage: Animal fatalities

Control/Treatment: Chronic wasting disease is both transmissible and infectious, but most details of its transmission remain to be determined. No treatment is available for animals affected with CWD. Once clinical signs develop, CWD is invariably fatal. Affected animals that develop pneumonia may respond temporarily to treatment with antibiotics, but ultimately the outcome is still fatal. Similarly, no vaccine is available to prevent CWD infection in deer or elk.

Foot and Mouth Disease

Hosts: This infectious virus spreads on surfaces and in the air, and impacts cattle, swine, sheep, goats, deer, and other cloven-hoof ruminant animals. It does not currently exist in Michigan or the United States and has not existed in the U.S. since 1929. However, the disease is of great concern because it is highly contagious and would have grave economic consequences for Michigan's livestock industry.

Symptoms: In cattle, blisters inside the mouth that lead to excessive secretion of stringy or foamy saliva and to drooling; and blisters on the feet that may rupture and cause lameness. Adult animals may suffer weight loss from which they do not recover for several months, as well as swelling in the testicles of mature males. In cows, milk production can decline significantly.

Damage: Though most animals eventually recover from FMD, the disease can lead to myocarditis (inflammation of the heart muscle) and death, especially in newborn animals. Some infected animals do not suffer from or show signs of the disease, but they are carriers of FMD and can transmit it to others.

Control/Treatment: The Michigan Department of Agriculture and Rural Development (MDARD) licenses and regulates Michigan's 500 livestock dealers, truckers, livestock sales, and auction markets to help monitor animal health and ensure the safe and humane handling of animals. The MDARD also monitors and controls the interstate and intrastate shipment of animals and animal products, to eradicate and control the spread of disease. If this disease were discovered in the United States, it would trigger national and state response plans and require rapid and coordinated response in order to control the disease and protect the nation's livestock industry.

Two threatening animal diseases: Chronic wasting disease and foot and mouth disease.

Programs and Initiatives

Note: These listings highlight the breadth of existing programs and initiatives currently under way, but are not intended to be comprehensive.

Michigan Aquatic Nuisance Species (ANS) Program

In 1996, Michigan developed its first comprehensive ANS state management plan to provide guidance on actions for the prevention, control, and impact-management for ANS that have invaded, or may invade, Michigan waters. This state management plan was updated in 2002, and includes a summary of accomplishments, goals, and activities. The MDNR was awarded funding through the Great Lakes Restoration Initiative in 2010, to update and continue the implementation of the plan. A core team of staff members and managers from the Fisheries, Wildlife, Water Resources, Recreation, and Law Enforcement Divisions (of the DNR and DEQ), as well as representatives from the Pesticide and Plant Pest Management Divisions (of the Department of Agriculture and Rural Development) and the Project Planning Division (of MDOT) are currently in the initial stages of updating the state management plan. The 2013 plan is accessible at https://www.michigan.gov/deq/0,4561,7-135-3313-276823--,00.html.

These efforts include the Asian Carp Control Strategy, which includes studies performed by the U.S. Army Corps of Engineers. The USACE Asian Carp Study stems from a nearly $80-million initiative from the White House Council on Environmental Quality in 2007, involving a multi-pronged federal attack against Asian Carp. The Asian Carp study examines the possibility of permanently shutting down the Chicago waterway system that links Lake Michigan to the Mississippi River Basin, and coordinating state efforts in response to the Asian carp threat. Although some actions may be taken before the study is completed, a final recommendation on how to stop the movement of the Asian Carp and other related species is expected to be made by 2013. However, the USACE has been accused of moving too slowly to prevent Asian carp and other exotic species from invading the Great Lakes. The USACE will release a short list of possible solutions in 2013 to quicken the process. The USACE will pick up the pace under a revised strategy in which it no longer will devise a single preferred method. Instead, the agency will put forward several options and leave it to congress and the public to decide.

Proposed Legislation to Prevention Asian Carp Invasion

Due to Asian Carp being detected beyond established barriers and less than six miles from direct access to the Great Lakes, a bill (The Permanent Prevention of Asian Carp Act) was created to direct the U.S. Army Corps of Engineers to study the watersheds of the Illinois, Chicago, and Calumet Rivers, and their tributaries, that drain directly into Lake Michigan, to determine the feasibility and best means of implementing the hydrologic separation of the Great Lakes and Mississippi River basins to prevent the introduction or establishment of populations of aquatic nuisance species along that pathway. In 2010, this bill was introduced in the U.S. House of Representatives (H.R. 5625) and the U.S. Senate, but it was merely referred to committee (and thus "died"). Numerous similar legislative efforts have suffered similar fates or otherwise not been acted upon, such as the Asian Carp Prevention Act of 2013. The latest congressional bill is H.R. 4001, the Defending Against Aquatic Invasive Species Act of 2014, which was rated as having a slightly higher chance of making progress than the earlier efforts.

The Sea Lamprey Control Program

Administered by the Great Lakes Fishery Commission, this program may be the best example of integrated pest management in North America. The program costs over $20 million per year, but has been tremendously successful in protecting the multi-billion-dollar Great Lakes fishery for millions of persons who fish or are involved in a related sector of the economy. Sea lamprey control efforts have resulted in a 90% reduction in sea lamprey populations in most areas of the Great Lakes. http://www.glfc.org/control.php

National Strategy and Implementation Plan for Invasive Species Management

The National Strategy and Implementation Plan for Invasive Species Management was developed by a team of researchers and specialists. This plan is responsible for preparing the Forest Service to deal with the ecological and economic problems associated with the types of invasive species that affect the nation. The plan maps out a strategic direction for Forest Service programs, which include Research and Development, International Programs, State and Private Forestry, and the National Forest System.

Animal and Plant Health Inspection Service

The Animal and Plant Health Inspection Service (APHIS) is responsible for protecting and promoting U.S. agricultural health, administering the Animal Welfare Act, and carrying out wildlife damage management activities. The APHIS mission is an integral part of U.S. Department of Agriculture's (USDA) efforts to provide the nation with safe and affordable food. In recent years, the scope of APHIS' protection function has expanded beyond pest and disease management. Because of its technical expertise and leadership in assessing and regulating the risks associated with agricultural imports, APHIS has assumed a greater role in the global agricultural arena. Now, the agency must respond to other countries' animal and plant health import requirements and negotiate science-based standards to ensure that America's agricultural exports, worth over $50 billion annually, are protected from unjustified trade restrictions. In response to needs expressed by the American people and Congress, APHIS' protection role also includes wildlife damage management, the welfare of animals, human health and safety, and ecosystems vulnerable to invasive pests and pathogens. In carrying out its diverse protection responsibilities, APHIS makes every effort to address the needs of all those involved in the U.S. agricultural sector.

The United States Geological Survey (USGS)

The U.S. Geological Survey plays an important role in federal efforts to combat invasive species in natural and semi-natural areas. USGS services include the early detection and assessment of newly established invaders, the monitoring of invading populations, contributions to the understanding of the ecology of invaders and the understanding of factors involved in the resistance of habitats to invasion. The USGS is also involved in the development and testing of prevention, management, and control methods. USGS science centers conduct research relevant to invasive species in Michigan, and these are located at La Crosse, Wisconsin (the Upper Midwest Environmental Science Center), and Ann Arbor, Michigan (the Great Lakes Science Center). Each state in the U.S. is also home to a USGS Water Science Center, some of which conduct or support research relevant to invasive species in the Great Lakes.

The USGS maintains databases that may assist with the monitoring and reporting of invasive species occurrences, as well as provide information on their control. An example of these resources is the Nonindigenous Aquatic Species Database, at http://nas.er.usgs.gov. Sophisticated modeling capabilities, to predict the potential distribution of invasive species, are also available through the National Institute of Invasive Species Science in Fort Collins, Colorado.

NOAA Great Lakes Environmental Research Laboratory (GLERL)

This agency includes research on aquatic invasive species, and focuses on the biological and ecological effects of these species in the Great Lakes, and on the prevention of new species introductions. GLERL houses the NOAA National Center for Research on Aquatic Invasive Species (NCRAIS), which helps to coordinate the agency’s aquatic invasive species outreach efforts across the U.S.

Eastern Michigan University Detroit River International Wildlife Refuge Study

Researchers from Eastern Michigan University made an effort to study and help contain the spread of invasive species at the Detroit River International Wildlife Refuge, along 5,700 acres of the Detroit River and Lake Erie. In November

2010, EMU was awarded $487,000 by a program that is part of the National Oceanic and Atmospheric Administration. The purpose is to expand upon work that had examined the spread of Phragmites australis (which impairs the refuge's economic and environmental viability), that had set up monitoring points, looked at efforts to control the reed, and also measured effects on water quality. The purple loosestrife and reed canary grass are among the invasive plant species that also might be studied. For the next phase of the project, researchers plan to use a combination of on-the-ground surveys, water quality analysis, and remote satellite detection of invasive species to study their spread. Locations will be mapped, and data will be presented in a new way that is designed to help refuge officials in making management decisions.

Michigan Invasive Plant Council

The Michigan Invasive Plant Council (MIPC) is a non-profit organization that spans a wide array of groups, including government agencies, commercial enterprises, conservation organizations, educational institutions, and the gardening public. MIPC is an affiliate organization of the Southeast Exotic Pest Plant Council and its mission is to protect Michigan from the threat of invasive species. The council develops and publishes an invasive species list; facilitates the exchange of information concerning the management, control, and monitoring of invasive plants; provides a forum for all interested parties to discuss issues relating to invasive plants; serves as an educational, advisory, and technical support council for all aspects of invasive plants and related issues; and helps to prevent future introductions of new invasive plants.

Emerald Ash Borer (EAB) Awareness Week

EAB Awareness Week provides information on the steps that everyone can take to prevent the spread of EAB infestation, as well as fostering a cooperative spirit between citizens, communities, government and industry to reduce the risk that the insect poses to the 700 million ash trees blanketing the state. During the week and throughout the year, the Michigan Department of Agriculture and Rural Development (MDARD) urges Michigan residents and visitors to learn about EAB, be on the look-out for and immediately report possible signs of infestation, and adhere to policies regarding the transport of ash trees, materials, and all firewood. Each spring, many outreach, education and compliance activities are planned (or will be highlighted) to help increase awareness and understanding of the EAB. The EAB Awareness week is typically held during the last week in May.

Michigan Chronic Wasting Disease Task Force-Final Report

In 2003, Governor Granholm signed an executive order creating a task force to address the threat of Chronic Wasting Disease in Michigan's deer and elk populations. The task force includes five members appointed by the Governor, who serve as the voting members of the task force. The directors of the Department of Agriculture (now MDARD), Community Health, Natural Resources, Environmental Quality, State Police, and Transportation serve as non-voting members of the task force. In October of 2003, the task force presented its findings and recommendations in a report delivered to the Governor. Please see https://www.michigan.gov/dnr/0,4570,7-350-79136_79608_90516---,00.html.

Michigan Cooperative Suppression Program – Gypsy Moth Infestations

The main goal of the Cooperative Suppression Program is to provide technical and funding assistance to county governments. This allows them the opportunity to provide protection from severe gypsy moth populations. The objectives are 1) to reduce the risk of severe defoliation and 2) to reduce the nuisance created by large caterpillar numbers. A county, interested in participating in the Cooperative Suppression Program, enters into an agreement with MDARD to conduct the program. MDARD provides training, technical support and operational guidelines to the county. The training and guidelines are used to identify areas for treatment. The State of Michigan enters into a contract with an applicant for treatment of the qualified areas and the county is granted up to 50% cost-share for the cost of conducting the program.

Aquatic Invasive Species Awareness Week

In a continued effort to raise public awareness about the negative impacts caused by aquatic invasive species, the State of Michigan has established the Aquatic Invasive Species (AIS) Awareness Week, usually the second week in June. An aquatic invasive species is defined as a waterborne, non-native organism that threatens the diversity or abundance of native species, the ecological stability of impacted waters, or threatens a commercial, agricultural, aquacultural, or recreational activity. The AIS Awareness Week recognizes that Michigan's expansive shorelines and inland waters draw millions of tourists and recreational users each year, and that appropriate preventive steps must be taken to protect the state's water resources from invasive aquatic species. The AIS Awareness Week is sponsored by the MDEQ, working in collaboration with other state and federal agencies as well as private and nonprofit organizations.

Some Hazard Mitigation Alternatives for Invasive Species

- Restrictions on the import and transport of species carriers.
- Adjustments to hunting, fishing, and other policies and regulations related to wildlife populations.
- Use of barriers to prevent invasive species travel.
- Use of competing species or other population control techniques.

Emphasis in Local Hazard Mitigation Plans

No local hazard mitigation plans have yet identified invasive species as one of their top hazards.

I. Natural Hazards
D. Geological Hazards

The following outline summarizes the significant geological hazards covered in this section:

1. Climate Trends
2. Ground Movement
    a. Earthquakes
    b. Subsidence
3. Celestial Impacts
    a. Space Weather
    b. Meteorites and other impacting objects

Although "landslides" and "mudslides" could be included here as an additional hazard, these have instead been included within the flood chapter, under the Hydrologic Hazards section of this document, since the primary known risks involve situations involving extreme precipitation and flood events that cause hill surfaces to erode and their materials to be carried down with the runoff waters. A new chapter on <u>climate trends</u> has been included here in this edition of the hazard analysis. Although "Climate Change Considerations" subsections had been included in previous editions, and were retained in this update, the growing discussion and emphasis upon the topic seemed to require a comprehensive overview of its main points and an examination of the main evidence underlying these discussions. Michigan's vulnerabilities to ground movement are addressed in two chapters on <u>earthquakes</u> and <u>subsidence</u> hazards. **Erosion is** not in itself typically considered an emergency event, except in cases involving encroachment into shoreline developments near a river or lake, and these have been **dealt with in the Great Lakes Shoreline Hazards chapter** within the Hydrological Hazards section of this plan. New information from the Western Upper Peninsula has led to a re-assessment of the subsidence hazard as requiring higher-priority studies and activities than had previously been estimated. A chapter from the previous edition of this analysis, called celestial impacts, has been split into two chapters, because the two main types of impacts (the effects of solar storms on our modern infrastructure, and the impact of physical objects upon developed areas), turned out to have significantly different expected impacts, with what is now called <u>space weather</u> being judged to have a much greater chance of producing emergency-level impacts within the near and medium-term future, whereas the serious levels of impact from meteorites and other objects are only likely within very long time-scales. Although meteorite impacts are quite easy to understand and visualize, and do have a rare potential to be globally catastrophic, it is the seemingly abstract and less well-known effect of "space weather" that has the greatest probability of causing widespread disruption of important communication, utility, and transportation systems through its potential effect upon satellites, radio-based communications, and induced electrical currents within pipelines and other conductive materials.

<u>Overlap Between Geological Hazards and Other Sections of the Hazard Analysis</u>
In addition to the hydrologic impacts upon erosion and mudslide events, other overlaps are notable. The most serious Michigan earthquakes would be expected to damage some of the utilities infrastructure in the southern part of the state, and could contribute to the occurrence of an energy emergency. Some flooding could result from broken water mains. There may be some potential for oil and gas pipeline operations to be disrupted, as well. Seismic activity could cause serious subsidence events to collapse structures, roadways, or other infrastructure. Transportation accidents that may result from these hazards could cause the release of dangerous hazardous materials. The real potential for a (national level) catastrophic incident exists in the event of a major seismic event involving the New Madrid fault line, but the Western Upper Peninsula has a special vulnerability due to the extent and locations of its abandoned mine lands.

Celestial impacts involving solar flares can cause infrastructure failures and have the potential to cause major transportation accidents and delays, primarily involving airplanes and seagoing vessels but also any GPS-based navigation and directional systems. The impacts of physical bodies upon the Earth and its atmosphere are usually minor but rarely will have the potential to be catastrophic, capable of causing damage equivalent to a nuclear attack and the associated casualties, mass fires (including wildfires), infrastructure failure, severe winds, and physical damages associated with the nuclear attack hazard (but without as intense of radiological effects). The crash of satellites and space vehicles includes risks of hazardous materials contamination across large areas where debris is scattered.

CLIMATE TRENDS

How Michigan's place within a larger climate system is calculated to affect its hazard profiles.

NOTE: **This chapter is in two parts.** A short, two-page overview of basic concepts appears below, and is aimed at all audiences. A more complicated summary of research findings then takes up the bulk of the chapter, and includes details that are most appropriate for readers who have a basic scientific background. General readers who do not have much scientific training can continue to read more about this topic within the subsections titled "Climate Trend Considerations" that appear in many other chapters of this document.

Introductory Overview

Most of this document's analysis of natural hazards is based upon a known history of past events, and treats the past as a straightforward indicator of the present and future. There are cases, however, in which historical records reveal past conditions that were much worse than what we experience today. For example, the drought conditions of the 1930s were much more severe than any that Michigan has felt within more recent decades. But could these conditions reappear, and is Michigan ready for them if they do? Sometimes, historical patterns seem to repeat themselves, and we can learn lessons from how previous generations had dealt with these hazards in the past, even with the less-advanced technology that was available during those previous times.

In other cases, the analysis of Michigan's hazards has revealed cases in which modern conveniences have been relied too heavily upon, as a means of protecting us from risk. As long as those modern technologies are available and perform well, everything may be fine. But in cases where a long-term power failure occurs, or there is a breakdown in electronic communications, or a shortage of vital fuel supplies, a large proportion of Michigan's residents are likely to be placed at risk, because they have come to be dependent upon these most modern systems, and previous technologies may no longer be readily available to substitute for the more advanced technologies when things go wrong. Cyber-attacks, the loss of important communication satellites, or a long-term power outage can lead to severe, largescale problems if they persist for more than just a few days. These "technological hazards" can also be caused by natural phenomena such as solar storms that knock out the electronics of satellites and utility suppliers, or severe windstorms or tornadoes that cause unusually large power failures. How did Americans of a hundred years ago deal with hazards such as drought, heat waves, severe cold, or pandemic influenza events? Might we have something to learn from conditions of the past that could help us today if our modern conveniences and technologies become unavailable for weeks, months, or a year at a time? It has become clearer in recent years that such dependencies and vulnerabilities do exist within the extensive array of modern conveniences that so many of us take for granted. How would average families cope, if there is a widespread fuel shortage and they have no way to use their cars, or if there is a cyber-attack or satellite-disrupting solar storm that doesn't allow the use of modern cell phones, credit cards, GPS, bill-paying, and bank access for weeks or months?

In addition, there is strong evidence that some of our natural hazards are on a worsening trend over time. Rather than fitting into known "up and down" cycles (even complicated ones, such as the water levels of the Great Lakes), some hazards have now been measured as increasing in severity, such as the level of **precipitation** and the number of high-temperature records (which in recent decades have greatly outnumbered the number of low-temperature records). As scientists have learned more about the complex natural systems of our planet and the numerous cycles and trends it exhibits, we have gradually become aware of longer-term patterns that go beyond mere **weather** (short-term, local events) and involve larger patterns of **climate** (longer-term, geographically larger patterns). When we look at average temperature and precipitation patterns in any part of the world, we are looking at the climate of that area as a guide for what weather patterns to expect as a normal phenomenon for that area. Indeed, the very concept of drought is defined in terms of what levels of precipitation are normal for that area. The standards used to define a drought within a desert area are different from the standards used to define drought within a tropical rainforest setting.

As an example of some longer-term patterns that have been identified, consider the trends identified in terms of "El Nino" and "La Nina," in which geographically large oceanic cycles cause medium-term trends in which Michigan weather has colder and warmer phases on a fairly regular (but not completely precise) schedule. There are also solar cycles which can be characterized in terms of their average lengths, although each specific cycle cannot be predicted in advance. We can merely keep making observations and being prepared to react to the patterns, and the extremes, that have been observed in the past.

On a still longer-term scale, we are aware of historical phenomena such as the "Little Ice Age" that involved unusually cold temperatures in the North Atlantic Realm a few centuries ago. Geologically, there have been very long-term patterns in which the Earth's magnetic poles periodically reverse. There are also longer-term patterns involving Earth's position with respect to the Sun, and even the Sun's position with respect to the galaxy. Some of these patterns date back before human existence, and are so long-scale that they need not be considered within this document. Other patterns are evident in the near-term records, such as precipitation levels. Not all trends have known explanations, and might be mere statistical "artifacts" that disappear as more information is collected, such as the possible Michigan trends noted within the earthquake chapter in this document.

We can also compare different regions of the world and increase our preparedness, based upon things that other lands have had to deal with. For example, some parts of the world are experiencing **desertification**, as less precipitation falls and various types of vegetation start to disappear in that part of the world. These places see their desert areas become larger, replacing what used to be functional agricultural lands with far less useful soil types and vegetation that can survive with less water, but which is generally less useful for human use. Michigan, by contrast, has been growing "wetter" over time, with no known explanation that can be characterized in terms of a "cycle" that can be predicted to reverse. This is one of the most important climate trends which this analysis has decided to address with a new chapter distinct from those of individual hazards. General trends of longer-term, global-scale climate cause a gradual effect upon the short-term, local-scale weather events that we will tend to expect, and predict, over time. Gradual increases in the average amount of precipitation are expected to result in an increasing number of heavy rain and flood events, and, for a few decades, increasingly frequent major snow events within lake-effect zones. The historical increase in technology-dependent and generally urban lifestyles (even if "suburban" or "exurban," they still tend to rely heavily upon the use of cars, phones, and computers) appears to increase the vulnerability to persons with such lifestyles when technologies and fuel availability get disrupted by floods, power failures, pipeline breaks, and other hazards. Therefore, this new chapter is provided to provide a general overview of larger and longer-term issues of climate that are expected to affect a great number of the specific hazards that are described within the many chapters that follow.

One of the topics in which a great amount of new research has been accomplished in recent decades involves the relationship between global-scale patterns and more specific regions or locations such as Michigan. For example, the United States has for many decades felt less impact from slight overall warming trends that have been found to be part of a global pattern. Although this relatively lighter American impact had been a boon in many ways, the most recent trends, with massive wildfires and drought problems in western states, for example, suggest that the global averages are increasingly felt within the United States as well. Global averages are not the same as national or state conditions. After all, Michigan can and has experienced record cold winter weather conditions during the very same season in which other parts of the world were experiencing record warm temperatures. That is simply the nature of averages.

The way that known and suspected trends are expected to be felt in Michigan has been included within subsections throughout various chapters in this document, where deemed relevant and supported by sufficient evidence. For example, the chapters on ice and sleet storms, snowstorms, and so on, contain subsections that are called "Climate Change Considerations." Where evidence points to worsening trends (e.g. floods), lessening trends (e.g. drought), or no clear trends at all (e.g. lightning), these subsections endeavor to connect new information about larger climate systems to Michigan's own experiences, risks, and vulnerabilities. Since this document has expanded over time to include a consideration of a very large number of different types of hazards, both natural and human-related, mild and catastrophic (e.g. fog versus nuclear attack), it is considered appropriate to now add a new chapter assessing broad climate conditions that might affect a large number of Michigan's specific hazards over time.

This concludes the general overview of the topic of this chapter. The following lengthy section provides an extensive array of concepts and information that is designed to be most useful and appropriate for readers who have at least some background familiarity with science, the use of graphs to portray information, and the sometimes-complex relationships that characterize **systems** in which many components can interact in ways that sometimes reinforce and sometimes counteract each other's effects.

More Detailed Overview

Most of the analysis of natural hazards is concerned with damaging weather events. **Weather** involves short-term meteorological events and patterns, but overall patterns of precipitation and temperature add up over the course of decades and centuries to form patterns of **climate**. These events can also be viewed at different scales, with a shorter-term perspective often being appropriate to identify and assess **microclimates**, while a scope of geological epochs, eras, and even eons may be necessary to fully understand trends in the global system (and the solar and galactic systems in which it exists). Detailed records, measurements, and quantitative analysis are the most appropriate tools to analyze long-term, complex systems that long exceed our normal human lifespans and local, personal perspectives. For centuries, scientific research methods have provided a time-tested means of amassing information and assessing ideas through careful observations, measurements, and the development of logical frameworks that explain how all verified information fits together.

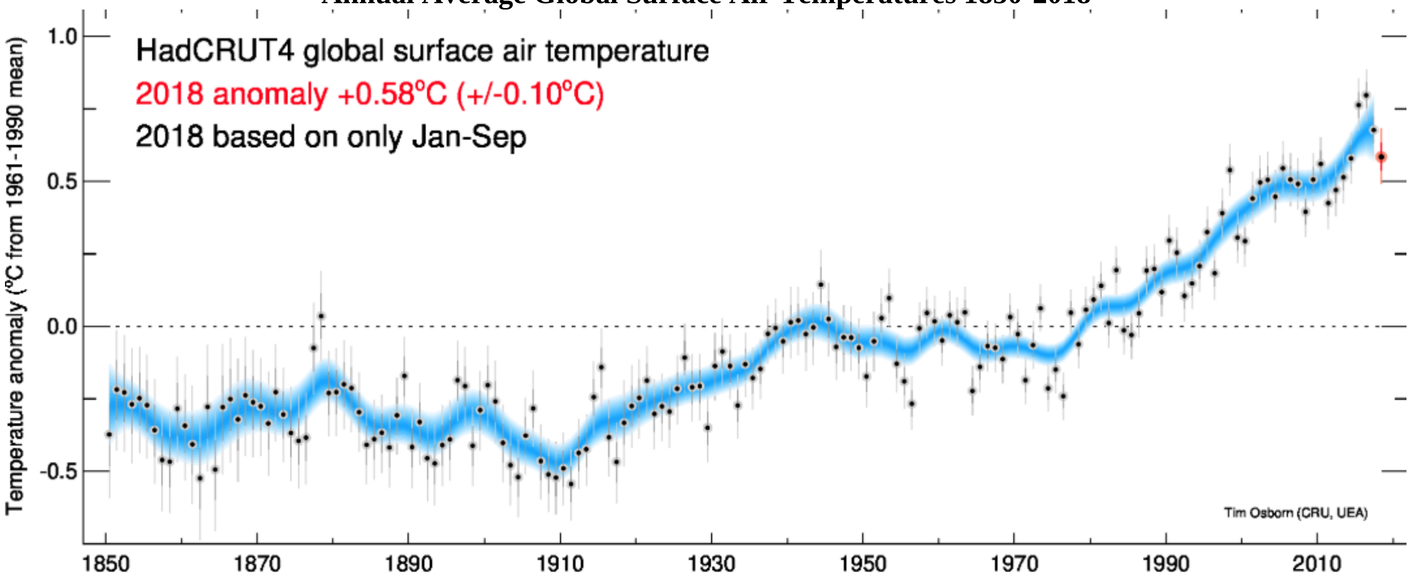
Without using a clear means of measurement, systematic record-keeping, and analysis, individuals will usually face difficulties when trying to sense changes in longer time-scales (e.g. at least three decades) that are relevant to climate, since winters might "feel" colder to an aging person who occasionally clears snow than they had during that person's youthful days of active outdoor play during winter. Similarly, the droughts and heat waves of the 1930s were simply too long ago for many Michigan residents to have experienced. (Even someone who is currently 90 years old will not have clear firsthand memories of the peak drought period from 1929 to 1932.) In order to answer questions such as "Do waves of heat and drought recur each century?" we will have to supplement our historical records (which in Michigan started to be systematically compiled statewide during the 1890s). The answers obtained through the scientific method are often much more complex and challenging than the simple cycle suggested in the question above.

The longer-term aspect of climate also tends to conflict with the fairly short time-scales usually addressed in urban planning and emergency management. Climate deals in time scales that range in length from several decades to many millennia, while hazard mitigation planning tends to address 5-year periods and deals with specific events that form temporary emergencies. Previous editions of this document saw a challenge in incorporating climate trend information into a 3-to-5-year plan update cycle when it hadn't been clear that longer-term climate trends could meaningfully fit into that relatively short time-frame for this type of planning. The solution previously used was to consider where climate trends might result in changes in specific hazards, and to then describe such trends within the individual chapters dedicated to each of those hazards. For example, excellent data on Michigan droughts date back to 1895, and it showed a clear trend toward a lessening of the drought hazard as the state's precipitation levels have been increasing over time. The topic of long-term climate is now being addressed in its own distinct chapter within the geological section of this document. Improvements in the collective understanding of the topic, along with an increase in discussion and speculation about it, have made it essential to include in this new edition.

Please note that this document adopts the position that it is usually inappropriate to attribute single specific events to broad causal patterns. A single flood event or hurricane is not by itself appropriate evidence to constitute evidence for a warming climate, any more than a single very cold winter can provide evidence for a cooling climate. Instead, massive collections of data about temperature and precipitation must be organized systematically through the use of descriptive statistics. Even the simplest such presentation of the data is able to reveal patterns of interest. We often compare weather events, such as a hot day or cold night, with the expected norms (averages) for that particular location during a certain time of the year. The chapter on extreme temperatures has presented such average temperatures in Michigan, as they vary from month to month, and other sections have presented geographic differences between the northwestern edges of the Upper Peninsula and the far southeastern area containing Metropolitan Detroit. These differences can by themselves be significant, with some places feeling far "wetter" than others because they are located near at least one of the Great Lakes, while other areas are more drought-prone and distant from the coasts. For a longer-term and larger-scope view of Michigan's climatic situation, this chapter will start by considering average annual temperatures since the 1800s.

The following graph shows trends in <u>global</u> air temperatures since 1850, as compiled from global weather stations. Please note that the scale of this graph is chosen to emphasize small changes, as is currently appropriate to this topic of global trends—the numbers on the left side of the graph represent the number of degrees Celsius by which each year's global average varies from an historical norm (which is labeled as zero). This chosen norm could be arbitratily changed, but the data would still show an overall relative change in which average temperatures today are notably higher than they had been in any decades going back to 1850. (The mid-19th Century could be considered to represent a "pre-industrial average," in global terms, since industrialization had only occurred in limited portions of the world.) After some fluctuations, a low point before 1910 is followed by an increase through World War II, followed by a flattened period through the mid-1970s, then shows a period of faster increase afterward. The total increase during this recent time-frame is shown to exceed one-degree Celsius (which equals 1.8 degrees on the Fahrenheit scale).

Annual Average Global Surface Air Temperatures 1850-2018



Source: https://crudata.uea.ac.uk/~timo/diag/tempdiag.htm

A few questions should immediately be addressed. One question involves the scale of the change: How much does an increase of one degree Celsius actually matter? A second question involves the relevance of this change for Michigan, which constitutes only a very small portion of the entire Earth's surface and is located at temperate latitudes. Finally, a third question involves the limits of considering a data set that goes back only 168 years, which is longer than any single human lives, but represents just a tiny fraction of the entire age of the Earth: How does the recent temperature increase compare with temperatures from earlier periods of time, and is it explained by longer trends?

With regard to the first question, scientists have found that a one-degree scale of global temperature change tends to involve a greater occurrence of record-setting events in particular local and regional areas of the world. Some parts of the world have felt impacts much faster and more severely than other parts of the world. The types of measured local impacts do not always match what might intuitively be expected. For example, changes in ocean currents can cause some places to cool, in cases where currents had been bringing tropical warmth to cooler temperate lands. Average temperatures alone do not tell us about the wide range of actual temperatures that regularly occur around that average. Michigan still has very cold winters as well as very hot summers. However, as Michigan's wide temperature range occasionally and seemingly randomly breaks old records—both hot and cold—a pattern does become clear that when an average temperature increases for a sufficient amount of time, the number of new temperature records set on the warm side tend to outnumber the number of record cold events. Both records may continue to be felt in various places around Michigan, but the number of record warm temperatures have been outnumbering the number of record cold temperatures. According to meteorologist Paul Gross (2010), record high temperatures outnumbered record low temperatures by a two-to-one ratio. More recent discussion with that author reveals that this ratio has been increasing over time.

Another source of complexity is that there is much more to the global system than just air temperatures at its surface. Land and water temperatures tend to change less quickly than air temperatures do (although exceptions do exist at longer time scales). One of the key principles of thermodynamics is that where temperature differences exist, the energy from warmer substances will tend to flow into cooler areas until an equilibrium is reached. Meteorological systems involve complex but somewhat predictable patterns by which (predominantly solar) heat warms substances on our planet's surface and in its atmosphere, and the heat gets redistributed to areas of the planet that hadn't yet been warmed to the same extent (such as deep ocean waters and polar areas that were receiving less sunlight). Earth's observed patterns can be described as part of a dynamic system in which there is plenty of variety stemming from multiple forces, but within that variety we can find some clear patterns—daily cycles of hot and cold, seasonal cycles of winter and summer, and longer-term cycles such as El Nino and La Nina.

Following the basic principles of thermodynamics, then, above average air temperatures tend to be felt in specific patterns in which higher temperature records tend to most often occur in the coolest situations, such as fewer days of extreme winter cold, warming temperatures in the coldest parts of the planet, and the transfer of heat into the relatively cold parts of the planet's oceans. The global map below, then, shows one of many comparisons that have been made between recent average temperatures, involving both air and water, and an historical norm (in this case, three decades between 1981 and 2010).

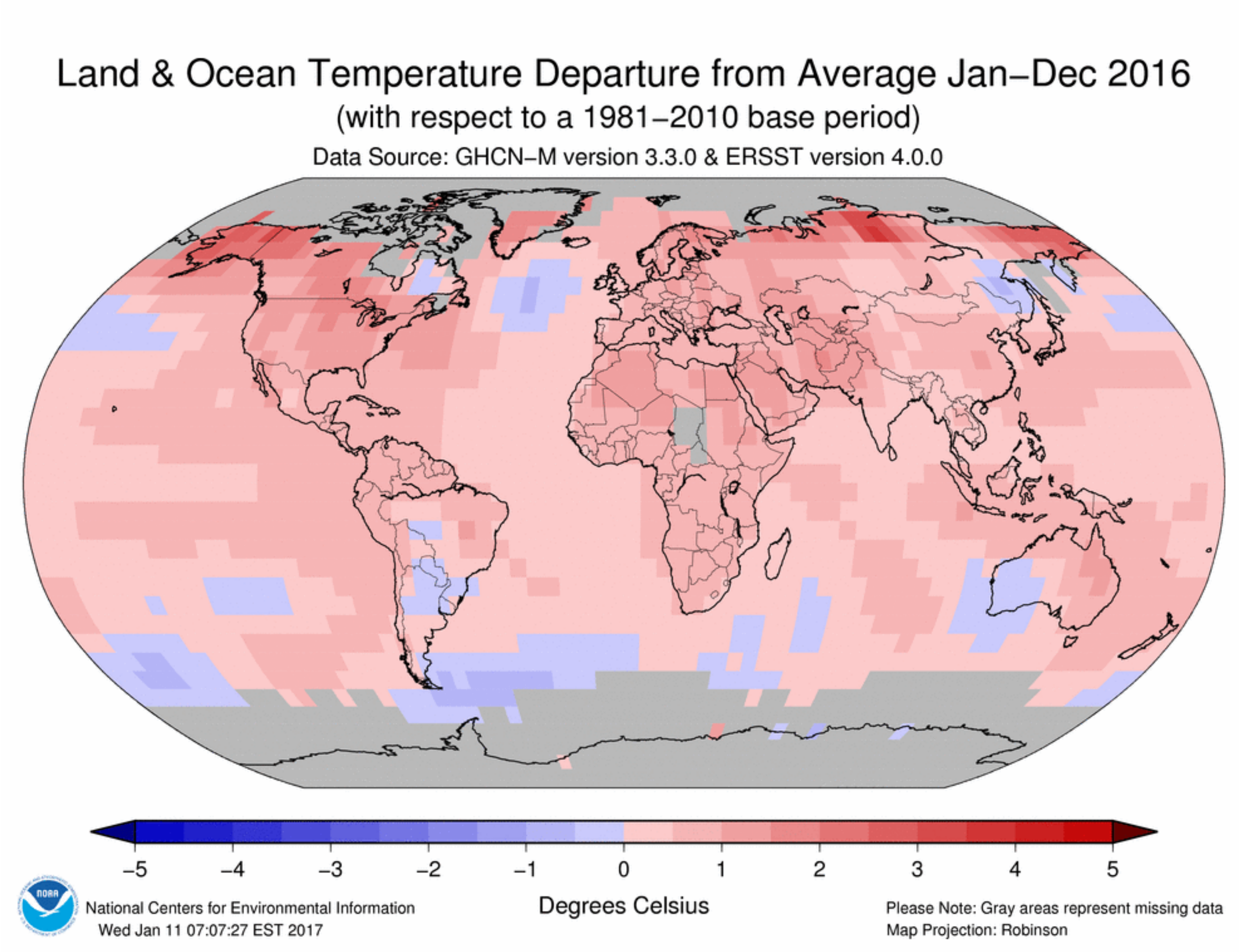


Image source: https://www.ncdc.noaa.gov/sotc/global/201613

A color version of that map shows some parts of the planet with an average temperature below the recent historical norm, but most parts of the planet showing average temperatures above that norm. (Readers who are using a black and white printed version of this document should note that the digital version includes a colored map showing the great majority of the continents in shades of red, on the right side of the Degrees Celsius scale shown at its bottom.) Although this map has chosen a much different historical frame of reference, the data is still consistent with a higher-than-normal temperature average. Some periods of time involve more heat transfer into oceans (and a slowed increase in average surface air temperatures), while other periods of time display more changes in the air. However, measurements around the world have confirmed that the amount of heat energy within the Earth's ecosphere has shown a recent increase.

In itself, most areas of the world would not consider this recent one-degree Celsius increase to be of great concern. The concern instead involves the overall pattern revealed by collected data. As shown previously in the temperature graph, temperatures in the late 19th Century varied but did not stray very far from the "pre-industrial" temperature norms. The first decades of the 20th Century actually showed a dip below that average, and this sort of fluctuation is commonplace within this type of data. The phenomenon that is considered noteworthy involves the pattern of lifting above those historical norms, instead of the temperature averages performing a "random walk" around that historical average (sometimes above it, then below it, and eventually back again). Starting in the 1930s, the temperature data show the global average lifting above the historical norms, but not returning to it. Variations continue to be seen, but began to occur around an overall norm that now involved an upwardly slanted line, rather than a flat horizontal line. The upward trends become very clear after 1980, in which variation involves slower or faster rates of long-term increase, but always an increase, rather than an offsetting cooling trend back toward the historical norms. Therefore, the important thing about these data is not so much the temperature increase that has already been observed, but the larger pattern in which temperatures are rising over time at an increasing rate. The pattern in the graph is essentially that of an exponential increase. It is this increase in the rate of temperature change that now makes this topic suitable for inclusion within relatively short-term documents such as this one, which was not the case just a few decades ago, when the main questions involved analyzing cyclical variations around historically established norms. The following information shows more clearly the pattern that has become a new frame of reference for weather-related hazards that vary with temperature.

The National Oceanic and Atmospheric Administration compared all 136 years of this global data dating back to 1880, and found that the warmest years in these modern historical records are all the most recent ones—the warmest years all occurred within the past 2 decades. This is shown in the following table (although please recall that our national and state data do look different from this data for the entire world, and are worth assessing separately).

Eighteen Warmest Years (1880-2017) – This table lists the global combined land and ocean annually-averaged temperature rankings for each of the 18 warmest years on record (some of which were tied with each other).

RANKED (1 = Warmest)	YEAR (from 1880 to 2017)	Degrees (Fahrenheit) above average
1	2016	+1.69
2	2015	+1.62
3	2017	+1.51
4	2014	+1.33
5	2010	+1.26
6	2013	+1.21
7	2005	+1.19
8	2009	+1.15
9	1998	+1.13
10	2012	+1.12
11-13 (tie)	2003, 2006, 2007	+1.10
14	2002	+1.08
15-16 (tie)	2004, 2011	+1.03
17-18 (tie)	2001, 2008	+0.97

Source: Adapted from https://www.ncdc.noaa.gov/sotc/global/201613 with 2017 information added from http://www.noaa.gov/news/noaa-2017-was-3rd-warmest-year-on-record-for-globe

Many efforts have been made to model new temperature norms with a curved line, rather than a flat horizontal line, to compare new weather measurements with the past several decades and to continually verify whether all new information is consistent with these trends, and what projections can be made about the next few decades. However, it is important to first assess one of the main questions that had been mentioned earlier: what longer-term data do we have that might place the past 118 years into a greater context? If we can assess much longer-term historical patterns and variations throughout the planet's history, can we explain the recent temperature rise, and predict whether and when it might reverse itself as a result of longer-term cycles?

There is only a finite history of reliable and comprehensive records of temperature measurements made by trained meteorologists around the world who have shared common scientific standards that make their data directly comparable. When we want to look at temperature patterns around the world that represent periods of time before the rise and spread of modern meteorology, it is necessary to look at types of evidence that can be examined around the world and that can provide reliably measurable indicators of past temperatures. For example, very old trees grow by different amounts each year, in a way that reflects each year's seasonal conditions and has clearly measurable patterns involving tree ring width and quality, when such trees are cut apart for examination (the field of dendroclimatology). However, since multiple factors affect tree growth, not just temperature, and there are limited numbers of trees available to represent very long-ago time periods around the world, many alternative methods are necessary to assess these questions in a manner as rigorous and comprehensive as they deserve. One of the more long-term and widely available indicators of past temperature patterns around the world can be found in areas where precipitation has accumulated for centuries and millennia, and has been preserved within the ice that still covers the area. Tools can extract "ice cores" at locations around the world, for examination to detect differences chemically associated with temperature differences (e.g. isotope ratios of oxygen or deuterium).

Additional methods ("**proxy data**") to assess past temperature and climate conditions include:

- The study of historical documents that provide information about historical droughts, precipitation, floods, crop yields, and the dates of freezes and thaws in local water bodies.
- Assessing the heat patterns within layers of accumulated soil and bedrock, examined in very deep boreholes.
- The chemical analysis of various other locations in which substances accumulate over time and can be excavated to examine conditions of the past. For example, corals exhibit changes in their oxygen-isotope ratios, the layers of $CaCO_3$ in cave stalactites can be studied and dated, and the bottom of natural lakes to assess the character and contents of accumulated sediment and soil deposits (e.g. pollen analysis, oxygen isotope ratios).
- Related geologic evidence concerning changing water levels within isolated (closed basin) lakes, and other precipitation-related studies, where temperature patterns are known to affect rates of evaporation, humidity, and precipitation.

These techniques allow the inclusion of more than a thousand data sets that apply to the most recent two centuries, hundreds of data sets that describe the past millennium, and dozens that cover a two-thousand-year period.

Geologic studies also provide data involving longer-term phenomena such as glacier formation and movement. Although it is evident that the Earth had seen previous periods in which temperatures were much higher than they are now, most of those warm periods pre-date the existence of humanity. Except where extremely long-term patterns might need to be considered in order to explain current trends, the key comparisons for a hazard analysis should necessarily involve temperature and climate conditions that had existed during the time of humanity's existence. It is well known that an "Ice Age" (which was eventually determined to have started about 2.5 million years ago), was interrupted by a warm (Holocene) epoch that started nearly 12,000 years ago. This is more properly known as the start of the most recent **interglacial** period and roughly corresponds to the time of earliest known permanent human settlements. Today's current global temperature averages are warmer than any time since the mid-Holocene warm period of approximately 6,000 years ago. During warm periods like this, continental glaciers shrink greatly and retreat up to the polar areas, while alpine glaciers (in the cold mountainous locations) may persist but also shrink in size. Michigan's landforms were greatly shaped by the retreat of continental glaciers during the early Holocene, and the global extent of both polar and alpine glaciers has been shrinking overall during recent decades (with glaciation retreating in many more places than it has been expanding).

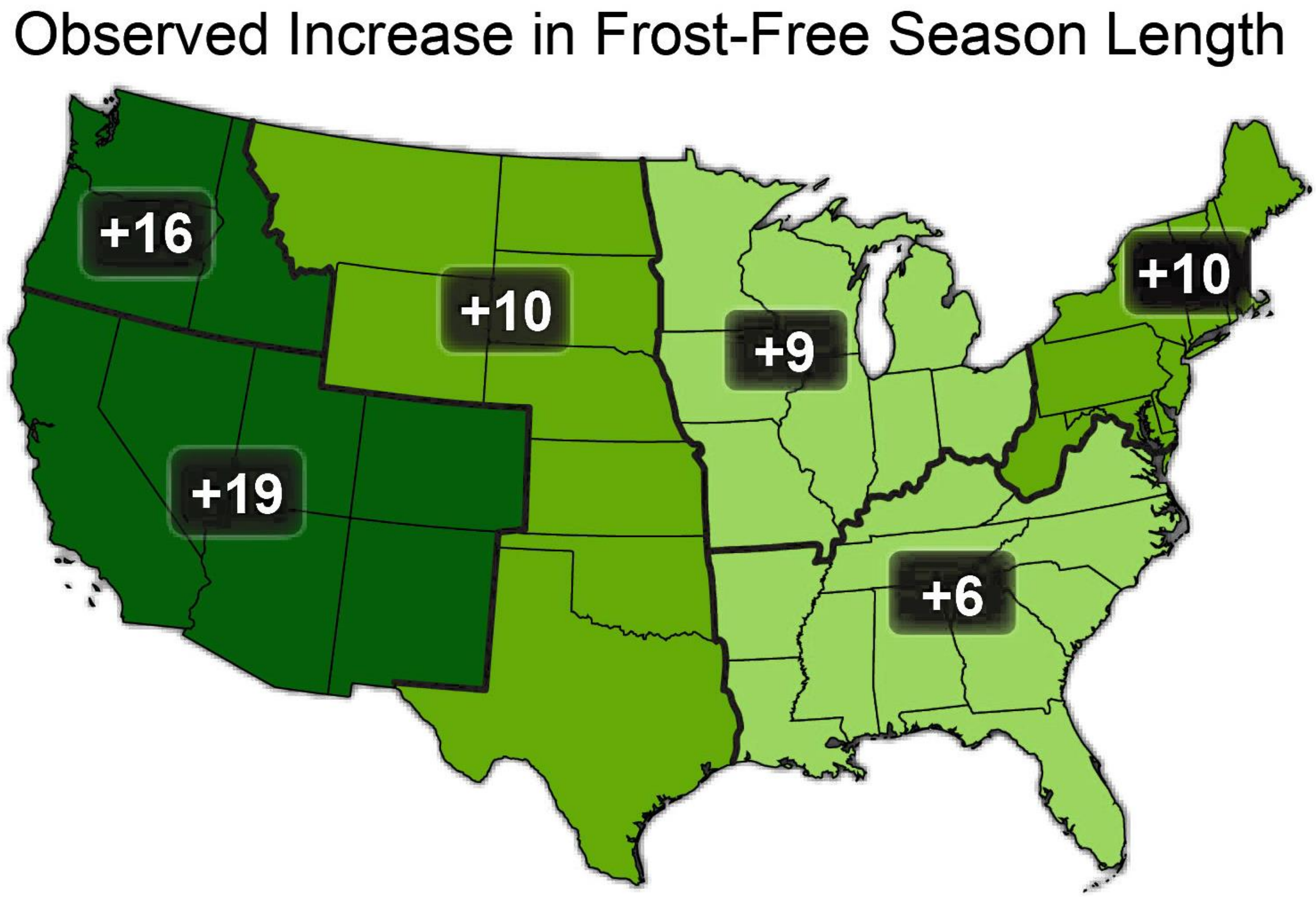
The precise effects of these changes upon a specific place tend to be difficult to predict with precision. Changes in large-sized oceanic currents (**thermohaline circulation**—patterns in which warmer water goes into cooler realms where it gets cooled, and in which cooler waters simultaneously flow to areas where they absorb heat and become warmed) can cause some areas of the planet to cool or warm very quickly, as heat gets carried to different places as such currents weaken, stop, or change. Although predictable ocean current patterns do form, they do not form simple predictable cycles that endure for extremely long, in geologic terms, because the size and shape of continents and oceans change over long periods of time (first confirmed by mid-20th Century scientific discoveries involving **plate tectonics**).

However, modern digital technologies have allowed impressive recent advances in scientists' ability to model current patterns with increasing precision. The predictive capacity of these models does of course become less reliable when the models attempt to project too far into the future. There are a great many models that extend their projections a few decades ahead, correspond fairly well with each other, and allow expected conditions around the world to be mapped out within a reasonable time frame (such as 2035 or 2050). The application of global models to predict specific conditions in one area of the Earth is very difficult, and so for the purposes of this short-term, state-level hazard analysis, such models' projections may be noted but will not be overemphasized in comparison to data that is specific to the State of Michigan. Rather than rely too heavily upon longer-term global models to generalize about Michigan's next several years, emphasis has been placed upon trends in historical Michigan data. Many sciences and indicators are interconnected and relevant to Michigan's hazards, as well as the impacts of meteorological variation—especially those from physical geography (short-term time frame), climatology (long-term time frame), geology, ecology, astronomy, biology, chemistry, and physics.

The Michigan Hazard Analysis focuses on how identified hazards may be worsened or lessened by climate trends, retaining an emergency management focus and focusing upon recent history, current events, and near-term projections which merely assume that documented recent trends will continue for the next decade or two. For example, nationally, the droughts and heat which were so devastating in the 1930s, seem to have comparable events repeating now in other parts of the country, but not in Michigan. As shown in the drought chapter in this document, Michigan has seen fewer droughts in recent decades, and a notable trend toward increasing precipitation. This has been worsening Michigan's risks of damaging flood events over time. It is consistent with the principle that higher average temperatures allow air to hold greater levels of moisture. Although it is not yet clear whether Michigan is seeing any change in the frequency of severe thunderstorms, recent climate trends do suggest that Michigan's gradually increasing amounts of precipitation is increasingly occurring within heavy events (both in the form of heavy rains during warmer weather and, at least for another decade, heavy snowfall during cold weather). One of the hazards suggested by climate trends is the risk of increased weather variability, as some of these heavy precipitation events will over time tend to set new records. One of the serious problems Michigan currently faces is in the effect of weather variations upon crops (e.g. frost vulnerability).

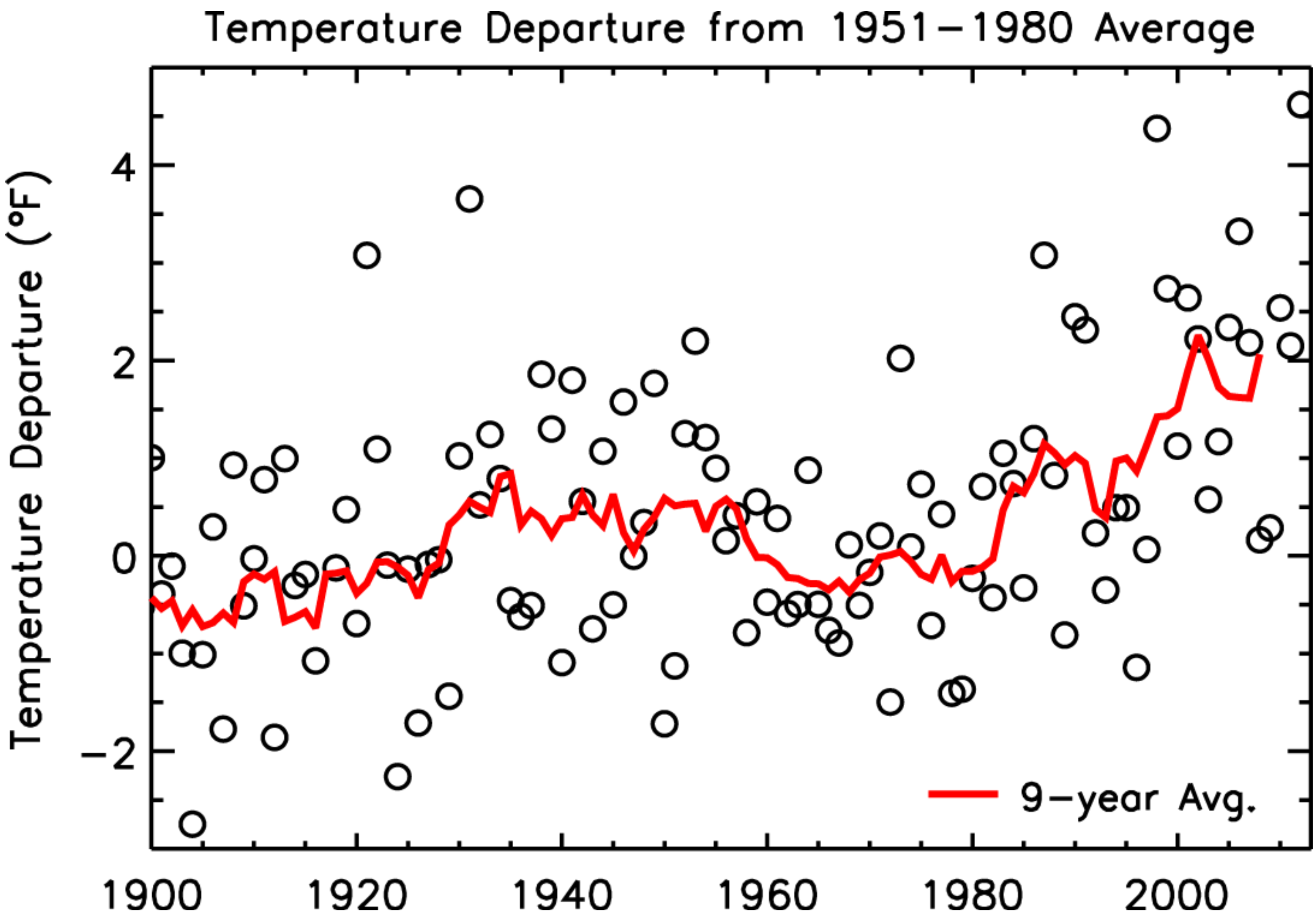
When it comes to temperature trends, what do the data show for Michigan, specifically? As already noted, the occurrence of record warm temperatures have been outnumbering record cold temperatures, but this hasn't meant that Michigan has been suffering from new all-time high temperatures. Rather, the key temperature-related pattern in Michigan has involved an increasing number of temperate days during its cold seasons, and a gradual increase in the length of the growing season. In the southern portion of Michigan (which is in a slightly different climatic region than the northern parts of the state), there appears to be a greater risk of ice storms and freezing rain, which tend to occur when temperatures are around 32 degrees Fahrenheit. There is a gradually increasing number of times during winter, on average, in which the temperatures allow snow to melt and ice storms to occur—a time when flooding also becomes more likely since deeper soils may still be frozen and less capable of absorbing moisture from above, and ice jams may also clog important streams and drainage channels.

However, winter is certainly not disappearing from Michigan anytime soon! A surprising effect that may be occurring (and which received much media attention as a "polar vortex") is that although gradual large-scale warming patterns tend to be occurring the most in cooler places and seasons (rather than making the hottest areas hotter), researchers have noticed that the effects of this trend near arctic regions is to lessen the temperature differences lessen between arctic/polar regions and more temperate zones to their south. Because of this, more temperate areas such as Michigan might be more likely to experience the extreme cold brought by polar fronts during winter. (Research is taking place to investigate variability in jet stream patterns.) Despite the occurrence of these wintry events, however, a gradual decrease in the average number of winter days can cause the average temperatures to show an increase. The average date of the last frost (during spring) has been shifting earlier, while the average date of the first frost (in fall) has been occurring later. The growing season is longest near the Great Lakes, whose presence delays the onset of the first fall frost. But throughout the state of Michigan, the growing season now averages more than a week longer than it had been in 1970. Some major crops are also badly affected by the effects early spring thaws can have upon their growth cycles, shifting them into a state of vulnerability to recurring frosts.



Observed change in the frost-free season length in the United States (in days), from 1958-2012.
Source: GLISA site at http://glisa.umich.edu/climate/temperature

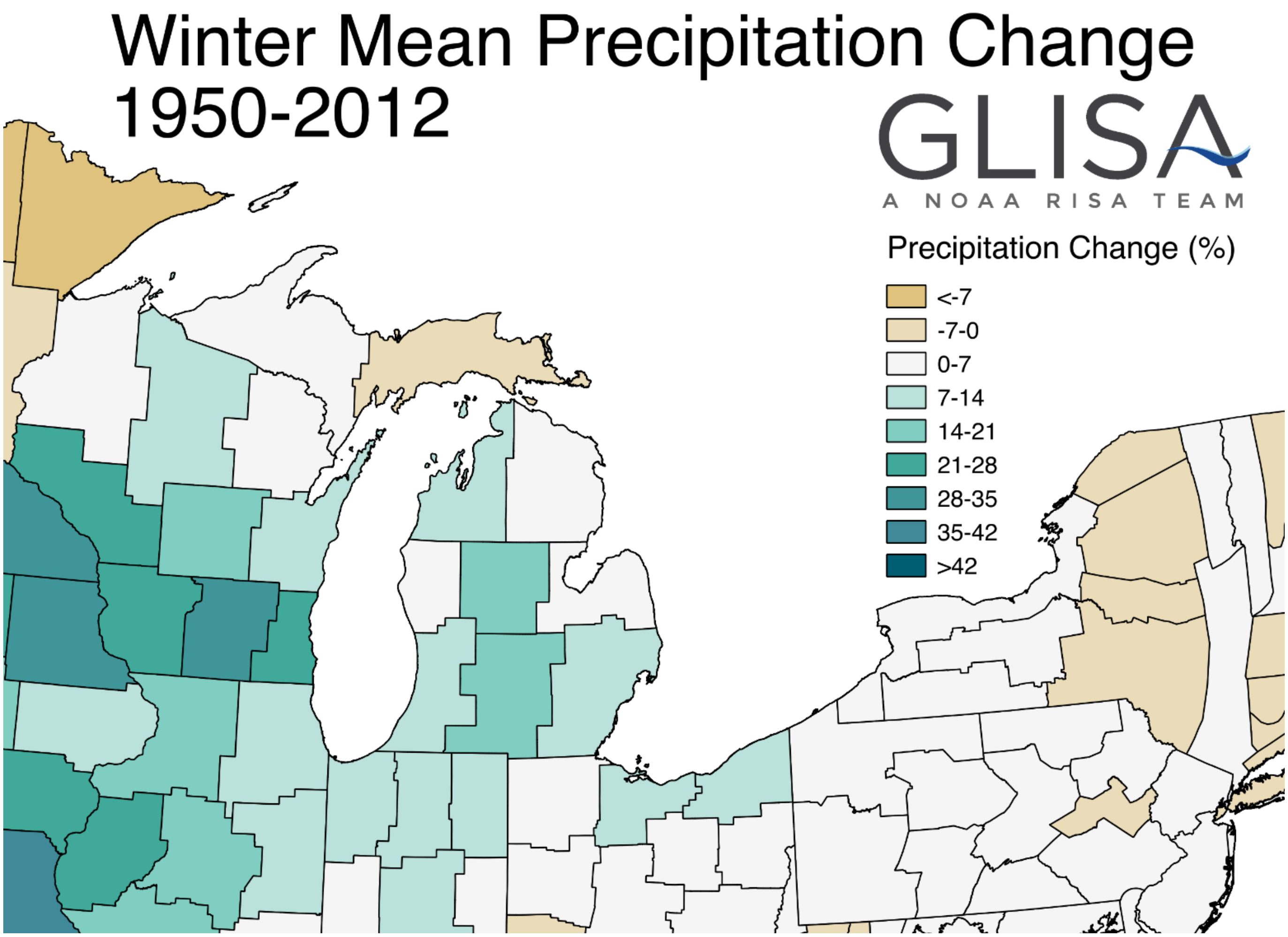
For decades, much of the United States had been experiencing far less of the warming that had been measured elsewhere in the world, but as shown in the map above, this now especially appears to be changing in the Western U.S., which has suffered increasing problems from droughts and wildfires in recent years. The Great Lakes region has seen more moderate changes, so far. However, according to the Great Lakes Integrated Sciences and Assessments agency (GLISA), affiliated with the National Oceanic and Atmospheric Administration (NOAA), the University of Michigan, and Michigan State University, the eight Great Lakes states have seen an average annual temperature increase of 2 degrees Fahrenheit since 1900, involving more change in average winter temperatures than in other seasons. A similar increase in air temperatures, possibly greater, is projected to occur by the mid-21st Century. A graph follows, illustrating the actual historical temperature trend from the beginning of the 20th Century to the present, expressed in terms of a comparison with three of the cooler 20th Century decades (1951-1980). Many graphs of historical temperatures, including this one, show previous periods of cooler temperatures alternating with periods of warmer temperatures (although these are not precise and simple periodic cycles of exactly the same duration). A common feature of these graphs, however, is that such patterns all tend to be subsumed into an overall pattern of increase starting around 1980.



Since 1900, annual average temperatures have increased by 2.0°F (1.1°C) across the 8 U.S. Great Lakes states.
Source: GLISA site at http://glisa.umich.edu/climate/temperature

Over time, as average temperatures rise, the chance of extreme summer heat will also increase. The number of days with a maximum temperature greater than 90°F has been estimated to start increasing, with current regional projections suggesting a shift from 15 per year (in 2010) to at least 36 days per year across the Midwest. This could result in events as intense as the 1995 Chicago heat wave eventually occurring as frequently as every year or two. The waters of the Great Lakes have warmed faster than the nearby air temperature, consistent with the principle that warming tends to occur more in cooler areas and substances. For example, the northernmost of the Great Lakes, Lake Superior, saw summer surface water temperatures increase by more than 4 degrees since 1979. A general pattern of lessened winter ice cover (for a shorter duration) may contribute to an increase in some areas' precipitation levels. According to GLISA, the onset of first ice cover on the region's inland lakes is at least 6 days later than during the mid-19th Century, and the breakup of ice in the spring is also days earlier. Shortening winters and longer-exposed lake waters are also connected with patterns involving the earlier occurrence of lake stratification (temperature patterns considered to amplify the effects of warmer summer air temperatures when they occur).

However, the overall effect upon winter precipitation is complex. The following map shows how different climate regions within the state have seen their winter precipitation levels either rise or fall during the past 60+ years.



Source: GLISA http://glisa.umich.edu/media/images/PrcpWinterChange.png

The shading shown in the map identifies a decline in winter precipitation in the Eastern Upper Peninsula since 1950, during the same period in which some parts of Michigan saw much greater precipitation levels. The Michigan categories shown on this page's map range from a lower boundary of -7% to an upper boundary of +21%. Most parts of the state have seen either slight or significant increases in their measured winter precipitation levels (ranging from 0 to 14%, in the categories shown above).

Details like this have been added to the appropriate chapters within this updated edition of the Michigan Hazard Analysis. It is common for trends to exist for limited periods of time, either as normal parts of natural cycles or in conjunction with more unusual patterns, and for such trends to be unequally felt in different geographic areas at different times. Climatology deals with longer-term measurement and analysis patterns that can help to make sense of such complexity.

Explaining the Data

Within Emergency Management, the term "mitigation" usually refers to some action that reduces or eliminates the impact of hazards. In many recent discussions of climatic trends, however, the term "mitigation" has often been used with respect to activities that would seek to slow or reverse the observed increase in large-scale temperature averages. If such trends cannot be controlled, other actions would try to ameliorate the negative impacts that are expected from a continued warming trend, and such actions have been termed as "climate adaptation" activities. The use of these different terms has the potential to create misunderstandings during discussions between different disciplines, and care should therefore be taken to communicate as clearly as possible. For purposes of this document, hazard mitigation retains its traditional meaning within the emergency management profession, and climatological considerations are viewed primarily in terms of the various effects that known trends might be expected to have upon the set of natural, technological, and human-related hazards that remain the central focus of this document.

The idea that has sometimes been referred to as “climate change mitigation” tends to involve either pollution-control activities, economic incentives, or geoengineering proposals that, although laudable and highly worthy of continued research, do differ from the traditional hazard mitigation activities that are already known to have widespread support from planners and practitioners throughout the state. This updated chapter has the aim of further encouraging discussion and coordination among the many disciplines that are involved in the already large array of hazards that Michigan faces. It is essential, however, to consider the degree that climatic variation might itself constitute a newly identified hazard for emergency management and other disciplines to directly address.

One of the obstacles that had existed during the first decades of modern research on this topic, and still continues to be a large problem when it comes to media presentations and political processes, is that the first awareness of verifiable temperature differences came from those professional scientists whose jobs routinely involve the collection, assessment, analysis, and verification of various kinds of data, including weather data. It is often very difficult even for specialized journalists to interpret and successfully present the most important concepts to a general public readership. Wider discussions and political processes often do not enjoy the same level of rigorous scrutiny and double-checking that scientists accept as the norm for their research—very high standards that are in fact the very basis for science’s special status as a means of investigating and analyzing many questions, some of which are very simple while others can be exceptionally complex. Numerous sciences have developed enormously during the past 500 years, since the Gutenberg printing press revolutionized communications and led to a huge exchange of ideas that challenged many long-established beliefs and institutions. Various scientific disciplines, developing over the course of the centuries since that time, have created large sets of very specialized words that help them to sort through very complex topics and clearly communicate with each other about those topics. It can be easy for persons who are not highly trained in science, generally, or particular fields of science, specifically, to misunderstand the concepts and reasoning that underlies the use of these words. In this section, just a few important concepts will be presented, to help readers make sense of the fundamental scientific processes that are regularly being reported upon and discussed.

The fundamental aspect of science is to favor direct observations as the most useful and trustworthy source of information about a subject. Originating in democratic traditions and blossoming within those traditions, science is at heart a fundamentally democratic process that invites discussion and arguments as a normal activity to test ideas and to accumulate evidence that can receive the widest possible agreement as to its quality and trustworthiness. This makes science different from many other realms of human activity, in which there is far less expectation that every smallest aspect of each idea will eventually be rigorously scrutinized and also subject to relentless criticism. Certain kinds of readily observable facts do quickly receive widespread agreement among nearly all fair observers, but the scientific process still allows everyone to question anything and everything, because this is a valuable way to become as certain as possible that the ideas and information are constantly being tested to make them as valuable and reliable as possible. Skepticism is therefore an essential component within modern science—extremely useful not only for students and citizens who are just starting to learn about some of the areas which scientists have been investigating, but also useful for the top scientists themselves to occasionally make a “breakthrough” discovery or a powerful new conceptual or theoretical insight.

As observations get made, described, measured, and discussed, scientists also engaging in a process of theory construction. In science, a theory does not quite mean what many persons seem to intend when they use the word in casual conversation to refer to something that is essentially speculative. A theory does indeed have its birth in some sort of speculative idea, but that idea must first get shaped into a testable statement—called a hypothesis—and a true theory, in the proper scientific sense of the word, refers to a set of ideas that provides an explanation for how entire sets of verified observations fit together consistently and shape each other. For example, observations of how things moved was found to be related to the masses of objects within a larger system of mutual attraction, and led to the theory of gravity. This was one of the most foundational ideas within the physical sciences, and for centuries has been repeatedly verified to be an impressively accurate system for understanding, predicting, and engineering mechanical phenomena. It is a classic example of what scientists seek to create when they construct a theory that makes sense of enormous amounts of observational data. The fact that Newton’s powerful original theories have subsequently been refined, centuries later, by Einstein and many others, does not detract from the fact that they still remain accurate for most ordinary applications. Theories are useful to the extent that they fit all known facts. As mismatches or anomalies are detected, various refinements to the theory are proposed, and assessed by other scientists on the basis of observed evidence.

With respect to climatic data, then, the key questions are: what explains the rise in average global temperatures, can we predict whether this trend will continue, and can we do anything to reverse the trend if it eventually becomes catastrophic in its extent? During the past half century, scientists in multiple fields have pieced together a great deal of important knowledge about planetary ecosystems, and the explanation that is widely agreed among scientists to fit the data the best has been termed an "anthropogenic" source of increased temperature. The main idea here is that in addition to all the identified natural cycles that have been associated with changes in average temperatures in the past, an additional factor involving atmospheric changes has begun to override the other factors in its strength, leading to net average temperature increases rather than a continuation of previous averages and the cycles around them. As geological sciences matured during the 20th Century, extensive knowledge was gained about earth's history, and even those of other planets (planetary geology). Earth's history is broadly defined in terms of eons, and various times in Earth's past were found to involve markedly different patterns of volcanic activity, atmospheric composition, distributions of organisms, ocean chemistry, and overall ecosystem characteristics. For example, oxygen-breathing life did not arise until the Earth's atmosphere had been sufficiently changed by the previous proliferation of plant matter to increase the oxygen supply to what it is today. By contrast, when astronomers teamed up with engineers to send probes to Venus, they were surprised to find that the planet's thick atmosphere is extremely hot and poisonous. The connection between atmospheric composition and a planet's temperature and ecosystem was becoming clearer.

Climatologists, already knowing about the composition of the Earth's current atmosphere (by volume, in dry tropospheric air: 78% nitrogen, 21% oxygen, and 1% all other gases), noticed a significant association between the increase in average temperatures and the concentration of particular types of gases which they termed **greenhouse gases** (GHG), because their composition is known to cause larger quantities of heat to be absorbed into rather than reflected by the atmosphere, just as the unusual atmosphere of Venus had caused it to become increasingly hot over time.

Astronomers, geologists, paleobiologists, climatologists, oceanographers, and many other scientists had markedly improved our understanding of Earth's history and systemic processes within the past century. A great many patterns have been observed, involving planetary and astronomical cycles. For example, our Sun has a sunspot cycle that currently averages about 11 years in length, and varying amounts of energy are emitted by the sun over time. However, this cycle does not match up with or account for the warming trend that has persisted for several decades now—solar cycles have been found to be associated with only a portion of the observed temperature trends, such as a periodic slowing or hastening within an overall warming trend. Ordinary seasonal cycles have been extremely well-known since prehistoric times. Subtle forms of astronomical cycles have been detected by astronomers, involving the distance and tilt of the Earth with respect to the Sun, and even the rotation of our entire Milky Way galaxy, but these astronomical cycles occur over extremely long periods of time. Within the graph shown at the beginning of this chapter, and similar representations of Earth's temperature data, the strongest cycle currently attributable to known natural cycles is that involving the ocean-driven variations known as **El Nino** and **La Nina**. But the recent warming trend is overriding the strength of those cycles.

Could there be some as-yet unidentified phenomenon that accounts for recent temperature rises, other than the increasing concentration of greenhouse gases in the atmosphere? It is possible, but the strength of the identified association between average temperatures and GHG concentration already explains enough of the trend that most scientists have accepted the usefulness of that correlation as an indicator of future trends. It would be very nice if the warming trend could be revealed to be just a temporary phenomenon that will soon reverse, but even if this is the case, a sufficiently large trend might itself involve challenging disastrous events to be dealt with in the course of such natural reversals. For example, volcanic activity has been observed to generate clouds that have a reflective and shielding property that causes an overall cooling in the atmosphere. If such a phenomenon could act as a natural planetary corrective mechanism that restores global temperatures to previously expected norms, then various countries might still need to deal with the risks from a series of volcanic eruptions, and the effects they would have upon agricultural production and other activities.

In the meantime, the anthropogenic explanation does offer the possibility of reversing climatic trends in a way that might not be possible if warming had been caused by some natural cycle that might be beyond our control. Although the planet has, during its long history, gone through many changes, human societies have not seen the vast majority of those changes and therefore did not need to be tested by the vast challenges that they would present if they were to recur during our lifetimes.

This raises another important question: why are many persons so greatly concerned with the warming trend that has been observed? The answer involves the lack of known forces that would reverse the trend within the coming decades, unless perhaps collective projects can succeed in geo-engineering either a reversal in atmospheric GHG concentrations or some alternative means of lowering the current heat-trapping pattern currently observed. How long can the warming trend persist, and how extreme might it become, if it is not reversed through some natural or engineered means? And does the current trend truly indicate an unprecedented phenomenon?

Scientists exploring these patterns have become increasingly aware of the importance of **feedback loops**. A negative feedback loop involves forces that act as a kind of corrective mechanism, like a spring, in which too much movement from some normal position will cause an increasing force that pulls something back toward its preferred state. A positive feedback loop, by contrast, involves conditions that reinforce movement away from some starting condition. For example, a bank account that collects compounding interest is an example of a positive feedback loop: as interest payments get added to the account's balance over time, an increasing amount of interest gets earned, and the amount of money in the account continues to increase, at an increasing rate. Positive feedback loops are typical of phenomena that show an exponential increase, which characterizes the generalize curve in the initial temperature graph at the start of this chapter—something not only increases over time, but does so at an increasing rate, because some aspect of the growth is reinforcing itself and encouraging more growth.

In the case of climate, there are some negative feedback loops identified, but a larger number of positive feedback loops that on balance seem inclined to keep driving the rate of temperature increase upward over time. For example, two of the directly-observable phenomena that confirm an average overall temperature increase involve the amounts of ice and glacier cover in high altitude (mountainous) and high latitude (arctic/polar) areas around the world. Although there are some glaciers that have been advancing in size, the vast majority are shrinking. And although some parts of Earth's polar ice have been observed to increase, the overall trend is toward shrinkage—especially in the Arctic Ocean, which the U.S. Department of Defense expects to soon become navigable as a result of lessened ice cover. Areas that had been covered with snow and ice tended to reflect a great deal of the Sun's energy, and did not absorb much heat. But as increasing areas have waters and land surfaces exposed by melting ice and snow over time, the exposed land and ocean waters do absorb more heat than the ice had, making the melting of ice into a positive feedback loop that gradually leads to more melting. Various other feedback mechanisms have been found, such as the release of methane and other greenhouse gases, which had been trapped under that ice and then absorb increasingly greater quantities of solar energy. Negative feedback loops include certain types of pollutants, such as sulfate aerosols (also produced by volcanic activity), and clouds, which help to reflect sunlight back into space before it can reach surfaces that are warmed by absorbing its energy. Another form of negative feedback that could slow a warming trend comes from the tendency of a warmer and wetter climate to favor the growth of plants and forests, which can thus absorb more carbon dioxide and help to lessen the its concentration in the atmosphere. Still, the current balance of feedback within the global system is in the positive direction, toward continued warming.

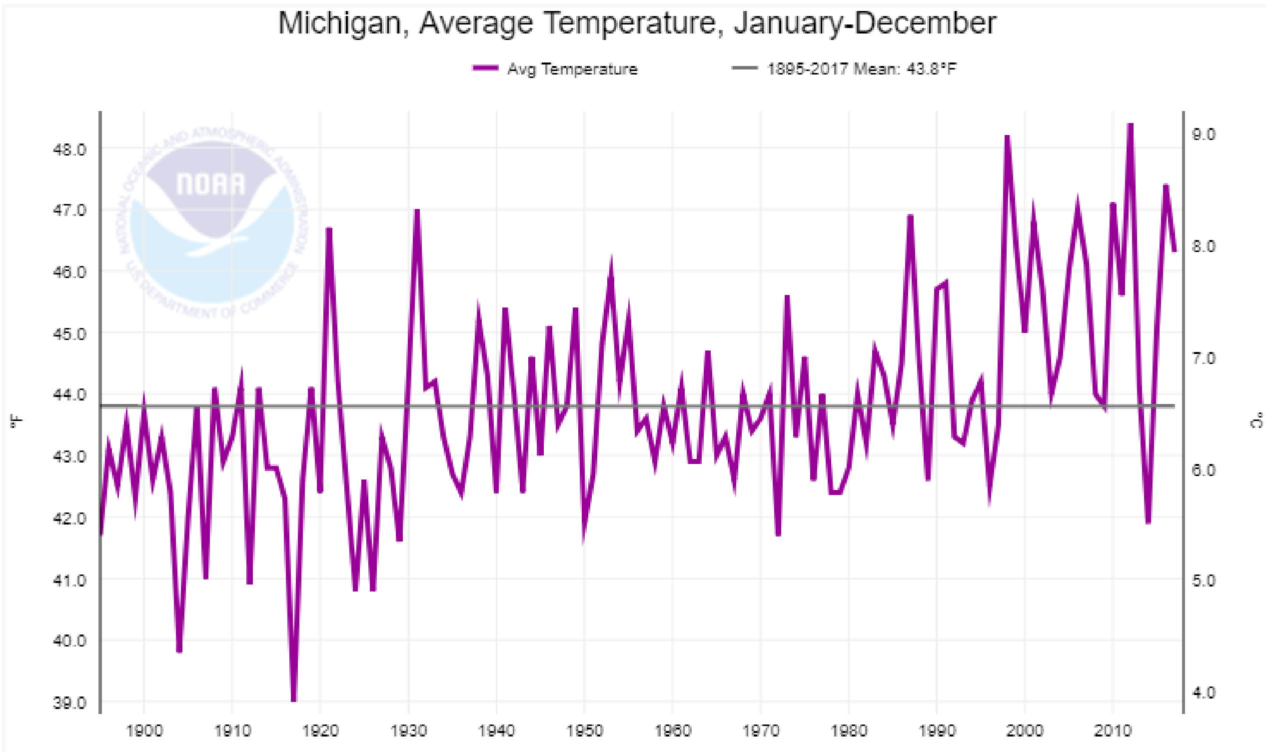
The projected effects of different GHG emission levels tend to be large because average global temperatures were found to be generally proportional to the concentration of greenhouse gases, some of which (e.g. CH_4 and H_2O) have a positive feedback loop that reinforces the additional absorption of solar energy. The proportionality of each greenhouse gas concentration level with temperature trends is often not a simple linear relationship. Today's atmospheric concentration of carbon dioxide is about 30% higher than it was 150 years ago, apparently due to a century and a half in which global population had doubled twice, shifted into predominantly urban and industrial economic modes, installed massive new amounts of infrastructure, endured two world wars and dozens of smaller ones, and saw massive expansion in per-person extractive, manufacturing, transportation, and other production processes.

Between production, transportation, heating and cooling, and other activities, all of which require energy, thousands of pounds of emissions are generated each year for each person. There has been an increasing interest around the world in reducing these emissions, even if only to help improve the local air quality within cities. Although the United States had greatly improved its own urban air quality during recent decades, that same time period saw a huge production boom in newly industrializing countries, whose cities sometimes have some of the worst air quality yet recorded. Global demand for less-polluting technologies is therefore extremely high, and many businesses have been profitably innovating to better satisfy this already huge and still-growing demand. Renewable and alternative energy sources are becoming more affordable over time—solar, wind, hydroelectric, geothermal, etc. Some touted biofuels have unclear net benefits, but other innovations have demonstrated real benefits in terms of both profit and sustainability. Some of the proposed areas for improvement harken back to traditional conservative values about responsibility and thrift (e.g. "waste not, want not"), as well as the sense of civic responsibility from the "Greatest Generation," in which economic depression and war needs demanded efficiency and some level of personal sacrifice for a greater good ("use it up, wear it out, make it do, or do without"). Some ideas involve small sacrifices to realize tangible benefits, such as indoor HVAC settings that are slightly warmer in the summer (when people are acclimated to higher outdoor temperatures anyway) and slightly cooler in the winter (when people and their clothing have similarly adjusted to colder weather.) Choosing Energy Star appliances can lower energy bills, reusing shopping bags can help lower costs, and so on.

Another concept that has led to increasing concerns is that of **tipping points**, in which a system has exceeded the ability of its negative feedback mechanisms to recover from a change. Limited variation is normal within any system that involves a stable equilibrium—in which properties of that system keep pulling it back toward some initial or preferred state. A ball rolling back and forth in a curved bowl will be pulled toward the bottom of that bowl, and will eventually stop there to rest, but a ball that sits on the top of a hill is at risk of rolling down that hill, never again to return to its original starting point at the top. Some atmospheric changes might be susceptible to an engineered reversal, but changes in ocean chemistry and circulation might not. Similarly, the current stabilizing function of ice caps, ice sheets, and glaciers would not have any clear substitute once they have melted. Just as it takes time for a fast-moving car to stop after the brake pedal has been pressed, many persons are concerned that warming patterns will take time to offset, and that there might not be enough time to prevent a threshold from being crossed that causes changes beyond our ability to effectively manage or reverse them, even over a long period of time (e.g. extinct species cannot be replenished). Many of Earth's previous warming trends had taken a longer time to occur, thus allowing more chance for organic systems to adapt. Although near-term warming has been calculated to be of benefit to some geographic areas, the effects in general are expected to be very challenging. For example, melting permafrost tends to expose mud rather than quickly useable soils, many species are unable to "follow the climate" through migration, many great cities are increasingly threatened by oceanic sea level rise (the majority of which comes from thermal expansion rather than ice melts), and desertification is increasing in many populated but relatively poor areas of the world. For these reasons, an increasing number of persons have expressed great concerns and stressed the urgency of taking effective action, in the hope that the threats might prove manageable, and with the idea that the effectiveness of actions will be greater if they are accomplished sooner, since such actions would become more difficult over time as a result of feedback loop effects.

While researching more information about these types of tipping points, and ways they might be avoided, we can also compare the present to the past and ask: what temperature levels and climate conditions have humans already dealt with? The concern is not with the fact that modern technology allows those who can afford it to live comfortably within a base in frigid Antarctica or in air-conditioned luxury within a hot desert high-rise building, but rather with the impacts that a worst-case scenario might have upon larger systemic issues such as sustainable food production, public health, worsening natural disasters, geopolitical conflicts, and large-scale migrations. During the entire Holocene epoch (since about 12,000 years ago), the warmest global temperatures occurred about six thousand years ago, as a result of one of the long-term astronomical cycles referenced earlier. This period did have warmer summer temperature averages in the Northern Hemisphere, and warmer winters at high latitudes where reduced ice cover had occurred, but 21st Century temperature averages have been approaching that epochal peak and are projected to match it during the next century. The implications are likely to be large enough that it is worth thinking about them in advance.

To specifically consider the final question involving Michigan's own experience involving temperature trends, a NOAA temperature graph appears below and covers the years from 1895 to 2018:



https://www.ncdc.noaa.gov/cag/statewide/time-series/20/tavg/12/12/1895-2018?base_prd=true&firstbaseyear=1895&lastbaseyear=2018

This Michigan graph displays the average annual temperature data for the past 123 years, with a reference line that represents the mean Michigan temperature during that entire period of time. As with temperature graphs at other scales, we again find that a gradual increase in temperature is the predominant trend, especially since 1980. The general expectation is that such an increase will continue at least to the end of the century.

A Michigan Hazard Mitigation Perspective

This document focuses upon the next five years in Michigan, from an Emergency Management perspective, and therefore hasn't emphasized long-term national and international policy. While acknowledging the importance of collective efforts being promoted or implemented around the world, the emphasis here is upon ways in which climatic trends and variability may affect the specific hazards described throughout this document's other chapters. Therefore, this chapter provides an overview of the subject, and more specific information is briefly included within the chapters on each of the hazards that has the clearest connection (or strongest potential connection) with climate trends.

General climate mitigation activities that tie in with national policy will need to be addressed through broader measures than this Michigan document employs. Although there are understandable concerns about the potential for regulation to create economic impacts, new "green" technologies and consumer choices do offer the potential new growth opportunities for American industry, whose advanced capabilities make it a natural leader in most types of emerging technologies. The demand for more efficient, less polluting processes and technologies is expected to increase, especially in poorer and densely populated areas of the world. Although some of the proposals for "climate change mitigation" could bolster emergency management goals involving local disaster resilience, the full import of such proposals is still being evaluated in terms of their political and economic implications. This Michigan document's narrower focus upon the mitigation of specific hazards helps to keep our state's comparatively short-term emergency management activities moving forward in their own specific forms of protection. Emergency managers are invited to gradually consider and prepare for longer-term patterns, knowing that past events can recur or worsen, even if all the precise reasons for trends or cycles are not yet clear, or might require special training to evaluate.

Earthquakes

A shaking or trembling of the ground (or earth's crust) caused by tectonic activity or other seismic forces.

Hazard Description

Earthquakes range in intensity from slight tremors to great shocks. Their duration may range from a brief instant to several minutes, or come as a series of tremors over a longer period of days or weeks. The energy of an earthquake is released in multiple types of seismic waves. Earthquakes usually occur without warning. In some instances, advance warnings of unusual geophysical events may be issued. However, scientists cannot yet predict exactly when or where an earthquake will occur. Earthquakes tend to strike repeatedly along faults, which are formed where tectonic forces in the earth's crust cause the movement of rock bodies against each other. National earthquake risk maps have been produced, showing areas where different levels of earthquake are more likely to occur. Earthquake monitoring is conducted by the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and universities throughout the country.

The actual movement of the ground in an earthquake is seldom the direct cause of injury or death. Most casualties result from structural collapse, falling objects and debris, or transportation accidents. Disruption of communication systems, electric power lines, and gas, sewer and water mains can occur in certain portions of Michigan, as a result of the strongest known events. Distant earthquakes (out-of-state) could also be problematic for Michigan if they cause disruptions in the delivery of fuels, or require Michigan to accommodate large numbers of evacuees from a disaster area (as is currently expected should a major New Madrid earthquake event recur near Memphis, Tennessee). Water supplies can become contaminated by seepage around water mains, and such seepage can lead to subsidence events after enough erosion or dissolution has occurred in subsurface materials. Severe-enough damage to roadways and other transportation systems may create food and other resource shortages, even if such damage occurs outside of Michigan. In addition, earthquakes may trigger other emergency situations such as fires and hazardous material spills, thereby compounding the difficulties of the situation.

A fault line is where a fault meets the ground's surface, but many faults dip at an angle away from their surface location, and therefore earthquakes that occur at some depth will often not line up with the fault at the surface. Faults do not only occur at the boundaries of large geological plates. There are many small plates that exist, as well as faults that are internal to or perpendicular to plate boundaries.

Hazard Analysis

No severely destructive earthquake has ever been documented in Michigan. However, several mildly damaging earthquakes have been felt since the late 1700s. The exact number is difficult to determine, as scientific opinion on the matter varies—many of the oldest events could have been caused by explosions such as those associated with mining activities, or with subsidence events (q.v.) involving mine collapses, rather than actually being earthquakes in the ordinary geological sense of the term. Most of Michigan's confirmed earthquakes involved limited damage (if any), which tended to be limited to cracked plaster, broken dishes, damaged chimneys, and broken windows.

In recent years, national attention has been focused on the New Madrid Seismic Zone. This zone extends from approximately Cairo, Illinois through New Madrid, Missouri to Marked Tree, Arkansas, and includes important parts of the major metropolitan area associated with Memphis, Tennessee, thus having the potential to result in a national emergency in which many states would have to provide aid, and evacuees from the disaster zone would need to at least temporarily relocate in distant areas, which is expected to include Michigan. During the winter of 1811-1812, a series of severe earthquakes shook the area. The three worst earthquakes destroyed the town of New Madrid, created Reelfoot Lake in Northwestern Tennessee, and caused ocean-like swells on the Mississippi River. Richter Scale estimates for the events ranged between 7.0 and 8.0. The 1811-1812 earthquakes also included hundreds of aftershocks, some with magnitudes estimated to be between 6.5 and 7.6 on the Richter Scale.

The Richter Scale itself is logarithmic in character, with each additional number representing a ten-fold increase in energy. The following description of an alternative scale, the Modified Mercalli Scale, provides detail about approximately what impacts are felt at each level of earthquake intensity.

The New Madrid Seismic Zone is significant because scientists predict a substantial probability that a catastrophic earthquake will occur within the zone sometime during the next few decades. Michigan may be somewhat affected by such an earthquake, but probably only to a limited extent (within its southwestern counties) in terms of direct effects. A repeat of the 1811-1812 earthquakes is unlikely in the near future, but is a serious medium-term risk. If it occurs, it could result in unprecedented damage, disruptions, and casualties for a U.S earthquake event. The immediate and long-term relief and recovery efforts could place a significant, prolonged burden on regional and national economies.

The map on the next page shows the worst anticipated impact upon Michigan from a major New Madrid earthquake event. The level of impact is described in terms of numeric categories along the following scale:

The Modified Mercalli Scale of Seismic Intensity

I: Not felt by people.
II: People at rest or in tall buildings may feel movement.
III: Many indoors feel movement; hanging objects swing; like the vibrations from a light truck passing by.
IV: Most persons indoors feel movement, and a few persons outdoors; like the vibrations from a heavy truck passing by.
V: Almost everyone feels movement; dishes break, and small unstable objects move; liquids may spill.
VI: Everyone feels movement; many persons run outdoors; walking is difficult; breakables fall and break; plaster may crack.
[NOTE: VI is the worst level of severity known to potentially affect Michigan.]
VII: Cars shake; chimneys, tiles, and plaster may fall from buildings; slight damage to well-built buildings; considerable damage to poorly built structures.
VIII: Difficulty steering cars; tall structures and chimneys may fall.
IX: Well-built buildings may suffer considerable damage; houses can move off their foundations; underground pipes break.
X: Most buildings and foundations are destroyed.
XI: Most buildings collapse.
XII: Almost everything in the area is destroyed.

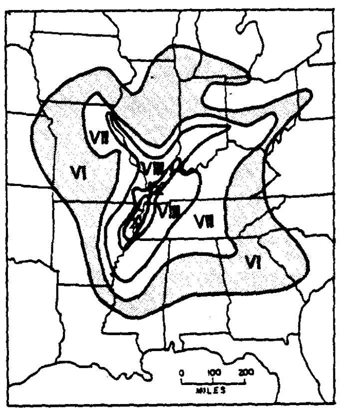
It can be seen in the map that most of Michigan is not located in an area subject to major earthquake activity. Although there are faults in the bedrock of Michigan, they are now considered relatively stable. The largest fault identified on some maps is an historic one, the Keweenaw Fault, which settled about a billion years ago and hasn't been active since that time. However, some faults or suspected faults require additional study, including an area in the southwestern Lower Peninsula. According to the U.S. Geological Survey, although Michigan is in an area in which there is a relatively low probability of earthquake occurrences, the area may be affected by distant earthquakes that occur in the New Madrid Seismic Zone and upstate New York. The New Madrid Seismic Zone poses the most significant threat, unless some other seismic event causes the subsidence of abandoned mine lands within populated areas of the Upper Peninsula. Based on scientific studies, portions of southern Michigan could be expected to receive minor damage were such an earthquake to occur (see the map at the end of this chapter).

The greatest impact on the state might come from damage to natural gas and petroleum pipelines. If a major earthquake occurs in the winter, many areas of the state could be severely impacted by fuel shortages. Damage would probably be negligible in well-designed and well-constructed buildings. However, poorly designed and constructed buildings could suffer considerable damage under the right circumstances.

In recent years, various reports have associated hydraulic fracturing ("fracking") resource extraction methods with increased seismic activity. This has been considered for this analysis, and the evidence so far seems to suggest that even within the states that have the heaviest levels of this activity, the resulting disturbances have all been small in scale, termed "microseismic" events. Therefore, there is currently no expectation that Michigan's risk of a damaging earthquake would be increased by hydraulic fracturing techniques.

Earthquake Threat in Michigan

Source: U.S. Geological Survey



Regional map of maximum intensities that would result from a magnitude Ms=7.6, maximum intensity earthquake anywhere along the New Madrid Seismic Zone.

The map above shows an approximate area where the worst damage (Intensity VI) might result from a major New Madrid earthquake event. North of the shaded region could experience Intensity V effects. If another line is drawn, parallel to that demarcating the northern limit of the Intensity VI area, but shifted northward to include the "Thumb area" of Michigan, then that would approximate the area with Intensity V potential effects from the worst New Madrid earthquake event. Most of the rest of the state would experience a maximum of Intensity IV effects from such an event. Notice in the descriptions on the previous page that these intensity levels may be felt by (and cause alarm in) many persons, but rarely results in much physical damage or injury.

Earthquake Risk Calculation

Although earthquakes are generally not considered a major hazard in Michigan, other states have had so many problems with this hazard that very detailed techniques have been developed to estimate earthquake risks. Each area of the country has been assessed by geologists (according to types of bedrock, fault line proximity, and other factors) and sorted into general zones of earthquake risk. (For a national map showing this, see the web site at http://earthquake.usgs.gov/research/hazmaps/.) These zones are expressed in terms of a probability that significant ground movements will be felt. For example, there may be a 10% chance of an area experiencing significant ground movement within a 50-year period, (which is similar to the "500-year" floodplain, since the annual probability of such an event calculates as roughly .0021). Another component of risk calculation would be to estimate the amount of damage that is likely when such an event occurs. Official measures use the concept of Peak Ground Acceleration (PGA, which is also abbreviated as %g). The key task is to translate the severity of (PGA) ground motion into estimates of structural damages and other economic costs. FEMA has developed a computer application (HAZUS) to give estimates of these earthquake effects.

Michigan has a comparatively low risk of experiencing damaging ground movements. Because of this low risk, however, many designers and developers did not take into consideration the possibility that an earthquake *might* occur. Some of Michigan's communities may actually be quite vulnerable to earthquake effects—especially Michigan's underground utilities—in cases where developed areas were not designed to withstand <u>any</u> ground movements.

Urban areas and active mine land or quarry areas may experience seismic effects as a result of blasting activities, subsidence, structural collapses, vibrations from trains and trucks, or explosions (such as from industrial accidents or terrorist activity). Even the sonic boom of a bursting meteor reportedly registered as a 2.0 on the Richter scale, near New Haven (St. Clair County), but such minor levels of seismicity are not included in this chapter's earthquake history (a minimum Richter level of 2.5 qualifying it here as a minor event). Still, a meteor blast such as that which had occurred at Chelyabinsk, Russia was reported to have registered as a 4.2 on the Richter scale. It is therefore worth considering a strengthening of infrastructure as well as interior design enhancements to resist both natural and other types of seismic impacts, vibrations, and stresses that may occur from either natural or technological hazards (such as an industrial explosion or train derailment). The main concern at this time is the stability of structures that may already be prone to spontaneous collapse, such as the abandoned mine lands that underlie some populated areas, especially in the Western Upper Peninsula.

Impact on the Public, Property, Facilities, and Infrastructure

Earthquakes have the potential to cause impacts on an area's infrastructure and energy if a significant event occurs. Impacts could include higher prices for energy and supplies, and the potential for limited supplies of needed goods and resources. A major event, such as a large-scale temblor in the New Madrid Zone, may constitute a National Emergency event (on the scale of Hurricane Katrina), in which there is a need for mutual aid to be provided to states which were strongly affected, and the intake of evacuees from those states. There is a moderate potential for limited property damage to occur in areas of southern Michigan that are more prone to experiencing seismic activity, and these damages could be inconvenient for homeowners and businesses, facilities, and infrastructure, but are not expected to be severely interrupted unless there are cases of under-engineered infrastructure that lacks earthquake resilience. It is not known to what extent this might be the case throughout Michigan, since earthquakes are not normally considered significant within the state.

Impact on the Economic Condition of the State

The most serious risk probably stems from a situation in which a major out-of-state earthquake causes an interruption in Michigan's energy supply. A sustained interruption, or even just a sharp rise in prices, could cause substantial slowing in productivity throughout several key economic sectors. Ideally, any such event would merely be temporary, and substitute energy sources might then be obtained from elsewhere, even if the current supply lines are severely damaged. Otherwise, economic impacts are likely to be very limited, and probably not particularly noticeable to ordinary residents.

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

Response operations have the potential to include search and rescue activities, which involve special risks and requirements for training and equipment, if an event does involve some sort of structural collapse or severe subsidence. Earthquake-related infrastructure failures or road subsidence may inhibit efficient and safe response to the incident, and may interfere with the access and use of resources needed for normal and emergency response activities. A hypothetical energy shortage or disruption (most likely from the impact of an out-of-state event) might potentially interfere either with the ability of some types of operations and services, or with the difficulties in budgeting sustained operations after the cost of fuel or other necessities has gone up sharply as a result of some disaster-caused shortage. For the most part, however, Michigan's normal earthquake events are not expected to cause these types of difficulties, unless an unprecedented event involves serious subsidence in the Western Upper Peninsula, or the breakage of some un-resilient pipeline or critical infrastructure component in the states south-southwest, more vulnerable regions.

Impact on the Environment
A significant earthquake has the potential to cause problems for the environment, both directly and indirectly. Ground movement may disrupt wildlife habitats and change an area's landscape. Secondary environmental impacts caused by a significant event may involve a hazardous materials release into the ground, air, or water from damaged buildings and infrastructure. Fortunately, it is unlikely that an earthquake, even a significant-magnitude New Madrid event, would cause great environmental impacts in Michigan. However, if there is a vulnerable, un-resilient component of a pipeline (for example) which then breaks and releases oil or some other contaminating substance, then it is possible that a major environmental incident could arise from even a moderate earthquake. Such a possibility probably exists, but the actual vulnerabilities or resilience of the state's critical infrastructure are not currently known.

Impact on Public Confidence in State Governance
The public may perceive earthquake effects in terms of a governmental failure to plan for and maintain appropriate standards for infrastructure durability and hardening. Some questions may also be raised about whether sufficient geological research had been conducted in the area, and about whether there was a successful means of providing advance warning that the area might experience an earthquake. If there are substantial vulnerabilities in infrastructure, or in a former mining area, which leads to a major disaster, then residents would understandably question whether the state could have been more proactive in investigating and mitigating such risks.

Earthquakes Affecting Michigan
The following table presents a list of earthquakes that have been felt in Michigan. The most severe confirmed earthquake event centered in Michigan was the 4.7 magnitude event of 1947, which caused some damage to (mainly residential) structures in the southwest region of the Lower Peninsula.

Tectonic Earthquakes Occurring or Felt in Michigan

Date	Origin	Magnitude
4-20-1793*	Porcupine Mt, MI	N/A
12-16-1811 (3 events)	New Madrid, MO	7.9, N/A., N/A
1-22-1812	New Madrid, MO	N/A
1-23-1812	New Madrid, MO	N/A
1-25-1812	New Madrid, MO	7.0
2-3-1812	New Madrid, MO	N/A
2-7-1812	New Madrid, MO	7.5
2-8-1812 (4 events)	New Madrid, MO	N/A
10-20-1870	La Malbaie, QUE	N/A
8-17-1877*	Greenfield, MI	3.2
9-19-1884	Lima, OH	4.8
9-1-1886	Charleston, SC	7.7
10-31-1895	Charleston, MO	6.7
5-26-1909	Aurora, IL	5.1
3-1-1925	La Malbaie, QUE	7.0
8-12-1929	Attica, NY	5.2
11-1-1935	Timiskaming, QUE	6.2
3-2-1937	Anna, OH	5.0
3-9-1937	Anna, OH	5.4
2-12-1938*	Porter, IN	4.0
3-13-1938*	Gibraltar, MI	3.8
3-14-1938*	Gibraltar, MI	N/A
3-9-1943	Lake Erie, OH	4.5
9-5-1944	Massena, NY	5.8
8-10-1947	Coldwater, MI	4.7
11-9-1968	El Dorado, IL	5.5
9-15-1972	Rock Falls, IL	4.5
4-3-1974	Lancaster, IL	4.7
2-2-1976	Pt. Pelee, ON	3.4
7-27-1980	Sharpsburg, KY	5.1
8-20-1980	Harrow, ON	3.2
11-29-1982	Scotts, MI	2.5
10-7-1983	Blue Mtn. Lake, NY	5.1
1-31-1986	Perry, OH	5.0
7-12-1986	St. Mary's, OH	4.6
6-10-1987	Lawrenceville, IL	5.2
11-25-1988	Saguenay, QUE	5.9
9-2-1994	Central Michigan	3.4
9-25-1998	Sharon, PA	5.2
10-23-2001*	Prairie Lake, MI	2.9
4-18-2008 (2 events)	West Salem, IL	5.4, 4.8
2-10-2010	Elgin, IL	3.8
6-23-2010	Val-Des-Bois, QUE	5.0
5-2-2015	Scotts, MI	4.2
6-30-2015	Burlington, MI	3.3
4-19-2018	Amherstburg, ONT	3.4

N/A means that the magnitude information was not available.
* May not have been a natural earthquake. Explosive blasting, mine collapse or other subsidence, and large meteorite impacts can all cause tremors to be felt that may give persons the impression that an earthquake has occurred.
Source: Michigan State University Earthquake Information Center / East Lansing Seismic Station, USGS Earthquake Catalog
https://earthquake.usgs.gov/earthquakes/search/

Historical earthquake occurrences appeared to have an element of a cyclical nature about them, with some decades containing numerous events, surrounded by decades with only a few events, and followed by periods with nearly no occurrences at all. Over time it may be that (probably due to increases in population and development) the number of occurrences gradually increases within this cycle, although this is uncertain. (The pattern is not extremely clear and long, and may just happen to be a statistical artifact.) The potential pattern is illustrated through the listing of natural tectonic earthquake events by decade, with arrows pointing to small peaks of earthquake activity approximately every 50 years. (This is shown on the next page.)

This hypothesis that there may be a kind of cyclic trend is based purely upon an inspection of the historical data. A recent text, Michigan Geography and Geology (editor in chief, Randall Schaetzl), includes a chapter on earthquakes and states that "about once every 50 years, a magnitude 3-4 event occurs within the state, south of a line between Grand Rapids and Pontiac." Although the event information (listed above) had fit pretty well into this pattern, the most recently updated information from the same source has not quite fit perfectly into the proposed pattern, for instead of the earthquake activity dropping to zero after a clear peak during the 1980s, it has instead fallen into a pattern of about two events per decade. Thus, there seem to be more earthquakes being felt recently than might have been expected, according to the previous patterns. It is possible that, due to improvements in detection, this level of disturbance might be comparable to the periods that would have been marked with zeroes in the past, and that the next occurrence of a peak (in the 2030s?) may therefore involve a record number of events, if there is indeed a gradual trend toward an increased number of disturbances.

1790s:	0	
1800s:	0	
1810s:	12	←These were all New Madrid events and aftershocks, and may not fit into a cyclic trend for Michigan
1820s:	0	
1830s:	0	
1840s:	0	
1850s:	0	
1860s:	0	
1870s:	1	
1880s:	2	←Possible peak in a cyclic trend
1890s:	1	
1900s:	1	
1910s:	0	
1920s:	2	
1930s:	3	←Possible peak in a cyclic trend
1940s:	3	
1950s:	0	
1960s:	1	
1970s:	3	
1980s:	8	←Possible peak in a cyclic trend
1990s:	2	
2000s:	3	
2010s:	5	←Recent trend might not quite match the proposed 50-year cycle unless it is shaped by improved detection programs

Programs and Initiatives

The Federal government has several programs and initiatives in place to help reduce the earthquake threat, two of which impact Michigan. The most recent, and perhaps most prominent, is the development of the National Response Framework (NRF) to coordinate federal assistance to a catastrophic earthquake or other similar disaster. Coordinated through the federal Department of Homeland Security (DHS), the NRF outlines the responsibilities of all federal agencies with a role in disaster response and/or recovery. Should a catastrophic earthquake ever impact Michigan, federal response and recovery assistance would be coordinated under the provisions set forth in the NRF.

Executive Order 12699: Seismic Safety

In January 1990, Executive Order (EO) 12699, Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction, was signed into law. This EO requires that appropriate seismic design and construction standards and practices be adopted for any new construction or replacement of a federal building or federally regulated building receiving federal assistance. The purpose of this EO is to reduce risks from failure of federal buildings during or after an earthquake.

USGS Earthquake Hazards Program and Earthquake Catalog

The U.S. Geological Survey maintains a database of earthquake events, and also provides numerous types of analytic information and products. Their web site includes a custom-searchable database, and provides many forms of statistics and maps that can be used to assess an area's risks. https://earthquake.usgs.gov/earthquakes/

Hazard Mitigation Alternatives for the Earthquake Hazard

The biggest Michigan threats would be to pipelines, buildings that are poorly designed and constructed, and shelving, furniture, mirrors, gas cylinders, etc. within structures that could fall and cause injury or personal property damage.

- Adopt and enforce appropriate building codes.
- Use of safe interior designs and furniture arrangements.
- Obtain insurance.
- "Harden" critical infrastructure systems to meet seismic design standards for "lifelines."

Assessment in Local Hazard Mitigation Plans

Earthquakes were identified as one of the most significant hazards in the local hazard mitigation plans for Calhoun, Clare, and Dickinson counties (an increase from 2014).

Subsidence

The lowering or collapse of a land surface, caused by natural or human-induced activities that erode or remove subsurface support.

Hazard Description

Subsidence (from the root word, subside) is the lowering or collapse of a land surface, due to the loss of subsurface support. It can be caused by a variety of natural or human-induced activities. Natural subsidence occurs when the ground collapses into underground cavities produced by the dissolution of limestone or other soluble materials by groundwater. Human-induced subsidence is caused principally by groundwater withdrawal, drainage of organic soils, and underground mining. In the United States, these activities have caused more than 17,000 square miles of surface subsidence in 45 states, with groundwater withdrawal (10,000 square miles of subsidence) being the primary culprit (according to a 1999 study). In addition, approximately 18% of the United States land surface is underlain by cavernous limestone, gypsum, salt, or marble, making the surface of these areas susceptible to collapse into sinkholes. Collapses that result from groundwater withdrawal can result in permanent reduction in an aquifer's total storage capacity.

Note: The topics of landslide and mudslide have primarily been associated with heavy rainfall and storm events, and are therefore covered within the hydrological section of this report

Hazard Analysis

Michigan contains extensive aquifer systems that had been identified by researchers as presenting a risk of groundwater-based subsidence. It also has many abandoned mines that are vulnerable to collapse, some of which are located under cities with notable population densities potentially at risk. Michigan also has some areas of organic soils that had been identified as presenting a possible subsidence risk. Karst geologic features are also present in several substantial regions of the state. Nationally, the average annual damage from all types of subsidence has conservatively been estimated to be at least $125 million. The National Research Council estimate of annual damage from various types of subsidence is outlined in the table below:

Land Subsidence: Estimated Annual National Damage

Type of Subsidence	Annual Damage ($)
Drainage of organic soils	40,000,000
Underground fluid withdrawal	35,000,000
Underground mining	30,000,000
Natural compaction	10,000,000
Sinkholes	10,000,000
Hydrocompaction (collapsible soils)	N/A
TOTAL:	**$125,000,000**

Source: National Research Council; Multi-Hazard Identification and Risk Assessment, Federal Emergency Management Agency

Although specific locational risk assessments have not yet been completed to try to analyze in detail which known mines might currently pose a subsidence risk to the developed areas or infrastructure located above them, more general spatial assessments have been performed for multiple counties. These assessments allow an awareness of the approximate locations of known mines of various types, and thus the identification of specific political jurisdictions that have had known mining activities within them. This can facilitate follow-up activities between agencies during the development and maintenance of local hazard mitigation plans in those areas. More information on this topic is provided after the following overview of Michigan's historical mining activities.

<u>Mine Subsidence</u>

In Michigan, the primary subsidence risk is estimated to be from abandoned underground mines. Although other states have had more severe problems with this hazard, many areas in Michigan are potentially vulnerable to mine subsidence hazards. Mine subsidence can occur with little or no warning and can result in very costly damage, potentially even causing many casualties if it affects a densely populated area. Mine subsidence occurs when the ground surface collapses into underground mined areas. In addition, the collapse of improperly stabilized mine openings is also a form of subsidence. Mine subsidence can cause damage to buildings, disrupt underground utilities, and threaten human lives. In extreme cases, mine subsidence can literally swallow whole buildings or sections of ground into sinkholes, endangering anyone who may be present at that site. Mine subsidence may take years to manifest. Collapses have occurred many decades after mines were abandoned.

Michigan's rich mining heritage has played a significant role in the state's development into a world economic power. Due to its diverse geology, Michigan has a wide variety of mineral resources, most notable of which are copper ore, iron ore, coal, sand, gravel, gypsum, salt, oil and gas. It is not surprising then that underground mining has occurred on a significant scale throughout Michigan's history. The principal types of underground mining that occurs, or has occurred in Michigan, include coal mining, metallic mineral mining, salt mining, gypsum mining, and solution mining.

Copper mining first put Michigan on the map as a major mining area. Although native copper ore occurs in other parts of the world, at one time the quantity of Michigan's quality native ore was unsurpassed. From the mid to late 1800s, Michigan's Keweenaw Peninsula mines produced more native copper ore than any other mining area in North America. Near White Pine in Ontonagon County, the target strata in the White Pine mining operations were on an anticline that was mined both at depths as shallow as 100 feet and as deep as 2900 feet. Over-mining of pillars in shallow parts of the mine caused collapse and subsidence at the surface, on mine property, during the 1980s. The "Copper County" area generally crosses Gogebic, Ontonagon, Houghton, and Keweenaw Counties.

Based upon MDNR maps of underground mine locations, the following local jurisdictions have been identified as having a noteworthy overlap between the location of known copper mines and properties and infrastructure that are currently in use within or near such areas:
Houghton County, including some areas near Highways U.S. 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 U.S. 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, Rockland Township (including some areas near Highway U.S. 45).
Additional copper mine locations may exist within these and other counties, but have not yet been judged to be of sufficient density, size, or proximity to warrant additional investigation.

The Western Upper Peninsula has had significant **iron ore mining** operations since the mid-1800s. The iron producing areas are referred to as ranges, since the iron deposits generally occur on the slopes or at the base of remnants of ancient mountain ranges. Michigan has three ranges: 1) Gogebic Range, which extends from Gogebic County into Wisconsin; 2) Marquette Range, in Marquette County; and 3) Menominee Range, in Dickinson and Iron Counties. Most near-surface iron deposits in these three ranges have been exhausted, so underground mining became the primary extraction technique. Nearly two billion tons of iron ore have been extracted from these areas. Although economic forces led to the closure of many of the underground iron mining operations, a couple of open-pit mines still operate in the region. The "Iron Range" area generally includes the counties of Baraga, Dickinson, Gogebic, Iron, Marquette, and Menominee.

Based upon MDNR maps of underground mine locations, the following local jurisdictions have been identified as having a noteworthy overlap between the location of known iron mines and 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 U.S. 2), Felch Township (including some areas near Highway M-69), Iron Mountain, Norway, Norway Township (including some areas near Highway U.S. 2), and Waucedah Township (including some areas near Highway U.S. 2).
Gogebic County: Bessemer, Bessemer Township, Ironwood, Wakefield (including some areas near Highway M-28), Wakefield Township (including some areas near Highway U.S. 2).

Iron County: Caspian, Crystal Falls, Crystal Falls Township (including some areas near Highway U.S. 2 and U.S. 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 U.S. 41/M-28), Ishpeming (including some areas near Highway U.S. 41/M-28 and Business Route 28), Ishpeming Township, Michigamme Township (including some areas near Highways U.S. 41/M-28), Negaunee (including some areas near Highway U.S. 41/M-28, and Business Route 28), Republic Township, Richmond Township, and Tilden Township.
Additional iron mine locations may exist within these and other counties, but have not yet been judged to be of sufficient density, size, or proximity to warrant additional investigation. An MDNR map for Menominee County was not yet available online, for reference within this analysis.

Michigan also has one of the world's largest underground **salt** accumulations. The thickest salt beds lie under most of the Lower Peninsula. These formations are, in some places, over 3,000 feet thick and composed of layers of salt and other minerals. Michigan ranked first or second in national salt production from 1880 to the late 1920s. The bulk of the salt production was from natural brines pumped from six salt formations. Salt was also produced from artificial brines that were derived by injecting freshwater into salt formations and retrieving the resulting brines (called solution mining). The old Detroit salt mine produced rock salt using the "room and pillar" method until 1983. (The room and pillar method involves creating large underground expanses [rooms] in which to mine, supported by pillars [natural or artificial structural members] that support the ceilings of these rooms.) The Detroit salt mine was approximately 1,100 feet below ground, and encompassed approximately 1,100 acres of subsurface land. The room and pillar method is being used only in the single salt mine that is still operating in Michigan, by the Detroit Salt Company, which has an excellent safety record. Salt is also being produced from brines extracted at various locations within the state. An MDNR map of underground mines in Wayne County currently shows just one location in the City of Melvindale. Unlike various mines in rural areas, no information has suggested that the current extent of the salt mine locations in that area are either unknown or in questionable condition, so it hasn't been considered higher priority than the abandoned and unmapped mines that exist in various other parts of the state.

Gypsum has been mined in Michigan since 1841. In the Grand Rapids area, gypsum is mined by the "room and pillar" method. Open pit mining is used in the Alabaster region (Iosco County). In both of these areas, gypsum beds directly underlie thin layers of glacial drift. Closed topographic lows observed in both areas are believed to be due to groundwater solution of the gypsum and subsequent collapse of the overlying material. An MDNR map of underground mine locations within Kent County suggests that these mines may not be close enough to buildings and infrastructure to pose a known risk.

Michigan also once supported a thriving **coal mining** industry. Records indicate that over 165 different coal mines operated in Michigan's coal-bearing region, which includes 31 counties in the south-central portion of the Lower Peninsula. Over 100 of the 165 known coal mines in the state were located in the Saginaw Bay area. (See the map two pages following for an outline of Michigan's Coal Basin.) Coal was first discovered in Michigan in 1835 in Jackson County. From that discovery, several small underground and surface coal mines were opened in that area of the state. In 1861, coal was discovered near Bay City, and in 1897 commercial coal mining began in Bay County. That led to the establishment of numerous additional mines in Saginaw, Tuscola and Genesee counties, which tended to be larger, deeper and more extensive mines. That was the start of Michigan's coal mining industry.

The state's underground coal mines were an average of 110 feet deep, and were worked by the "room and pillar" method. Michigan had continuous coal mining from 1897 to 1952, when the last underground coal mine near St. Charles, Saginaw County, closed. From 1860 (the year mine records were first kept) until 1975 (the year the last surface coal mine closed), the 165 commercial coal mines produced a total output of over 46 million tons of coal. The maximum coal output was achieved in 1907, when Michigan's 37 operating coal mines produced two million tons per year - enough to supply 16% of Michigan's then total demand for coal.

Additional mines are noted on MDNR maps, such as those involving ores such as silver and gold, graphite, multiple types, or unknown mine types. These various mines all appear to be located away from roads, structures, and areas likely to have underground infrastructure, with the exception of one community: Marquette County's Ishpeming Township, where a roadway appears to be close to an old mine location, and may warrant additional investigation.

The legacy of underground mining can be felt in numerous locations across the state. Many of the underground mining areas, whether active or abandoned, are vulnerable to subsidence in some form. The map that follows indicates the areas in the state that are potentially vulnerable to mine subsidence. Unfortunately, records of abandoned mines are often sketchy and sometimes non-existent. Therefore, it is often difficult to determine exactly where all mines were located. Many areas of Michigan may have developed over abandoned mines and may not even be aware of it. Oftentimes, the only way a community, business owner, or resident becomes aware of a potential hazard is when subsidence actually occurs and damage or destruction results.

Water-Related Subsidence

Compaction of soils in some aquifer systems can accompany excessive ground-water pumping and cause subsidence. Excessive pumping of such aquifer systems has resulted in permanent subsidence and related ground failures. In some systems, when large amounts of water are pumped, the subsoil compacts, thus reducing in size and number the open pore spaces in the soil that previously held water. This can result in a permanent reduction in the total storage capacity of the aquifer system. More than 80% of the identified subsidence in the United States is a consequence of human impact on subsurface water. Three distinct processes account for most of the water-related subsidence: compaction of aquifer systems, drainage and subsequent oxidation of organic soils, and dissolution and collapse of susceptible rocks.

An increasing number of urban subsidence events have resulted from infrastructure failures, such as water main breaks, which cause road surfaces to collapse. Construction-related incidents have also occurred in Michigan, as described in the section on Significant Subsidence Incidents.

Groundwater in the pore spaces of an aquifer supports some of the weight of the overlying materials. When groundwater is depressurized or even removed from aquifers, where the materials are very compressible and pore pressures can be high, compaction may occur. This subsidence may be partially recoverable if pressures rebound, but much of it is not. Thus, the aquifer is permanently reduced in capacity, and the surface of the ground may also subside. The picture on the next page shows the unconsolidated aquifer systems in Michigan. (Note: The role of groundwater in supporting some overlying materials should not be taken to imply that the flooding of abandoned mines is helpful to prevent subsidence. According to USGS feedback, the hydraulic forces of water within flooded abandoned mines are a source of additional risk, rather than serving a useful function.)

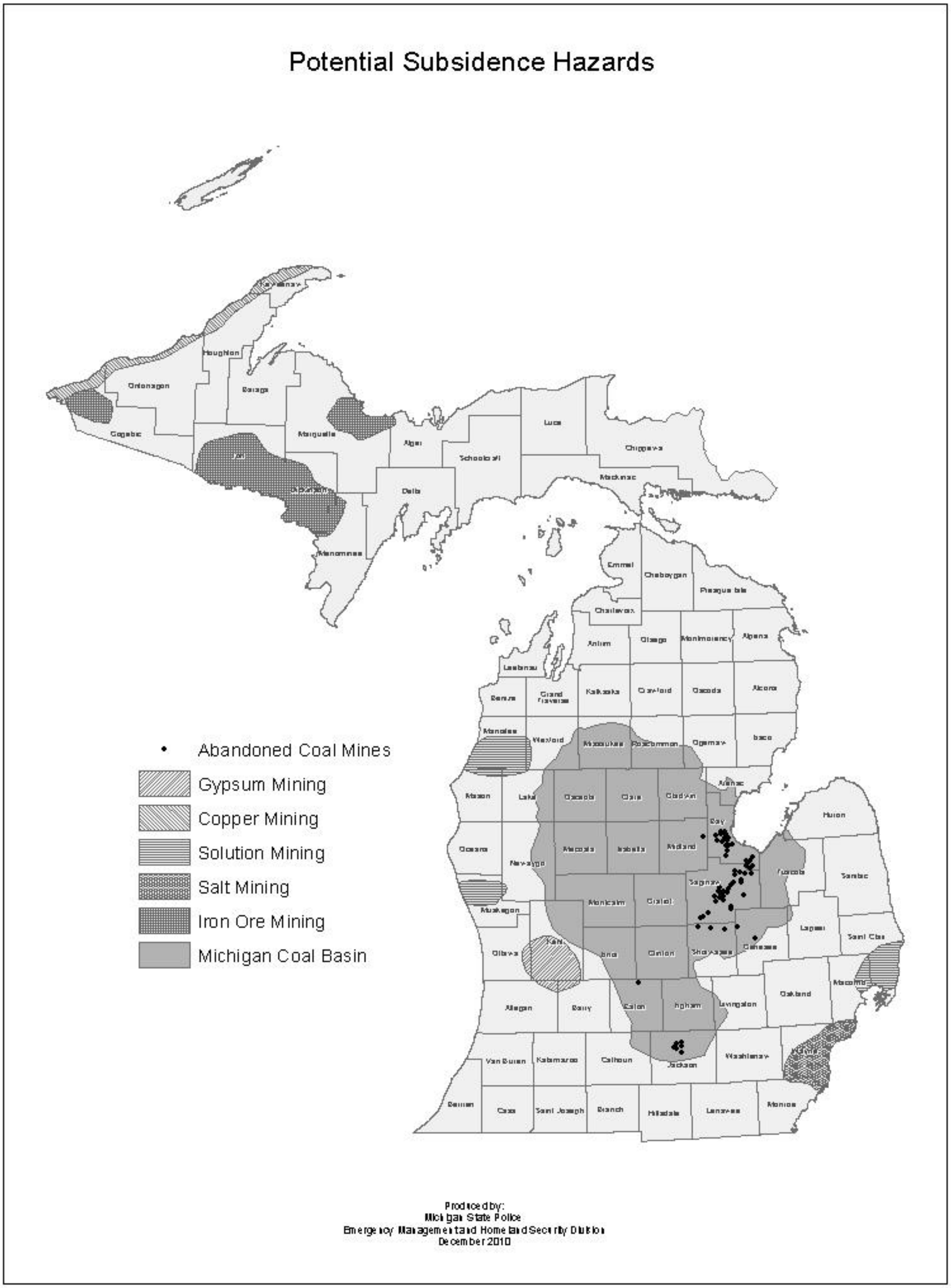
Land subsidence may also occur when **organic soils** (rich in organic carbon) are drained for agriculture or other purposes. The most important cause of this subsidence is microbial decomposition, which, under drained conditions, readily converts organic carbon to carbon-dioxide gas and water. Compaction, desiccation, erosion by wind and water, and prescribed or accidental burning can also be significant factors. The picture on a subsequent page shows the location of the organic soils in Michigan.

Collapsing cavities are commonly triggered by ground-water-level declines caused by pumping and by enhanced percolation of ground water. Collapse features tend to be associated with specific rock types, such as evaporites (salt, gypsum, and anhydrite) and carbonates (limestone and dolomite). These rocks are susceptible to dissolution in water and the formation of cavities. Salt and gypsum are much more soluble than limestone, the rock type most often associated with catastrophic sinkhole formation. Evaporite rocks underlie about 35 to 40% of the United States, though in many areas they are buried at great depths. Collapse sinkholes may develop over a period of hours and cause extensive damage. The small picture on the second page following shows the approximate location of the concentrated areas of evaporite and carbonate rocks in Michigan.

In the past, there has been pressure for the Great Lakes states to export bulk quantities of water to various locations in the United States. If these plans to withdraw large amounts of water from the Great Lakes ever took place, it may have a major effect on the level of the ground water tables in Michigan, which might make subsidence a more common occurrence. Currently, broken water pipes and the improper discharge of rainwater are the most common causes of water-related subsidence in Michigan. It most commonly occurs on sandy or silty ground when the water from the leak washes out the fine particles beneath the foundation, causing voids that result in collapse or subsidence.

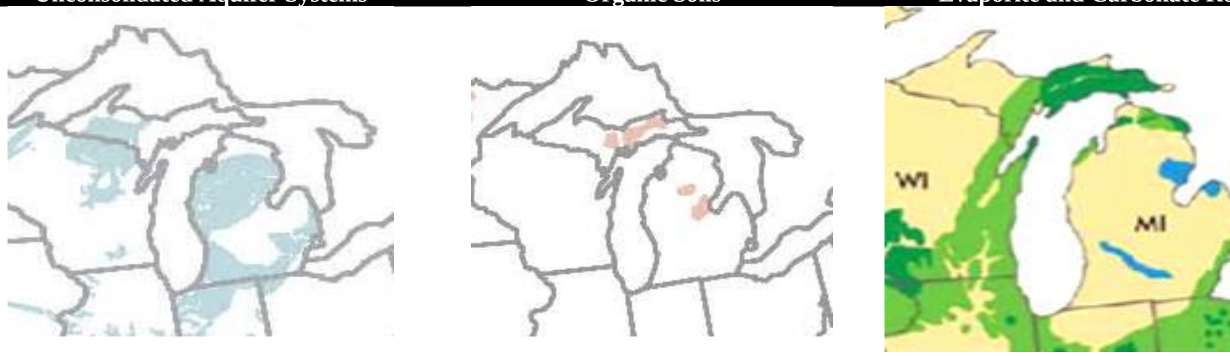
Mine-Related Subsidence Threats in Michigan

Source: Michigan Department of Environmental Quality, Office of Geological Survey



Water-Related Subsidence Threats in Michigan

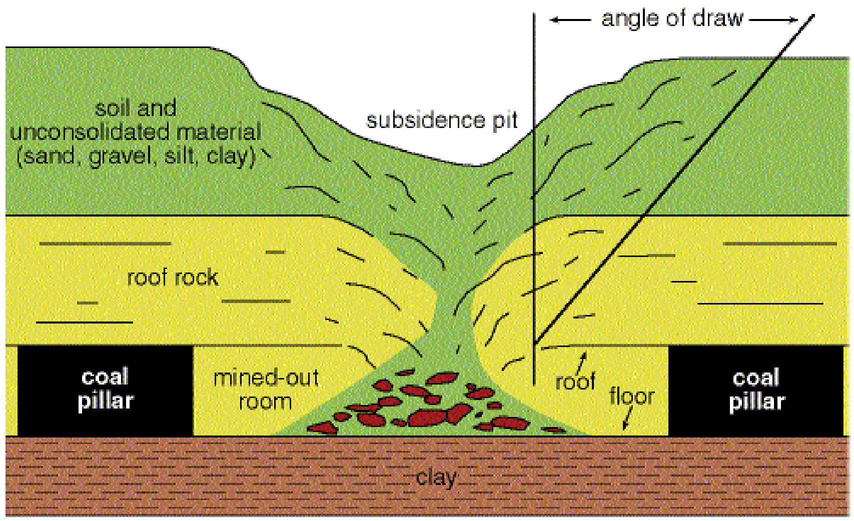
Unconsolidated Aquifer Systems	Organic Soils	Evaporite and Carbonate Rocks



Source*:* U.S. Geological Survey*, Ground Water and the Rural Homeowner, Pamphlet, 1982*

Overall, subsidence is not a very well-known hazard in most parts of Michigan, although it occurs with some regularity in older cities and areas with abandoned underground mines. The impacts of subsidence have usually been limited to individual sites and structures, but there is a potential in some sites for a disaster-level impact to suddenly arise without warning. Therefore, this new edition of the Michigan Hazard Analysis has markedly increased the seriousness and detail with which this hazard has been assessed. As noted previously, more detailed assessments are probably needed in numerous locations within the Central and Western Upper Peninsula.

Typical Mine Subsidence Cross Section



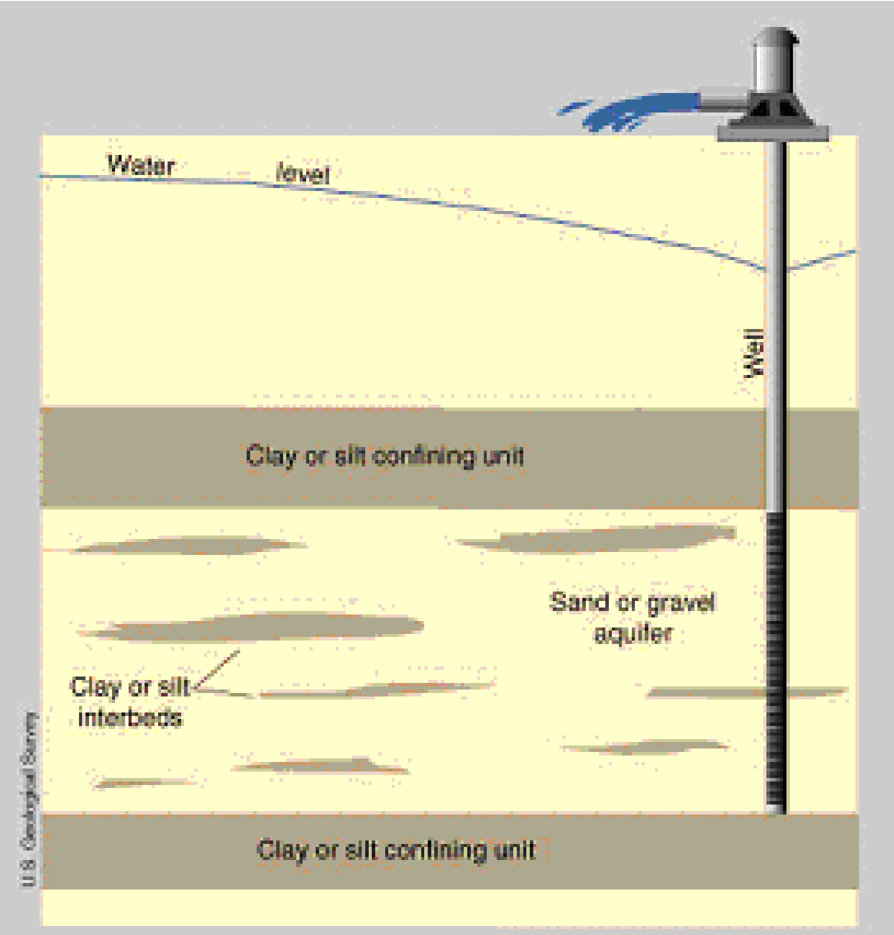
Diagrammatic cross section of typical subsidence resulting from mine-roof collapse. No scale implied.

Source: State of Ohio, Department of Natural Resources web page

Underground mining had fueled tremendous economic growth in many parts of the state, providing hundreds of thousands of jobs through direct mining or related industrial production activities. Mining helped put Michigan on the map as a world economic power, and even today it continues to be a major economic activity in some areas of the state. On the other hand, underground mining has also left a legacy of subsidence or threat of subsidence in some parts of Michigan. Old abandoned mines eventually begin to collapse under their own weight or human neglect, and oftentimes they swallow up whatever is built upon them. The pictures here show typical mine subsidence cross sections.

Typical Aquifer Subsidence Cross Section

Source: U.S. Geological Survey



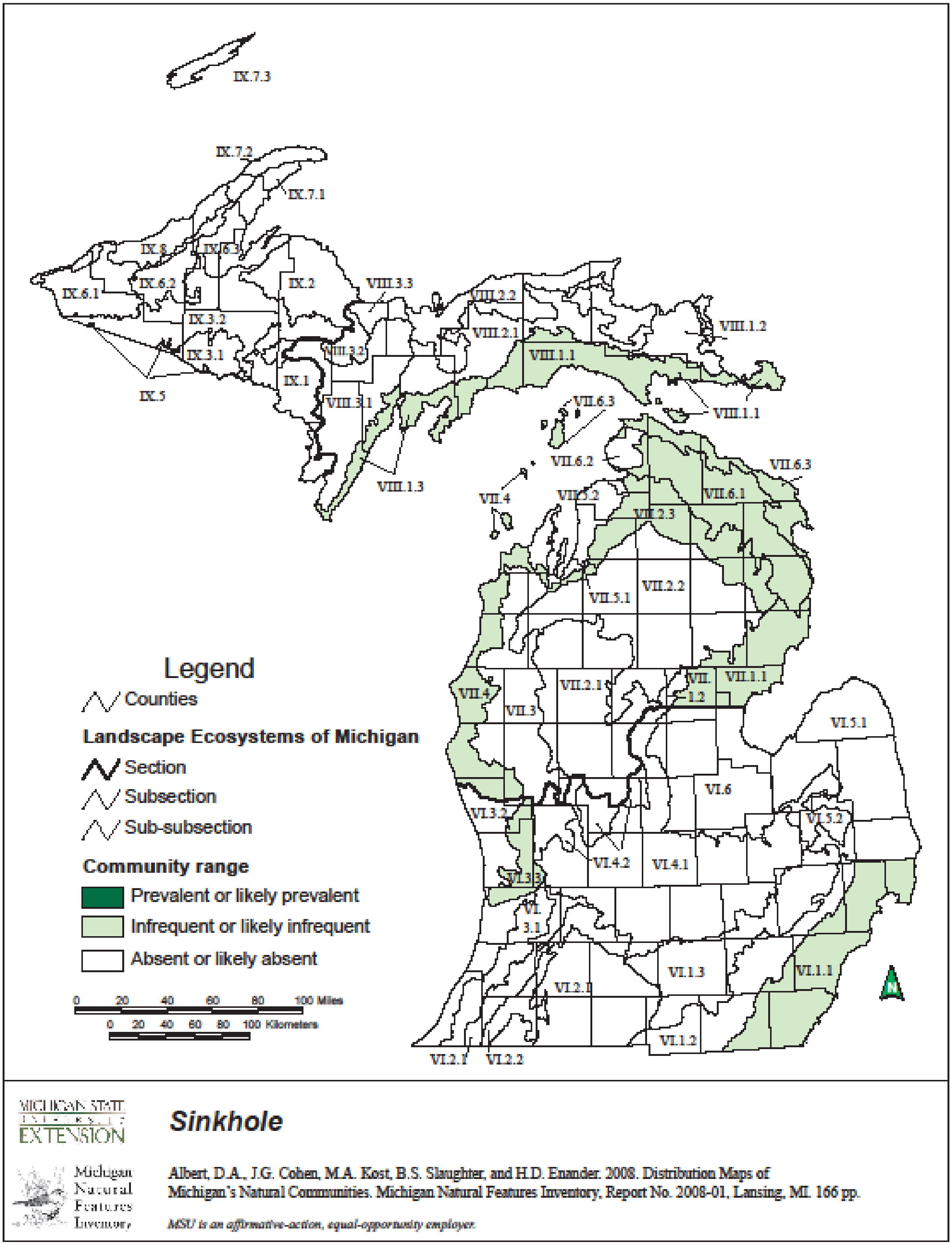
In some areas where ground-water pumping has caused subsidence, the subsidence has been stopped by switching from ground-water to surface-water supplies. If surface water is not available, then other means must be taken to reduce subsidence. Possible measures include reducing water use and determining locations for pumping and artificial recharge that will minimize subsidence. Optimization models, coupled with ground-water flow models, can be used to develop such strategies. The picture above shows a typical aquifer-related subsidence cross section.

Subsidence has often not received much attention from government agencies or the public. Other natural hazards, such as tornadoes, floods and severe storms receive much more attention because of their more frequent, widespread, and severe impacts. However, subsidence will continue to be a hazard that a large segment of Michigan's population continues to face. Major incidents that lead to disastrous damage levels have been nearly unknown in Michigan's latest century, but are possible, and smaller incidents have occurred in old mining areas. Overall, at least four moderate incidents per decade have been noted, of all types (urban or rural, mine-related or water-related).

Probably the most effective way to mitigate subsidence hazards is through careful investigation, followed by community education and awareness, and finally a coordinated stabilization effort to reclaim abandoned mine lands or prevent subsidence events caused by hydrological conditions and infrastructure failures. Local officials in subsidence-prone areas need to be aware of their community's potential vulnerability to subsidence, and that awareness needs to be communicated to the public. Communities that have experienced mineral and water mining activity in the past, or that have ongoing mining operations, should conduct a thorough investigation of potential subsidence sites as part of their community's hazard analysis process. Local records of mining activity might be the best available source of information on the potential extent of the problem. Local officials can use that information to make informed community development decisions, thus avoiding, to the extent possible, areas potentially vulnerable to subsidence.

Ideally, information about the locations and subsurface conditions of all mines in an area would be found, and testing or inspection could then determine their stability and safety. However, the information that does exist has no guarantee of being comprehensive, and since many mines exist on private property, the owners of that property often have an interest in not allowing any mine details to be publicized (lest the information cause trespassers to be attracted to the mines). MSP/EMHSD learned about valuable information that had been collected on this topic through an academic research process, but the information was not available to the general public. The information had been provided to the relevant counties as a part of their local hazard analysis process, and it was reported that the same type of information was also known to local Mine Inspectors. The best resource to consult for each local area is probably its Mine Inspector. Please refer to the list available at http://www.mg.mtu.edu/mining/mine_inspectors.htm.

Map of Michigan Sinkhole Risks



Source: MSU Extension website http://mnfi.anr.msu.edu/communities/community.cfm?id=10707

Impact on the Public, Property, Facilities, and Infrastructure

Although some incidents may cause private property damage and casualties, others may affect roadways or other public infrastructure, and thus cause a more general impact on the population of an area. Most past incidents have had limited effect upon the general public, but in time, some exception may arise. Roadways have now been identified that are in proximity to, if not completely overlaying, abandoned mine lands that therefore may be vulnerable to collapse, potentially injuring or killing persons traveling in vehicles or trapped within a collapse area. A recent rain event revealed that mudslides and structural collapse can occur as a result of rapid hydrological runoff within hilly areas of the state, and can cause fatal impacts. The number of houses and other buildings that may be at substantial risk has not yet been pinned down, but probably numbers over 100 on the basis of the identified mine locations mapped by MDNR. Infrastructure is likely to be affected just as surface roads are. The Gaastra incident in 2001 was an example of this (see the description later in this chapter). It is not yet clear what facilities may be at risk, but they probably include some that will impact the quality of life in some of Michigan's oldest communities (both small and large). Likely forms of infrastructure vulnerability include transportation, water supply, urban sewage, and underground pipelines for oil and gas. One of the most serious such events could have resulted from the 2016 incident in Fraser, which involved a major component of the water infrastructure within one of the most heavily and densely populated counties in Michigan, but fortunately was handled promptly and carefully in a way that limited its impacts to the broader metropolitan area.

Impact on the Economic Condition of the State

So far, the economic impacts have been moderate. Michigan may have been lucky up to now, in experiencing only a few incidents, most of which have occurred in less densely populated areas. Many costs have been borne locally, as in the case of the recent urban subsidence events within Detroit and Ann Arbor. Other communities, in smaller and more isolated locations, have seen serious local impacts, including cases in Iron Mountain (1999), Gaastra (2001), and Houghton (2017) requiring outside assistance to be provided. A worst-case incident might result in a major pipeline incident that causes large-scale environmental impacts and expensive response and recovery activities. Similarly, an unprecedented (but theoretically possible) level of mine land collapse might affect dozens of structures and close down one or two major highways in the Upper Peninsula, thus constituting a major disaster within the area. The further assessment and prevention of such an incident may require a considerable investment, to identify, prioritize, and mitigate the specific risks that may be identified. Uncertainty about the extent of risk from subsidence may cause collective dissatisfaction with the area in which the hazard is present (or perceived to be present), and (at an extreme) may lower property values and cause or exacerbate emigration from the area that is considered at-risk.

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

Special hazards are often present in old mines or ground subsidence areas, such as toxic gases and flooding, which may present a risk of further collapses or casualties during emergency response activities. Areas that involve deep spaces, into which personnel and equipment may fall, necessarily entail a more complicated and dangerous situation for responders. Toxic gases such as hydrogen sulfide are described within the oil and gas well chapter of the Michigan Hazard Analysis. A major subsidence event within an old central section of a city may involve critical facilities and social service agencies, and thus could cause some interruption in service delivery and continuity of operations, but fortunately this level of impact is an unlikely scenario, although additional research is needed to better estimate these vulnerabilities and to estimate their actual likelihood of occurrence. Such assessments could then be the basis for prioritizing the activities that may alleviate these risks, some of which might be difficult to afford and to fully fix in a short period of time after their detection.

Impact on the Environment

Environmental impacts stemming from subsidence are somewhat similar to those caused by an earthquake. In a severe event, or one that unluckily occurs in key location, an infrastructure component may be damaged and cause contaminated water, interrupted energy supplies, and could release pollutants or toxins into the air, soil, or waterways. The oil spill affecting the Kalamazoo River area in 2010 is an example of the possible impact that is possible.

Impact on Public Confidence in State Governance

The public may be prone to overestimate the amount of knowledge possessed by State government regarding areas and specific locations in which historic mines have existed. Subsidence events that involve damage to infrastructure or roadways may be attributed to disinterest or negligence, rather than to the actual lack of specific information about many of the risks. If a disaster strikes an area whose risks were not assessed quickly enough, distrust will result.

Significant Subsidence Incidents

May 13, 1912 – Mine Cave-In (Iron County)

Seven persons were killed in the Norrie Mine in Ironwood. The ceiling of the iron mine's 19th level gave way and caught 13 workers in its collapse. A rescue party immediately began working to remove debris. After about a day, the rescue efforts paid off and six of the workers were rescued. However, one of them died about a week later.

February 21, 1918 – Mine Cave-In (Iron County)

At the Amasa-Porter Mine at Crystal Falls, 17 persons died when a rush of water and sand flooded lower levels of the mine and caused a cave-in. A February 14 had gone through to the surface. After suspending underground operations until February 18 while pumps removed the water and bulkheads were inspected, iron-mining work resumed. Only one main hoisting shaft was available to access the mine, and hopes of rescue were dashed on February 25 when a second rush of water swept through the mine and drowned out its pump. The workers' bodies were not recovered until July 1919.

October 29, 1927 – Rockfall in Quincy Mine No. 2 (Houghton County)

Seven persons were killed in this Hancock-area copper mine as a result of rock falling in a shaft, entombing workers after an air blast wrecked part of the site. This event occurred deep under the surface, reportedly on level 41 of the mine at a depth of 4,300 feet. The mine had been in operation for 79 years without such an event, and the cause of the air blast was not understood.

May 3, 1940 – Road Collapse at Chapin Mine Pit (Iron Mountain, Dickinson County)

In the middle of the City of Iron Mountain (Dickinson County), a 150-foot-long section of the major highway through town (US 2) collapsed into a water-filled mine pit. The collapse occurred at about 2pm, and five vehicles parked nearby were buried in rubble. One car owner fell into the water while trying to save his car, and was assisted by bystanders. It was not clear at the time whether construction work on the highway had caused a weakening of support structures under the water, or whether the underlying mine had collapsed. According to the local newspaper report the following day, the pit had originally been dry but over years had eventually filled in with water about 90 feet deep. There was speculation that either a collapse within the mine had brought the road down, or that elements of highway construction work may have caused the roadway support structure to weaken and give way. The mine had reportedly ceased operations in 1932 and a powerful water-pump was moved out of the mine and donated to the county, allowing an accumulation of water within the inoperative mine areas. It was later realized that unequal hydraulic pressures on each side of the water-surrounded roadway support materials may have eventually caused the materials to weaken enough to give way and result in the sudden collapse of the roadway.

October 1984 - Jackson County

In October 1984, the abandoned Andrews Street Coal Mine in Jackson County partially collapsed, causing a detached garage, driveway and vehicle at a residence to collapse into a shallow sinkhole. A $12,000 emergency reclamation project was instituted in that subsidence incident. Note that maps for this county's mines were not found in the MDNR online archive.

October 1985 - Huron County

In October 1985, a subsidence incident occurred in Huron County that resulted in a sinkhole that swallowed up a portion of roadway. A $15,000 emergency reclamation project was instituted to mitigate the cause of the collapse.

May 1987 - Saginaw County

In May 1987, a subsidence incident in Saginaw County caused an attached garage and breezeway on a house to drop down several inches, damaging both structures. A $35,000 emergency reclamation project helped to mitigate the threat of future subsidence at that site.

June 1999 - Milan (Monroe County)

On June 29, 1999, northbound traffic on U.S. 23 at Milan was diverted for approximately 10 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. Although a definitive cause of the subsidence was not established, officials believe a leaking storm sewer may have contributed to the problem.

July 1999 - Iron Mountain (Dickinson County)

On July 27, 1999, an abandoned mineshaft in Iron Mountain (Dickinson County) 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. Officials were also concerned that further subsidence could have damaged nearby infrastructure, including a roadway. Because the cave-in posed a significant threat to public safety, a Governor's Emergency Declaration was granted to provide state assistance in securing the site and permanently capping the opening.

February 2000 – Detroit (Wayne County)

On February 9, 2000, a 15-foot sinkhole opened up on Seneca near Mack, on Detroit's east side. The sinkhole swallowed up a half-ton pickup truck. Fortunately, the truck's two occupants escaped serious injury. Officials believe a leaking underground pipe may have caused the subsidence.

August 2000 and April 2001 – Gaastra (Iron County)

On April 19, 2001, the City of Gaastra in Iron County sustained a cave-in of 3,360 cubic yards of soil at the abandoned Baltic Mine Pit in the city, just four feet from the City's main (and only) sewer line to the wastewater treatment plant. (When the sewer line was installed in 1984, there were 100 feet of ground between the line and the edge of the pit. From 1984 to 2001, the annual recession rate at the site was nearly six feet per year.) The April 2001 cave-in was the second major subsidence incident at that site, following on the heels of a similar cave-in that occurred in August 2000. Local and state officials feared that another subsidence incident at the site could cause the sewer line to break, resulting in significant public health, safety, and environmental concerns due to lack of sewer service, contamination of nearby water wells, and contamination of the Iron River. In addition, a major subsidence incident could also have caused a partial collapse of County Road 424 (which runs parallel to the sewer line), negatively impacting the area's residents and tourist-oriented businesses. To prevent further damage to the threatened sewer line, the City of Gaastra applied for a Hazard Mitigation Grant Program (HMGP) grant to relocate the line outside the subsidence area. Work on that project was successfully completed, including appropriate steps to stabilize the roadway shoulder and prevent further ground collapse.

March 2004 - Detroit (Wayne County)

On March 25, 2004, a sinkhole about 20 feet wide and 14 feet deep opened in the westbound lanes of Six Mile Road. It was determined that water main work done in the area in the previous six months had not been completed properly. Leaking water apparently washed away the soil underneath and created the sinkhole.

August 2004 - Sterling Heights (Macomb County)

On August 22, 2004, a sewer line break caused a section of 15 Mile Road in Sterling Heights to collapse, prompting residents in six homes to evacuate and the street to close for several weeks. After the break, two sinkholes formed and eventually merged, forming one hole 150 long and 45 feet wide. There were about 15 homes in the area that lost water service for several hours, and about 1,000 Detroit Edison customers lost power because utility poles were being removed for excavations to reach the sewer. About 7 million gallons of raw sewage were diverted daily from the collapsed sewer into the Mount Clemens sewage treatment plant, to prevent wastewater from entering basements or polluting county drains and streams. Repairs for this event reportedly cost $53 million, and had been preceded by two other breakdowns in that component of the system, starting in the 1970s. The event led to legal actions involving homeowners, the city, and the county. Some of these claims still hadn't been cleared up, as of 2017 .

May 20, 2010 – Detroit (Wayne County)

A sinkhole large enough to swallow a car appeared on May 20, 2010, and closed West Lafayette Street between Shelby and Griswald in downtown Detroit. The street began to crumble away after crews punctured a water line when working to demolish the historic Lafayette Building.

October 4, 2010 – Stephenson (Menominee County)

A 600-foot long crevice suddenly opened up in the ground surface—in some places only a foot wide and a few inches deep, but in other places more than 2 feet wide and 5 feet deep. Fortunately, this took place in an undeveloped area on private property, where no injuries were caused and no damage to buildings or physical infrastructure was reported. Vibrations were felt by nearly residents, who were uncertain whether they were feeling the effects of explosive blasting or some other force. Although this particular event resulted in no harm, the executive director of the Delta Conservation District (in Gladstone) was quoted in newspaper reports as stating that this type of phenomenon is not unusual in the Upper Peninsula. He stated that the cause of the fissure sounded like it was the result of rock fracturing below the surface—that areas containing fractured rock formations can result in fissures and sinkholes as the result of pressures generated by the annual freeze-thaw process (and that the same process could also form hills).

January 21, 2011 – Detroit (Wayne County)

A Detroit man was injured when the front end of his SUV 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. The sinkhole was on Pickford Street between Heyden and Vaughan.

August 18, 2011 – Detroit (Wayne County)

Another serious incident occurred in Detroit, this time on Beaubien between Chandler and Smith, when a partially collapsed sewer caused a massive sinkhole to appear in the street. An SUV driving over that part of the street was the last stress that the buckling pavement could take, and the car nose-dived as the road collapsed downward, shattering a water main in the process and causing the sinkhole to completely fill with water. Two women and an infant were successfully rescued from the vehicle, and some area residents were without water as the main was being repaired.

March 23, 2011 – Ann Arbor (Washtenaw County)

A crack in a concrete retention system caused a 40-foot sinkhole to occur on March 23, 2011, outside an underground parking structure's construction site in Ann Arbor. The combination of the state of the retention wall, the thawing of the ground, and sandy soils could have caused an underground cavity behind the concrete retention system to bubble up vertically to open the hole. Two businesses were closed for the day after the ground opened in their shared parking lot.

January 18, 2014 – Detroit (Wayne County)

A gaping sinkhole appeared in East Jefferson Avenue at Randolph Street near the Renaissance Center. The sinkhole formed when a manhole structure leading down to the water main about 14 feet beneath the road surface collapsed and filled with water. The resulting opening was about 8 feet wide and several feet deep, in the north lane, resulting in the closure of two westbound lanes on East Jefferson. Sometime overnight on Saturday night or Sunday morning, January 18-19, smaller road problems had expanded into this gaping hole. It is not known whether some cars suffered damage during its formation, but the area was soon cordoned off to be worked upon by repair crews. The repairs took over a week to complete, since there was an array of infrastructure beneath, including telecommunications lines, water and sewer pipes, and electrical wiring.

March 28, 2014 – Detroit (Wayne County)

A sinkhole that was 16 feet deep and 30 feet wide opened up at the intersection of Linwood Avenue and Monterey Avenue, in Detroit. The sinkhole was most likely caused by an underground sewer riser collapsing and eroding the soil nearby. The intersection remained blocked-off until repairs were completed.

December 24, 2016 – Fraser (Macomb County)

The emergence of a sinkhole the size of a football field resulted in several houses being damaged in Fraser. Damage estimates were around $75 million, and the area was declared a disaster area by Governor Rick Snyder. The Macomb Interceptor Drain had collapsed at that location, causing a 100-foot wide and 250-foot long sinkhole. The threat of collapse prompted the evacuation of 22 homes in the area. The sinkhole was eventually determined to have resulted from an operational error, made in 2014, when pipe maintenance work required a gate to be closed to hold back sewage while workers were in the pipe. Afterward, the gate was supposed to be gradually raised, allowing materials to be released into the pipe over the course of several hours. However, the pipe was instead allowed to refill all at once through an immediate gate retraction, causing fractures through which surrounding material could enter the pipe and get carried away. Over time, this led to a large enough gap to cause a collapse and damaging sinkhole at ground level. The effects of the damaged pipes had caused concern that a total of 11 communities in Macomb County, including the Selfridge Air National Guard Base, might be at-risk from ground shifts and service interruptions.

June 16 and 17, 2018 – Houghton County

Upper Peninsula storms led to heavy flooding and damage as a result of excessive rainfall. As much as seven inches of rain fell, resulting in many roads becoming impassable and covered by debris such as large chunks of concrete and asphalt. Roads in the Houghton and Hancock areas were washed out and dozens of sinkholes formed across the Keweenaw Peninsula. Area residents were asked to stay off the roads until the "water subsides and the debris has been cleared." Many residents were trapped inside their homes but residents who had been displaced could have stayed at the Calumet Colosseum in Calumet. Unfortunately, even the basement of a home was revealed to be treacherous, and a 12-year-old boy died when an nearby wall collapsed under the forces of the waters that were washing out roads, causing sinkholes, and flooding area homes. A massive mudslide tore through his family's home and left him trapped under debris in the basement. Some residents used boats to get around, though the U.S. Coast Guard warned people to stay out of recreational waterways because of the amount of storm debris. The agency also warned that the water was still very cold and could be deadly for that reason, as well. Governor Rick Snyder declared disasters in Houghton, Gogebic, and Menominee Counties. Houghton County was the hardest hit overall, of all the western portions of the Upper Peninsula affected by the storm. This was considered one of the most severe events in Houghton's history. Michigan Technological University and Finlandia University were temporarily closed because of the flooding and road conditions.

Programs and Initiatives

Michigan Department of Environmental Quality: Oil, Gas, and Minerals Division

The Michigan Department of Environmental Quality, Oil, Gas, and Minerals Division (MDEQ/OGMD), regulates metallic mining in Michigan. The OGMD's regulatory authority is granted under Parts 631, 635 and 637 of the Michigan Natural Resources and Environmental Protection Act, 1994 PA 451, as amended. The Division's activities include issuing permits for metallic mining operations, maintaining maps and records on mining areas, and regulating mine reclamation. In terms of mine subsidence, the OGMD works with local officials and the Office of Surface Mining Reclamation and Enforcement (OSMRE), U.S. Department of the Interior, to mitigate coal mine subsidence problems through special projects aimed at properly sealing mine shafts and otherwise ensuring the structural integrity of underground coal-mined areas.

Abandoned Mine Land Reclamation Program

This program within the U.S. Department of the Interior is designed to help reclaim coal mines abandoned before 1977. The program was created by the Surface Mining Control and Reclamation Act (SMCRA) of 1977. Their site at https://revenuedata.doi.gov/how-it-works/aml-reclamation-program/ notes that abandoned "mines pose risks to people and the environment. They can contaminate ground water, emit toxic waste, and cause injury when unsteady infrastructures collapse." The program has three levels of priority for the sites under consideration. Priority 1 sites involve the protection of public health, safety, and property from "extreme danger," including restoration of the land, water, and environment. Priority 2 sites involve protection from "adverse effects." Priority 3 sites involve the restoration of land, water, and environments "previously degraded by adverse effects of coal mining practices pre-1977."

Surface Mining Control and Reclamation Act

There is very limited state funding for mine subsidence mitigation. Therefore, most of the funding for such projects comes from the federal government. The primary federal funding source is the Abandoned Mine Lands (AML) Reclamation Fund in the Surface Mining Control and Reclamation Act (SMCRA), P.L. 95-87, administered by the U.S. Department of Interior's OSMRE. AML funds are derived through a tax on coal production targeted at reclaiming land and water resources adversely affected by pre-1977 coal mining. These funds can also be used for mine subsidence mitigation measures and salt sealing, which Michigan has done on numerous occasions. Normally, priority is given to those emergency projects that involve mine lands that present an immediate danger to the public health, safety or general welfare. Typically, such emergencies include landslides near homes and across roads, subsidence occurring under houses and public buildings, mine and coal waste fires, and open mineshafts discovered near populated areas.

Subsidence Insurance

Unlike states such as Illinois, Ohio, Pennsylvania, Kentucky and West Virginia, which have state insurance programs for homes and businesses in subsidence-prone areas, Michigan does not have such a program. As a result, home and business owners and communities that are affected by subsidence must rely on whatever private insurance payments they can collect for subsidence-related damages, or they must pay for damages out-of-pocket. (Subsidence-related damage is generally not covered under a standard homeowner's insurance policy.)

National Association of Abandoned Mine Land Programs

Michigan is a member of the National Association of Abandoned Mine Land Programs, a national advocacy group that provides a forum and clearinghouse for addressing issues and problems pertaining to mine subsidence and reclamation. Michigan's participation is beneficial in that it gains tremendous knowledge of the experiences of other states in reclaiming mine sites and mitigating subsidence. In addition, Michigan also gains knowledge about current reclamation and mitigation technologies that could be applied to problem areas in the state.

National Institute for Occupational Safety and Health – Mining Disaster Records

NIOSH provides an historical resource with information about historical mining disasters. The searchable database is available online at https://www.cdc.gov/niosh/mining/statistics/content/allminingdisasters.html.

Mine Safety and Health Administration

MSHA is part of the United States Department of Labor, and works to prevent death, illness, and injury from mining incidents, promoting the safety and health of mine workers. It maintains a database of incidents, investigates disasters, and produces reports about them. Their Mine Data Retrieval System is available at https://arlweb.msha.gov/drs/drshome.htm.

Local Mine Inspectors

Information about the locations and subsurface conditions of mines has no guarantee of being comprehensive in an area, and since many mines exist on private property, the owners of that property often have an interest in not allowing any mine details to be publicized (lest the information cause trespassers to be attracted to their property). However, known mines are subject to inspection, to determine their stability and safety. Valuable information is available for certain counties and their local Mine Inspectors. Locally specific information should be sought from the relevant Mine Inspector for that area. Please refer to the list available at http://www.mg.mtu.edu/mining/mine_inspectors.htm.

Michigan Underground Abandoned Mine Inventory
This information was compiled though research by faculty associated with Michigan Technological University, but may be difficult to access. https://researchworks.oclc.org/archivegrid/data/717282963

MDNR Maps of Michigan's Underground Mines
This information was used in the update of this chapter, and contains detailed maps of each county that has a local mine inspector (see below). Maps are available for 8 counties in the central and western Upper Peninsula (with a variety of mines, mostly iron, copper, and silver), and also for Kent County (gypsum mines) and Wayne County (salt mine). Located at http://www.dnr.state.mi.us/spatialdatalibrary/pdf_maps/Geology/Mines/, the maps are part of Michigan's spatial data library online. **Please notice that subsidence incidents have occurred in counties not yet mapped, and therefore this map set should not be considered comprehensive. There may also be unmapped mines existing within the 10 counties whose maps have been made available.**

Hazard Mitigation Alternatives for Subsidence

- Identifying and mapping old mining areas and geologically unstable terrain, and limiting or preventing development in high-risk areas.
- Filling or buttressing subterranean open spaces (such as abandoned mines) to discourage their collapse.
- Hydrological monitoring of groundwater levels in subsidence-prone areas.
- Insurance coverage for subsidence hazards.
- Real estate disclosure laws.

Assessment in Local Hazard Mitigation Plans

Subsidence was identified as one of the most significant hazards in the local hazard mitigation plans for Baraga, Clare, Dickinson, and Houghton counties (an increase from 2014).

SPACE WEATHER

An impact or threatened impact from solar geomagnetic storms, coronal mass ejections, or similar phenomena that may damage or destroy Earth's electronic satellite systems, interfere with radio communications and navigation systems, create health risks for air travelers, and disrupt electrical utility and pipeline systems.

Space weather is a term that describes the patterns of emissions from our Sun. Ordinary radiation emissions can be considered calm "weather," but there are periodic flare-ups and blasts of much greater energies that send charged particles that impact upon the Earth's atmosphere and magnetosphere. These **solar geomagnetic storms** can cause widespread failures of important satellite, electronic, communication, navigation, guidance and electric power systems—which have all formed a very important part of our modern technology and lifestyles. This hazard is considered fairly likely in the near term to cause notable disruptive effects, large economic impacts, and even some direct health risks to persons who are flying in aircraft in the far northern or southern areas of the planet, where the exposure to charged particles occurs in greater quantities.

An important type of impact involves the interference or disruption of modern electronic and communications systems, including those upon which our modern aviation networks rely. Solar flares and storms are important because of their potential impacts and possible disruption of these complex modern communication systems—satellites, television, radio, GPS, power supply networks, and the extensive human and technological infrastructure that relies upon those communication and utility networks.

On the ground, disrupted power systems can result in widespread power failures, and the movement of the mass of charged particles in geomagnetic storms can cause induced currents to flow within pipelines, unless special design features have inhibited such currents. An increase in ions (charged particles) that interact with the Earth's magnetosphere and then strike our upper atmosphere can cause a glow within the evening skies (which, in the northern hemisphere, includes the famous aurora borealis). Such "northern lights" become increasingly prominent, and extend farther to the south, during the most active **solar storms**. Government agencies actively monitor space weather, but for those who have not heard any government reports, their warning of solar storm activity may come from noticing these brighter glows in the night sky—especially in most Michigan locations where such "northern lights" are not normally seen.

Hazard Description and Explanation

The Sun does not "burn" in the traditional sense that we usually experience that common heat-generating process on Earth, but rather emits huge amounts of energy from the continuous processes of nuclear fusion that take place in the Sun's core. The gravitational pressures of the Sun's enormous mass, pulling toward itself, are thus generally offset by outward pressures from the fusion processes that take place within it. Enormous amounts of energy are then radiated from the Sun, including most of the spectrum of electromagnetic waves from harmless radio frequencies up through high-energy X-rays. These emissions include infrared (heat) radiation, ultraviolet, all colors of visible light, x-rays, microwaves, and radio waves. The intensity of these forms of radiation varies, and gamma waves are normally only emitted during solar flare events (to be explained shortly).

It should also be understood that in the midst of all these solar interactions of matter and energy are powerful magnetic forces, which also affect the distribution of heat energy in and around the Sun and sometimes cause cooler areas, called **sunspots**, to form for a while, readily visible even with crude forms of observational equipment. (Although an observer should never look directly at the Sun, a pinprick of solar light projected onto a surface provides one basic means of seeing a Solar image). The relatively low temperatures of sunspot areas, however, are coupled with a rise in energy <u>above</u> the Sun's surface. **Solar prominences** are arches of plasma that soar above the Sun's surface, in a pattern that is itself shaped by the powerful magnetic fields present. In some cases, these magnetic fields have become too twisted to maintain such forces within the ordinary arch patterns, and a **solar flare** is generated, which releases a huge amount of energy from the Sun. Normally, a **solar wind** exists in the form of milder pressures exerted by emitted photons, ions, and other particles that flow outward from the Sun until they are eventually halted (beyond the orbit of Neptune, at an area called the heliopause) by the pressure of interstellar gases. Within the realm of the Sun's planets, however, the solar wind is an ongoing feature of the space environment, constantly sending energy and charged particles outward.

Space weather is a term that denotes the impacts of the Sun's activity upon the bodies within this heliosphere (the volume of space inside the heliopause areas), including our own Earth. As is observable with ordinary weather on Earth, there are some clear patterns that are exhibited by space weather. More turbulent space weather is produced during times when more sunspots are present (called a solar maximum), and space weather is calm during times when sunspots are rare and small (or not even detectable at all, called a solar minimum). A **sunspot cycle** exists, in which sunspot activity periodically shifts between a minimum and maximum level. As with our Earthly seasons, however, it cannot be known in advance exactly how turbulent or calm things will be at a given moment during the sunspot cycle—only that calmer periods regularly give way to more turbulent periods. As to the regularity of the sunspot cycle itself, although it has been found that the average amount of time between a solar minimum and a solar maximum is about 11 years, the actual length varies quite a bit within each cycle. Within the documented cycles so far, the time interval between a minimum and maximum has been as long as 14 years and as short as 8 years.

In addition, it has been observed that long periods can occur with little or no apparent sunspot activity. The "Maunder minimum," which occurred between the years 1645 and 1715, is the primary example of such long-term variation from the normal cycle, but it is not yet known what caused it, or when it might recur. The Earth's atmosphere serves as a shield for us against many types of particles and radiation zipping across space, and Earth is also surrounded by a **magnetosphere** that similarly provides protection against most of the charged particles traveling through space. There are some weak spots in the Earth's magnetic field, however, that exist near its two magnetic poles and allow many ions to penetrate, where they collide with atoms in the Earth's upper atmosphere and glow to produce the beautiful auroras in the skies of the arctic regions of the north and south. In addition, the Earth is surrounded by "belts" of charged particles (called Van Allen belts) which are hazardous to spacecraft and astronauts. These are known and predictable conditions of calm space weather, however, and the actual hazard is the turbulence that is generated by large solar flares, causing problems with radio communications, damage to satellites, and even disruptions in power delivery networks on the Earth. Currently, as of early 2019, sunspot cycle number 24 (since a starting point in 1755) is almost over, having started in a solar minimum reached in December 2008, proceeded through a solar maximum that was reached in April 2014, and now reaching a new minimum again as the count of observed sunspots has dropped to nearly zero.

Another type of solar disturbance is a **coronal mass ejection** (CME), in which built-up pressures cause a sudden outward burst of gases (and accompanying magnetic fields) at tremendous speeds, with impacts that reach far across interplanetary space. Like solar flares, CME events are a cause of geomagnetic storm events on Earth (usually 1 to 4 days after the solar event), and they occur more frequently during periods with more sunspots. One of the additional effects of space weather involves increased exposure to ionizing radiation (e.g. harmful x-rays), especially among those in aircraft at high altitudes and along polar flight paths. Extra costs, in fuel and delays, are imposed upon airlines during periods of harmful space weather.

Hazard Analysis

Space weather can be very expensive for those who use or rely upon satellites. During a solar maximum, the Earth's upper atmosphere expands and increases the drag upon satellites within low orbits, which will then require boosting in order to remain aloft. Electronic circuits can malfunction and cause interruptions or complete losses in operational capacity. Space missions may also need to be delayed, in order to ensure their safety and success. Special design features may require additional expenses, to mitigate the effects of space weather. Communication disruptions can inhibit navigation and hinder the safe management of air and sea traffic.

Induced electric currents occur within conductive materials when magnetized material of sufficient moves nearby and has a sufficiently powerful charge. Space weather creates such a phenomenon, when the planet is impacted by a moving mass of charged particles. The induced currents from space weather can affect electrical utility systems and pipeline infrastructure, potentially weakening and damaging these systems as well increasing the chance of electronic malfunctions.

Three space weather scales are in use by NOAA/NWS to summarize the intensity and estimated potential impacts of three different types of space weather effects. Each uses a 5-category classification scheme, and the three scales denote (1) geomagnetic storm intensity (G-scale), (2) solar radiation storms (S-scale), and (3) radio blackouts (R-scale). Weaker events are given a number of 1 on the scale, and extreme events are rated as a 5. In this document, selected material is summarized below. For more detailed information, please refer to the NOAA web site at http://www.swpc.noaa.gov/NOAAscales/.

NOAA Space Weather Scales

NOTE: Each type of space weather may occur separately. Descriptions of all three types of space weather warnings are here combined into one table merely to conserve space.

HF means high frequency (radio waves), but other radio frequencies may also be affected by these events.

LF means low frequency (radio waves). F: refers to event frequency.

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 G1 S1 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. F: about 900 days per solar cycle.	S1 events result in minor impacts on HF radio in polar regions. F: about 50 such events per solar cycle, each of which can last more than 1 day.	R1 events cause weak or 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. F: about 950 days per solar cycle.
Moderate G2 S2 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. F: 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. F: about 25 events per solar cycle, each of 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. F: about 300 days per solar cycle.
Strong G3 S3 R3	G3 events may require voltage corrections at power systems and may trigger false alarms on their protection devices. Satellite orientation problems may need correction. Increased atmospheric drag and component surface charging may occur. Intermittent LF radio navigation problems may occur. F: 130 days per solar cycle.	S3 events can expose persons 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. F: 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. F: about 140 days per solar cycle.
Severe G4 S4 R4	G4 events may cause widespread voltage control problems for power systems, and mistaken exclusion of key assets from a power grid 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. F: 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. F: 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. F: about 8 days per solar cycle.
Extreme G5 S5 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 experience 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. F: 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. F: 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. F: fewer than 1 event per cycle.

* Pregnant women are particularly susceptible to radiation risk.

The space weather hazard appears likely to cause one or more serious infrastructure failures in the near future, due to the extent of our reliance on complicated electronic and satellite systems that are vulnerable to disruption. In addition to power failures and phone communication breakdowns, it is also quite possible for the disruption of radio and navigational systems to cause risks for air and marine traffic. Even if cautious transportation providers are diligent about maintaining safety during such events, considerable economic impacts and delays can result from the electronic breakdowns caused by solar geomagnetic storm events. Geomagnetic storm impacts tend last 1 to 2 days, and to occur between 15 and 90 hours after a coronal mass ejection event, which can allow a little bit of warning time, as spacecraft such as the Advanced Composition Explorer (ACE) can now measure the strength of an event and report back in time for notification to allow perhaps 15 to 20 minutes of advance warning time for protective response actions to occur. Solar radiation storms may also allow about 20 minutes of warning time, and can last for hours while damaging satellites. Line-of-sight radio functions are usually fine, but longer-distance operations are normally impaired over the day-lit portion of the Earth. Radio blackout events tend to impact just the side of the Earth that is facing the sun (the "day side"), and can occur without any warning. Estimates vary about the worst potential impacts upon satellite systems, because the most severe known level of event has not yet been experienced during our current age of digital communication networks. Some estimates have proposed that 10 to 15 percent of all satellites could be rendered inoperative in the most severe level of event, and that type of impact would be very expensive. In lesser (yet more common) events, satellite jamming might be expected for mere seconds or for periods up to 15 minutes long.

Research is progressing to associate sunspot groups with the likelihood of solar storm activity affecting the Earth. The large groups that are more magnetically complex are likely to pose the highest threat, corresponding to higher "McIntosh classes" (a classification system by which scientists can quickly refer to patterns in sunspot quantities and arrangements), and reportedly also likelier within the "descending phase" within the solar cycle (when fewer sunspots are appearing), although the reason for that correlation is not yet clear.

Impact on the Public, Property, Facilities, and Infrastructure

Space weather impacts can result in transportation delays and communication interference, and some cases may result in fatal transportation accidents, large economic losses, and widespread power supply interruptions. Key facilities for electrical infrastructure have been affected in the past, but the industry has reported many improvements during the past 30 years, to reduce the chance of a widespread blackout as a result of a major solar storm. Most personal property is not damaged by these events, although radio function and digital communications may often be temporarily impaired. The key built infrastructure that is most at-risk in Michigan appears to be some of its pipelines and power grids.

Impact on the Economic Condition of the State

Although Michigan would not be expected to feel space weather impacts by itself, in isolation from other states, there is the possibility that particular infrastructure failures might happen to occur specifically within Michigan. Thus, although temporary communication disruptions might be felt throughout the entire continent at the same time, particular utility systems might happen to fail within Michigan and have a disproportionate impact within the state. This would be a likely source of economic impact. Although an event like Quebec's massive 1989 power loss is reportedly less likely now, as a result of precautions taken by electric utilities, some disruption in plane flight schedules, utility function, and communication systems is likely to have an economic impact. Although the level of impact is too difficult to predict, the particular timing of the disruption might happen to have an unusually negative effect on some particular industry within Michigan. If high-technology Michigan companies have their satellites taken out of service by the effects of a very severe event, the effects might be too expensive for such businesses to bear, while the other businesses they serve could similarly find that key processes are interrupted and therefore result in costs far more than had been planned (or budgeted to accommodate). Important tourist attractions might rely upon digital communications technologies that are then disrupted by space weather. Some pipeline services might be impacted and cause other types of cascading effects, if there is an unexpected gap in the supply of fuel for energy, industrial production, or digital information processing (although the latter should allow more potential for running off of back-up power systems. Many high-technology economic sectors rely upon efficient satellite relays for their operation. Airline scheduled and flight paths would also be disrupted during a major event. The longest impacts would involve the replacement of satellites and vulnerable utility system components. The potential for extensive power outages and electronic system disruptions could make this one of the least well-known but potentially most economically damaging types of hazards that might occur in the near future. A limited general awareness of this hazard, as well as the relative scarcity of its most extreme events (the standard having been set in 1859), may explain why advance planning and hazard mitigation activities have rarely been seen.

Impact on the Environment

It has been speculated that space weather may be connected with global climate, but this is primarily due to the possibly coincidental occurrence of a "Little Ice Age" (lower average temperatures in America and Europe) during the same time that the Maunder minimum in solar activity was observed. The specific mechanisms that would underlie such a connection have not yet been figured out and therefore such a link should probably still be considered to be purely speculative. On the favorable side, solar activity helps to shield us from some of the biologically damaging cosmic rays that come from elsewhere in the universe.

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

The impacts of space weather include interruptions in the function of radios, satellites, electronics, and even power supply systems that may be needed for emergency response. Response activities that involve electronic navigation technologies and Global Positioning Systems may need to fall back upon the use of less technologically advanced means to accomplish their mission, but in most cases, such "legacy systems" either no longer exist or are simply unable to handle the operations of the newer technology. In a severe event, it is likely that some sort of service interruptions would occur within sectors that rely upon radio or satellite communication, transportation, and navigation systems. Although this might potentially include numerous types of businesses that cannot all be listed here, FEMA has noted that these systems are vital for emergency response activities.

Impact on Public Confidence in State Governance

The potential impacts of space weather will require greater public awareness in order to build an understanding about existing weaknesses and the expense that might be involved in correcting those weaknesses, where possible. If a major event does bring down one or more important systems (for example, satellite communications), some might question whether it was wise to have placed so much reliance upon any particular system that was revealed to be vulnerable.

Significant Events

NOTE: Although many of the events listed here occurred out of state, some of them were nevertheless large enough to have direct impacts upon Michigan, due to the sheer magnitude of the impacts. A couple of events date back to the 19th Century, to give an indication of the magnitude of what is possible. One event describes a "close call" whose impact could have been very large if it had occurred one week earlier than it had. Thus, some of these events are included because they help to indicate the range of threat posed by the hazard—events outside of Michigan usually represent the largest known events or threats, while events involving Michigan tend to represent the typical level of recorded impacts in the state.

March through October, 1847 – United Kingdom

Twelve years prior to the Carrington Event (see below), an "anomalous current" had been reported on British telegraph lines in the vicinity of Derby, Rugby, and Birmingham, which may have been the first detected effect from geomagnetic storms upon electronic infrastructure. It occurred in conjunction with a brilliant aurora that was observed on March 19 of that year. Other disturbances were reported, one on September 24 being reported as nation-wide, from South Devon up to Scotland.

August 28 to September 2, 1859 – International, "Carrington Event"

After a couple days of visibly expanded auroras in the sky, telegraph disruptions were also noted in diverse parts of the world. On September 1, a large solar flare was briefly observed by astronomer Richard Carrington, and also independently recorded by Richard Hodgson. Just before dawn of the next day, however, brilliant auroras were visible in skies around the world, telegraph systems severely malfunctioned, and various damages (and minor injuries) resulted from sparks and equipment failures. This was the first solar flare observation and it was also clearly seen that the phenomenon was connected with malfunctions in electronic communications systems on Earth. No solar flare of this magnitude has been seen in the 150 years since this occurred. Based upon evidence from arctic ice, it was estimated that the 1859 solar geomagnetic storm was the most intense in the past 500 years, nearly twice as much as the second-largest event. (Even though certain intensities have since been matched, no storm since has been able to simultaneously match this one, on all types of intensity measures.) Were such an event to happen again today, it has been estimated that tens of billions of dollars in damage would be done to more than 1,000 satellites that orbit the Earth. These satellites are essential for the safe and smooth operation of airlines, spacecraft, and various communications systems.

May 16, 1921 – International, "Great Storm"

An extremely strong geomagnetic storm occurred—the strongest such storm since 1859. According to one study, if a storm of this magnitude were to occur today, it could result in large-scale electrical blackouts that would affect more than 130 million persons across the northwestern U.S. (including Michigan) and the Pacific Northwest. These figures were based upon estimates of regions susceptible to power grid collapse, and the 1921 storm was considered to be about 10 times as strong as the one that did cause power failures in 1989. Extra-high-voltage transformers were considered to be a particular vulnerability in these projected blackout areas, with places like New Hampshire, New Jersey, and Pennsylvania at particularly high risk in the interconnected grid. This has been estimated as a level of event that has a 1% annual chance of occurring in an average year.

August 4, 1972 – Illinois

A huge solar flare ended up causing the failure of long-distance telephone communications across Illinois. AT&T redesigned its power system for transatlantic cables as a result of this event. Electric grid disturbances were also reported in widespread locations around North America. This event involved the fastest "transit time" of ejected solar material that had been measured. Recently, a paper reported that these storms had an effect upon U.S. military operations, including the unintended detonation of many of its DST mines within the wartime Southeast Asian operational area (Knipp, Fraser, Shea, and Smart, 2018). In some ways, this may have been the most severe event seen during the space age. Had astronauts been in space at the time, it would have been dangerous for them.

March 13, 1989 – Canada and Eastern United States

Geomagnetic storms caused by a huge solar flare involved various disruptions in the transmission of electrical power, causing a widespread blackout across most of Quebec and affecting 6 million persons for a period of up to 9 hours. Specifically, when five transmission lines went down, the system was unable to withstand the loss of their 21,350-megawatt load, and collapsed within the subsequent 90 seconds. The blackout closed schools and businesses, shut down the Montreal Metro Airport, and delayed flights from other airports. Street traffic backups took place, since traffic signals and traffic control systems no longer functioned smoothly. Workers in downtown Montreal were stranded in dark offices, stairwells, and elevators. Elsewhere, power surges caused by the geomagnetic storm (geomagnetically induced currents, or GICs) caused power transformers in New Jersey to be overloaded and damaged. The functioning of long-distance telephone cables were also affected by auroral currents, major power substations experienced voltage swings, generators went offline, and the U.S. Air Force temporarily lost its ability to track satellites. Costs from the loss of power exceeded $100 million, including stalled production processes, idled workers, and spoiled products. This was considered to be the strongest geomagnetic storm of the space age, and it has been reported that the broader power grid covering the Northeastern and Midwestern U.S. was "within seconds of collapse."

January 1994 – Canada

Inclement space weather caused electric charges to build up and then discharge within the electronic components of two expensive communications satellites. One satellite was disabled for about 7 hours, due to damage to its control electronics. A second satellite went out of service entirely, when its backup systems also became damaged, requiring 6 months of service before its functions were restored. The satellite 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 of the event were estimated at between 50 and 70 million U.S. dollars.

January 11, 1997 – International

A satellite that had cost $200 million was incapacitated by the impact of a coronal mass ejection. After efforts to restore the satellite's function failed, it was officially decommissioned.

April-May, 1998 – International

The failure of the attitude control system of an expensive Galaxy IV satellite (the cost of such satellites is usually on the order of $200 to $250 million) disrupted the function of about 45 million electronic paging devices. Various other satellite problems were noted, and researchers eventually concluded that these problems were "caused, or at least exacerbated by" the impacts of geomagnetic conditions originating from "highly disturbed" solar conditions. Although the satellite problems occurred in May, weeks of problematic space weather that had started back in April was considered to have eventually led up to May's events.

October 19 to November 7, 2003 – International, "Halloween Storms"

Geomagnetic storms took place in late October and November, and although power grid operators had learned from the March 1989 event and were better able to withstand the storms' effects, there were some heavy impacts upon the aviation sector from this event. The Federal Aviation Administration had implemented a WAAS (Wide Area Augmentation System) to better guide navigation and aviation system control, and a part of what WAAS supports is the ability of air traffic to maintain safe distances from each other. The vertical navigation component of WAAS was disabled for approximately 30 hours across most of the United States during the late October storms. These "Halloween storms" interrupted GPS function, blocked high-frequency radio, damaged power transformers in South Africa, and forced emergency procedures to be implemented at nuclear plants in Canada and the northeastern United States.

January 2005 – International

Space weather at this time included solar radiation storms. In addition to the loss of HF radio communications, such storms can cause elevated radiation exposure to persons in aircraft flying at high latitudes (e.g. across polar regions). The use of polar routes has increased dramatically since the 1990s, since such routes can reduce travel time and fuel costs (by avoiding strong wintertime headwinds). Aircraft must divert to lower-latitude routes during such radiation events, resulting in delays, increased flight times, missed connections, higher costs, and greater fuel consumption.

December 2005 – International

A geomagnetic storm caused the disruption of satellite-to-ground communications and GPS (Global Positioning System) navigational signals. Although this disruption only lasted about 10 minutes, it threatened the safety of commercial air flights and marine traffic during that time.

December 6, 2006 – International

A burst of solar radio wave energy caused a disruption in the function of GPS units across the entire sunlit side of the Earth (the Western hemisphere in this case). Some users of navigation systems found their capacities disrupted for many minutes, which was of particular significance for military aircraft.

July 23, 2012 – International

The STEREO solar observatory (see below) detected and measured one of the largest solar storms ever recorded. The trajectory of the emissions were fortunately not directed at Earth during the time of the event, or it would have resulted in the type of extreme storm that has here been estimated as a "worst-case scenario." It has been calculated that if the solar eruption had taken place just one week earlier, then the Earth would have been aligned to receive the impacts, and the results would have been equivalent to another "Carrington Event" (see 1859 entry, above) but with far more extensive electronic systems and investments at risk than had been true in the past.

Programs and Initiatives

Solar Monitoring and Measurement Programs

Various spacecraft are gathering data on solar flares, coronal mass ejections (CMEs), and charged-particle emissions (solar storms and space weather). These include:

- The Solar and Heliospheric Observatory (SOHO) (http://sohowww.nascom.nasa.gov/) is a collaborative international project between the U.S. National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). It was launched in 1995. Among its solar studies, it tracks the intensity of solar winds and flares, and has also been responsible for the discovery of 2000 comets.
- Hinode – A Japanese satellite that engages in solar missions coordinated with other space agencies around the world, Hinode employs optical, ultraviolet, and X-ray equipment that measures the Sun's magnetic field, the Sun's corona (turbulent outer atmosphere), and the solar particles that are radiated.
- Solar Terrestrial Probes (STP) – Currently, the Solar Terrestrial Relations Observatory (STEREO) is the third of NASA's Solar Terrestrial Probes program and has been engaging in 3-D observations, imaging, and

measurements of solar activity since 2006. Using a pair of spacecraft, the combined views cover most of the solar surface at all times, including the far side of the Sun, and make use of extreme ultraviolet waves to better detect and analyze coronal activity. A phone application is available from NASA that allows solar monitoring and the receipt of alerts to be transmitted to users' phones. The STEREO web site is located at http://www.nasa.gov/mission_pages/stereo/main/index.html. On February 3, 2011, the two STEREO craft reached positions directly opposite each other, 180 degrees apart on each side of the Sun, allowing the entire surface to be monitored simultaneously. A Magnetosphere Multiscale (MMS) mission began in 2015, to study three important plasma processes in the Earth's magnetosphere and thus to better understand space weather processes.

- Advanced Composition Explorer (ACE) – Launched in 1997, NASA's ACE provides solar wind monitoring and measurement in nearly real-time. From its space location 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. ACE instruments provide information about energetic ions and electrons, magnetic field vectors, high energy particle flux, and solar wind ions. The ACE web site is found at https://www.swpc.noaa.gov/products/ace-real-time-solar-wind.
- Solar Dynamics Observatory – This program was designed by NASA to help understand the causes of solar variability, and its impacts on Earth. Launched in 2010, the mission focuses on the Sun's magnetic field, solar coronal activity and plasma, space weather, and the irradiance underlying planetary ionospheres. The SDO web site is at https://sdo.gsfc.nasa.gov/.

NOAA/NWS Space Weather Prediction Center

This agency is the primary point of contact for a space weather event. A web site at http://www.swpc.noaa.gov/ allows continuous access to information about space weather, including the convenient classification of space weather into NOAA's convenient 5-category schemas (e.g. from G1 to G5). Alerts and warnings are also accessible through this web site, along with a number of Space Weather User Groups, covering topics such as navigation, radio, electric power, and satellite operators.

Grid Reliability and Infrastructure Defense Act (GRID)

In 2010, the U.S. House of Representatives passed an act that included the following language specifically directed toward mitigating some of the impacts of geomagnetic storms:

"Geomagnetic storms.--Not later than 1 year after the date of enactment of this section, the Commission shall, after notice and an opportunity for comment and after consultation with the Secretary and other appropriate Federal agencies, issue an order directing the Electric Reliability Organization to submit to the Commission for approval under section 215, not later than 1 year after the issuance of such order, reliability standards adequate to protect the bulk-power system from any reasonably foreseeable geomagnetic storm event. The Commission's order shall specify the nature and magnitude of the reasonably foreseeable events against which such standards must protect. Such standards shall appropriately balance the risks to the bulk-power system associated with such events, including any regional variation in such risks, and the costs of mitigating such risks."

The full text of the act can be found at http://www.fas.org/irp/congress/2010_cr/grid.html.

Space weather has not yet been identified as one of the most significant hazards in any of Michigan's local hazard mitigation plans.

Hazard Mitigation Alternatives for Space Weather

- Awareness campaigns for industries and systems involving satellite communications, GPS, or radio communications that could be disrupted by space weather events. In addition to the use of GPS for navigation, aviation, and military applications, that technology is also important for offshore drilling operations, precision farming, transportation, and mapping and surveying. Therefore, it is very important to protect these systems.
- Operating procedures that include back-up systems allowing complex systems (e.g. air traffic control) to continue to function when key technological systems (e.g. GPS, radio communications, satellites) malfunction. For example, some "legacy" systems might be retained as a back-up, new GPS signals and codes could be used to remove ranging errors, and protective and back-up components could be installed in vulnerable systems.

- The use of special procedures, equipment, and redundancies by utility systems (e.g. electrical power and pipeline systems) to minimize the potential for geomagnetic effects to cause inappropriate shutdowns, impaired or lost functionality, and system damage. For example: the provision of reserve system capacity may offset the effects of geomagnetic storms; or the temporary disconnection of vulnerable components for their own protection.
- Additional back-up satellites, for communications and navigation, may be needed to limit the damaging effects of a major solar storm, which may put current satellite equipment out of action and require their rapid replacements. The importance and cost of satellite systems may not be well-known to the general public. As of 2009, the existing fleet of 250 commercial satellites constituted a total investment of about $75 billion, and involved an annual revenue stream estimated at over $250 billion.

METEORITES AND OTHER IMPACTING OBJECTS

An impact or threatened impact from a meteorite, asteroid, comet, satellite, space vehicle, space debris, or similar objects that may cause physical damages or other disruptions.

Hazard Description

Among the potential celestial impact hazards are the potential the effects of large masses impacting upon the Earth's atmosphere or surface. Most such forces are extraterrestrial in origin—meteors or meteorites that were originally **asteroids** or **comets** from elsewhere in the solar system—but consideration also needs to be given to the crashing of human space vehicles and artificial satellites. First, natural objects will be considered, that can forcefully explode in the atmosphere as meteors, or that reach the ground to impact as meteorites.

Meteors burn up in the atmosphere, but in the process may cause strong winds and explosive blast forces to then strike the Earth's surface. It must be emphasized that even in cases where a large meteor does not actually strike our planet's surface, the explosive energies from its impact upon the many layers of atmosphere can create an intense heat and blast area, along with very strong winds, and can release more energy than even the largest nuclear bombs. This was demonstrated in the 2013 event in Chelyabinsk, Russia, in which about 1,000 persons throughout the metro area were injured, primarily as a result of glass windows that were shattered by the meteor's shock wave.

Meteorites are physical objects that have at least partially survived their plunge through the atmosphere and then actually strike the ground or sea at the Earth's surface. Any massive, fast-moving objects that impact upon either the ground, the oceans, or the atmosphere can cause widespread destruction and disruption of both human and natural systems, including secondary hazards such as earthquakes, shoreline floods, severe winds, and infrastructure failures. Fortunately, events of that magnitude are extremely rare, and highly unlikely to occur within the time-frame of this plan. However, an extensive discussion of impacting physical objects is given here to inform readers about the full range of potential impacts, from the trivial to the catastrophic. In the unlikely event that a very serious incident does occur, or threaten to occur, readers can have some background knowledge to better understand the hazard.

Space vehicles and **satellites** occasionally fall to Earth, causing a state of heightened alert as information about its decaying orbit is gathered and tracked to see whether the crash is likely to occur in an inhabited area. This event occurred most recently in April 2018, in which the Chinese Space Station Tiangong-1 was falling to Earth and Michigan's State Emergency Operation Center monitored that descent so that any risk to Michigan could be perceived in advance to allow the preparation of appropriate response activities. The debris from such vehicles often involves one or more forms of hazardous materials and therefore should not be handled casually by untrained persons.

Then there is a set of cases involving unusual events such as which loud sonic booms or flaming fireballs are seen in the sky and reported to law enforcement and emergency management agencies. This chapter seeks to assist such agencies (and the general public) in better understanding and recognizing these events, and being able to explain them to others. Trivial meteor events are observed routinely during every year's well-studied **meteor showers**, when Earth is passing through parts of its orbit in which numerous small particles had been left by passing comets, and which then harmlessly burn up in the atmosphere, visible as small points of moving light that are often referred to as "shooting stars." But less frequent **bolide** events, in which a larger meteor hits the atmosphere with such force that it violently flares up, often with an accompanying sonic boom, and literally appears as a giant fireball, explosion, or bright pulse of light as it continues to plunge toward the ground. In Michigan, this occurred most recently in January 2018, and eventually was confirmed to be a small meteorite whose rocky and fragmented remains were found (the area of which is called a **strewn field**), scattered within Livingston County near Hamburg.

Although it has been estimated that a serious impact from a physical body upon the Earth occurs approximately once every 50 to 100 years, the fact that much more of the Earth has been covered by human developments within the recent past has caused increasing concern over this hazard. When Earth's population was much smaller, events had tended to occur in areas with few if any inhabitants, so that it was very difficult to find any confirmed cases of an injury directly caused by a meteorite. However, the well-known theoretical risk of impacts became reality across the Chelyabinsk (Russia) metropolitan area on February 15, 2013, in which the force of the blast wave from a meteor caused shattered windows, and more than 1,500 injuries. One of the lessons learned from Chelyabinsk is that even though the type of damage was mostly minor (since windows are easy to replace), many of the injuries might have been prevented if there had been a greater public awareness of the concept of a blast wave. Upon seeing a huge flash of light in the sky, an informed observer could potentially recognize that the observed light may really just be an initial warning indicator of the full event. Light travels faster than any massive objects, and so a flash of light from a distant explosion will necessarily be seen before the arrival of the impact forces of a blast wave and its accompanying strong winds. For this is effectively what happens during a large meteor event—an explosive blast occurs in the atmosphere as a meteor plunges through it. When traveling at supersonic speed through the atmosphere, a meteor will generate a loud "sonic boom" just like a fast jet plane. But if the meteor is large enough, then the force of the displaced air from that blast may continue to travel to the Earth's surface, to strike those who are still watching the meteor. Even though most visible meteors are harmless because they are relatively small and far away, the actual size and distance of the meteor is often too difficult for ordinary observers to determine. Therefore, those who witness a sizeable blast in the sky should be aware of the potential for the light to be followed by a sonic boom and also potentially by an explosive blast wave and strong winds. Instead of staying near windows or in the open, gazing upward, some injuries could have been prevented by people going into interior rooms away from windows that face the event. <u>The same protective principle also applies to any large explosive event</u>, whether an industrial accident, natural gas pipeline blast, tanker explosion, or a detonated bomb. Distant observers might only experience a moment's delay before being struck with blast force, heat, and winds from the explosion, and might have been able to use that moment to take cover to protect themselves.

Since most of the Earth's surface is covered by ocean waters, most meteorites would be expected to strike an ocean rather than a continent. However, there is still the potential for a large-enough ocean strike to be widely damaging, if the meteorite is fast and massive enough to create tsunamis and seismic activities as a result of its impact. Fortunately, this kind of event is also extremely rare, but is something that those who live in coastal areas should be aware of. For example, a strong impact on one side of Lake Michigan could cause waters to eventually swell over the property on the other side of the lake.

Extensive evidence of previous celestial impacts upon Earth has been discovered, including evidence of an ancient large crater site located in southwest Michigan, but the vast majority of Earth's past impacts have had their evidence erased from normal observation by the ongoing geological processes that take place over time. Even the largest of impact sites would no longer be evident to normal observation after a period of about 200 million years (usually much, much less). Such an amount of time is less than 5% of the Earth's overall age, but it has been found that impacts used to occur much more frequently during the earlier periods in Earth's history (i.e. nearer to the period of planetary formation) than they do in recent geological periods. Clearer evidence of the many historical impacts can be seen on other celestial bodies that are less geologically active, such as the craters visible on Earth's own Moon.

The vast majority of meteorites began as either **asteroids** or **comets** before striking the Earth. Each type of body has different characteristics and risks associated with it, described in the following paragraphs. An unknown quantity of other objects might also be able to strike the Earth, originating from beyond the solar system, but the risks from such impacts cannot readily be known and are probably very low within the near future. One example, however, was seen in October 2017. Named Oumuamua, it was the first and only known interstellar object to be detected and measured as it passed through the solar system. Its closest approach to the Sun (about 24 million miles) had occurred on September 9, 2017, and the dimensions of its elongated shape included a length that was initially estimated at 800 meters long, but a later study reached a dissenting conclusion involving a length of no more than 440 meters. Nevertheless, that magnitude is more than enough to have posed a serious threat if it were to strike the Earth or its atmosphere. Such objects were then estimated to pass through the solar system perhaps once or twice per year, most of which would have gone by completely undetected.

<u>Asteroids</u>

Most asteroids are located in the main asteroid belt and have well-defined orbits there between 200 and 310 million miles from the Sun, but thousands of asteroids also exist in other parts of the solar system. There are groups of "Trojan" asteroids that share an orbit with Jupiter, for example, located 60 degrees both ahead of and behind that planet in its orbit around the Sun. Asteroids that have paths located near enough to Earth's orbit are classified as Near-Earth Objects (NEOs). Four major types of NEOs have been defined (Amors, Apollos, Atens, and Altiras), two of which (Apollos and Atens) have paths that cross over Earth's orbit. As of early 2019, there were nearly 20,000 NEOs identified. Of these identified NEOs, nearly 2,000 were classified as Potentially Hazardous Asteroids (PHAs—having the potential to come within 466,000 miles of the Earth's orbit; by comparison, the average distance of the moon is 238,900 miles). NASA's NEO discovery and tracking program had originally sought to identify all nearby objects that have a dimeter of 1 kilometer or larger. As of Feburary 16, 2019, nearly 900 such objects had been identified. The NASA mandate was later expanded to try to document 90% of all NEOs that have a diameter of at least 140 meters (459 feet), and the tally of those objects has just exceeded 8,500. (For current figures, please refer to the Discovery Statistics site at https://cneos.jpl.nasa.gov/stats/totals.html.) Fortunately, the vast majority of these objects pose no near-term risk to the Earth. Those that have even a minor chance of eventually striking Earth (i.e. within the next several decades) receive further study to better pinpoint the precise trajectory of the object over time. The results of such additional study eventually confirms that there is no impact expected, although surprises still arise from as-yet unclassified NEOs that are suddenly detected nearby ("near misses"). Some of these events are provided in the section on "Significant Events," to give readers a better indication of what has been observed and why some of these objects can be considered a threat.

One near-Earth asteroid that had been identified as meriting careful monitoring is 101955 Bennu (1999 RQ36). It was made the target of a space mission and has recently been reached by the NASA spacecraft OSIRIS-Rex, which has begun scouting the asteroid for the best locations where it can land and collect information about the asteroid's composition and structure. This project will provide new information expected to help inform any future asteroid-impact mitigation activities that might become necessary in the future. For up-to-date information on this mission, please refer to the website at https://www.asteroidmission.org/.

Because of the locations of most asteroids within the solar system, the typical meteorite of asteroid origin impacts the Earth at an average angle of 45 degrees and a speed of 10 miles per second, but a wide variation around this average is possible. Among this variation in velocity, the type and extent of damage that results from an impact would also vary with variables involving the meteorite's mass, composition, and location of impact.

Comets

More than 99% of all meteorites come from asteroids, but some comet impacts have also been confirmed (9 are known, constituting less than 0.03% of all meteorites). The main difference between comets and asteroids is that comets tend to have elliptical orbits that carry them out beyond the "nebular frost line" (located about 700 million miles from the Sun, and well beyond the main asteroid belt) and thus their composition includes a substantial amount of icy and frozen matter. Comets usually lose about 0.1% of this matter each time they pass by the sun, due to the effects of warming and the pressure of solar radiation, and this matter trails behind them in their long "tails," which include charged particles (with associated magnetic fields) and can stretch across many tens of millions of miles of space. Where such tails cross the Earth's orbit, this matter (typically small and harmless to us) generates sometimes spectacular "meteor showers" as it periodically burns up in the Earth's atmosphere at regular times during the year. After a certain number of orbits, however, the comet simply breaks apart. Even though comets are less dense than the average asteroid, a comet's heavy nucleus can be sizeable (from several hundred meters to over 40km in diameter), and a comet impact upon the Earth would typically occur at a speed of 31 miles per second—about three times as fast as the average asteroid, with a proportionally larger momentum of destructive energy if the amount of mass is the same. It is worth noting here that the maximum impact velocity upon the Earth for any object orbiting the Sun would be no more than 44.5 miles per second—160,000 miles per hour—but that the maximum measured velocity of any known meteorite so far was 64,000 miles per hour (seen as a fireball across the western U.S. on April 22, 2012 and later named the Sutter's Mill meteorite).

Comets are classifiable by their orbital period, with long-period comets taking more than 200 years to travel around the Sun, and short period comets taking less than that. Just as near-Earth asteroids are a subclass of near-Earth objects, there is also a subclass called near-Earth Comets (NECs), which are all short-period comets. The short-period comets are further subdivided into Halley-type comets with orbital periods between 30 and 200 years, and Jupiter-type comets with orbital periods of less than 30 years. Long-period comets originate in the farthest reaches of the Solar System (the Oort Cloud) and approach the Sun and Earth from every direction, while short-period comets originate from the nearer "Kuiper Belt" that exists just beyond Neptune and is approximately in the same plane as all of the major planets. Short-period comets thus would approach us from more predictable, shallow angles. A comet only begins its distinctive glow, however, when it approaches to within 3 and 5 Earth-distances from the Sun (3 to 5 astronomical units). Since short-period comets tend to last for only a matter of hundreds or perhaps thousands of orbits, their number seems to be replenished by a reservoir in our solar system, and their orbits eventually become shifted by gravitational perturbations. The Oort Cloud probably contains about a trillion comets, but most of these remain so far away that we remain unaware of them. The Kuiper Belt contains billions of comets, and the average diameter of one that comes near to the Sun is about 10 km. NASA has identified 107 NECs as of early 2019, none of which are expected to strike the Earth in the foreseeable future.

If advance notice of an approaching meteor, asteroid, or comet is available, then widespread alerts might be prompted by this information, much as the explosive breakup of the Space Shuttle Columbia in 2003 had required warnings and alerts across multiple southwestern states, due to the possibility of persons and property being affected by falling debris. (See the event descriptions that appear later in this chapter.) In the case of the Cosmos 954 and Space Shuttle incidents, such debris needed special handling, both for purposes of investigation and out of concern for personal safety, since some of it could have contained hazardous substances. The threat of a major meteorite impact would be much more dangerous and far-reaching in scope. One clear example of the potential damage was seen in the impact of the comet Shoemaker-Levy 9 on the planet Jupiter, in 1994, which resulted in blasts that were estimated as the equivalent of ten million megatons of explosives. In comparison, the 1979 Mount St. Helens eruption was roughly 5 megatons, and the 1885 Krakatoa eruption in Indonesia was about 100 megatons. Following the Shoemaker-Levy comet impact, Congress authorized new research to analyze this type of hazard.

Hazard Analysis
A couple of scales have been developed to numerically summarize the extent of risk associated with comets and asteroids. One scale is called the Palermo scale, but since that is tricky to interpret, the Torino Scale has instead been featured in media reports since its initial presentation at a United Nations conference in 1995, and it was adopted by the International Astronomical Union in 1999. Both scales take into consideration the amount of destructive energy that an impact could cause, and the probability of such an impact occurring. It is common for newly discovered objects to have their initial classifications on these scales subsequently downgraded, as additional information is collected that more precisely defines the exact path of the object. In other words, an object that is initially classified as having some potential of an impact, and thus being worthy of closer study, is usually later reclassified as additional information reveals that little or no significant impact potential exists. Objects with lower numbers on the Torino scale indicate little or no concern. Within the past 20 years, only one object (99942 Apophis) had temporarily been classified as high as a 4 on the Torino scale. Being an asteroid large enough to cause regional devastation if it struck, Apophis had initially been estimated to have a 1-in-45,000 chance of striking the Earth on April 13, 2036, but as more information was obtained about its trajectory, that estimate was downgraded to only a 0.000009 probability, as is currently classified as 0 on the Torino scale. The asteroid's approach will eventually be spectacular to observe, though, as it is predicted to come as close as 18,300 miles away from the Earth's surface as it passes. (In Celestial terms, this is a very near miss, because that distance is smaller than the circumference of the Earth.)

Below is the official explanation of Torino Scale ratings, which only apply to potential impacts up to 100 years in the future. In addition to numerical categories from 0 to 10, the scale is also color-coded in five categories, from white to red.

THE TORINO IMPACT HAZARD SCALE:

No Hazard (White Zone)

0: The likelihood of a collision is zero, or is so low as to be effectively zero. Also applies to small objects such as meteors and bodies that burn up in the atmosphere, as well as infrequent meteorite falls that rarely cause damage.

Normal (Green Zone)

1: A routine discovery in which a pass near the Earth is predicted that poses no unusual level of danger. Current calculations show the chance of collision is extremely unlikely with no cause for public attention or public concern. New telescopic observations very likely will lead to re-assignment to Level 0.

Meriting Attention by Astronomers (Yellow Zone)

2: A discovery, which may become routine with expanded searches, of an object making a somewhat close but not highly unusual pass near the Earth. While meriting attention by astronomers, there is no cause for public attention or public concern as an actual collision is very unlikely. New telescopic observations very likely will lead to re-assignment to Level 0.

3: A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.
4: A close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of regional devastation. Most likely, new telescopic observations will lead to re-assignment to Level 0. Attention by the public and by public officials is merited if the encounter is less than a decade away.

Threatening (Orange Zone)

5: A close encounter posing a serious but still uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than a decade away, governmental contingency planning may be warranted.
6: A close encounter by a large object posing a serious but still uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether or not a collision will occur. If the encounter is less than three decades away, governmental contingency planning may be warranted.
7: A very close encounter by a large object, which if occurring this century, poses an unprecedented but still uncertain threat of a global catastrophe. For such a threat in this century, international contingency planning is warranted, especially to determine urgently and conclusively whether or not a collision will occur.

Certain Collisions (Red Zone)

8: A collision is certain, capable of causing localized destruction for an impact over land or possibly a tsunami if close offshore. Such events occur on average between once per 50 years and once per several 1000 years.
9: A collision is certain, capable of causing unprecedented regional devastation for a land impact or the threat of a major tsunami for an ocean impact. Such events occur on average between once per 10,000 years and once per 100,000 years.
10: A collision is certain, capable of causing global climatic catastrophe that may threaten the future of civilization as we know it, whether impacting land or ocean. Such events occur on average once per 100,000 years, or less often.

Note: A color graphic of the current Torino Scale is available at https://cneos.jpl.nasa.gov/sentry/torino_scale.html.

The Palermo Technical Impact Hazard Scale is a bit different, with values less than -2 reflecting events for which no consequences are likely, values between -2 and 0 indicating situations that merit careful monitoring, and values above zero indicating situations that merit some level of concern. This document presents only the Torino scale in its entirety, since that scale was developed for general public-information uses.

About 40,000 to 60,000 tons of extraterrestrial material falls onto the Earth each year, but most of it is mere dust. Slightly larger materials fall during regular cycles called meteor showers, but again most of it is small enough to harmlessly burn up (through ablation) as it hits the Earth's atmosphere at high speeds. During meteor showers, the material is typically leftover debris from comets that had crossed the Earth's orbit in the past, and most such material is very small and harmless to us. Material that does survive ablation in the atmosphere and strike the Earth's surface will land in random locations, and since 70% of the Earth's surface is water, these meteorites mostly go unnoticed by ordinary people. The general risk to Michigan is actually statistically calculable, by considering the proportion of the Earth's total surface area that is occupied by Michigan's land area. This is approximately 2.9×10^{-4}, or 0.00029. The frequency of global impact events can then be multiplied by this factor to estimate the frequency of impact events directly upon Michigan's land area. This results in the following estimates, on average, for different sizes of impacts upon Michigan's land itself:

- About 1 to 5 impacts per year that are larger than 100 grams (golf-ball size) – This may kill an individual that is struck, but since most space is not occupied by a person at any particular moment, such a thing is exceptionally rare, and (until the 2013 Chelyabinsk event) there have only been a couple of confirmed meteorite injuries worldwide. Instead, such incidents are more likely to simply cause limited property damage to a car or home, although their appearance in the sky can appear impressive and be accompanied by a sonic boom. Example: the Washtenaw County strike of 1997 (described in the "Significant Events" section).
- About one impact per century involving an object of more than 100kg (220 pounds), and about one impact every 1700 years involving an object of more than 1000kg (about 2200 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, but actual damages are likely to be only moderate unless a dense urban area or critical facility happens to be struck. Example: The Park Forest, IL event of 2003.

- About one impact every 350,000 years involving an object of more than 100,000kg (about 220,000 pounds) – This is the type of impact that resembles an atomic blast, exploding brightly in the sky and producing a very strong blast wave and severe winds that would cause extensive building damages and collapse at ground level, and would flatten forest lands. Example: the Tunguska, USSR event of 1908.

Although that last type of event is so rare that it need not be of general concern for Michigan, the probability of such an event affecting some part of the U.S. and potentially causing a national emergency is a bit larger, but still remote. It is most probable that the next such event will occur elsewhere in the world (on the order of about one or two events per century) and, although potentially devastating to that area, Michigan's role would probably only involve the voluntary donation of humanitarian aid to the disaster area. One foreseeable scenario could involve an asteroid impact in the ocean, which causes tsunami impacts upon a nearby coastline of the U.S. Waves could be more than 100 feet high from the impact of an asteroid with a diameter of 1300 feet, although that scale of event would only be expected about once in 80,000 years. These types of large events—the kind that would actually form sizeable craters and cause catastrophic national or global impacts (including major seismic and volcanic effects and global cooling from gaseous effects and dust, smoke, and particulates deposited into the atmosphere)—are rare enough that no extensive description will be provided here. Past events of that type are well-established in a geological timeframe, but not in a human historical timeframe.

Since meteors flare up brightly in the sky, some persons have speculated about whether meteorites could then cause wildfires to start up. As it turns out, this is generally not the case. The flaring fireballs are caused by ablation, as the very fast meteors encounter the atmosphere and friction generates heat, but a great amount of material typically burns away very quickly during this process, followed by miles of additional falling before ground impact, during which time the contact with blowing air exerts a cooling effect. The vast majority of meteorites are actually cool when they strike the ground. It would take a very large impact to bring a degree of heat that is capable of igniting a forest fire, and impacts of that size are very rare. That type of rare, large impact would also tend to flatten forest lands at the same time, with blast pressure and wind effects that could offset much of the fire risk. A large (Tunguska-sized) event would cause forest fires, along with huge amounts of other damage, and it is conceivable that a smaller-sized (but still very rare) impact might cause wildfire ignition if there are already drought conditions present that have greatly increased the natural wildfire risk. But in general, wildfires will not be caused by meteorites, and in view of these principles, the weight of evidence goes against the hypothesis that any of Michigan's historic wildfires were of meteoritic origin.

Part of the usefulness of this analysis is meant to involve the presentation of information that might alleviate confusion throughout Michigan's communities and residents, in case some event actually does occur, or some warning of an impending impact eventually be given out. In the former case, those who already have some information about meteors, and the potentially spectacular appearance of either sky or ground impacts, would have a means to make sense of an unusual bolide or impact event and would be less likely to mistake the event for a nuclear explosion, missile attack, or aircraft accident. A greater general awareness of the variety and nature of Michigan's hazards should eventually translate into a lessened demand for emergency services and information. For example, it might take only 30 seconds to explain to a knowledgeable citizen that a meteor impact caused a huge explosion in the sky (and an impact on the ground), whereas a less-knowledgeable citizen might seek 20 minutes of reassurance that the explosion was not nuclear, that the incident was not connected with a crashing airplane or a confidential military experiment, and so on. The provision of advance information that realistically describes and assesses the nature of unusual events can help to provide a framework in which the correct interpretation and response actions can be undertaken more quickly and efficiently.

In cases involving an official alert about an impending impact or potential impact, many persons would need information that allows them to understand the nature of the threat, and the techniques that may be used to prevent or mitigate its impacts. For example, there is an enormous difference between an alert that provides only a few weeks of notification, and one that has identified a need for action over the course of several decades. A *National Near-Earth Object Preparedness Strategy and Action Plan* was published in June 2018 as a result of extensive coordination between NASA, FEMA, and many other agencies. It calls for the development of communications plans and processes, to be implemented at the federal level. For more details within this document itself, please see https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf.

It should be realized that although the atmosphere and air around us seems to be "light" and only a small obstacle to movement under normal conditions, that air nevertheless has enough substance to sustain heavy aircraft in flight, to hold aloft huge thunderstorm clouds full of rain, allow fast-moving winds to cause damage, and so on. A meteor crashing into our atmosphere thus encounters enormous physical resistance, and releases tremendous amounts of energy as the result of the friction and impacts of plunging through large quantities of ever-thickening air layers at enormous speeds. This energy can result in large (and loud) blast waves, even if the meteor's trajectory is oblique enough to cause it to "bounce off" the atmosphere, rather than plunging through it and hitting the ground. For example, if a towel is wrapped around a bowling ball, a baseball can easily be bounced off the top of the bowling ball without leaving a dent or scratch in the bowling ball's surface, but it would still make a clearly audible noise and could crush any small insect that happened to be crawling underneath the towel. The towel can be seen as an analogy for our ecosphere on the surface of the planet, and the visible results of such an atmospheric impact could include great bursts of flame, damaging shock waves, severe winds, deafening noise, and disrupted weather patterns.

While this chapter is not intended to focus upon planetary life-ending scenarios (which are remotely possible but extremely unlikely to occur within our lifetimes), it does consider the possibility of a major impact (averaging once per century) that may cause either an area of widespread destruction within the United States, or an impact somewhere else in the world that may cause unusual effects to be felt in distant locations. If a Tunguska-sized event (see the 1908 entry in the list of Significant Events later in this section) were to affect a densely populated area, the results could be extreme enough to constitute a National Emergency. (Please refer to the human-related hazards chapter describing "Catastrophic Incidents," for more discussion about this, as well as the Nuclear Attack chapter, for more information about problems such as shock waves and mass fires which may arise from large blasts.)

This chapter also considers more common events that have fairly limited effects and damages, but may be associated with a significant degree of uncertainty about the area and population that could be struck by such impacts. Our public awareness of these possibilities has increased, resulting in a need for additional information to inform citizens about the actual risks, effects that different types of celestial impact may have, and present-day means to prevent or mitigate some of the worst possible impact scenarios. Even though the number of meteorite events has probably not increased in recent times, at least one type of vulnerability has increased in that an impact today is more likely to affect an inhabited area than it was in the distant past. The global population is nearly four times what it was a century ago, and (especially in the richer nations) this population growth has been accompanied by a much larger portion of the land area that has been built-up for urban uses. Just since World War II, the population of the United States has more than doubled, and even in areas with a relatively stable population, residential neighborhoods take up a lot more space today than they previously had in the period of time before the suburban "explosion." A random impact point today is more likely to affect lands that are developed to at least a moderate residential capacity, which could result in many casualties.

Although most comets and asteroids have very consistent trajectories that change only very slowly, in terms of human history, Earth-threatening space bodies still remain undetected by humans. There is also the possibility that their traditional orbits may be unexpectedly disrupted by collisions with other bodies, or by gravitational effects such as that exerted by Jupiter on Comet Shoemaker-Levy 9, which caused that comet's eventual impact into the planet. "Jupiter-family comets" are those in which a normal (safe) orbit of a comet or asteroid may be "suddenly" altered in a manner that causes it to become a threat to Earth. In either case (a newly discovered object or one whose course is changed), the possibility exists that a serious impact threat may suddenly be discovered. However, extensive observations and calculations have been taking place to identify and track all potential threats of this kind. For more information on efforts to detect and track all potentially hazardous asteroids, please visit the NASA planetary defense website at https://www.nasa.gov/planetarydefense.

It is likely that the next major meteorite impact will occur somewhere in the world other than Michigan, and that Michigan's role as part of the United States would at most involve the provision of support to the impacted area and its surroundings. If a major impact happens to occur in North America, then state-level mutual aid may result, and possibly even the intake of evacuees, as had taken place during the Katrina and Rita hurricane disasters of 2005. Several recent bolide events have been documented in the Great Lakes area, but have caused no known damage to the state's area during its European historical era over the past four centuries. It is possible that certain unexplained seismic events reported in the Upper Peninsula more than two centuries ago may have been caused by celestial impacts. For the most part, however, the meteorite hazard is important to know about mainly for preparedness and informational usefulness, rather than due to an actual pattern of severe damaging effects upon Michigan.

Impact on the Public, Property, Facilities, and Infrastructure

A celestial impact from an object that is either sufficiently massive or fast-moving can have an effect that is comparable to nuclear blasts, in terms of the amount of energy released in the form of pressure (shock) waves and thermal effects (heat/fire). Additionally, major earthquake activity would be felt in areas that normally wouldn't have had to worry about such effects. An impact into major water bodies can cause intense tsunamis to occur, and severe winds could also result in extensive physical damages many miles (or hundreds of miles) away from the main impact site. Depending upon the mass and velocity of the meteorite, the impact on the public may range from the barely noticeable to the complete destruction of the entire area, with the most powerful impacts having effects similar to those described for nuclear attack (minus the radioactive fallout and electromagnetic pulse), earthquake, severe winds, wildfires, and storm seiches (shoreline flooding), all described in their own sections in this document. Severe impacts are so rare that they have not been experienced at all within Michigan's history. The actual pattern of impacts to date has involved very limited damage to private property, and no impedance of critical facilities or infrastructure. If the historical pattern of damage were to have affected facilities and infrastructure instead of the occasional private structure, the impacts of a typical event would still not normally be very great. For an example, please refer to the description of the Park Forest, IL event within the "Significant Events" section in this chapter. That case illustrates the worst meteorite damages documented so far within the United States, and although it caused some damages, there were no injuries and it was at most a moderate-level emergency event. Any worse situations are so rare as to effectively be discounted from consideration within state-level plan that involves a 5-year implementation and update timeframe.

Impact on the Economic Condition of the State

Although a rare, catastrophic-level event within Michigan would obviously be crippling to its economy, the types of events that are realistically expected within the next few decades are not expected to have any significant effect upon Michigan's production or market-oriented activities. Certain types of costs are likely whenever there is an emergency alert in response to a particular event or threat, but those tend to be well within the normal range of activities routinely undertaken by agencies who deal with emergencies.

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

A small impact incident would not be likely to cause much risk for responders, unless the impact was upon a structure that became weakened to the point of potential further collapse. The presence of hazardous materials should be expected at an impact site that involves space-vehicle components, or in which key agricultural, industrial, or infrastructure facilities have been heavily damaged. Catastrophic impact incidents are extremely rare, but may result in search and rescue operations, as well as various firefighting operations and infrastructure failure impacts dealt with simultaneously. A catastrophic impact event could require extensive use of mutual aid and state/federal disaster and emergency assistance, with the possibility that all normal response resources would be disabled within the area of impact, and would need to be replaced by resources from adjacent local areas, or even from beyond the state. Underground sheltering would be a useful way to increase the odds of survival from the wind/shock/frame effects of a huge bolide event, which would likely pass quickly and then enable responders to deal with rescue operations, fires, infrastructure failures, and the organization of mutual aid. Fortunately, the impacts that are statistically expected to occur (within the time-frame of our lifetimes, or shorter) are not expected to have any impact upon service delivery or continuity of operations.

Impact on the Environment

An extremely large impact, even if not in Michigan, could cause a National Emergency situation to arise, which Michigan may have to help to respond to and recover from (please refer to the chapter on catastrophic incidents). A direct meteorite impact on land could destroy an entire area, and cause fires, earthquakes, and other hazards for a large area around the impact. The same types of effects can also result from the atmospheric blast and heat impacts of a large bolide event, even if the celestial body itself does not strike the ground. A large impact in one of the Great Lakes could cause substantial flooding, seiche, and erosion impacts along areas at or near the lake's coasts. Fortunately, all of these events are so rare that they are not expected to occur in Michigan within the foreseeable future. Instead, the likeliest source of environmental impact from this hazard would be the presence of hazardous materials within the debris from a crashed space vehicle or large satellite. The 1978 incident involving the Cosmos 954 satellite or the 2018 alert involving the Tiangong-1 space station are examples of such threats, in which the general public should be informed to officially report and not to handle any debris found from such devices and space vehicles.

Impact on Public Confidence in State Governance

If a major impact occurs in Michigan or the Great Lakes, some persons might feel disgruntled if no advance warning was able to be provided. Familiarity with this type of hazard has probably grown during the past several years, but still might not be widespread. One of the reasons that this hazard is now being included in state plans is to help provide information that will improve people's understanding of it. Moreover, since a significant celestial impact event could easily be mistaken for a nuclear blast, a missile or aircraft incident by many persons, an educational process could be useful in overcoming the possible negative effects caused by such assumptions. For example, if a large bolide is seen, or a meteorite actually damages an area, it will be helpful for people to have been familiar with what the event actually might be, rather than assuming that it was a deliberate hostile action that may involve secondary radiation and security impacts, or assuming that a mass evacuation or escalated level of security alert may be needed. Rather, if it is understood that there is a natural phenomenon that in some cases may resemble that of a large explosion, then people's behavior and attention can be more properly guided toward activities and attitudes that are appropriate for a natural disaster rather than those for a homeland security alert.

Significant Events

NOTE: Although many of the events listed here had occurred outside of Michigan, some of them were nevertheless large enough to have direct impacts upon Michigan, due either to the sheer magnitude of the impacts or to the widespread nature of an alert. Some of the listed events occurred an extremely long time ago, while some are extremely small but recent events within Michigan, to give an indication of the range and magnitude of what is possible. Some events merely describe "close calls" and events whose limited impact at the time would have been much greater had occurred at a slightly different time or location. (Our current development density is much greater and involves much larger populations than had been present in the past.) To help indicate the range of threat posed by the hazard, selected events outside of Michigan are included in order to represent the largest known events or threats, while events involving Michigan tend to represent the typical level of recorded impacts in the state.

<u>Ancient-Archaic Events</u>

Approximately 1.8 billion years ago – Sudbury, Ontario

One of the largest known impacts took place around Sudbury, Ontario, leaving impact effects that measure 155 miles in diameter. The impact site's geological structure had been discovered in 1883 but not fully explained until 1964. Debris ejected from the impact site was thrown as far as the Midwestern U.S., including Michigan. This was an impact of global significance. The heat directly generated by this cataclysmic impact would have killed any humans within at least 500 miles from the impact site (which includes all of Michigan), if humans had been living in the area at the time.

Approximately 450 million years ago – Cass County

An impacting object struck what is now southeastern Cass County (Calvin Township), and left effects that are still geologically detectable today. The event is known as the Calvin 28 crypto-explosive disturbance, and the Calvin impact area is about 5 miles in diameter, located mid-way between the Village of Vandalia and the Michigan-Indiana State Line. About the same time (in geologic terms), a much larger impact occurred on what is now the northern coast of Lake Superior (the Slate Islands in Ontario) and formed an impact structure about 19 miles in diameter. The map above shows the Cass County impact area (Source: University of New Brunswick's Earth Impact Database website).

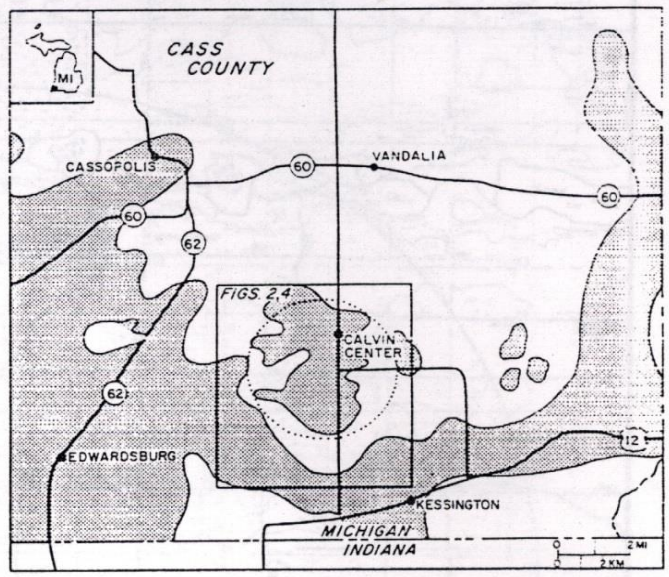


Figure 1. Map of the southeastern part of Cass County, Michigan, showing location of the Calvin 28 cryptoexplosive disturbance (dotted circle). Shaded area, Ellsworth Shale; unshaded area, Coldwater Shale.

Several hundred million years ago – Indiana and Ohio

A Kentland, Indiana impact leaves a crater estimated to have originally measured 8 miles in diameter. A smaller (5-mile diameter) Ohio impact later had Native American burial mounds built on its site, and is now known as the Serpent Mounds.

Approximately 65 million years ago – Global

A large impact on the Yucatan peninsula of Mexico took place at the end of the Cretaceous (geological) period. The impact area is known as Chicxulub, and although it is not evident to ordinary observers today, the ancient impact structure was geologically measured at approximately 100 miles in diameter. The Chicxulub impact has been considered to be a direct or contributing cause of the extinction of many prominent species of life on Earth at the time, including the large reptilian dinosaurs. There may be galactic cycles that make major, species-threatening impacts more likely during certain periods of time than others, with mass extinctions seeming to correlate with intervals of between 26 and 32 million years in length (over the past 250 million years), perhaps caused by some celestial event that sweeps Oort Cloud or Kuiper Belt objects from the outer parts of the Solar System toward Earth, or by the effects of a nearby star going supernova. Certain regions of the Milky Way Galaxy, which the Sun passes through on a grand cycle that repeats every 225 to 250 million years as it orbits the galaxy's center, may expose the Earth to more celestial bodies than are normally seen in the Solar System during the more stable, intervening time periods. Since the most recent mass extinction period was about 11 million years ago, there is no expected threat of this type during our lifetimes. Recently, evidence has been claimed for an even larger impact site, at around the same time, off the west coast of India. A surge in volcanic activity took place in the same geological time frame as the impact events and thus may have been a result of them.

About 37 million years ago – Ontario

Another impact occurred near the huge Sudbury, Ontario site (see the first event listed in this section) and today is known as Lake Wanapitei, which is just under 5 miles in diameter.

About 50,000 years ago – Arizona

A major impact formed an impact structure now known as the Barringer Meteor Crater in Arizona, which measures 570 feet deep and 1.2 miles in diameter. Evidence suggests that it was formed by an iron-nickel asteroid measuring about 100 feet in diameter, moving with an original velocity of 45,000 miles per hour. The impact probably caused hurricane-force winds more than a dozen miles from the impact site, the formation of a huge cloud of dust and debris, and the displacement of more than 300 million tons of rock.

Circa 900 C.E. or later – Alberta

An impact near Whitecourt (Alberta, Canada) left a crater that is more than 100 feet wide and is now known as the Brenham Crater.

Circa 1000 C.E. or later – Kansas

A Haviland, Kansas impact leaves a crater about 50 feet wide. During the same approximate time period, an impact occurred at Sobolev, Russia, leaving an impression about 3 times as wide.

Modern Events

July 1, 1770 – International, "Lexell's Comet"

Lexell's comet (D/1770 L1) was computed by astronomers as having passed only about 1.4 million miles from Earth (less than 6 times the average distance of the Moon, or about 1.5% of the distance to the Sun). This was the nearest such Earth encounter to be measured astronomically rather than in terms of its actual impact effects as a meteorite (until the very recent tracking of smaller and slower objects). Now considered to be a "lost comet," its orbital period had been calculated at the time (by Lexell) to be 5.6 years, eventually leading to the idea that space objects may be propelled toward Earth by a gravitational encounter with Jupiter—a circumstance that is one of the potential sources of comet and asteroid impact threats that would provide little or no advance warning. The comet was initially observed on June 15, 1770, and was last observed moving away from the Sun on October 3 of the same year.

1863 – Arabian Peninsula, "Wabar Craters"

An event more than 300 miles southeast of Riyadh, Saudi Arabia, left an impact site of probably at least five craters (Wabar Craters) in the desert, one of which was more than 100 meters in diameter. The impact compressed desert sand into rock. The date of the event is approximate, because the impact site itself was not reported until 1932, but was then considered in retrospect to match up with fireball reports that had come from the city of Riyadh in 1863. It has been calculated that the impact occurred with the force of a Hiroshima-sized atomic bomb, but fortunately in this case, it affected only an uninhabited desert area. This is the first in a series of major modern impacts that tend to occur about every 50 years, on average.

June 30, 1908 – Russia, "Tunguska Event"

A large impact event occurred in Tunguska, Russia (in Siberia), in which a large object blasted into the atmosphere in a manner that created a forceful, spectacular, and destructive impact. Although the object was evidently destroyed in the air (leaving no impact crater like so many rocky meteoroids have), the force of this destruction has been estimated as equivalent to between 5 and 30 megatons of TNT, flattening an estimated 80 million trees over an area of approximately 830 square miles (a surface area equivalent to that of a disc 32½ miles in diameter). Unusual levels of acid rain followed the bolide event. Research from Cornell University concluded that the event was "very likely" a comet impact (with most of its mass in the form of ice that would dissipate in the atmosphere), since high-altitude noctilucent clouds (which normally occur only with certain types of icy, high-altitude conditions) were sighted across Europe for several days (as much as

3,000 miles away), and caused the night skies to glow. Estimates about the frequency of this scale of impact vary from once every thousand years to once per century. This is the second in a series of major modern impacts that tend to occur about every 50 years, on average.

February 12, 1947 – Russia, "Sikhote-Alin Event"

A bolide event that included many meteorites took place in far-eastern Russian Siberia (Sikhote-Alin), fortunately occurring in a relatively isolated and undeveloped area, between China and Japan. The event was reported as a fireball, brighter than the Sun, at 10:38 am (local time). As the bolide descended at an angle of 41 degrees, it left a trail of smoke and dust 20 miles long that remained visible for several hours. The meteorite was broken into fragments as it fell at roughly 31,000 miles per hour. Upon reaching an altitude of about 3.5 miles, the bolide culminated in a giant explosion, scattering its remaining debris over an impact area of about one-half square mile. The largest impact crater in this area measured 85 feet wide and 20 feet deep. The total mass of all the meteorites from this event has been estimated as just under 1,000 tons, with the largest fragment later weighed at 1,745 kilograms and displayed in Moscow. This is the third in a series of major modern impacts that tend to occur about every 50 years, on average.

March 30, 1954 – Alabama Meteorite Injury

A woman was injured at home by an 8-pound meteorite that had crashed through her roof and rebounded to strike her, injuring her left hip, arm, and abdomen. This has been the only confirmed U.S. meteorite injury to date.

September 17, 1966 – Lake Huron Bolide

A bolide event occurred over Lake Huron, Michigan, involving an air blast estimated as the equivalent of 1/3 ton of TNT, approximately 8 miles above the surface of the water. Although no material from a meteorite was found to help determine more information about the size and characteristics of this meteor, this is not surprising since the location of the event probably placed any meteorite remnants at the bottom of Lake Huron. The bolide illuminated the whole of south-western Ontario and adjacent regions at about 8:48 pm, as it was seen traveling northwest across Lake Erie and the tip of Ontario, toward Lake Huron. At least a dozen loud "detonations" were reported from the Ontario area near the lake a few minutes after the fireball's passage. Astronomers later calculated that the meteor was about 8 miles up as it crossed over Lake Huron, and probably reached the lake's surface fewer than 18 miles west of the city of Kincardine, Ontario. The meteor was traveling about 10.6 miles per second (38,000 miles per hour) and was brightly luminous for at least 10 seconds.

February 8, 1969 – Pueblito de Allende, Mexico, Meteorites

A large shower of stony meteorites fell near a village in the Mexican border state of Chihuahua. More than two tons of meteorites fell in that incident.

August 10, 1972 – Western U.S. and Canada, Meteor

Since the angle of approach varies widely, some meteors simply graze or bounce off the atmosphere. In 1972, such a fireball was seen in the sky from Utah to Alberta.

January 1978 – International, "Cosmos 954" Satellite Crash

A Soviet satellite, Cosmos 954, which had been launched in September of 1977, was being monitored by U.S. agencies and by November was found to have a decaying orbit. By January, it had become apparent that the satellite had lost its attitude stabilization system. Such satellites were known to be powered by small nuclear reactors, using fuel that was 90 percent enriched Uranium-235. Thus, whenever and wherever this satellite fell to Earth, it had the potential to contaminate things and persons coming into contact with it. The U.S. National Security Council arrived at an estimate that there was only about a 1 in 10,000 chance that a human would be injured in the crash, but because of the political aspects of an enemy nation's nuclear satellite crashing onto friendly territory, it became important to treat the incident with more weight than what that small risk might normally be credited with. Operation Morning Light was thus created, in December of 1977, with the Department of Energy given lead responsibility for the possibility of a domestic crash site. Even though a crash site for the projected landing orbit was only supposed to have an 8% chance of being on land, plans were made for such a contingency, which would involve the finding of radioactive debris, decontamination of affected land areas, and the treatment of any persons within an unsafe distance of such debris. After about 10 days of careful inquiries with the Soviet government, various types of confirmation were received about the satellite's nature and condition. On January 24, the satellite entered the atmosphere over Queen Charlotte Island, British Columbia, and at 6:53 am, finally crashed near the Great Slave Lake, just north of the Province of Alberta, in Canada. Aircraft and Nuclear Energy Search Teams were then dispatched to Canada, to assist with clean-up operations.

July 11, 1979 – International, "Skylab" Crash

The Skylab Space Station, which had been put into orbit in 1973 but abandoned in 1974, had its orbit finally deteriorate to the point where it plunged to Earth. Delays in the launch of the Space Shuttle program had prevented the station from being salvaged by restoring it to a sustainable orbit. Instead, considerable uncertainty was expressed in the media about where the station might return to Earth, and with what potential for destructive impacts. Skylab re-entered the atmosphere on July 11 and the calculated area at-risk turned out to be in the Southern Hemisphere around the Indian Ocean. Debris impact areas on land were identified in Western Australia, the largest fragment being a heavy metallic object about 5 feet in length.

October 9, 1992 – New York, "Peekskill Meteorite"

The "Peekskill Meteorite" damaged a parked car in Peekskill, New York, after creating a bright fireball in the sky that was seen across several states. The original meteor (estimated to be 1 to 2 meters wide) had fragmented at a height of about 41.5 km, then again about 20 seconds later, until the largest portion was under a foot in diameter.

July 15 to 24, 1994 – International, Comet Shoemaker-Levy Impact

Comet Shoemaker-Levy 9 crashed into the planet Jupiter, after being broken into 21 fragments by gravitational forces, and caused enormous impacts, which quickly became visible to telescopes on Earth. (The impact took place on the far side of Jupiter, but the planet quickly rotated and allowed the impact points to be visible). The energy released by this impact was estimated as greater than many thousands of 50-megaton nuclear bombs, as the comet's debris was vaporized and released enormous amounts of heat, temporarily exceeding the amount given off by the entire (exothermic) planet as a whole and also exceeding the temperature of the surface of the Sun. The impacts caused atmospheric spots to appear that were comparable in size to the diameter of the Earth. The comet had first been detected by astronomers only 17 months prior to its impact. It was calculated that on the comet's previous approach toward Jupiter on July 7, 1992 (which tore it into fragments), its distance from the planet was only 16,000 miles (less than the circumference of the Earth). It was estimated that the largest fragment of the comet may have exceeded 2 miles in diameter. As a result of this impact, the U.S. Congress asked NASA to propose how to identify and track all large space objects with the potential to impact the Earth. A funded agency mission then followed, to identify all sizeable asteroids and comets passing near the Earth's orbit.

March 19, 1996 – International, Near-Earth Object

A celestial "close call" involved asteroid 1996 JA1 (large enough to cause catastrophic damage), which came within 280,000 miles—nearly as close as the Moon.

September 1, 1997 – Salem Township (Washtenaw County), Meteorite

After numerous persons reported a bright daylight meteor and sonic booms, the meteoric object broke up into at least three parts. One meteorite (called the "Worden Meteorite") then struck a residential garage roof (in Salem Township, midway between the villages of Salem and Brookville), as the family was nearby working in their back yard. They had heard a whistling sound passing overhead, and then investigated a boom and crash, finding the garage full of plaster dust, pieces of drywall, and insulation. There was a dent in the roof of a car that was parked in the garage, and the meteorite itself was found on the floor nearby, along with a couple of associated fragments. The large meteorite weighed about 1.5kg, and its dimensions were about 6 inches long, 4 inches wide, and an inch thick.

June 14, 2002 – International, Near-Earth Object

Another "near miss," in celestial terms, as asteroid 2002 MN passed within 75,000 miles of the Earth, but wasn't spotted until three days after it had already passed. An impact from the asteroid would have been of Tunguska-like force (see the description for that 1908 event).

Feb 1, 2003 – National, Space Shuttle Columbia Explosion Debris Fields

The Space Shuttle Columbia broke apart violently when returning from a mission, causing a widespread alert about the potential for falling debris across the southwestern United States. More than 2,000 debris impact sites were eventually reported, but fortunately these were predominantly in sparsely populated areas. NASA issued warnings that the shuttle debris could contain hazardous materials and that it should remain untouched (and instead be reported to authorities upon discovery).

March 26, 2003 – "Park Forest Meteorites" in Suburban Chicago, Illinois

Hundreds of small meteorites fell across residential areas in the suburbs of Chicago. Although meteors were visible from Michigan and the meteorites landed fairly close to Michigan territory, it must be noted that this event is highly unusual, having been described as "the most densely populated region to be hit by a meteorite shower in modern times." The original meteoroid was calculated to have been between 1 and 7 thousand kilograms (possibly more) before it broke apart in the atmosphere. About 30 kilograms of meteorite fragments were recovered, the largest of them weighing 5.26kg. Numerous holes were punched through windows, roofs, and ceilings in homes, and also a fire station. One roof hole was caused by a meteorite that weighed only 545 grams. There were about 18 documented fragments comparable to that size, or larger, across a couple of square miles of neighborhoods.

September 20, 2007 – Southern Peru, Meteorite

After a loud explosion was heard, residents of an isolated village found a large crater measuring 41 feet in diameter near Lake Titicaca and filled with water. A 1.5 magnitude earthquake was detected in the area. The unusual aspect of this incident is that many villagers subsequently reported symptoms such as headaches and nausea. It has been proposed that the impact of a meteorite, along with the heat that was generated, caused the release of toxic fumes from the ground.

February 4, 2011 – International, Near-Earth Object

An asteroid designated as 2011 CQ1 was the closest "near miss" on record so far, as this object came only about 3,400 miles away from Earth. Earth's gravitational pull at that distance was strong enough to change the asteroid's trajectory by 60 degrees, indicating just how close the object was, in astronomical terms.

June 27, 2011 – International, Near-Earth Object

An asteroid designated as 2011 MD passed only 7,600 miles above the Earth's surface. It was discovered by LINEAR and its size was less than 20 meters in diameter. The object was close enough to markedly change its trajectory as it passed.

February 15, 2013 – Chelyabinsk, Russia, Meteorite and Shock Wave

A brightly glowing meteor became visible in the sky, and was soon followed by a shock wave that shattered windows throughout a wide portion of the major Russian city of Chelyabinsk. Over 1,000 persons were reported as injured by shattering glass throughout the city. Damage to a couple of industrial facilities also resulted, as the blast wave caused large doors to buckle and weakened structural components to the point of collapse. The meteorite's impact location was later located in a rural area, much reduced in size from the body that had originally blazed through the atmosphere. This was the first historical incident in which many injuries occurred as a result of this type of hazard. The physical size of this meteorite was much smaller than the Sikhote-Alin event of 1947 or the Tunguska event of 1908. It is fortunate that only the meteoritic blast wave was felt by the city, but this event is strongly indicative of the extent of damage that this hazard can cause. The destruction could have been far worse if the trajectory of the meteorite had been different. Meteorite fragments weighing about ¾ ton were later retrieved from the impact site at Chebarkul Lake, about 40 miles away. The meteorite was determined to have originally been one of the Apollo Near-Earth Asteroids, approximately 60 feet in its original size and with a mass of about 11,000 tons before it started to burn up in the atmosphere. The total impact energy was calculated by NASA to be the equivalent of about 440 kilotons of TNT. Purely by coincidence, many persons were already thinking about asteroids, because they were anticipating the near-Earth approach of an already-known body, asteroid 2012 DA14, which passed harmlessly by the Earth about 16 hours later, with a completely different (and thus unrelated) approach trajectory than the meteorite had shown. The Chelyabinsk meteorite had been traveling west-northwest above the earth's northern hemisphere, approaching from the general direction of the Sun, but the path of asteroid 2012 DA14 was going in a nearly perpendicular direction, and at its nearest it was about 17,000 miles away from the Earth's surface. The temporal proximity of the two bodies was mere coincidence, although 17,000 miles is quite close, in celestial terms, for a 150-foot diameter asteroid to pass by, allowing it to be clearly photographed from the Earth during its passage. This may be considered the fourth in a series of major modern impacts that tend to occur about every 50 years, on average—three of which have occurred in Russia. Damages were estimated at $33 million.

November 1, 2016 – International, Near-Earth Object

This was another "near miss" event, involving asteroid 2016 VA, which was discovered only the day that it approached Earth. It passed by at a distance of about 48,000 miles, four times closer than the moon. The size of that Aten asteroid was estimated as similar to the one that landed near Chelyabinsk in 2013.

January 16, 2018 – Southern Michigan Bolide and Meteorites

A meteor flared up very visibly within the early night sky. In some places, loud sonic booms were reported. Five miles southwest of New Haven (Macomb County), a seismic measurement of magnitude 2.0 was reported at approximately the same time as the meteor passed by, which might indicate the loudness of the sounds from the sonic booms (although a 2.0 seismic event is very weak, as described in the chapter on Earthquakes, q.v.). Although the bolide had been reported by hundreds of persons from seven states, this was predominantly a Michigan event. A strewn field with multiple meteorite fragments was soon found within Hamburg Township (Livingston County), and the meteorite samples found there are named Hamburg, after that community. All meteorite fragments were quite small, the largest of them weighing 102 grams. Twenty meteorite pieces were found, with an estimated total mass of 1 kilogram. No known damage resulted from this event.

March-April, 2018 – Tiangong-1 Space Station Alert

In March, the orbit of a Chinese space station, Tiangong-1, had decayed enough that it was clear that it was plummeting into the atmosphere and that some of its debris could survive the re-entry process, posing a hazard if it struck one of Earth's land areas. In addition to the problems of life and property damage from any large metal components as they landed, Tiangong's corrosive fuel, hydrazine, would have posed a contamination risk if tainted fragments fell in populated areas. The likeliest paths for Tiangong's decaying orbits had been calculated and showed that there was a higher chance of debris falling within particular mid-latitude zones of the Earth, which included the most heavily populated parts of southern Michigan. It was estimated that some parts of the space station might weigh as much as 220 pounds when crashing to Earth. Therefore, the State Emergency Operations Center went into a monitoring mode to be ready to coordinate activities if Tiangong's impact area did turn out to involve Michigan. The Michigan Satellite Reentry Response and Recovery Plan was utilized and updated in March, and fortunately it became clear by early April that the actual crash site would not be in Michigan. The remains of the Tiangong-1 space station all landed safely in the South Pacific Ocean on April 2.

December 18, 2018 – Bering Sea Bolide

The most powerful meteor since the 2013 Chelyabinsk event occurred above the Bering Sea. A meteor exploded into a large fireball and unleashed energy that was calculated to be 10 times that of the 1945 atomic bomb detonation at Hiroshima. The uninhabited area meant that no harmful effects occurred to persons or property. The event was documented by two NASA instruments on a satellite, and these images were widely distributed in media reports and at NASA's website.

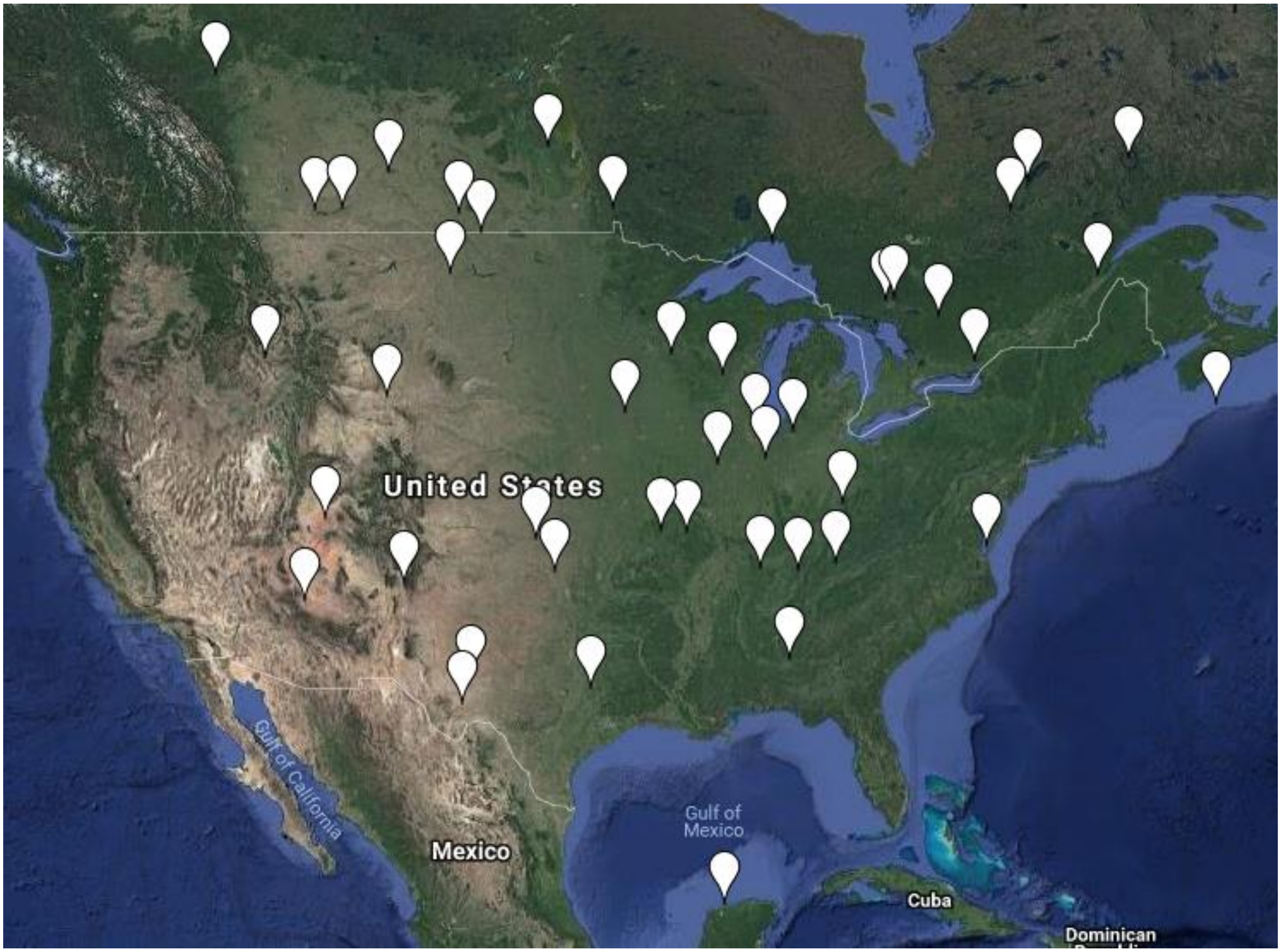


Image showing identified impact crater sites across a portion of North America

Source: The Earth Impact Database website: http://www.passc.net/EarthImpactDatabase/New%20website_05-2018/NorthAmerica.html)

Programs and Initiatives

In recent decades, a number of programs and research projects have examined this hazard, sought and documented additional information about near-Earth objects (NEOs), and developed models of the potential risks and effects of an impact. Although most historic meteors went unnoticed (or unrecorded as such) in earlier times, today's satellite systems allow practically every meteor to be detected as it ignites in the atmosphere. The following listings include a set of detection programs, and a couple programs relevant to event response.

Near-Earth Object Detection Programs

Various agencies and universities have set up or coordinated in the creation of detection programs designed to locate and measure the characteristics of Near-Earth Objects. The goal of NASA's 1998 Near-Earth Object (NEO) Observations Program was to locate at least 90 percent of all NEOs that are at least 1km in diameter. During the current decade, about 95% of the newly discovered Near-Earth Objects were discovered through NASA's detection program—especially the Pan-STARRS and Catalina Sky Survey programs, which together accounted for 90% of new discoveries. Most of the detection activities involve systematic telescope surveillance, measurements, complex modeling, and orbital projection. Programs include the following:

- Catalina Sky Survey program – Based in Arizona, this NASA-funded project has a mission to discover and track NEOs in an effort to meet the congressional mandate of cataloguing at least 90 percent of NEOs larger than 140 meters in diameter, and thus to help identify potentially hazardous asteroids.
- Lincoln Near-Earth Asteroid Research (LINEAR) project – Based at MIT, funded by NASA and the USAF.
- Lowell Observatory NEO Survey (LONEOS) program – Centered in Flagstaff, Arizona.

- Near-Earth Asteroid Tracking (NEAT) system – Operated by NASA's Jet Propulsion Laboratory in conjunction with the U.S. Air Force on Mt. Haleakala, Hawaii.
- Palomar Planet-Crossing Asteroid Survey.
- Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) – Hawaii program supported by the U.S. Air Force. Detected the Oumuamua interstellar object in October 2017.
- Raptor – A stereoscopic observation system operated by Los Alamos National Laboratory.
- The Sentry System – Operated by the NASA Jet Propulsion Laboratory.
- Spaceguard – Started by NASA in 1998, this is a global survey devoted to asteroid analysis.
- The Spacewatch program – Run by the University of Arizona in Tucson at Kitt Peak, Arizona.
- Various space missions have occurred to gather more information about asteroids and comets, and more are planned for the future, especially OSIRIS-REx, which is orbiting the asteroid Bennu and will gather useful physical evidence within a couple of years. Some past missions have included Vega 1, Vega 2, Giotto, Suisei, and Sakigake (1986 flybys of Halley's Comet); Galileo (1995 observations of the Shoemaker-Levy comet impact); Near-Earth Asteroid Rendezvous (NEAR—asteroid investigations from 1997 to 2001); Deep Space 1 (comet rendezvous in 2001), Stardust (comet material collected and returned for analysis in 2006); Hayabusa (aka MUSES-C – asteroid landing and probing form 2005 to 2010); Rosetta (asteroid flybys from 2008 to 2010, and comet interception mission scheduled for 2014-2015); and Deep Impact/EPOXI (comet rendezvous in 2005 and flyby in 2010). Additional missions can be expected to provide even more information.

More information about these programs can be found at their associated web sites on the internet.

NASA Asteroid Redirect Mission

This program had the goal of detecting, capturing, and redirecting an asteroid into a safe orbit. Its primary activities were discontinued in late 2017, but some aspects of its associated elements will continue. For more details, refer to the NASA overview presentation at https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission.

Planetary Defense Coordination Office

This NASA program includes elements to detect potentially hazardous comets and asteroids, and to track and characterize them, but also is responsible for leading coordinated planning for a federal-level response to any actual event. Its web site is found at https://www.nasa.gov/planetarydefense/overview.

The Double Asteroid Redirect Test (DART)

NASA is developing a mission to test technologies that could potentially redirect an asteroid that presents some level of risk to the Earth. The DART mission will involve the first demonstration of a kinetic impact technique to change the trajectory of an asteroid in space. Please see https://www.nasa.gov/planetarydefense/dart for more information.

Meteorites and impacting object hazards have not yet been identified as among the most significant hazards in any of Michigan's local hazard mitigation plans.

Hazard Mitigation Alternatives for Celestial Impacts

- Advance planning for catastrophic scenarios. For example, the U.S. Air Force used an asteroid strike for its December 2008 Interagency Deliberate Planning Exercise. The after-action report for that exercise was posted online at https://cneos.jpl.nasa.gov/doc/Natural_Impact_After_Action_Report.pdf. An asteroid detected at a distance equivalent to that of the Earth's Moon could still give 8 hours of advance warning for the evacuation of coastal areas (to mitigate loss of life from a projected sea impact).
- Continued surveillance and analysis of Near-Earth Objects, and support for agencies that are engaged in such work. For example, since 1975, the Department of Defense has amassed extensive data about meteors entering the atmosphere, finding that hundreds per year explode in the atmosphere with explosive energy of at least 1 kiloton.
- Existing technologies could allow the diversion of a large asteroid or comet, if a sufficient lead time is available. Objects on a collision-course, with an impact date from 10 to 100 years in the future, might be diverted or reduced by the use of conventional rockets and explosives. (Such action would be coordinated in the United States by the Departments of Defense and Energy, and would likely include international partners.) Explosives would require knowledge of an object's composition to be effective. Laser targeting could be used to change an object's velocity, although weeks or months may be required to obtain a large enough effect. With a sufficient amount of

warning time (on the order of years), other mitigation techniques could include attaching a solar sail to the object, an interception/landing mission, and/or use of the "Yarkovsky effect" in which asteroid temperatures could be changed to affect its orbit.

- Various space missions have occurred to gather more information about asteroids and comets, and more are planned for the future. Some past missions have included Vega 1, Vega 2, Giotto, Suisei, and Sakigake (1986 flybys of Halley's Comet); Galileo (1995 observations of the Shoemaker-Levy comet impact); Near-Earth Asteroid Rendezvous (NEAR—asteroid investigations from 1997 to 2001); Deep Space 1 (comet rendezvous in 2001), Stardust (comet material collected and returned for analysis in 2006); Hayabusa (aka MUSES-C – asteroid landing and probing from 2005 to 2010); Rosetta (asteroid flybys from 2008 to 2010, and comet intercept mission scheduled for 2014-2015); and Deep Impact/EPOXI (comet rendezvous in 2005 and flyby in 2010). Additional missions can be expected to provide even more information.

Appendix A: Presidential Declarations in Michigan: 1953-2019*

Date of Incident	Type of Incident	Affected Area	Type of Declaration / Federal ID Number**
6/16/18-6/18/18	Severe storms, flooding, landslides, mudslides	3 counties: Gogebic, Houghton, Menominee	Major Disaster (4381)
6/22/17-6/27/17	Flooding	4 counties: Bay, Gladwin, Isabella, and Midland	Major Disaster (4326)
8/11-13/14	Urban flooding	3 counties: Macomb, Oakland, and Wayne Co.	Major Disaster (4195)
4/25/14	Contaminated water	City of Flint (Genesee Co.)	Emergency (3375)
4/16/13-5/14/13	Flooding	16 counties: Allegan, Baraga, Barry, Gogebic, Houghton, Ionia, Kent, Keweenaw, Marquette, Midland, Muskegon, Newaygo, Ontonagon, Osceola, Ottawa, and Saginaw Co.	Major Disaster (4121)
7/14/08	Thunderstorms, flooding	12 counties: Allegan, Barry, Eaton, Ingham, Lake, Manistee, Mason, Missaukee, Osceola, Ottawa, Saginaw, and Wexford Co.	Major Disaster (1777)
9/07/05	Hurricane evacuation	All 83 counties	Emergency (3225)
5/20/04-6/8/04	Thunderstorms, flooding	23 counties: Barry, Berrien, Cass, Eaton, Genesee, Gladwin, Ingham, Ionia, Jackson, Kent, Livingston, Macomb, Mecosta, Muskegon, Oakland, Ottawa, Saginaw, Sanilac, Shiawassee, St. Clair, St. Joseph, Washtenaw, and Wayne Co.	Major Disaster (1527)
8/14-17/03	Electric power failure	14 counties: Calhoun, Eaton, Genesee, Hillsdale, Ingham, Kalamazoo, Lapeer, Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Co.	Emergency (3189)
4/10/02-5/9/02	Flooding	6 counties: Baraga, Gogebic, Houghton, Iron, Marquette, and Ontonagon Co.; plus the Keweenaw Bay Indian Community	Major Disaster (1413)
12/11-31/00	Blizzard, snowstorm	39 counties: Allegan, Barry, Bay, Berrien, Branch, Calhoun, Cass, Clare, Clinton, Eaton, Genesee, Gladwin, Gratiot, Hillsdale, Huron, Ingham, Ionia, Isabella, Jackson, Kalamazoo, Kent, Lapeer, Livingston, Macomb, Mecosta, Midland, Montcalm, Muskegon, Oakland, Osceola, Ottawa, Saginaw, St. Clair, St. Joseph, Sanilac, Shiawassee, Tuscola, Van Buren, and Washtenaw Co.	Emergency (3160)
9/10-11/00	Urban flooding	2 counties: Oakland and Wayne Co.	Major Disaster (1346)
5/2-10/99	Wildfire	2 counties: Marquette and Mackinac Co.; (Grant Recipient: Michigan Dept. of Natural Resources)	Fire Suppression
1/2-15/99	Blizzard, snowstorm	31 counties: Alcona, Allegan, Arenac, Barry, Berrien, Cass, Crawford, Ionia, Iosco, Jackson, Kalamazoo, Kent, Lenawee, Macomb, Marquette, Mecosta, Monroe, Montmorency, Muskegon, Newaygo, Oakland, Oceana, Ogemaw, Osceola, Oscoda, Otsego, Ottawa, St. Joseph, Van Buren, Washtenaw, and Wayne Co.	Emergency (3137)
7/21/98	Thunderstorms, severe winds	2 counties: Macomb and Wayne Co.	Major Disaster (1237)
5/31/98	Thunderstorms, severe winds	13 counties: Bay, Clinton, Gratiot, Ionia, Kent, Mason, Montcalm, Muskegon, Newaygo, Oceana, Ottawa, Saginaw, and Shiawassee Co.	Major Disaster (1226)
7/2/97	Tornadoes, flooding	5 counties: Genesee, Macomb, Oakland, Saginaw, and Wayne Co.	Major Disaster (1181)
6/21-7/1/96	Rainstorms, flooding, tornado	7 counties: Bay, Lapeer, Midland, Saginaw, Sanilac, St. Clair, and Tuscola Co.	Major Disaster (1128)
12/93-5/94	Underground freeze	10 counties: Charlevoix, Cheboygan, Chippewa, Delta, Gogebic, Houghton, Mackinac, Marquette, Ontonagon, and Schoolcraft Co.	Major Disaster (1028)
9/10-19/86	Flooding	30 counties: 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 Co.	Major Disaster (774)
9/5-6/85	Flooding	6 counties: Alcona, Genesee, Iosco, Lapeer, Saginaw and Shiawassee Co.	Major Disaster (744)
3/12-20/82	Flooding	2 counties: Berrien and Monroe Co.	Major Disaster (654)
7/15-20/80	Severe winds	10 counties: Allegan, Berrien, Calhoun, Cass, Jackson, Ottawa, St. Joseph, Van Buren, Washtenaw, and Wayne Co.	Major Disaster (631)
5/13/80	Tornado	2 counties: Kalamazoo and Van Buren Co.	Major Disaster (621)
1/26-27/78	Blizzard, snowstorm	Statewide	Emergency (3057)

Presidential Declarations in Michigan: 1953-2019* (cont.)

Date of Incident	Type of Incident	Affected Area	Type of Declaration / Federal ID Number**
3/2/77	Drought	44 counties: Alcona, Alger, Alpena, Antrim, Arenac, Baraga, Benzie, Charlevoix, Cheboygan, Chippewa, Clare, Crawford, Delta, Dickinson, Emmet, Gladwin, Gogebic, Grand Traverse, Houghton, Iosco, Iron, Isabella, Kalkaska, Lake, Leelanau, Luce, Mackinac, Manistee, Marquette, Mason, Mecosta, Menominee, Missaukee, Montmorency, Oceana, Ogemaw, Ontonagon, Osceola, Oscoda, Otsego, Presque Isle, Roscommon, Schoolcraft, and Wexford Co.	Emergency (3035)
1/26-31/77	Blizzard, snowstorm	15 counties: Allegan, Barry, Berrien, Cass, Chippewa, Hillsdale, Kalamazoo, Kent, Monroe, Muskegon, Newaygo, Oceana, Ottawa, St. Joseph, and Van Buren Co.	Emergency (3030)
3/20/76, 3/2-7/76	Ice storm, tornadoes	29 counties: 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 Co.	Major Disaster (495)
8/20/75-9/6/75	Rainstorms, severe winds, flooding	16 counties: Allegan, Clare, Genesee, Gratiot, Ingham, Isabella, Mecosta, Midland, Montcalm, Muskegon, Newaygo, Oceana, Osceola, Ottawa, Saginaw, and Shiawassee Co.	Major Disaster (486)
4/18-30/75	Flooding, rain, tornadoes	21 counties: Allegan, Barry, Berrien, Calhoun, Clinton, Crawford, Eaton, Genesee, Ingham, Ionia, Kalamazoo, Kent, Lapeer, Livingston, Macomb, Oakland, Ottawa, Saginaw, St. Clair, Shiawassee, and Van Buren Co.	Major Disaster (465)
4/3/74	Tornado	1 county: Hillsdale Co.	Major Disaster (429)
4/12/73	Severe storms, flooding	14 counties: Arenac, Bay, Berrien, Huron, Iosco, Macomb, Menominee, Monroe, Saginaw, Sanilac, St. Clair, Tuscola, Van Buren, and Wayne Co.	Major Disaster (371)
12/1/72	Severe storms, flooding	9 counties: Arenac, Bay, Berrien, Iosco, Macomb, Monroe, St. Clair, Tuscola, and Wayne Co.	Major Disaster (363)
4/5/72	Snowstorm, freezing rain	9 counties: Allegan, Barry, Calhoun, Clinton, Eaton, Ingham, Ionia, Jackson, and Kalamazoo Co.	Major Disaster (330)
4/11/65	Tornadoes, severe storms	16 counties: Allegan, Barry, Bay, Branch, Clinton, Eaton, Gratiot, Hillsdale, Kalamazoo, Kent, Lenawee, Monroe, Montcalm, Ottawa, Shiawassee, and Washtenaw Co.	Major Disaster (190)
4/5/56	Tornado	4 counties: Benzie, Leelanau, Manistee, and Ottawa Co.	Major Disaster (53)
6/8/53	Tornado	3 counties: Genesee, Iosco, and Monroe Co.	Major Disaster (6)
5/21/53	Tornado	1 county: St. Clair Co.	Major Disaster (4)
Totals for 1953-2019:	**38 Incidents**		**29 Major Disasters; 8 Emergencies; 1 Fire Suppression**

Notes

*Does not include separate Secretary of Agriculture or Small Business Administration (SBA) disaster declarations, which are issued under other authorities. Declarations after 1974 were issued under PL 93-288 (Disaster Relief Act), as amended by the Robert T. Stafford Disaster Relief and Emergency Assistance Act (1988) and the Disaster Mitigation Act (2000).

**Indicates federal declaration number assigned by FEMA or its predecessor agencies

Governor's Declarations in Michigan: 1977-2019

Date of Incident	Type of Incident	Affected Area	Type of Declaration**
3/14/19	Flooding	Newaygo County	Emergency
2/7/2019	Severe Winter Weather	City of Grand Rapids	Emergency
2/7/2019	Flooding	Ionia County	Emergency
1/29/2019	Extreme Cold	All 83 counties	Emergency
7/26/2018	Drinking Water Contamination	Kalamazoo County	Disaster
7/25/2018	Flooding	Houghton County	Disaster
7/12/2018	Flooding	Houghton County	Disaster
6/16/2018	Flooding	Gogebic, Houghton, and Menominee Co.	Disaster
2/19/2018	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
6/22/17	Flooding	Bay, Gladwin, Isabella and Midland Counties	Disaster
12/24/16	Sewer Collapse/Sinkhole	City of Fraser; Macomb County	Emergency
10/16/16	Flooding	Chocolay, Skandia, and West Branch Townships; Marquette County	Disaster
7/12/16	Severe weather	City of Wakefield (Gogebic Co.), Township of Bessemer (Gogebic Co.), Township of Erwin (Gogebic Co.); Gogebic Co.	Disaster
8/2/15	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
6/22/15	Tornado	City of Portland, Orange Township, and Portland Township (Ionia Co.)	Disaster
9/26/14	Bridge collapse	City of Detroit (Wayne Co.)	Emergency
8/11/14	Urban flooding	Macomb, Oakland, and Wayne Co.	Disaster
4/25/14	Contaminated water	City of Flint (Genesee Co.)	Emergency
4/12/14	Flooding	Isabella, Mecosta, Missaukee, Muskegon, Newaygo, Osceola, Roscommon, and Wexford Co.	Disaster
2/13/14	Deep frost	Charlevoix, Cheboygan, Chippewa, Delta, Emmet, Gogebic, Luce, Mackinac, and Marquette Co.	Emergency
6/18/13 5/7/13	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
5/25/12	Wildfire	Luce and Schoolcraft Co.	Disaster
5/11/12	Flooding	Genesee County	Emergency
5/31/11	Thunderstorms	City of Battle Creek (Calhoun Co.); Calhoun Co.	Emergency
7/27/10	Oil pipeline spill	Calhoun Co.	Disaster
6/9/10	Thunderstorms, tornadoes	Monroe Co.	Emergency
7/21/09	Tanker truck explosion, fire	Oakland Co.	Emergency
6/19/08	Thunderstorms	Lake, Manistee, Osceola, Ottawa, and Wexford Co.	Emergency*
6/13/08	Thunderstorms	City of Saginaw and City of Lansing (Ingham Co.); Allegan, Eaton, and Mason Co.	Emergency*
8/27/07	Tornado	City of Fenton (Genesee Co.)	Emergency
8/9-10/07	Wildfire	Luce Co.	Emergency
7/28/06	Thunderstorms, heavy rain	Oscoda Co.	Emergency
2/27/06	Severe winds, ice storm	Montcalm Co.	Emergency
9/4/05	Hurricane evacuation	All 83 counties	Disaster
6/3/04	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

Governor's Declarations in Michigan: 1977-2019 (cont.)

Date of Incident	Type of Incident	Affected Area	Type of Declaration**
4/30/04	Insect infestation (Emerald Ash Borer)	Genesee, Ingham, Jackson, Lapeer, Livingston, Macomb, Monroe, Oakland, Washtenaw and Wayne Co.; Cities of Fraser, Sterling Heights, and Warren (Macomb Co.); Cities of Birmingham, Lathrup Village, and Southfield (Oakland Co.); City of Ann Arbor (Washtenaw Co.); Cities of Allen Park, Dearborn, Dearborn Heights, Detroit, Livonia, River Rouge, Romulus, Trenton, and Wayne (Wayne Co.); Bloomfield Township (Oakland Co.); Canton and Plymouth Townships (Wayne Co.)	Emergency
8/15/03	Power failure	Macomb, Monroe, Oakland, Washtenaw, and Wayne Co.	Emergency
5/15/03	Flooding	City of Marquette, Marquette Township, and Negaunee Township (Marquette Co.)	Emergency
5/10/02 4/30/02 4/16/02	Flooding	Baraga, Houghton, Iron, Marquette, and Ontonagon Co.; City of Ironwood (Gogebic Co.)	Disaster
12/29/01	Heavy snow	Emmet Co.	Emergency
10/26/01	Severe winds	Kalamazoo Co.	Disaster
3/9/01	Flooding	Genesee Co.	Disaster
9/20/00	Urban flooding	Wayne Co.	Disaster
6/7/00	Gasoline pipeline rupture	Blackman Twp. (Jackson Co.)	Emergency
8/5/99	Subsidence (mine shaft cave-in)	Dickinson Co.	Emergency
7/5/99	Tornado	Oscoda Co.	Disaster
1/15/99	Blizzard, snowstorm	City of Detroit (Wayne Co.)	Emergency
9/27/98	Severe winds	Otsego Co.	Emergency
9/1/98	Thunderstorms, severe winds	City of Niles (Berrien Co.)	Emergency
7/24/98 7/23/98	Thunderstorms, severe winds	Wayne Co.; City of Dearborn (Wayne Co.); City of Warren (Macomb Co.)	Disaster
6/5/98 6/4/98 6/3/98	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
4/1/98	Flooding	Alpena Co.	Emergency
7/6/97 7/3/97	Tornadoes, flooding	Genesee, Macomb, Oakland and Wayne Co.; City of Detroit (Wayne Co.); Village of Chesaning (Saginaw Co.)	Disaster
6/27/97	Rainstorms, flooding	Allegan and Ottawa Co.	Disaster
6/26/96 6/21/96	Rainstorms, flooding, tornado	Bay, Lapeer, Saginaw, Sanilac, St. Clair, and Tuscola Co.; City of Midland (Midland Co.)	Disaster
5/22/96	Flooding	Berrien Co.	Disaster
12/13/95	Snowstorm	City of Sault St. Marie (Chippewa Co.)	Emergency
7/8/94	Flooding	Lapeer, Tuscola and Sanilac Co.	Disaster
3/10/94 3/4/94 2/23/94, 2/25/94	Underground freeze	Charlevoix, Cheboygan, Chippewa, Delta, Gogebic, Houghton, Mackinac, Marquette, Ontonagon, and Schoolcraft Co.	Emergency
4/20/93	Flash flood	Shiawassee Co.	Disaster
7/16/92	Heavy rain	Gogebic Co.	Disaster
7/14/92	Tornado	Cass Co.	Disaster
10/6/90	Tornado	Genesee Co.	Disaster
9/16/90	Ship explosion, fire	Bay Co.	Emergency
5/9/90	Wildfire	Crawford Co.	Emergency
6/8/89	Flooding, severe winds	Branch, Kalamazoo and St. Joseph Co.; Village of Manchester (Washtenaw Co.)	Disaster
6/9/88	Fire	City of Corunna (Shiawassee Co.)	Disaster
8/18/87	Airline crash	City of Romulus (Wayne Co.)	Disaster
10/28/86 9/15/86 9/12/86	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
2/21/86	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
9/13/85	Heavy rain, flash flood	Alcona Co.	Disaster
9/10/85	Heavy rain, flooding	Genesee, Lapeer, and Saginaw Co.	Disaster

Governor's Declarations in Michigan: 1977-2019 (cont.)

Date of Incident	Type of Incident	Affected Area	Type of Declaration**
4/13/85	Great Lakes flooding, wave action	Arenac, Bay, Macomb, Monroe, Saginaw, St. Clair, Tuscola, and Wayne Co.	Disaster
1/15/85	Ice storm	Allegan, Barry, Berrien, Calhoun, Eaton, Genesee, Ingham, Jackson, Kalamazoo, Lapeer, Livingston, Oakland, and Van Buren Co.	Disaster***
7/15/83	Wildfire	Schoolcraft Co.	Disaster
3/19/82	Flooding	Berrien and Monroe Co.	Disaster
7/21/80	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
5/13/80	Tornado	Kalamazoo and Van Buren Co.	Disaster
8/9/78	Sewer main break	Macomb Co.	Disaster
6/30/78	Thunderstorms, severe winds, hail, rain	Berrien Co.	Disaster
6/28/78	Thunderstorms	Allegan Co.	Disaster
1/26/78	Blizzard, snowstorm	Statewide	Disaster
12/10/77	Snowstorm	City of Hamtramck (Wayne Co.)	Disaster
4/6/77	Tornado, severe winds	Clinton, Eaton, Kalamazoo, and Livingston Co.	Disaster
1/28/77	Blizzard	Allegan, Barry, Berrien, Cass, Chippewa, Eaton, Hillsdale, Ionia, Muskegon, Newaygo, Oceana, Ottawa, Sanilac, Shiawassee, and Van Buren Co.	Disaster
Totals for 1977-2019	**83 Incidents**		**52 Disaster Declarations; 31 Emergency Declarations**

Notes

*Some incidents have resulted in multiple declarations for the same incident (each jurisdiction declared separately). These are counted as one declaration only for the purposes of this list.

**Declarations since 1977 were issued under 1976 PA 390, as amended (Michigan Emergency Management Act).

***A "State of Emergency" was also declared for this incident under 1945 PA 302 (Emergency Powers of Governor Act).

Appendix B: Change Log

<u>July 2022:</u>
The Dam and Levee Failures chapter (page 208) finished a revision process to comply with evolving standards required by the High Hazard Potential Dam (HHPD) Grant Program, administered by FEMA. In order to remain grant eligible, a new version of the chapter was inserted as amendatory language into this 2019 Michigan Hazard Analysis publication. No other chapters saw changes. Necessary ancillary edits were made to the title page, table of contents, and change log.

Changes to the Dam and Levee Failures chapter focused primarily on newer data for HHPD compliance. Other data not necessary for HHPD compliance will be revised when the plan is ordinarily due to be updated in 2024.