About RMCO

The Rocky Mountain Climate Organization (RMCO) works to reduce climate disruption and its impacts. We do this in part by spreading the word about what a disrupted climate can do to us and what we can do about it. Visit www.rockymountainclimate.org to learn more about our work.

About NRDC

The Natural Resources Defense Council (NRDC) is an international nonprofit environmental organization with more than 1.3 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world’s natural resources, public health, and the environment. NRDC has offices in New York City; Washington, DC; Los Angeles; San Francisco; Chicago; Bozeman, Montana; and Beijing. Visit us at www.nrdc.org.

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Acknowledgements

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The cover photo, of Grand River floodwaters outside an office building in Grand Rapids in April 2013, is copyright by Cory Morse, MLive.com, and reproduced by permission; all rights are reserved. The map in Figure 4 on page 5 was prepared by Juan Declet-Barreto, NRDC, using a base map by Esri.
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**MORE EXTREME STORMS**

This new analysis shows that the annual frequency of Michigan storms of two inches or more of precipitation in a single day has increased by 89% between 1964 and 2013. This is a far larger change than is true for smaller storms, as shown in Table ES-1.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>2-Inches-Plus Storms</td>
<td></td>
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<tr>
<td>1–2 Inches Storms</td>
<td></td>
</tr>
<tr>
<td>Under-1-Inch Storms</td>
<td></td>
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</table>

Table ES-1. Trends over 50 years (1964-2013) in the annual frequencies of Michigan storms by size: those with two inches or more of precipitation in a day, at least one inch but less than two inches, and less than one inch. These trends are all statistically significant with a 95 percent confidence level.

The largest storms, those with two inches or more of precipitation in a day—called extreme storms in this report—are rare. Over the 50 years of this analysis, a location in Michigan averaged two of these large storms every three years. While rare, these extreme storms can be highly destructive, which makes the large increase in their frequency of great significance in Michigan.

Figure ES-1 on the next page shows Michigan’s annual rates of extreme storms for 1964 through 2013 (the circles), as well as the linear trend—the straight line that is the best statistical fit with those annual frequencies.
Trend 1964 to 2013:
89% increase over 50 years

Figure ES-1. Average frequency of days with 2 inches or more of precipitation per station per year. Dots indicate annual values of average frequency per station, and the dark red line the 1964-2013 linear trend line.

The analysis done for this report also considered changes in precipitation patterns in different parts of Michigan:
• the Upper Peninsula;
• the northern Lower Peninsula—north of latitude 44° north, or essentially north of the tip of the Thumb; and
• southern Michigan—the southern half of the Lower Peninsula, south of latitude 44° north.

From 1964 through 2013, the annual frequency of extreme storms in southern Michigan more than doubled, with a 128% increase over 50 years—nearly half again as large as the 89% increase for the entire state, and much higher than the rates of increase in the other parts of the state. The sharp increase in the frequency of extreme storms in southern Michigan is especially important because this is where most people in the state live.

FLOODS, HEALTH EFFECTS, AND OTHER IMPACTS

Extreme storms matter in Michigan because of their impacts—most importantly, destructive flooding. Floods are to Michigan and other states in the Midwest what hurricanes are to the Atlantic coast areas—the most destructive type of regularly occurring natural disaster in the region. Across the United States, flooding is the second most costly type of natural disaster, ranking behind only hurricanes and ahead of drought, earthquakes, coastal disasters (including storm surges, coastal flooding, and erosion), tornadoes, and other types of natural disasters.

Michigan’s vulnerability to flooding caused by extreme storms is illustrated by 2013. In that year, which had the fourth most two-inches-plus storms in Michigan in the past half century, extreme storms in April
2013 caused flooding so extensive that it led to a federal disaster designation covering 16 counties in the state. In 2008, the year out of the past 50 years with the most extreme storms, those storms led to flooding destructive enough to have 11 Michigan counties designated by the federal government as a major disaster area.

A particular vulnerability that Michigan has to extreme storms stems from the state’s reliance on combined sewer systems, an older type of system which carries both storm water and sewage in the same pipes. Michigan has 46 combined sewer systems, the third-largest total in the nation. Combined sewer systems are designed to overflow when stormwater exceed their capacities, discharging untreated sewage and stormwater directly to nearby water bodies. These combined sewer overflows (CSOs) can spread untreated human and industrial wastes, and people can become sick by drinking or being exposed to the contaminated water.

For this report, a new analysis was made of how many of a representative sample of recent overflows from combined sewers in Michigan were linked to this report’s definition of an extreme storm—one with two inches or more of precipitation in a single day. Of the largest recent CSOs from each of 17 combined sewer systems in Michigan having overflows, 13 were associated with two inches or more of precipitation in a day. This illustrates the importance of extreme storms in driving CSOs and threatening the health of the people of Michigan.

MORE POLLUTION, MORE STORMS

The increase in extreme storms documented in this report is part of a global increase in heavy precipitation that scientists say stems from human disruption of the natural climate. Under the laws of physics, warmer air holds more moisture than cooler air does, increasing the likelihood for extreme precipitation when a storm does occur in a hotter climate. Scientists have documented, across the nation and the planet, larger change in extreme precipitation than in median precipitation. That this expected change is already underway has added to the confidence of scientists that human influences are already changing Earth’s climate.

Scientists also project that if emissions of heat-trapping pollution continue to grow, further increases in large storms will result, especially in the Midwest. Climate projections commissioned by the Michigan Department of Natural Resources and others include that with low future emissions of heat-trapping pollution, by mid-century the frequency of Michigan two-inches-plus storms could be one or two storms per decade higher than in 1961-2000, and by late in the century about two or three storms per decade higher, with variations in different parts of the state. With medium-high future emissions, by mid-century the increases could instead be about one to three storms per decade and by late in the century about three to six storms per decade. The important point from these projections, shown in Figure ES-2 on the next page, is that the frequency of extreme storms in Michigan is expected to increase more if future emissions in heat-trapping pollution are higher, and less if future emissions are lower.
Projected Changes in Decadal Frequency of Michigan 2-Inches-Plus Storms

A. 2046-2065
Low Emissions

B. 2046-2065
Medium-High Emissions

C. 2081-2100
Low Emissions

D. 2081-2100
Medium-High Emissions

Figure ES-2. Projected changes in the frequency of Michigan two-inches-plus storms, in the average number of storms per decade compared to 1961-2000. Averages of downscaled results from nine global climate models each for low and for medium-high future emissions.
ACTIONS TO ADDRESS EXTREME STORMS

To address the increase in extreme storms and floods, Michigan can both prepare for those events and limit its emissions to do its part to reduce the future severity of those events. Actions by both the state and local governments can play a role in limiting the worst effects of climate change and the extreme storms it fuels, and will be most effective if undertaken with a framework of national (and global) actions and in concert with actions by the private sector.

Some specific steps have been taken by the state government and by some local governments in Michigan to prepare for a further increase in extreme storms and their impacts, but more actions are needed. An important first step in preparing for climate change impacts is assessing local vulnerabilities. Many states have prepared statewide vulnerability assessments, but no comprehensive statewide assessment of climate change impacts has yet been prepared specifically focused on Michigan’s vulnerabilities.

Holding down future emissions of heat-trapping pollution would lead to smaller future increases in the frequency of extreme storms, so emission reduction actions ultimately are important to address extreme storms. Again, some specific steps have been taken by the state government, by some local governments in Michigan, and by others, but more actions are needed for Michigan to do its part to reduce emissions enough to help avoid unacceptable impacts from extreme storms and other events being fueled by a disrupted climate.
1. INTRODUCTION

An August 2014 storm deluged Detroit with up to six inches of rainfall in eight hours, flooding the metro area, causing about $1.1 billion in damages, and leading to a federal disaster designation.¹ In April 2013, widespread storms dropped more than two inches of rainfall in a day, flooding sixteen Michigan counties, and also prompting a disaster designation.² These events are part of a pattern documented in this report, which presents new evidence that in Michigan large storms have become much more frequent over the past half century. For Michigan, the increasing number of extreme storms is one of the state’s greatest vulnerabilities to human-caused climate change.

The increase in the number of extreme storms in Michigan is part of a pattern of more extreme weather, across the globe and in the United States. Increasingly, scientists are concluding that many types of extreme weather are being driven by human alteration of the climate.³ In Michigan, the most significant form of extreme weather is heavy precipitation, as it is the primary cause of major floods, which in the United States are second only to heat waves as the most deadly type of extreme weather and second only to hurricanes as the most costly type of natural disaster.⁴

Section 2 of this report documents the changing pattern over the past half century of precipitation in Michigan, presenting the results of a new analysis showing that extreme storms in the state have become much more frequent since 1964, while the frequencies of smaller storms have changed much less. The greatest increase in extreme storms has been in southern Michigan, where most Michiganders live.

Section 3 links extreme storms to Michigan floods, showing why it matters so much that extreme storms there are becoming more frequent. The section also includes a new analysis linking extreme storms to combined sewer overflows, showing how an increase in extreme storms is a public health risk.

Section 4 documents that the large increases in extreme storms detailed here are consistent with worldwide and regional increases in extreme precipitation that have been attributed to human-caused climate change. The section also documents that extreme storms are projected to continue becoming more frequent, with future changes depending on emission levels of heat-trapping pollution.

Section 5 identifies actions that can be taken in Michigan to address the increase in extreme storms.

An Appendix details the sources and methodologies for the new analysis reported here.

“Observations show that heavy downpours have already increased nationally. . . . For the heaviest, most rare events, there is strong evidence from observations and models that higher temperatures and the resulting moister atmosphere are the main cause of these observed and projected increases.”

U.S. Global Change Research Program⁵
2. More Extreme Storms

Big storms can mean big floods, and the largest of storms are coming much more often in Michigan. The annual frequency of storms of two inches or more of precipitation in a single day has increased by 89% between 1964 and 2013. In southern Michigan, where most of the state’s people live, the change has been much greater—a 128% increase over those 50 years. We consider these to be the most important changes in Michigan’s precipitation patterns over the last half century.

This information comes from a new analysis done for this report of daily precipitation records from 37 weather stations in Michigan. Those stations were selected for having complete or nearly complete records for the period of analysis and for having a geographic distribution that makes them representative of the state and the regions within it. (See the Appendix for details on the weather stations and the methodology used in the analysis.) This analysis is unique in its focus on Michigan, its inclusion of enough geographically distributed weather stations to support not only statewide but sub-state conclusions, and its inclusion of data through the end of 2013.

STORMS BY SIZE

The most significant change in statewide Michigan precipitation trends is revealed by an analysis of changes in storms by size. Large storms have become more frequent by a far greater rate than is true for smaller storms. Table 1 shows the changes over 50 years in the annual frequencies of Michigan storms of different sizes: those with less than one inch of precipitation in a single day, those with at least one and less than two inches, and those with two inches or more. All such trends identified in this report are the change over 50 years, from the start (in 1964) to the end (in 2013) of a linear trendline representing the best statistical fit with the data (as illustrated in figures 1, 2, and 3.) Unless indicated otherwise, all such trends identified in this report are statistically significant with a 95 percent confidence level.

<table>
<thead>
<tr>
<th>Storms by Size</th>
<th>Frequency Of Storms</th>
<th>Precipitation Per Day</th>
<th>Annual Precipitation Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Inches-Plus Storms</td>
<td>+ 89%</td>
<td>+ 4%</td>
<td>+ 94%</td>
</tr>
<tr>
<td>1–2 Inches Storms</td>
<td>+ 24%</td>
<td>no change</td>
<td>+ 25%</td>
</tr>
<tr>
<td>Under-1-Inch Storms</td>
<td>+ 12%</td>
<td>- 6%</td>
<td>+5%</td>
</tr>
</tbody>
</table>

Table 1. Trends over 50 years (1964-2013) in the annual frequencies of Michigan storms by size: those with two inches or more of precipitation in a day, at least one inch but less than two inches, and less than one inch. See the Appendix for details on sources and methodology.
The largest of storms, those with two inches or more of precipitation in a day—called extreme storms in this report—are rare. Over the 50 years of this analysis, a typical location in Michigan averaged two of these large storms every three years. While rare, these extreme storms can be highly destructive, which makes the large increase in their frequency of great significance in Michigan. (See Section 3 of this report for details of the impacts of these storms.)

Figure 1 below shows Michigan’s annual rates of extreme storms for 1964 through 2013 (the circles), as well as the linear trendline, as described above. That line in the figure displays the same 89% increase over 50 years shown above in Table 1. The rate of change was not uniform over this period; of the five non-overlapping 10-year periods within these 50 years, the largest change was in 1974-1983, which had a 67% increase over 10 years, and the second largest change was in 2004-2013, which had a 22% increase.

Of the 10 years with the most two-inches-plus storms, five have been in the first 14 years of the 21st century, including three of the top four: 2008 (the top year), 2010 (third highest), and 2013 (fourth). Of these, 2008’s number of extreme storms was far ahead of all other years, with 26% more than 1986 (the second-place year).

Section 3 presents accounts of the flooding that occurred in the years with the most extreme storms—especially in 2013, 2008, and 1986, years which had not only many extreme storms but also some of the worst floods in Michigan’s history. The information in that section makes it clear that the increasing frequency of extreme storms is of great consequence to the people of Michigan.

Figures 2 and 3 on the next page show the annual rates and trends for storms of at least one inch but less than two inches of precipitation in a day, and for storms of less than one inch. Figures 1, 2, and 3 are all
sized so that the steepness of the trend lines is shown according to a consistent scale. A trend line showing, for example, a 50% increase over 50 years would be as steep in any one figure as in the others. As a result, these figures, taken together, visually illustrate how extreme storms have increased in Michigan much more than have smaller storms.

**Michigan Frequency of 1–2 Inches Storms, 1964–2013**

![Figure 2. As Figure 1, but with respect to storms of at least one inch and less than two inches of precipitation in a day.](image)

**Michigan Frequency of Under-1-Inch Storms, 1964–2013**

![Figure 3. As Figure 1, but with respect to storms of less than one inch in a day.](image)

**TOTAL PRECIPITATION**

The total amount of annual precipitation (from storms of all sizes) in Michigan has increased at a rate of 12% over 50 years (the analyzed period of 1964–2013). This increase was driven by a similar change in the annual number of days with precipitation, which increased by a 13% rate over those 50 years. The average amount of precipitation in an individual wet day did not change significantly over the 50-year period. Similarly, the size of extreme storms in Michigan did not become significantly larger, when measured in terms of the amount of
precipitation per event for a storm with two inches or more of precipitation in a day. Over the 50 year period analyzed here, the average size of these storms increased by only 4%. However, storms lasting for hours but not a full day (which can sometimes cause flash floods) or for two or more consecutive days could have different trends than those reported here.

EXTREME STORMS: REGIONAL TRENDS

The analysis done for this report also considered changes in precipitation patterns in different parts of Michigan:

- the Upper Peninsula;
- the northern Lower Peninsula—north of latitude 44° north, or essentially north of the tip of the Thumb; and
- southern Michigan—the southern half of the Lower Peninsula, south of latitude 44° north.

Figure 4 below shows the demarcation between the northern Lower Peninsula and southern Michigan for this analysis and the location of the weather stations used in this analysis. (For the identification of the stations, see the Appendix.) The regional analysis is based on 10 stations in the Upper Peninsula, nine in the northern Lower Peninsula, and 18 in southern Michigan.

Figure 4. Location of weather stations analyzed for this report, and the diving line (latitude 44° north) between the northern Lower Peninsula and Southern Michigan as those regions are defined for the regional analysis in this report.
Table 2 below shows that over the 50-year period analyzed for this report, the annual frequency of extreme storms in southern Michigan more than doubled, with a 128% increase over 50 years—nearly half again as large as the 89% increase for the entire state, and much higher than the rates of increase in the other parts of the state. The sharp increase in the frequency of extreme storms in southern Michigan is especially important because this is where most people in the state live.

<table>
<thead>
<tr>
<th>Region</th>
<th>2-Inches-Plus Storms</th>
<th>1–2 Inches Storms</th>
<th>Under-1-Inch Storms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Peninsula</td>
<td>+ 62%</td>
<td>+ 6%</td>
<td>+ 9%</td>
</tr>
<tr>
<td>Northern Lower Peninsula</td>
<td>+ 42%</td>
<td>+ 25%</td>
<td>+ 21%</td>
</tr>
<tr>
<td>Southern Michigan</td>
<td>+ 128%</td>
<td>+ 29%</td>
<td>+ 9%</td>
</tr>
</tbody>
</table>

Table 2. Trends over 50 years (1964–2013) in the annual frequencies of storms of different sizes (as in Table 1 on page 2) for regions in Michigan (see the text for descriptions). Trends are statistically significant except for all trends in the Upper Peninsula, for 2-inches-plus storms in the northern Lower Peninsula, and for 1-2 inches storms in southern Michigan. See the Appendix for details of sources and methodology.

Figure 5 on the next page shows the frequency of two-inches-plus storms in southern Michigan and the trend line over the period 1964-2013. This figure is similar to Figure 1 (on page 3), except with respect to the region rather than to the entire state, and is scaled the same as that figure for accurate comparison between them. As with the statewide change, the increase was not steady throughout the period, with the largest change over the last ten years (2004-2013), which had a 58% increase over those 10 years, and the second largest change in 1974-1983, which had a 48% increase.

Figure 5. As Figure 1 on page 3, except with respect only to southern Michigan, defined here as the Lower Peninsula south of latitude 44 north. See the Appendix for details of sources and methodology.

Over the past 50 years, the ten with the most extreme storms in southern Michigan include five in the 21st century: 2008 (the top year), 2000 (third most), 2013 (fifth), 2011 (sixth), and 2009 (ninth).
EXTREME STORMS: SEASONAL TRENDS

The analysis for this report also considered changes in the seasonal frequencies of Michigan’s two-inches-plus storms. Table 3 below shows that the frequency of extreme storms has increased in all seasons, with the largest increase—and the only one that is statistically significant—in spring. (A general rule of thumb is that it takes about 10 inches of snow to equal one inch of water, so a two-inches-plus storm made up of snow would be a snowfall of about 20 inches or more.)

<table>
<thead>
<tr>
<th>Season</th>
<th>Trend</th>
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<tbody>
<tr>
<td>Winter</td>
<td>+130%</td>
</tr>
<tr>
<td>Spring</td>
<td>+335%</td>
</tr>
<tr>
<td>Summer</td>
<td>+44%</td>
</tr>
<tr>
<td>Fall</td>
<td>+114%</td>
</tr>
</tbody>
</table>

Table 3. Trends over 50 years in the seasonal frequencies of 2-inches-plus Michigan storms from 1964 through 2013. Seasons are December-February (winter), March-May, June-August, and September-November. Only the spring trend is statistically significant. See the Appendix for details of sources and methodology.

The large percentage increase in spring extreme storms shown in Table 3 is consistent with projections by scientists that in the Upper Midwest human-caused climate change will particularly increase spring and early summer extreme precipitation. This may be considered one piece of evidence, along with others (see Section 4), that the increase in Michigan’s extreme storms is being fueled by human-caused climate change.

CONSISTENCY WITH PREVIOUS STUDIES

Many previously published scientific studies have found for the planet as a whole, the conterminous United States, and for the Midwest the same trends this new analysis shows for Michigan—that extreme precipitation has increased at a higher rate than has total precipitation. As a 2008 U.S. government interagency scientific report on climate and weather extremes summarized, “All studies indicate that changes in heavy precipitation frequencies are always higher than changes in precipitation totals.”

In a 2012 report, the Rocky Mountain Climate Organization (RMCO) and the Natural Resources Defense Council (NRDC) documented that across the eight midwestern states the frequency of three-inches-plus storms more than doubled between 1961 and 2011. That report was similar in many respects to this one, but focused on three-inches-plus storms, which represent the top 0.3% of all wet days across the full Midwest—about the same percentage as two-inches-plus storms in Michigan, which represent the top 0.4% of wet days in that state. Three-inches-plus storms in Michigan, by contrast, represent only 0.08% of wet days, too few for reliable analysis of trends. This report also is based on an analysis of 37 Michigan weather stations, compared to 23 in the RMCO-NRDC Midwest report (out of a total of 227 across the region).

For Wisconsin, the Wisconsin Initiative on Climate Change Impacts reported that the frequency and magnitude of heavy rainfall events have increased in that state. Madison, for example, had nine days with three inches of precipitation in the last decade, compared to three such days in the decade with the most such storms out of the five previous decades.
3. Floods and Other Impacts

Extreme storms matter in Michigan because of their impacts—most importantly, destructive flooding. One particular consequence of flooding in Michigan can be overflows of outdated combined sewer/stormwater systems, which handle both sewage and stormwater runoff in a single system. When runoff is heavy enough, the systems can overflow, potentially contaminating nearby drinking water supplies and cause public health problems. A new analysis done for this report, detailed below, links large combined sewer overflows (CSOs) with extreme storms, illustrating how the increase in large storms documented in this report is a risk to the health of Michigan residents.

Floods

Floods are to Michigan and other states in the Midwest what hurricanes are to the Atlantic coast areas—the most destructive type of regularly occurring natural disaster in the region. Across the United States, flooding is the second most costly type of natural disaster, ranking behind only hurricanes and ahead of drought, earthquakes, coastal disasters (including storm surges, coastal flooding, and erosion), tornadoes, and other types of natural disasters. An increased frequency of extreme storms, as documented for Michigan in this report, can increase soil moisture and thereby reduce the water holding capacity of the soil for subsequent storms. The result is that more rainfall becomes surface runoff, which can cause flooding.

2013 Flooding

In 2013, the year with the fourth most two-inches-plus storms in Michigan in the past half century, storms in April 2013 caused flooding so extensive that it led to a federal disaster designation covering 16 counties in the state. This disaster illustrates well the impacts of the heaviest precipitation events. On April 10, four Michigan weather stations had storms of more than two inches that set record amounts of rainfall for the date, and helped create the conditions for the flooding of later in the month. Then, on April 18, eight Michigan stations had record-breaking rainfall of two inches or more, and on April 19, one more did. Fortunately, another 3 to 4 inches of rain forecast for April 20 did not materialize. Still, much of southern Michigan received a total of more than eight inches of rain in the month. Widespread flooding resulted, with the Grand River in Grand Rapids peaking at its highest level ever, nearly two feet above the previous record level reached in 1985.

Just one of the 16 counties covered by the federal disaster designation—Kent County—had $10 million in damages. Just one action by the City of Grand Rapids to protect its citizens, the emergency construction as the 2013 flooding was underway of a wall to keep floodwaters out of the city’s wastewater treatment plant, cost $700,000. The Grand River ended up falling just short of overtopping the emergency wall, averting flooding that could have put the wastewater plant out of business for perhaps a month or more, but 435 million gallons of partially-treated sewage still overflowed from the plant and into the river.

“Weathering models for the future suggest that rain events like this one will come more frequently and with greater severity than before.”

George Heartwell, Mayor of Grand Rapids
2008 Flooding

Of the 50 years covered by the precipitation analysis done for this report, the year with the most extreme storms was 2008, for both Michigan as a whole and southern Michigan. That year’s extreme storms were concentrated in the first half of June, and were destructive enough to have 11 Michigan counties designated by the federal government as a major disaster area. From June 1 through June 15, parts of the northern Lower Peninsula had 8 inches or more of rain, and parts of southern Michigan had 6 inches or more. The heaviest storms were on June 12, when two of the Michigan stations analyzed for this report each had their highest rainfall amounts for any day in the past 50 years—over 7 inches at Manistee, and over 5 inches at Lake City. Some other areas in Manistee and Mason counties had as much as 11 inches of rain over six hours. Trees were knocked down, buildings damaged, parts of roads were washed away, and some bridges were made unstable or impassable. Two people were drowned when they drove off a washed-out road and into a creek, where their car sank. Flooding on the Big Sable and Little Manistee rivers exceeded a 500-year flood event, and on the Pine River was between a 200- and 500-year flood event. Ludington State Park was evacuated and closed for four days for fear of a possible collapse of the dam from the high water and because of flooding in the campground.

The June 2008 extreme storms and flooding in Michigan were part of a region-wide episode of extreme storms and flooding that, in all states, caused a staggering $16.2 billion (in 2013 dollars) in damages, with even greater rainfall totals and worse flooding in several other states. Figure 6 below shows rainfall totals across the Midwest for the first half of June, which in some places exceeded 12 inches. The most devastating flooding across the region was precisely in these areas or just downstream of them. This illustrates one of the significant dangers of more frequent extreme storms—when they occur in close succession, the first storms can fully saturate the ground, so the later storms are especially likely to lead to flooding.

Figure 6. Total precipitation in inches, June 1-15, 2008. Source: Midwestern Regional Climate Center.
1986 Flooding

Michigan’s second-place year for extreme storms was 1986, when those storms caused “the worst flooding event ever recorded in the state,” according to the National Weather Service (NWS).28 Over three days in September of that year, 6 to as much as 11 inches of rain fell on the Saginaw Valley and the Thumb, causing extensive flooding. The town of Vassar was hardest hit—“inundated,” the NWS said. There, the Cass River rose to nearly 25 feet, five times its normal height and more than 10 feet above flood stage.29 There also was substantial flooding in Saginaw, Midland, and Bay City. Damages were estimated at $400 to $500 million, 30 counties were declared a federal disaster area, and 10 people in the state were killed.

Infrastructure damage from the Great Flood of 1986 included the failure of 14 dams, flooding or structural damage to about 30,000 homes, and failures of four bridges on primary highways and hundreds of secondary road bridges and culverts, making 3,600 miles of roadway impassable. Agricultural damage was substantial, especially in the Saginaw River basin, where dikes were breached and thousands of acres of crops were ruined. Altogether, more than 10% of the state’s crop land was affected, and more than 1,200 farm-related structures were flooded.30

EFFECTS ON PUBLIC HEALTH

Extreme storms can kill people. For example, the Great Flood of 1986 led to at least 10 deaths in Michigan—a hunter, a woman who drove her car off a road and into a flooded river, two children swept away by a flooded stream, two boaters who drowned, and two men who were electrocuted while using sump pumps to empty flooded buildings. Two farmers, seeing the loss of all their crops, committed suicide.31

More often, though, extreme storms cause a myriad of public health problems, as summarized below.

Contamination of Drinking Water

Consumption or exposure to contaminated water can cause illnesses and even deaths. According to a U.S. government report, floods can lead to transmission of water-borne diseases, both directly by contaminating freshwater sources with untreated or partially treated sewage, and indirectly by causing the breakdown of water supply and sewage treatment infrastructure facilities.32 More than 100 different types of waterborne bacteria, viruses, and protozoa can enter drinking water systems and cause infections in people.33 The importance of floods—and the storms that cause them—are underscored by calculations that over half of all waterborne disease outbreaks in the United States are triggered by storms in the top 10% of precipitation magnitude.34

An extreme example was in Milwaukee in 1993, following the city’s heaviest rainfall in half a century, which caused flooding believed to have washed a disease-causing parasite into Lake Michigan, contaminating water used by city residents for drinking water. The result was the largest drinking-water contamination ever documented in the United States, with 54 people killed and over 400,000 sickened. This outbreak also led to $31.7 million in medical costs and $64.6 million in productivity losses.35

Although adequate data are lacking on the extent of waterborne disease in the country, it is believed to be a growing problem.36 By increasing the frequency of extreme storms, climate change is expected to make water contamination an even more serious problem in the future.37

Combined Sewer Overflows

In Michigan and other midwestern states, health-threatening water quality problems often stem from combined sewer systems, an older type of systems which carry both stormwater and sewage in the same pipes. Michigan has 46 combined sewer systems, the third-largest total in the nation.38 Combined sewer systems, to avoid backing sewage and stormwater into basements and onto streets, are designed to overflow when stormwater exceeds their capacities, discharging untreated sewage and stormwater directly to nearby water bodies. These are called combined sewer overflows (CSOs), which can spread untreated human and industrial wastes containing dangerous pollutants, including bacteria, toxic chemicals, pesticides, oil and grease, sediment, nutrients, and trash, all of which can harm water quality.39 People can become sick by drinking CSO-contaminated water, eating contaminated shellfish, or from contact with contaminated water either in flooded streets and basements or when recreating in downstream water bodies.40

“It is common for local rivers and streams to be considered dangerous to human health after heavy rains due to CSO pollution.”

U.S. Environmental Protection Agency41
Extreme storms also can cause failures worse than designed discharges from an overtaxed combined sewer system. In the Michigan flooding of June 2008, excessive stormwater caused Ludington’s sewer main and a 50-feet section of a road to collapse, sending 90% of the city’s raw sewage flowing directly into Pere Marquette Lake for 60 hours. An estimated 15 million gallons of untreated sewage and 10 million gallons of storm water went into the lake. The health department closed three public beaches and three boat launches near Ludington.\textsuperscript{42}

**New Analysis of CSOs and Storms**

For this report, a new analysis was made of how many of a representative sample of recent combined sewer overflows in Michigan were linked to this report’s definition of an extreme storm—one with two inches or more of precipitation in a single day. Of the 17 CSOs in the sample, 13—or 76 percent—were associated with extreme storms.

The analysis is based on data supplied to the authors of this report by the Michigan Department of Environmental Quality (MDEQ).\textsuperscript{43} The analysis covers the largest reported single overflows for each of the 17 wastewater treatment plants that had at least one combined sewer overflow event with 50 million gallons or more of overflow per event in Michigan in 2008 through 2012, as reported by MDEQ, and information on local precipitation amounts associated with those CSO events, as compiled by Rocky Mountain Climate Organization (RMCO) from daily precipitation records for the weather stations closest to the plants. (There were a total of 292 Michigan CSOs of this size in 2008-2012, and only the single largest event in each system was analyzed.)

As stated above, of these 17 representative large CSOs, 13 were caused at least in part by storms of two inches or more of precipitation in a day (sometimes in conjunction with other storms). This powerfully illustrates how extreme storms in Michigan lead directly to CSOs and the public health effects they can cause, and how continuing increases in the frequency of extreme storms can increase risks to public health in Michigan.

The results of this analysis are shown in Table 4 on the next page.

*Of the largest combined sewer overflows in recent years at 17 Michigan sewer districts, three-quarters were associated with storms of more than two inches of rainfall in a day.*
## Locally Largest Combined Sewer Overflows in Michigan And Associated Rain Storms, 2008-2011

<table>
<thead>
<tr>
<th>Wastewater Plant</th>
<th>Overflow (millions of gallons)</th>
<th>Dates</th>
<th>Precipitation (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detroit</td>
<td>8,817</td>
<td>Nov. 27–Dec. 9, 2011</td>
<td>2.1 on Nov. 23, then 5.0 over Nov. 27–Dec. 9 (single-day high of 1.6).</td>
</tr>
<tr>
<td>Southgate/ Wyandotte</td>
<td>461</td>
<td>Nov. 27–Dec. 2, 2011</td>
<td>2.1 on Nov. 23, then 3.8 over Nov. 27–Dec. 2 (single-day high of 1.6).</td>
</tr>
<tr>
<td>Saginaw</td>
<td>375</td>
<td>Aug. 10–11, 2012</td>
<td>2 on Aug. 10, then 3 the next day.</td>
</tr>
<tr>
<td>Dearborn</td>
<td>361</td>
<td>Jun. 11–21, 2009</td>
<td>3.7 on June 11.</td>
</tr>
<tr>
<td>Bay City</td>
<td>164</td>
<td>Apr. 26–May 3, 2009</td>
<td>1.6 on Apr. 26.</td>
</tr>
<tr>
<td>South Macomb Sanitary District</td>
<td>153</td>
<td>Mar. 7–9, 2009</td>
<td>1.3 on March 8, then 0.7 the next day.</td>
</tr>
<tr>
<td>Lansing</td>
<td>138</td>
<td>Sep. 12 –14, 2008</td>
<td>2.7 on Sep. 13, then 2.7 the next day.</td>
</tr>
<tr>
<td>Wayne County/ Redford/Livonia</td>
<td>118</td>
<td>May 26, 2011</td>
<td>2.6 on May 26.</td>
</tr>
<tr>
<td>Niles</td>
<td>90</td>
<td>Jan. 7–15, 2008</td>
<td>0.9 on Jan. 7, then 1.7 the next day.</td>
</tr>
<tr>
<td>Grand Rapids</td>
<td>80</td>
<td>July 2–3, 2008</td>
<td>3.2 on July 2.</td>
</tr>
<tr>
<td>North Houghton Co. Water and Sewage Authority</td>
<td>58</td>
<td>Apr. 7–30, 2008</td>
<td>0.3 maximum daily totals (twice) during the CSO event.</td>
</tr>
<tr>
<td>Wayne County/ Inkster</td>
<td>53</td>
<td>Jun. 5–6, 2010</td>
<td>3.3 on June 6.</td>
</tr>
</tbody>
</table>

Table 4. Combined sewer overflows (CSOs) with the largest outflows in selected Michigan wastewater treatment systems from 2008 through 2012, and associated rainfall totals. Listed for each system with a CSO of at least 50 million gallons of outflow in 2008-2012 is the single largest such event, and associated precipitation information for the closest Global Historical Climatology Network weather station. Because precipitation records typically are taken in the morning and cover the previous 24 hours, the precipitation totals shown for a date usually cover a portion of that day and a portion of the previous day. Data sources: Michigan Department of Environmental Quality and NOAA. 

13
Threats to Private Wells

Michigan has more than one million households, more than any other state, served by private drinking water wells.45 Private wells are at risk of contamination from flooding, which can cause health problems for people drinking from them.46 The Michigan Department of Environmental Quality urges residents whose private water wells have been exposed to flooding to immediately refrain from using the water until it has been tested and found to be free of coliform bacteria, which represents an acute health threat, as floodwater can contain bacterial contaminants such as fecal coliform and Escherichia coli (commonly known as E. coli) bacteria, which represent an acute health risk. Floodwater also can contain other contaminants from sewage systems and other sources, as well as fertilizers, pesticides, and other chemicals.47

Contamination of the Great Lakes

Contaminants washed into the Great Lakes by extreme precipitation can cause dangerous levels of both bacteria and algae.

Michigan has more than 600 public beaches stretching along more than 3,200 miles. In 2012, according to the Natural Resources Defense Council's annual Testing the Waters report on water quality at public beaches across the nation, 20% of Michigan beaches had at least one water sample exceed state water quality standards, and there were a total of 324 instances in which Michigan beaches were closed or subject to public health advisories (counting each such day at one beach as one instance).48 Contamination of water quality at beaches in Michigan, as well as throughout the Great Lakes region, often results from extreme precipitation. Of beaches studied in 12 Great Lakes cities, closures in eight, including Detroit, were significantly linked to heavy storms the prior day.49

Extreme storms also are one of the major factors that can cause the layers of green, toxic algae that have covered Lake Erie in recent years. In 2011, a record-setting algae bloom covered 2,000 square miles, from Detroit to Cleveland. A team of scientists recently identified its causes:
• long-standing agricultural practices that regularly yield phosphorus runoff from farms;
• extreme precipitation that carried much more of the phosphorus than normal into the lake;
• and a reduction, caused by separate weather conditions, in the normal circulation of lake waters.

The study also found “that all of these factors are consistent with expected future conditions.” Unless something is done, “we can therefore expect this bloom to indeed be a harbinger of future blooms in Lake Erie.” For March through June, the critical months when agricultural run-off of phosphorus into Lake Erie can set up algal blooms, the scientists projected that with a high level of future emissions of heat-trapping pollution storms of about 1.2 inches or more per day could be twice as common by 2080-2099 as in 1986-2005.50

These conclusions also underscore the importance of the conclusion from the original research done for this report that spring has had the largest increase of any season in the frequency of Michigan extreme storms (see Table 3 on page 8.)

Some of algae blooms in the Great Lakes are harmless, but when the blooming organisms contain toxins, other noxious chemicals, or pathogens, they can cause the death of nearby fish and foul up nearby coastlines, and produce harmful conditions to aquatic life as well as humans.51 In people, consumption of large amounts of harmful algae can result in muscle cramps, twitching, paralysis, and cardiac or respiratory failure.52

Indoor Air Pollution

Flooding in homes and other buildings can create breeding grounds for mold, viruses, and bacteria, which can cause disease, trigger allergic reactions, and pose health risks long after the flood.53 Basements, of course, are particularly susceptible to flooding. In Chicago, some of the largest economic impacts of extreme precipitation in the Chicago area in recent years have been property damage from basement flooding, and city officials are now aware that more frequent and destructive basement flooding could result from climate change.54 In Michigan, where many communities have long had problems with basement flooding, this could be an issue, too.

OTHER IMPACTS

Power Outages

The major threat to the reliable delivery of electricity to customers is from storms, especially from storms accompanied by lightning strikes or high winds and from power line interruptions from heavy snowfalls.55 Such storms can cause power outages. The extreme storms in southern Michigan in April 2013 (see page 9) caused a loss of power to nearly 100,000 customers of DTE Energy that lasted up to three days.56 Nationwide
since 2000, the number of storm-related power outages has increased, increasing repair and other costs for utilities and consumers and causing economy-wide costs from work interruptions, lost productivity, and other consequences. National costs have been estimated at $20 to $55 billion annually.57

Transportation

Transportation, vital both to the needs and convenience of individuals and to operation of Michigan’s economy, can be disrupted by extreme storms, which can flood and wash out highways, roads, and bridges and disrupt air and rail travel.58 According to an article written by staff members of the state’s Department of Transportation, in Michigan, closure of a typical freeway for an hour can cost $200,000 in lost economic activity, and the closure of all state roadways for a day would cost the state’s economy about $250 million.59

In the Michigan flooding of June 2008, numerous roads in the region were affected. A quarter mile of the highway between Manistee and Ludington was washed out, forcing an 80-mile detour and costing $250,000 to rebuild. In Mason County, stretches of 42 roads were closed, and in Manistee County nine were. Other road washouts occurred in Missaukee, Wexford, and Osceola counties.50

A greater tale of destruction comes from the Chicago area, where a record-breaking 24-hour rainstorm in July 1996 caused widespread flash flooding across the metro area, damaging highways, roads, and railroads, keeping many commuters from being able to reach Chicago for up to three days, and delaying or rerouting more than 300 freight trains.61

Agriculture

Agriculture can be harmed by extreme storms in several ways. Spring storms can delay crop planting, field flooding can cause crop losses, heavy rainfall can create excess soil moisture and erode soil, and storms with strong winds can flatten crops.62 In Michigan, of the $400 million to $500 million in damages caused by the Great Flood of 1986, about $120 million was from damages to crops, which were near harvest time.63 Another example of agricultural damage from extreme storms comes from the July 1996 downpours in and around Chicago, which, although centered on the metropolitan area, reduced crop yields in surrounding rural areas enough to cause a $67 million loss of farm income.64
4. More Pollution, More Storms

The increase in extreme storms documented in this report is part of a global increase in heavy precipitation that scientists say stems from human disruption of the natural climate. Scientists also project that if emissions of heat-trapping pollution continue to grow, further increases in large storms will result, especially in the Midwest.65

**ATTRIBUTION TO HUMAN-CAUSED CLIMATE CHANGE**

Human actions are already changing the climate, both through increases in temperatures and also through related changes, including increases in extreme precipitation. That global temperatures are now higher and that human activities are causing them are now well-established. In 2013, the Intergovernmental Panel on Climate Change (IPCC) reported that, "It is extremely likely [a 95 to 100% probability] that human influence has been the dominant cause of the observed warming since the mid-20th century."66 According to both the IPCC and a national climate assessment prepared by the U.S. government in 2014, natural factors would have led to global cooling over the past 50 years, except those natural factors were trumped by heat-trapping pollution.67

For years, scientists have pointed out that, under the laws of atmospheric physics, higher air temperatures should lead to more extreme precipitation. This is because, as a result of "very basic physics," warmer air holds more moisture than cooler air does, increasing the likelihood for extreme precipitation when a storm does occur in a hotter climate.68 Scientists therefore expect that temperature increases will lead to a larger change in extreme precipitation than in median precipitation.69 Observations that this projected change is underway—across the planet and in the United States have added to the confidence of scientists that human influences are already changing Earth’s climate.70

“The increase in heavy precipitation events is associated with an increase in water vapor, and the latter has been attributed to human-induced warming.”

U.S. Climate Change Science Program71

In 2011, the first study was published demonstrating that human increases in heat-trapping gases have contributed to increases in heavy precipitation.72 The authors based their conclusions on a "fingerprinting" technique of climate scientists—using climate models and statistical analysis to separate the likely influences of heat-trapping pollutants from natural climate variability. Comparing observed precipitation extremes at 6,000 Northern Hemisphere weather stations from 1951-1999 with simulated reconstructions for the same time period by multiple climate models, they found that:

[H]uman-induced increases in greenhouse gases have contributed to the observed intensification of heavy precipitation events found over approximately two-thirds of data-covered parts of Northern Hemisphere land areas.73

Detecting a clear human role in changing extreme precipitation patterns at a smaller geographic scale is much more difficult, and scientists have not yet reported any such conclusions for Michigan or any similarly sized area in North America.74 However, with respect to flooding caused by extreme precipitation in the United Kingdom in the fall of 2000, scientists performed such a "detection and attribution" study, which showed that the likelihood of that flooding having occurred was approximately doubled by human influences on the climate.75
The number of dots that can be connected is rising. Perhaps most importantly, as a leading climate scientist, Kevin Trenberth, recently wrote, when the question is whether any particular extreme event is caused by human-driven climate change, "The answer is that all weather events are affected by climate change because the environment in which they occur is warmer and moister than it used to be."76

A threshold may already have been crossed, so that major floods perhaps now should no longer be considered purely natural disasters but instead mixed natural/unnatural disasters.

FUTURE EXTREME STORMS

The Intergovernmental Panel on Climate Changes projects with "high confidence" that across the world as a whole extreme precipitation will increase with further climate change.77 According to both the IPCC and the U.S. government’s 2014 national climate assessment, the higher the levels of future emissions of heat-trapping gases, the greater the changes in heavy precipitation are projected to be.78

The Michigan Department of Natural Resources and the Upper Midwest and Great Lakes Landscape Conservation Cooperative of the U.S. Department of the Interior, using methods developed by the Wisconsin Focus on Energy, recently commissioned projections of future Michigan climatic conditions. These projections, by the Center for Climatic Research of the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison, include projected increases in the frequency per decade of Michigan two-inches-plus storms, based on three different possible levels of future emissions of heat-trapping pollution.79 The reported results represent average projections from nine downscaled global climate models for each emission scenario. Figure 7 on the next page shows the results from the low and medium-high emission scenarios (but not from the third, intermediate scenario).

As Figure 7 shows, the projections are that with low future emissions, by mid-century the frequency of Michigan two-inches-plus storms could be one or two storms per decade higher than in 1961-2000, and by late in the century about two or three storms per decade higher, with variations in different parts of the state. With medium-high future emissions, by mid-century the increases could instead be about one to three storms per decade and by late in the century about three to six storms per decade. However, current climate models are not as reliable in projecting the frequency of extreme events as they are in projecting changes in average conditions, and they also appear to generally underestimate extreme precipitation.80 (For comparison, the data on actual occurrences of extreme storms in Michigan presented in Section 2, when translated into terms comparable to those shown in Figure 7, reveal that the first years of this century (2000-2013) have already seen an increase of about two storms per decade compared to a 1961-2000 baseline.) The projections shown in Figure 7 therefore should be taken as illustrations of possible future conditions, not as firm predictions. The important point from these projections is that the frequency of extreme storms in Michigan is expected to increase more if future emissions in heat-trapping pollution are higher, and less if future emissions are lower. On this point, the Michigan projections are strongly consistent with other projections, nationally and globally.81

The major role that future levels of heat-trapping pollutants will play in determining the future extent of heavy storms illustrates how important it is to reduce emissions to avoid unacceptable climate changes. The good news is that with new policies designed to reduce heat-trapping pollution, we can, in fact, realize a better future—if we choose to. (See Section 5.)
Projected Changes in Decadal Frequency of Michigan 2-Inches-Plus Storms

A. 2046-2065
Low Emissions

B. 2046-2065
Medium-High Emissions

C. 2081-2100
Low Emissions

D. 2081-2100
Medium-High Emissions

Figure 7. Projected changes in the frequency of Michigan two-inches-plus storms, in the average number of storms per decade compared to 1961-2000. Averages of downscaled results from nine global climate models each for low and for medium-high future emissions. Source: Center for Climatic Research, Nelson Institute for Environmental Studies, University of Wisconsin-Madison.
To address the increase in extreme storms and floods, Michigan can both prepare for those events and limit its emissions to do its part to reduce the future severity of those events. Actions by both the state and local governments are important, and will be most effective if undertaken with a framework of national (and global) actions and in concert with actions by the private sector.

**Climate Preparedness**

Climate change preparedness (or adaptation), in the words of a report by the National Academy of Sciences, involves “deciding how to cope with climate changes that we cannot, or do not, avoid so that possible disruptions and damages to society, economies, and the environment are minimized and—where possible—so that impacts are converted into opportunities for the country and its citizens.” The central recommendation in that National Academy report is that all decision makers—in national, state, tribal, and local governments and in the private sector, should identify their vulnerabilities to climate change impacts and the adaptation actions that would make them more resilient to current and projected impacts.

Key steps are assessing risks faced in a state or locality, and developing plans to address them.

**Vulnerability Assessments**

Many states have prepared statewide vulnerability assessments, of which an excellent example is that prepared in Wisconsin in 2011 by the University of Wisconsin-Madison, the Wisconsin Department of Natural Resources, and others. However, no comprehensive statewide assessment of climate change impacts has been prepared specifically focused on Michigan’s vulnerabilities, although the Michigan Climate Action Council (see below), unanimously recommended that: “The state of Michigan should undertake a comprehensive planning effort to assess and address the state’s vulnerability to climate change and adaptation opportunities.” Nor has a focused assessment been prepared of the Michigan impacts of a continuing increase in extreme precipitation in the state.

However, state agencies are involved in the Michigan Climate Coalition (MCC), founded in 2010 to gather stakeholders from across Michigan to help tackle climate change impacts. The MCC is sponsored by Michigan State University with in-kind support from the Michigan Department of Environmental Quality to facilitate climate adaptation in the state by tracking climate-related projects, translating technical reports into more user-accessible information, and identifying research gaps to further target. The MCC includes members from the private, public, and nonprofit sectors in Michigan, including the departments of Natural Resources, Environmental Quality, Agriculture, and Transportation; the University of Michigan and Michigan State University; and nonprofit organizations.

Apparentely the only systemic assessment of climate change vulnerabilities being conducted by the Michigan state government is by the Michigan Department of Community Health (MDCH), which used a grant from the federal Centers for Disease Control and Prevention to develop a strategic plan to address the public health effects of climate change in Michigan. The plan explicitly recognizes “that more flooding and water pollution due to heavy rainstorms” will result “in increased waterborne diseases outbreaks.” With additional federal grants, the department is working to implement more detailed assessments and adaptation plans to address the top risks.

Some local governments in the country have prepared their own assessments of local climate change risks. An example is one prepared by a team of outside experts and local government staff for the City of Chicago as part of its process in developing a local climate change action plan. Apparently the only Michigan example of a comprehensive local climate change assessment and plan is from Grand Rapids, where the West Michigan Environmental Action Council, in partnership with the Grand Rapids Office of Energy and Sustainability and
others in the community, prepared for the city government a Grand Rapids Climate Resiliency Report. The report is a comprehensive overview of local vulnerabilities and actions that can be taken to address them.

**Preparedness Planning and Management**

Future climate impacts need to be factored into a range of plans and decision making processes employed by state and local governments. Many states, but not Michigan, have completed comprehensive climate adaptation plans, and others have developed sector-specific plans to address particular climate change impacts. With respect to sector-specific plans relevant to increases in extreme storms, first and foremost, these impacts need to be considered in disaster preparedness plans that are approved by the Federal Emergency Management Agency (a requirement FEMA is in the process of developing). But decisions regarding funding, financing, and designing an array of water, stormwater, and wastewater infrastructure, transportation, energy, housing, and land use decisions would all benefit. Some states, like Wisconsin and New York, have developed fairly detailed climate plans, but still fall short, as Michigan has done, in integrating these findings into real decisions.

At the local level in Michigan, the City of Grand Rapids addresses climate change risks and preparedness in its sustainability plan. The City of Ann Arbor is working to factor climate changes issues into the full range of its various local plans. As just one example of a specific local policy, the city gives residents credits on their utility bills for green infrastructure measures that reduce stormwater runoff from their property.

Some of the most important actions in Michigan to reduce the risks from more extreme storms are those that lessen the chances of combined sewer overflows. With respect to CSOs, some examples of the progress being made are:

- By 2011, Michigan communities had avoided 77% of the number of CSOs that occurred in 1988, and additional control plans measures are planned to eliminate other CSOs, primarily the installation of retention basins to capture and hold combined sewage and rain water that otherwise would overflow into surface waters.
- Detroit, a historically major contributor to CSO events, is subject to a special phased Long Term Control Plan. Work completed in 2005 at a cost of $166.5 million dollars has achieved significant reductions in CSO volumes.
- Once Lansing’s CSO control plan, adopted in 1991, is completed, 1.65 billion gallons of combined sewage should be prevented from release into the Grand and Red Cedar Rivers.

Doubtless, though, more actions than those now underway will be needed to prevent future CSOs, in large part because current remedies rarely (perhaps never) are sized to prevent overflows from larger storms anticipated due to climate change.

Often the best way to avoid runoff-related pollution and overburdening water infrastructure is to reduce the volume of stormwater flowing to the storm drains. Green infrastructure restores or mimics natural conditions, so rainwater can go into the soil or evaporate into the air rather than going down drains. Examples of green infrastructure techniques are using porous pavement materials and planting rooftops with vegetation.

The City of Grand Rapids, for example, has installed at its water treatment facility a rain garden which has successfully captured all of the stormwater from major storms, preventing the stormwater from entering and affecting the treatment facility, at a cost of only about half what conventional infrastructure would have cost.

**EMISSION REDUCTIONS**

Holding down emissions of heat-trapping pollution reduces the extent of climate change, which fuels increases in extreme storms; so emission reduction actions are an important way to limit the worst storms. Across the nation, many state and local governments have adopted climate initiatives and energy policies that reduce emissions.

A 2008 Michigan law, the Clean, Renewable and Efficient Energy Act, established a Renewable Energy Standard requiring electric utilities to use renewable energy to produce at least 10 percent of their electricity by 2015, or to negotiate the equivalent using tradable renewable energy certificates. The state’s two largest utilities, Consumers Energy Company and DTE Energy, must achieve higher targets. The law also included an Energy Optimization (energy efficiency) standard requiring natural gas and electric utilities to reduce overall energy usage by specified targets. For 2012, utilities exceeded the law’s targets for that year by about 25%, which will lead to customer savings of about $936 million, compared to utility expenditures of $246 million, and reductions of about one million tons of heat-trapping carbon dioxide emissions.

A Michigan Climate Action Plan was developed in 2009 by a stakeholder group, the Michigan Climate Action Council, appointed by then-governor Jennifer Granholm. The plan includes measures to reduce emissions
of heat-trapping pollution, which, if fully implemented, could save Michigan residents an estimated $10 billion between 2009 and 2025. That plan, however, is not now being pursued. In 2013, Governor Rick Snyder announced his vision for a “no regrets” energy future by 2025, calling for an emphasis on eliminating energy waste, and replacing coal with newer, cleaner technologies, including the use of both natural gas and renewable energy resources.

Some local governments in Michigan are reducing emissions. The City of Grand Rapids has exceeded its emission reductions goal by bringing down emissions from city operations by more than 7% below 1990 levels. With grants from the Michigan Department of Environmental Quality and in partnership with the Michigan Suburbs Alliance, the smaller cities of Ypsilanti, Hazel Park, and Southgate each developed local climate action plans to reduce emissions and a model process for small-city climate action.

Although these and other examples show that some significant steps are being taken in Michigan to reduce climate-changing pollution, more actions are needed for Michigan to do its part to reduce emissions enough to avoid unacceptable impacts from extreme storms and other extreme events being fueled by climate change.
APPENDIX: RESEARCH METHODOLOGY

This Appendix details the sources and methodology for the RMCO analysis of precipitation data reported in Section 2.

The authors analyzed all daily precipitation records for 1964 through 2013 from 37 Michigan weather stations in the Global Historical Climatology Network (GHCN), using data obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration. The stations were selected based on the completeness of the data records for the analyzed period and to be generally geographically representative of the entire state of Michigan. With respect to data completeness, the stations have reported data with no identified quality issues (see below) for an average of 95.2 percent of all days in the full analyzed period. With respect to geographic representation, the stations were selected through the following process. First, the state was divided into grids of one degree of latitude by one degree of longitude. Such grids have previously been used in scientific studies to achieve geographic representativeness of weather stations in an analysis. For the nine grids that were entirely or nearly entirely comprised of Michigan land area, two stations per grid were selected for the analysis, one from the northern half of the grid and one from the southern half of the grid. For the grids with less Michigan land area, one station per grid was selected, except where the grid contained barely any Michigan land area or where no station with sufficient data was available. In three cases, no station with sufficient data was available within a particular half of a grid (in one case) or within a grid (in two cases), and in those cases stations just outside the half-grid or the grid were analyzed instead. The 37 analyzed stations are listed below. (The station locations are shown in Figure 4 on page 5.)

<table>
<thead>
<tr>
<th>Analyzed Weather Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Peninsula</td>
</tr>
<tr>
<td>Champion Van Riper</td>
</tr>
<tr>
<td>Bergland Dam</td>
</tr>
<tr>
<td>Hancock Houghton County Airport</td>
</tr>
<tr>
<td>Iron Mountain Kingsford Wastewater</td>
</tr>
<tr>
<td>Manistique Wastewater Treatment Plant</td>
</tr>
<tr>
<td>Marquette</td>
</tr>
<tr>
<td>Munising</td>
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<tr>
<td>Sault Ste. Marie Sanderson Field</td>
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<tr>
<td>Stambaugh 2 SSE</td>
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<tr>
<td>Whitefish Point</td>
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</tbody>
</table>

Table App-1. Weather stations used for this report’s analysis of daily precipitation records.
The time period analyzed was the 50 years from 1964 through 2013. Previous scientific analyses have showed there was no significant trend to changes in very heavy precipitation prior to about 1970, either across the contiguous United States or in the Midwest. As one team of scientists wrote after laboriously analyzing daily precipitation data since 1893, "it is probably a paradox that so much effort was made to collect, quality control, pre-process, and analyze data for the full 110 years, only to reveal that during the first 80 years no systematic changes occurred in very heavy precipitation frequency."

The daily precipitation data from GHCN stations are reviewed by NCDC for various possible errors, and if the records for a day suggest the possibility of one, a quality flag is attached to that day's data denoting the type of potential error. In the analysis for this report, daily data with any type of embedded quality flag were discarded from the analysis, and those days were treated as ones with missing data. This excluded data deemed suspect for having failed any of several NCDC quality checks, which include checks for accumulation totals, duplicates, gaps, internal consistency, streaks or frequent values, mega-consistency, naught values, climatological outliers, lagged ranges, spatial consistency, temporal consistency, temperature too warm for snow, and values beyond bounds. Data with measurement or source quality flags were not discarded, as those flags do not relate to the accuracy of the data but instead to such matters as how values were calculated and the sources for them. Missing data for particular days were addressed by converting the values for all reported days of a year to equivalent values for 365.25 days.

Trends identified in the report are statistically significant with a 95% confidence level, based on an ordinary least squares regression analysis, unless indicated otherwise.
NOTES


13. MRCC, “Midwest records” (see previous note).


18. Vande Bunte, “By the dollars” (see previous note).


28. NWS Forecast Office, Detroit/Pontiac, MI, “Memorable weather events in Southeast Michigan,” http://www.crh.noaa.gov/dtx/?n=dtxHistory2. Except as noted, all facts in this paragraph are from this source.
31. All facts in this paragraph are from Deedler, “Thumbnailsketch” (see note 29).
41. Center of Excellence for Great Lakes and Human Health (CEGLHH), NOAA, “Harmful algal blooms” (see previous note).


57. DOE, Energy Sector Vulnerabilities (see note 55).


60. Conradson, “Friday the 13th flooding” (see note 22), p. 2-3.


62. USGCRP, Global Climate Change Impacts (see note 37), pp. 74–75, 121; D. Niyogi and V. Mishra, “Climate-agriculture vulnerability assessment for the midwestern United States,” in Pryor, Climate Change in the Midwest (see note 10).

63. Deedler, “Thumbnail sketch” (see note 29).

64. Changnon, “Record flood-producing rainstorms” (see note 61).


68. USGCRP, Global Climate Change Impacts (see note 37), p. 24.


70. Gutkowski, “Causes” (see previous note), pp. 89–90, 98.

71. USCCSP, Weather and Climate Extremes (see note 4), p. 1.


73. Min, “Human contribution” (see previous note), p. 378.


77. IPCC, “Technical summary” (see note 69), p. 72.


82. The emissions scenario described here as the low-emissions scenario is known as B1 and the one described as medium-high is A2. See USGCRP, Global Climate Change Impacts (see note 37), pp. 22–23. Scenario A2 is referred to as a “high” scenario in that report and some other reports, but often and more accurately is referred to (as in this report) as a “medium-high” scenario, for example in work done for the California Climate Change Center. See, e.g., S. Moser and others, “The future is now: An update on climate change science impacts and response options for California” (California Climate Change Center, 2008), http://www.energy.ca.gov/2008publications/CEC-500-2008-071/CEC-500-2008-071.PDF.

83. See Nelson Institute for Environmental Studies, “LCC downscaling” (see note 79).


85. NRC, Adapting to Impacts (see previous note), p. 15.

86. WICCI, Wisconsin’s Changing Climate (see note 8).

93. R. Bierbaum and others, “Chapter 28: Adaptation,” p. 676, in USGCRP, Climate Change Impacts (see note 3).
97. Kershner, “Adaptation in Ann Arbor” (see previous note), pp. 103-105.
106. Michigan Climate Action Council, “Climate action plan” (see note 87).
113. Groisman, “Contemporary changes” (see previous note), pp. 64-85; Groisman, “Trends in intense precipitation” (see previous note), p. 1336.