Chapter 3: Climate Change and Threats

3.1 Introduction

A dramatic increase in the concentration of greenhouse gases in Earth’s atmosphere is causing warmer global temperatures.[[1]](#endnote-2) The effects of these warmer temperatures manifest in different ways at a regional scale based on geography, topography, and other natural climate factors. In the Great Lakes region, and specifically in southeast Michigan, changes in precipitation and temperature have been observed in the historical data records, and models predict many changes will grow in frequency and magnitude.[[2]](#endnote-3) Because natural systems have evolved within a range of relatively stable climate conditions, it is critical to consider the implications of current and future deviations from historical climate conditions when managing natural resources.[[3]](#endnote-4) The watershed management planning process is a critical time to capture and consider impacts of climate change on river systems. It is also an effective time to consider how the prioritization of strategies should adapt to dynamic conditions and how communities can prepare for extreme events. This chapter summarizes the best available climate information relevant for planners in the region and discusses the implications of changes in precipitation and temperature on critical watershed variables.

3.2 Climate Data Summary

The observed and projected changes in the climate data relevant to the Huron River watershed are consistent with the changes observed across southeast Michigan (described by NOAA as Michigan Climate Division 10: Southeast Lower Michigan)[[4]](#endnote-5) and at a high-quality, long-term observational station at the University of Michigan (located in the Middle Huron watershed). More broadly, they are consistent with trends described for the Upper Midwest and Great Lakes region. Air, water, and land surface temperatures are rising. The form, seasonal timing, and volume of precipitation is changing. Heavy precipitation events are becoming more frequent and more severe. These changes are directly affecting watershed management, planning, and implemented best practices in the Huron River watershed.[[5]](#endnote-6) [[6]](#endnote-7) [[7]](#endnote-8) [[8]](#endnote-9) [[9]](#endnote-10)

3.2.1 Regional Climate Summary

* The average air temperature across southeast Michigan increased by 2.8°F from 1952 through 2022.
* Average air temperatures in southeast Michigan are expected to rise by approximately 3.1°F to 5.2°F by 2050, relative to 1980-1999.
* Total annual precipitation measured in southeast Michigan increased by 19.69% from 1952 through 2022 and in Ann Arbor, increased by 48% from 1951 through 2021, relative to the 1951-1980 reference period.
* In the Midwest, the total volume of precipitation falling within the heaviest 1% of precipitation events increased by 42% since 1958.[[10]](#endnote-11)
* Total annual precipitation will likely increase in the future, though types of precipitation will vary (i.e., more winter precipitation in the form of rain). [[11]](#endnote-12)

*Table 3.1 Historic climate normal and projected changes in key climate parameters for the Huron River watershed and southeast Michigan. Data provided in this table is based on observational data in the Global Historical Climate Network-Daily (GHCN) dataset, projections from Climate Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5), RCP8.5, and a methodology for Dynamical Downscaling for the Midwest and Great Lakes Basin.*[[12]](#endnote-13)[[13]](#endnote-14)[[14]](#endnote-15)

|  |  |  |  |
| --- | --- | --- | --- |
| **Climate Parameter** | **Historic****Ann Arbor(1981-2010)** | **Change by Mid-Century, 2040-2059****(RCP8.5)**  | **Change by End of Century, 2070-2099** **(RCP8.5)** |
| **Average Temperature** | 49.8°F  | 3.1 to 5.2°F  | 6.5 to 10.0°F  |
| **Winter** | 27.1°F  | 2.0 to 4.4°F  | 5.0 to 8.5°F  |
| **Spring** | 48.4°F  | 1.9 to 5.5°F  | 4.6 to 11°F  |
| **Summer** | 71°F  | 4.0 to 6.4°F  | 8.2 to 12.0°F  |
| **Fall** | 52.2°F  | 3.2 to 5.9°F  | 6.9 to 11.7°F  |
| **Average Low Temperature** | 40.4°F  | 3.3 to 5.4°F  | 6.7 to 10.5°F  |
| **Average High Temperature** | 59.1°F  | 3.1 to 5.3°F  | 6.4 to 9.8°F  |
| **Days/Year Greater than 90°F** | 8 Days  | 13 to 30 Days  | 31 to 64 Days  |
| **Days/Year Greater than 100°F** | 2 to 4 Days  | 3 to 17 Days  | 11 to 38 Days  |
| **Days/Year Less than 32°F** | 122 Days | 27 to 23 Fewer Days  | Not Available  |
| **Total Annual Precipitation** | 36.7 in.  | 0.3 to 3.8 in.(1.0 to 10.3%)  | 1.3 to 6.2 in.(3.5 to 16.9%) |
| **Winter** | 7.9 in.  | -0.5 to 2.5 in.(-6.3 to 31.2%) | -1.48 to 1.79 in.(-18.7 to 27.8%)  |
| **Spring** | 9.3 in.  | -0.7 to 2.27 in.(-7.5 to 24.4%) | 0.04 to 2.9 in(<-1% to 31.2%) |
| **Summer** | 11 in.  | -0.7 to 2.9 in.(-6.4 to 26.4%)  | -1.0 to 0.8 in.(-9 to 7.3%)  |
| **Fall** | 9.4 in.  | -0.4 to 0.6 in.(-4.3 to 6.4%) | 0.53 to 1.89 in.(5.6 to 20.1%)  |
| **Heavy Precipitation Days/Year (>1.25”)** | 3.7 Days  | 0.4 to 2.8 Days  | 2.4 to 2.8 Days/Year  |

3.2.2 Average and Extreme Temperatures

3.2.2.1 Average Temperature

The average air temperature in southeast Michigan has risen 2.8°F, which is consistent with much of the Great Lakes region. The more localized Ann Arbor area, however, has seen a more moderate increase of 1.0°F from 1951 to 2021, and the historical annual average temperature from 1980-2010 was 49.8°F. Average seasonal temperatures have also increased. Winter and spring temperatures have risen at a faster rate and warming has been distributed relatively evenly between daytime high temperatures and overnight lows.

Relative to the 1980-1999 historical reference period. Average temperatures in Ann Arbor are projected to increase by approximately 3.1 to 5.2°F by mid-century under a high emissions scenario that’s consistent with the historic trajectory of increasing emissions (RCP 8.5, often described in the past as a “business as usual” scenario). The projected warming is distributed throughout the year, with the summer and fall season having somewhat higher projected ranges.[[15]](#endnote-16)

3.2.2.2 Hot Days

The number of days per year with high temperatures exceeding 90°F have begun to increase slightly over time. Year-to-year variability is high, however. Days exceeding 100°F are statistically infrequent, and the average annual occurrence has remained relatively flat and within the range of annual variability. Most years on record have experienced 2 to 4 consecutive days over 90°F, with events of 5 to 7 consecutive days occurring less frequently. By mid-century (i.e., 2050), models suggest an increase of anywhere from 13 to 30 more days per year over 90˚F, and an increase of 31 to 64 more days per year over 90°F by end of century. Models are not able, however, to tell us if those days will be consecutive or not.

The number of days per year with high temperatures at or above 95˚F has shown little to no change since the middle of the 20th century. Events of consecutive days experiencing maximum temperatures over 100˚F are also quite rare and have not significantly increased or decreased in frequency. By mid-century (i.e., 2050), models project 3 to 17 more days per year over 100˚F, and an increase of 11 to 38 days per year over 100°F by end of century. However, such extremely hot days will not likely

occur consecutively.

Heat waves can result from a combination of different drivers including high humidity, daily high temperatures, high nighttime temperatures, stagnant air movement, etc. In the future, models project an increase in the number of days experiencing high temperatures that could lead to additional heat waves, especially since air stagnation events are projected to increase. There is greater certainty that summer nighttime low temperatures will continue to increase, thereby making it more difficult to cool off at night during extended heat events. In addition, any periods of future drought may also contribute to extreme heat.[[16]](#endnote-17) [[17]](#endnote-18)

3.2.2.3 Cold Days

From 1981-2010, Ann Arbor experienced 122 days per year that fell below freezing (32°F), on average. Historical records show this number has decreased already. The city is projected to experience fewer nights below 32°F with decreases of 23 to 27 days by mid-century.

Significant for many natural ecosystems and built environments, models project modest decreases in the number of days falling below 20°F, with about 3 to 10 fewer days per year dropping below this threshold.

Days with temperatures at or below 10˚F are relatively common and have not experienced any clear trends over time. Consecutive days at or below 10˚F also common, and typically last for 2 to 7 days with less frequent occurrences lasting 8 to 15 days. In the future, there are projected to be substantially fewer 10°F cold days, so this type of event could become rare. Some models project few or no cold days dropping below this temperature by the mid or late century.[[18]](#endnote-19)

3.2.2.4 Changing Seasonality

The Watershed experienced approximately 170 to 180 days per warm season (reference period of 1981-2010) in which the minimum temperature remains above 32°F. This is referred to as the growing season length or freeze-free season. With warmer temperatures, the growing season length is expected to last for a longer duration each year, with many studies projecting growing seasons 1 or 2 months longer by 2100. The parameter of climate is strongly influenced by hyperlocal factors, including local land use, so while the broad trajectory of a warmer, longer growing season is clear regionally, actual observations in specific locations will vary.

3.2.3 Precipitation and Flooding

3.2.3.1 Total Precipitation

The amount of total annual precipitation in Ann Arbor has increased by 48% (14.5”) from 1951 through 2021. An increase in precipitation was observed in all four seasons, with the winter seeing the greatest percentage increase of 65.3% (3.8”). On average, most models project total annual precipitation in southeast Michigan to increase by 5 to 11 percent by mid-century compared to the period 1980-1999. The methodology presented in table 3.1 projects a broader range, though most models used in that analysis also project increases above 5%. Precipitation projections have a broad range of uncertainty, however, and seasonal variation and interannual variability are expected to increase in magnitude, potentially creating multi-year periods that either much wetter or much drier than the prevailing long-term trend.

3.2.3.2 Seasonal Precipitation Totals and Form

Across the Great Lakes region, projected changes in seasonal mean precipitation span a range of increases and decreases. This broad regional uncertainty is due in part to uncertainty in how the Great Lakes themselves will respond to warmer conditions. Generally, evaporation and decreasing soil moisture may play an increasingly important role on the region’s hydrologic cycle at the end of the century, reducing available moisture for precipitation. On the other hand, there is also evidence that warm, humid air masses advected farther north from a changing Gulf Stream pattern may deliver more precipitation to the Great Lakes basin. In the winter and spring, the region is projected to experience wetter conditions as the global climate warms. By mid-century, some of this precipitation may manifest in the form of increasing snowfall, but projected warmer conditions by end of century suggests such precipitation events will most likely be in the form of rainfall.[[19]](#endnote-20)

There has been a slight decreasing trend in historic heavy hourly snowfall (events with snowfall over 1”) with varying year-to-year conditions, and little to no change in hourly snowfall exceeding 2”. Generally, warmer temperatures in the future will cause some winter precipitation to fall in the form of rain rather than snow. As a result, annual snowfall is projected to decrease by 7” to 17” by mid-century, and decrease by 20” to 40” by end of century. Unlike areas in lake effect snowbelts, the Huron River watershed is not anticipated to see significant effects on precipitation due to potential changes in lake effect snow patterns. It is plausible that southeast Michigan may see some years without measurable snowfall by the end of the 21st century.

3.2.3.3 Rain Free Periods

Drought (defined here as periods of 3 weeks with less than 0.45” of rainfall) has been highly variable year-to-year, with slight decreasing trends in summer and fall events and a slight increasing trend in spring events. In the future, even though more annual precipitation is projected overall, more is anticipated to fall in shorter, extreme events. Thus, there will be longer periods of time that experience no rainfall, increasing the potential for drought. Most models project this effect to be most pronounced during the summer months. The drought conditions of 2021, along with the extreme rain events of June 25th-26th, are a prescient example of the types of weather conditions that will become more likely in the future.

3.2.3.4 Extreme Precipitation

The frequency and intensity of severe storms has increased. Ann Arbor has seen a 41.2% increase in the number of heavy precipitation events (36 storms from 1951-1981 compared to 51 storms from 1981-2010). Ann Arbor experienced an average of 3.7 days per year with precipitation totals that exceeded 1.25” from 1981-2010, and approximately 1 day per year with totals exceeding 2”. Daily precipitation events exceeding 3” are rare and generally occur once every 5 to 10 years.

Future projections of extreme precipitation vary tremendously at sub-regional scales and between individual models. There is broad agreement, however, that heavy precipitation events will continue to become more frequent and increase in magnitude. Southeastern Michigan is projected to experience approximately an 0.4 to 2.8 (11 to 78%) increase in days of 1.25” precipitation events by mid-century. Heavy precipitation events of more than 2” in a day (i.e., 24-hour period) are projected to increase by no more than one day (0.25 to 1 days) by mid-century and increase by slightly more (0.75 to 1.25 days) by end of century. Changes in the frequency of precipitation events of more than 3” in a day are difficult to project at the regional and subregional scale due to their relative infrequency, though most models project increases in frequency at a rate faster than that of smaller magnitude storms.

A 2020 study found that human activity is causing the intensification of extreme events across North America. With relatively conservative warming of 1°C, storms that historically would have been expected to occur every 20, 50, or 100 years will likely become 4 to 5 times more likely. Storms that historically would have been expected to recur in 20, 50, and 100 periods were projected to occur every 1.5 to 2.5 years, on average, with +3°C of global warming. This would represent a 13- to 40-fold increase in the occurrence of catastrophic storms. Warming of 3°C or more is well within the range projected by global climate models in when humans fail to substantially reduce global carbon emissions by 2050.[[20]](#endnote-21)

3.2.3.5 Increased Meteorological Variability

Emerging research indicates that climate change is increasing variability in weather patterns around the globe and within the Great Lakes region. While averages in temperature and precipitation have changed over time, extreme events have, by many metrics become more extreme and more frequent at rates outpacing changes in averages.[[21]](#endnote-22) For the Great Lakes region and the watershed, the practical implication is to plan for more powerful storms with greater potential for interceding dry periods, as explained above, along with greater intraseasonal variability.

An anecdotal example of such conditions occurred in the summer of 2021. The watershed experienced a rapid swing in conditions from moderate drought in June to above-normal water levels overnight during a major downpour. Two later storms resulted in 3-4 inches of rain within 12- to 24-hours each. Following NOAA Atlas-14 precipitation frequency estimates, the watershed therefore experienced at least three “50-year storms” over three months.

3.2.3.6 Flooding

Flooding results when rainfall volumes exceed the capacity of natural and built infrastructure to handle precipitation. Stormwater managers look at several different “design” storms (inches falling over a certain length of time) when designing and managing their systems. These “design” storms are effectively the probability of any given amount of precipitation falling in a set period of time, based on historical experience. Monitoring over time shows that the volumes falling during these “design” storms are increasing.

Table 3.2 below shows precipitation volumes in inches for both Bulletin 71 and Atlas 14, following the format: (Bulletin 71/Atlas 14). Bulletin 71 used data through 1986, and Atlas 14 added more recent data from 1987-2011.[[22]](#endnote-23) [[23]](#endnote-24) The percent change is reported in brackets. All percent change values are positive which means they are larger in Atlas 14. This data shows how the “design” storm thresholds have increased over time.

Note that Table 3.2 does not account for projected changes in these design storms. Broadly, future changes are expected to follow or exceed historical rates of change, with larger storms seeing a greater rate of change.[[24]](#endnote-25) While total annual precipitation for the Midwest is projected to increase by 5-10% by mid-century, heavy storms likely to occur once in 25 years are projected to increase by 20 percent.[[25]](#endnote-26)

*Table 3.2 Observed Changes in Precipitation Frequencies for the City of Ann Arbor from NOAA Bulletin 71 and NOAA Atlas 14.*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   | **1-Yr**  | **2-Yr**  | **5-Yr**  | **10-Yr**  | **25-Yr**  | **50-Yr**  | **100-Yr**  |
| 1-hr  | 0.88/0.969 [10%]  | 1.06/1.14 [8%]  | 1.29/1.44 [12%]  | 1.47/1.70 [16%]  | 1.69/2.07 [22%]  | 1.87/2.38 [27%]  | 2.05/2.69 [31%]  |
| 12-hr  | 1.63/1.82 [12%]  | 1.97/2.06 [5%]  | 2.39/2.50 [5%]  | 2.72/2.90 [7%]  | 3.13/3.54 [13%]  | 3.46/4.09 [18%]  | 3.79/4.68 [23%]  |
| 24-hr  | 1.87/2.09 [12%]  | 2.26/2.35 [4%]  | 2.75/2.83 [3%]  | 3.13/3.26 [9%]  | 3.60/3.93 [9%]  | 3.98/4.50 [13%]  | 4.36/5.11 [17%]  |

3.3 Effects on River Systems and Natural Areas

River systems of the Upper Midwest face numerous effects due to climate change. Water quality, water quantity, the watershed’s ecosystems services, and its functions as natural habitat will all face changes and may become impaired.

The IPCC Sixth Assessment Working Group 3 Report: Mitigation of Climate Change synthesized and reiterated the need for natural areas protection, for environmental and water quality, but also for the purpose of carbon emissions reduction. Globally, land protection is second only to solar power in its potential to reduce carbon emissions. There are therefore both local and global imperatives to take action to protect natural ecosystems throughout the Huron River watershed. Southeast Michigan wetlands may be of particular value, with high capacity to sequester carbon from the atmosphere, filter toxins from the air and water, while reducing flood risks and erosion.[[26]](#endnote-27)

3.3.1 Effects on Forests

Changing temperatures may change the distribution of trees and plants as well as their growing season.[[27]](#endnote-28) [[28]](#endnote-29) [[29]](#endnote-30)

Natural ecosystems in Michigan are being altered by warming temperatures, changes in precipitation, changes in land-use, and by an influx of invasive species. These factors commonly exacerbate the negative effects of each other.[[30]](#endnote-31) Warmer temperatures are driving many tree species northward, and many native species well-suited to their historical climate have not been able to migrate as fast as their optimal climate range is shifting. Tree species currently near the northern extent of their suitable range may decline in number as they will not likely be able to migrate fast enough to outcompete species suited to encroaching climate conditions from the south. Species currently populating forests in more southern extents of their range will likely continue to shift northward in distribution. Maple, Beech, and Birch forest stands are vulnerable to climate change and associated stresses. Sugar maples, for example, may become less productive while red maples, several variety of oaks, and hickory may gain a competitive advantage.

The migration of native species northward is uncertain, however, as the fragmentation of midwestern forests and the flatness of the terrain raise the possibility that the ranges of particular tree species will not be able to shift to future suitable habitats within the Midwest.[[31]](#endnote-32) To reach areas 1.8°F (1°C) cooler, for example, species in southern Michigan’s relatively flat terrain must move up to 90 miles (150 km) north to reach cooler habitat, whereas species in mountainous terrain can shift higher in altitude over much shorter latitudinal (north–south) distances.[[32]](#endnote-33)

3.3.1.1 Increased Stressors on Forests

Changes in climate will allow nonnative, invasive plants, insects, and pathogens to expand their ranges.[[33]](#endnote-34) [[34]](#endnote-35) [[35]](#endnote-36) Pests and diseases will also become further established with warmer winter temperatures, and some pest insects have already been able to expand their ranges northward.[[36]](#endnote-37). Increased spring precipitation has been favorable to bur oak blight in Iowa and some parts of Illinois.[[37]](#endnote-38) Forest pests and pathogens also disproportionately stressed ecosystems.[[38]](#endnote-39) [[39]](#endnote-40)

Non-native species and invasive species, on the other hand, particularly those limited by the northern extent of their temperature range, are often expected to spread rapidly and out-compete native species. It is also possible that nonnative plant species will take advantage of shifting forest communities and unoccupied niches if native forest species are limited. [[40]](#endnote-41) [[41]](#endnote-42) Nonnative invasive species such as honeysuckle, reed canary grass, and common buckthorn will likely be favored by future conditions brought on rapidly by climate change.[[42]](#endnote-43) The reproduction and survival of emerald ash borers, the destructive invasive insect that attacks native ash trees, will increase due to warming winters in the region. Mortality of black ash trees, is even more likely in the future than current conditions as winter temperatures continue to rise.27

3.3.2 Effects on Wildlife

Rapid climate change through the 21st century will stress most species in southern Michigan and accelerate the rate of species declines and extinctions with potentially severe implications for loss of biodiversity. Interactions between climate change and other stressors, such as invasive species, habitat loss and fragmentation, and hydrologic modifications.

As with forests and other ecosystems, Michigan’s relatively flat topography and high latitude position will force wildlife to shift their ranges (or retreat) particularly fast relative to species in other parts of the continental U.S. to keep up with the pace of even moderate rates of projected warming. Wildlife movements will often be limited by critically fragmented and diminished natural land cover, or lack of appropriate aquatic habitat. The presence of human-created barriers, such as large tracts of uninterrupted agricultural land or developed areas will exacerbate challenges for wildlife. The Great Lakes, and Michigan’s abundant inland lake systems also create natural barriers to migration for terrestrial wildlife. The combined effect of these natural and human-created stresses puts wildlife in the Midwestern United States at particular risk.[[43]](#endnote-44)

3.3.2.1 Changes in Bird Nesting and Migration Patterns

The wintering ranges of at least 305 North American bird species has shifted northward with warming temperatures by more than 40 miles since 1966. The trend is closely related to increasing winter temperatures and increasing overnight low temperatures, which have been rising in Michigan and in connected bird migration corridors.[[44]](#endnote-45)

Overall, the migration routes and wintering areas of birds have also shifted away from ocean and Great Lakes coasts since the 1960s. A shift away from the large water bodies may relate to warming winter temperatures. Inland areas tend to experience more extreme cold than coastal areas, and those extremes are becoming less severe as the climate warms overall, making previously less hospitable zones more hospitable.41

The seasonal timing of bird migration has also changed. Many bird species are migrating northward earlier in the spring and/or later in the fall. In extreme cases, warmer temperatures and available food supplies have allowed some bird populations to remain resident in one location and have not migrated. For long-distance migrants, change in migration timing can desynchronize birds from the phenology of their food sources, as every species may adapt in different ways, with different capacity, and at different rates.[[45]](#endnote-46)

Riverine habitat, wetlands, and other habitat types that bloom and emerge from winter earlier due to their proximity to water may provide increasingly critical oasis habitat and corridors through varying conditions for migrating birds. This may be particularly true in areas dominated by agriculture where nearby natural habitat is sparse, or in areas near migratory routes and adjacent to expansive agricultural areas like the Huron River watershed.[[46]](#endnote-47) [[47]](#endnote-48) [[48]](#endnote-49)

3.3.2.2 Effects on Fish and Aquatic Species

For freshwater and coastal species in southeastern Michigan, interactions between climate change, changes in land cover, and changes in hydrology will have significant effects. Land cover plays a very important role in determining the hydrologic and energy balance of a natural system. The removal or alteration of vegetation can and will shift these balances in ways could increase run-off, promote flooding, reduce precipitation and nutrient uptake, and deprive species of cool, shady relief, all of which would put stress on sensitive species and habitats.

Changes in air temperature and precipitation will affect water temperature and flow in streams and in groundwater inputs to spring ponds. Many lakes in Michigan and in the Huron River watershed stratify during the summer, with the coldest layer at the bottom.

As air and water temperatures warm and the seasonality of precipitation and runoff changes, the stability and duration of deep coldwater layers will be affected, reducing the suitability for coldwater fish. Dissolved oxygen will also be depleted to an extent stressful or harmful for many fish species during periods of prolonged stratification. The result may be the decline of coldwater fish populations.[[49]](#endnote-50) [[50]](#endnote-51)

The effects of climate change on freshwater mussels is still a developing area of research. There is broad concern among experts that rising temperatures may be negatively affecting freshwater mussel species, but there are relatively few studies applicable to any specific region of the country of the mussel species native to the Huron River watershed. Studies continue to indicate cause for concern and further caution.[[51]](#endnote-52)

3.3.4 Effects on Wetlands

Michigan and other northern latitudes are not immune to drought levels that stress ecosystems. Some climate models project an increased risk in summer droughts for the Great Lakes region, but the long-term, broad effects of such droughts on wetland areas is still uncertain. There is greater concern for some specific effects, such as loss of spawning habitat for fish species like pike due to increased temperatures, concentration of precipitation into larger storms, and greater evaporation.[[52]](#endnote-53)

Climate change may negatively impact vernal pools and other seasonally dependent wetlands. While climate models project increases in annual precipitation totals, the range of future projections in seasonal precipitation totals is large.[[53]](#endnote-54) Future evaporation rates over land areas in the late-spring, summer, and early fall are also expected to increase with warmer temperatures, which may polarize wet and dry seasons, stressing or eliminating vernal pools as viable habitats.[[54]](#endnote-55)

3.3.4 Effects on Erosion

Increased stream flow destroy habitat and scour the banks causing greater erosion. A greater frequency and magnitude of heavy precipitation events likely means the region will experience increased runoff, more rapid erosion, more pollutants being carried to the streams and river, and heavier sediment loads that can cause issues for fish life. The Middle Huron watershed straddles many particularly vulnerable landscapes that straddle both agriculture and areas of new, rapid urban and suburban development. These landscape types, without proper management practices, can erode rapidly as they are repurposed for residential and commercial development, or if the current management practices in agricultural areas are insufficient.

3.3.4.1 Related to Agricultural Landscapes

Riparian zones in agriculture areas such as those in the Upper Middle Huron are especially vulnerable to erosion due to climate change without improvements in management practice.

Soil erosion by water is one of the major environmental threats to sustainable crop production.[[55]](#endnote-56) [[56]](#endnote-57) It also adversely affects drainage networks, water quality, and recreation.[[57]](#endnote-58) [[58]](#endnote-59)  Increasing heavy precipitation frequency and magnitude increases soil erosion and the sediment transport capacity of surface runoff from agricultural lands, which could increase total soil erosion and sedimentation into the Huron River and its tributaries.[[59]](#endnote-60) Therefore, increasing soil erosion rates will not only reduce agricultural productivity, but will also accelerate the loss of carbon stocks and stored soil nutrients.[[60]](#endnote-61) In turn, this diminishes the cohesiveness of soil, creating a positive feedback for greater erosion.[[61]](#endnote-62)

The proportion of U.S. land area that experienced extreme precipitation remained steady until the 1980s but increased rapidly since then.[[62]](#endnote-63) In the coming century, this expansion is expected to continue to increase. Because much of the historical change has occurred within the lifetimes of active farmers and growers, it is common that practices learned during or before the 1980s are still being applied to areas now at much high risk of erosion. Conservation strategies that are still being implemented to reduce erosion and increase carbon sequestration often use obsolete estimates of expected conditions. Strategies should be improved by considering current and projected future climate extremes and changing local factors. In the Huron River watershed, this warrants greater collaboration and awareness-building among farmers, scientists regulators, and conservation organizations. Additional protective measures will be needed to safeguard progress that has been made to reduce erosion and water quality degradation.[[63]](#endnote-64)

3.3.5 Effects on Water Quality

3.3.5.1 Sewage Overflows and Treatment Plant Discharges

Climate change will intensify other stresses on aging infrastructure in the Huron River watershed. In recent years, the increase in heavy downpours has contributed to the repeated discharge of untreated sewage to the river or its tributaries in several communities. While communities with combined sewage-overflow systems are more vulnerable to sewage discharges due to extreme precipitation events, communities with separate sanitary and storm sewers are also at increasing risk. Insufficient storage and treatment capacity at wastewater treatment plants is a major factor.

3.3.5.2 Related to agricultural landscapes

Many water quality effects derived from agricultural land management are related to soil water excess. Southeastern Michigan has seen an increase in annual precipitation with the largest percentage increases in the spring and fall. These shifting precipitation patterns coupled with more extreme precipitation events may harm water quality by increasing the transport of sediment, nitrate, and phosphorus to surface water bodies. There is evidence that annual variation in nitrate loads are related to annual precipitation amounts especially in the presence of extensive subsurface drainage where significant leaching may occur. Parts of the Watershed area are extensively subsurface drained areas and these drains could carry nitrate from the during saturated soil conditions and heavy precipitation events, conditions expected to become more likely in the future.[[64]](#endnote-65)

Stronger, more frequent storms particularly in both extended wet periods and following extended dry periods will likely increase surface runoff and erosion. The mechanism for erosion differs in these conditions. During particularly wet periods, transport over saturated soil can increase the distance which nutrients and sediment are carried. It can also destabilize roots systems and compromise the integrity of subsurface soil. Following dry periods, surface soils may be compromised, and rapid transport of surface sediment is possible. Potential increases in soil erosion with the increases in rainfall intensity show that runoff and sediment movement from agricultural landscapes will increase. [[65]](#endnote-66)

The heavy rain event of June 26th, 2021 provided an example of the heavy rain on dry soils scenario. Multiple observational stations throughout the watershed recorded 4 to 6 inches of precipitation in 24 hours, with some stations recording the majority of that rainfall within a 3-hour period. Depending on the specific station precipitation total and the duration considered, the precipitation event was a 100- to 1000-year storm.[[66]](#endnote-67) But at least two other similar magnitude rain events have been observed in southeast Michigan since 2014, indicating the past recurrence intervals, which do not account for future climate change projections, are now extremely likely to underrepresent the actual annual recurrence probability of these heavy storms. This rain event followed months of moderate drought conditions as described by the National Integrated Drought Monitoring System.[[67]](#endnote-68) Rapid sediment transport was observed in many locations along creeks through agricultural areas in the Huron and neighboring watersheds. Turbidity in the Huron River was observed to be very high for at least 72 hours following the rain event, with Mill Creek contributing a significant sediment plume to the main stem of the Huron. Casual observations made by recreators in the river corridor reported significant woody debris and sediment buildup, creating safety hazards for paddlers. In addition to triggering advisories for paddlers to avoid the river during high flow, several paddlers reported avoiding the river due to its opaque appearance. These conditions following heavy rain on dry events are likely to continue to increase in frequency in the future. Effects in the Upper Middle Huron observed during this event, such as runoff loads, erosion, and sediment transport, provide a qualitative indication of vulnerabilities likely to become substantially more severe.

3.3.5.3 Waterborne Disease and Heat

Changing climate conditions are altering the distribution and prevalence of waterborne illnesses around the globe and within the United States, making it possible for disease vectors to become established in areas that were previously inhospitable to them.[[68]](#endnote-69)

Warming temperatures may be increasing the risk of infectious waterborne diseases in Michigan. Of particular concern for much of Michigan is Legionella. Legionella is a naturally occurring bacteria usually found in warm water. Exposure through inhalation of mists or vapors from contaminated water can cause lung infections known as Legionnaires’ disease or, in rare cases, Pontiac fever, collectively known as legionellosis. Legionella is the most frequently reported cause of water-related disease outbreaks in the U.S. and is usually associated with exposure to water in conditions of heat, stasis, and aerosolization that optimize transmission. Roughly 200 cases of Legionellosis are reported to the CDC from Michigan each year. Legionella species colonize outdoor water reservoirs including potable water systems and cooling towers, and the organisms grow rapidly at temperatures between 85°F to 110°F. Studies in the eastern U.S. and Europe suggest that Legionnaire’s disease outbreaks may be associated with warm humid weather, possibly due to increased Legionella growth stimulated by warming of potable water in reservoirs and plumbing. Warm temperatures may also increase population contact with recreational waters, increasing the opportunity for exposure to pathogens in the water.[[69]](#endnote-70)

3.3.5.5 Harmful Algal Blooms

Globally, climate change is driving increases in magnitude, duration, number of affected waterbodies, and health risks of harmful algal blooms.[[70]](#endnote-71) Unless additional conservation actions are taken, the growing frequency and severity of intense spring rainstorms in the Great Lakes region throughout this century will likely increase the number and extent of harmful algal blooms and “dead zones” in southeastern Michigan, though the effects on any specific river or lake system is uncertain. Prolonged warm periods during the summer, and reduced ice formation over lakes, allows lake temperatures to stratify earlier in the summer season, reducing vertical mixing in the water column.

More total spring precipitation and stronger storms, combined with the greater availability of phosphorous due to current agricultural practices, means that greater amounts of the nutrient could be scoured from farmlands and into surface waters, fueling algae blooms and hypoxic zones.[[71]](#endnote-72) [[72]](#endnote-73)

The agricultural practices that contribute to increased availability of phosphorous from fertilizer include no-till farming, a method of planting crops without plowing. The technique reduces soil erosion but also leaves high concentrations of reactive phosphorous in the upper surface soil, where it can be more readily flushed out during substantial rainfall. The combination of these factors has caused the western Lake Erie basin to reverse some of the nutrient loading reductions experienced since the 1990s.[[73]](#endnote-74)

While Huron River watershed drinking water sources are not particularly vulnerable to HABs (only Ann Arbor draws its drinking water from river surface waters), the Huron River watershed contributes nutrient runoff to Lake Erie, a drinking water source that has suffered significant impacts to drinking water due to the presence of HABs.[[74]](#endnote-75)

HABs do affect recreation on the Huron River. Most directly, swimming and fishing suffer, though repeated water quality issues may dissuade people from recreating near the river corridor even when there is little or no risk. Cyanobacteria in HABs is toxic and a skin irritant. Nutrient loading from agricultural and other sources in the above the Middle Huron have contributed to the outbreak of HABs in urban communities along Ford and Belleville Lake. Under future climate conditions (warmer summer temperatures and increased runoff) and without remediation of confounding factors, HABs will be more likely on sections of the Huron River in the future.[[75]](#endnote-76)

Ford Lake and Belleville Lake are commonly afflicted by algal blooms and harmful algal blooms. Both lakes are artificial, created by dams that have trapped phosphorus in the sediment for decades. Both lakes are located below the majority of agricultural activity and nutrient loading in the Huron River. Both lakes have seen prolonged summer warming periods with decreasing winter ice cover, conditions that can lead to increased likelihood of algal blooms. While there is no local action to reduce the incidence of water temperatures, runoff can be reduced through natural areas protection, and GSI implementation, limiting nutrient loading to the lakes and, in turn, limiting a key factor in the seasonal development of algal blooms.

3.3.6 Effects on Infrastructure

Effects of climate change on infrastructure in southeast Michigan are wide-ranging. Some effects, like the direct damage to stormwater infrastructure or built structures crossing waterways are virtually certain in the absence of intervention, due to the precipitation trends observed and projected. Some of these effects have already been recorded in the Huron River watershed. Heavy precipitation events have led to flashy flows which have overwhelmed stormwater drains, led to flooding, and damaged to infrastructure (bridges, roads, businesses, and residential homes). In some cases, high water tables and a changing groundwater-surface water interface has required deeper wells to protect drinking water.[[76]](#endnote-77)

As the failures of the Sanford and Edenville Dams on the Tittabawassee River demonstrated in 2020, dams are inherently vulnerable to an increasingly severe heavy precipitation and flooding events. Dams have failed on the Huron River in the past as well, and such failures will become more likely across the country due to climate change and aging infrastructure.

Likewise, bridges, pipelines, and other infrastructure that cross waterways, especially rivers, will also become increasingly vulnerable to scouring and erosion.[[77]](#endnote-78) The Middle Huron Watershed includes many urbanized areas that have a significant number of intersections with aging infrastructure. These intersections may be a substantial risk factor for the river over decades without attention or intervention.

Wastewater treatment facilities have been overwhelmed, resulting in damage and, more frequently, the release of untreated sewage.

The Dexter wastewater treatment plant was one such facility. In 2011, as construction just ended on an equalization basin meant to contain a 25-year storm event, the area was hit with a 100-year storm that flooded the new basin out. Staff were forced to bypass treatment units to relieve the hydraulic Ioading, releasing wastewater effluent that did not go through tertiary treatment to Mill Creek. Staff have learned to watch weather reports and anticipate operations in advance of storms to prevent failure from happening again. In Dexter, projects done to repair manholes and sewer lines have been effective in stopping storm surges from infiltrating the wastewater system.

3.4 Implications for Action Planning

3.4.1 Implications for Infrastructure Design and Planning

As described above, the changes in the recurrence of design storms between NOAA Bulletin 71 and NOAA Atlas 14 demonstrate that size and frequency of storms communities need to prepare for has already shifted. Recent studies indicate that the observed trend will continue or accelerate in the future. From Bulletin 71 to NOAA Atlas 14, the sizes of all design storms increased. The 100-year, 24-hour design storm, for example, increased in magnitude by 17% due to both an increase in the frequency and severity of precipitation events. By 2100, 25-, 50-, and 100-year design storms over the Great Lakes region and northeastern United States may occur every 1.5 to 2.5 years, a 10 to 40-fold increase in anticipated frequency relative to the recent past.[[78]](#endnote-79) This implies that much of the infrastructure in the watershed may be insufficiently designed to safely manage and attenuate the current distribution of storms and will be less able to manage future design storms.

The likely increase in the severity and frequency of severe storms carries implication for many elements of built infrastructure. Infrastructure in the intended path of stormwater management will be most affected. This includes drainage networks, culverts, and retention areas in place to present harmful or damaging runoff. Changing storm sizes also likely mean more areas will be vulnerable to flooding, yet floodplains as defined by FEMA do not include projections of future conditions or even guidance for planning future infrastructure in areas potentially vulnerable in the future.

3.4.1.1 Implications for Dams

The dam failures along the Tittabawassee River in May, 2020 have brought renewed attention to dam safety. Current regulations use past flow conditions for assessing the condition and capacity of dams. High-hazard dams, like many of those that exist in the Middle Huron River, are generally built and maintained to safely manage 200-year floods. The recurrence interval of those floods is affected by the recurrence intervals of extreme precipitation events and underlying total seasonal precipitation. The relation of storm size to in-stream flows is usually not quantified in most watersheds, making precise planning for dynamic conditions extremely challenging. The coupling of hydrological and climatological models is often an expensive and practical barrier to such assessments, but even if such information was readily accessible, regulations don’t require account of future potential changes in flow. Multiple trends in climatological and hydrological data from across the U.S. indicate this is a major vulnerability for dams and other in-stream infrastructure. The precipitation event that factored in the 2020 collapse of the Edenville and Sanford Dams was a 500-year weather event over much of Michigan, dropping an excess of 7.5 inches in 48 hours, yet an event of similar magnitude happened just 34 years prior over the same area of Michigan, and other low probability precipitation events have occurred more frequently than historical data suggests they should. It is probable that dams, bridges, and other in-stream, built infrastructure will face storms and flow conditions within their anticipated lifetime that are beyond their design specifications and for which their condition rating does not address.

Peninsular Paper Dam (Pen Dam) in Ypsilanti is of particular concern and HRWC is actively supporting the City of Ypsilanti to remove the dam. Pen Dam is a high-hazard dam since loss of life is probable following catastrophic failure. In 2022, EGLE downgraded the condition of the dam from “fair” to “low,” underscoring the urgency to remove the dam. Planning and assessment efforts to remove the dam are well underway with an anticipated removal of the dam in 2025. Impoundment restoration activities will run concurrently to dewatering of the impoundment and demolition of the dam and will continue for several years after the removal of the spillway.

As of 2023, the operators of French Landing Dam are working with Van Buren Township officials to relicense the dam for hydropower generation through the Federal Energy Regulatory Commission (FERC). The relicensing procedure is comprehensive and has revealed several opportunities to improve safety for recreation and flow management near French Landing Dam. In particular, the portage around this dam is considered the most dangerous along the entire Huron River Water Trail. The entire portage trail is subject to routine vandalism, and the downstream portage launch is a narrow set of wooden steps anchored to a concrete retaining wall. Given the position and dimension of the portage, along with flow management of the dam, it’s common for the wooden steps to be suspended several feet from sure footing for launching small watercraft. All options should be considered for improving, fortifying, or relocating the portage access points, as climate change will likely make flows even less predictable and more dangerous to people accessing the portage.

3.4.1.2 Proactive Planning for Dynamic Flood Risk

Proactive planning for continually increasing risk to infrastructure is warranted. The anticipated costs of climate change effects are expected to accelerate in coming decades, and required changes to infrastructure will become more costly and more challenging over time due to aging infrastructure and even greater weather variability. The ability of communities to adapt or avoid local-scale effects of climate change in the future relies heavily on actions taken before the adaptation are critical and necessary. The risk of catastrophic natural disasters is also likely to increase, and rebuilt infrastructure will better prepare communities for addressing potentially unavoidable failures during unprecedented weather events.

Preparing for future storms is challenging for communities without mandates in state or federal regulation, without critical data, and without available funding for large infrastructure projects. Some communities in the Middle Huron watershed currently use available historical data for design storms and, in the absence of quantitative assessment, apply an additional conservative factor to account for future infrastructure needs. This estimated factor assumes a 10-50% increase in the size of the applicable design storm, depending on the community, specific application, cost, and other factors. A more robust and sustainable approach is needed to quantify needs in specific watersheds and reliably fund large infrastructure projects.

3.4.1.3 Green Infrastructure

In many cases, building infrastructure to manage future storms and floods will be impossible or impractical, either due to costs or the rate of change in design storms. In such cases, the use of green infrastructure and natural areas conservation should be incentivized wherever possible to mitigate the pace and magnitude of future changes. Relying on natural ecosystems to attenuate stormwater, runoff, and flooding is inherently dynamic, whereas built infrastructure will always be at least partially static and likely to become obsolete in the future.

HRWC’s Natural Areas Assessment Program has mapped the remaining natural areas in the watershed and ranked them by a host of ecological criteria, as described in Chapter 2.1.3.2. Figure 2.6 provides a good guide to determining the most important areas of natural green infrastructure to protect. Another set of data to consider comes from The Nature Conservancy, and it maps, on a national scale, natural areas that provide resilience to climate change. A “Resilient” area is a place buffered from climate change because it contains many connected micro-climate that create different climate options for species in which to seek refuge from extreme weather changes. “Climate corridors” are narrow conduits in which movements of plants and animals becomes highly concentrated. A “Climate Flow Zone” is like a corridor but less concentrated. Areas with “Confirmed Diversity” contain known locations of rare species or unique communities based on ground inventory.[[79]](#endnote-80)

The EPA, USGS, the Trust for Public Land and numerous other state, federal, and private firms have found that Green Infrastructure either direct cost savings or value through indirect environmental services such as improvements to public health, though estimates range widely on the amount saved and hyperlocal factors play a major role in cost-benefit analysis.[[80]](#endnote-81)

3.4.2 Citizen Science, Education and Individual Action

Rapid changes in climate and the associated risks of flooding, erosion, and water quality are still not widely understood by many residents and community leaders. The HRWC, municipalities, and community partners will need to continue programs that inform residents and entities about the risks and potential solutions to the challenges we face. Continued and expanded citizen science programs that engage and educate watershed residents is one effective strategy that both serves to inform people and monitor changes over time. HRWC and partners intend bring members of the public into such citizen science efforts and provide an open forum to address any changes observed.

Individual household and property owner actions can amount to significant solutions. Landscaping decisions that reduce runoff, nutrient loading, and municipal stormwater treatment can significantly relieve burdens on built infrastructure while reducing overall community costs, for example. Rain gardens, rain barrels, using less fertilizer for aesthetic purposes, and planting appropriate vegetation are all strategies that can have significant and positive local impact.[[81]](#endnote-82)

3.4.3 Dam Operator Communication and Dam Management

French Landing Dam (Belleville Lake Dam) has created concerns for public safety and flow management. On numerous occasions since 2020, unexpected releases from French Landing Dam have noticeably lowered water levels on Belleville Lake and caused flooding downstream. Some minor private infrastructure, like private docks, tables, and signage, has been washed downstream following these events. In at least one case, the release was linked to a need to avoid complications within the dam, but communication to the Metroparks, state officials, and HRWC was limited, interfering with the ability of community partners to communicate what was happening and why. Improved communication from dam operators to municipal officials, regulatory officials, community partners remains a central need of watershed management in this area.

Changing climate conditions and development patterns that lead to less predictable and more extreme flows will require re-evaluating the way Huron River dams are controlled in response to large, sudden storms, how the lifespan of the dams may shorten, how equipped dams are to manage the range of projected storm sizes, and how maintenance costs may change in response to these factors. The designation of larger floodplain areas will likely be necessary in the event of a dam failure, which would require greater insurance coverage for dam owners and a greater number of nearby property owners required to hold flood insurance.

The installation of additional stream gages along the Huron River and its tributaries would be informative to dam operators in forecasting currently unpredictable flows. Over time, a network sufficiently dense stream gages would provide an effective understanding of how storm size and duration over various locations in the watershed translate to flows elsewhere downstream.

Stream gages and additional communication among dam operators will be essential to ensure that downstream dam operators can effectively respond to management actions taken by dam operators upstream. Toward this goal, HRWC currently facilitates a network of Huron River dam operators and is working with researchers at the University of Michigan to install stream gages throughout the watershed and monitor flows following precipitation events.[[82]](#endnote-83) As a part of this group, the operators of Ford Lake Dam, owned by Ypsilanti Township, have been especially communicative and serve as an instrumental example for other dam operators on the river.

3.4.4 Development Planning and Land Protection

The Great Lakes region and the Upper Midwest is one region of the United States where many experts expect to see gains in population driven by people migrating from other areas.[[83]](#endnote-84) The summer climate of Michigan will likely hit and subsequently pass what most people feel are optimal summer temperatures.[[84]](#endnote-85) In combination with abundant recreational waters, the Great Lakes region is predicted to remain attractive for tourism, residence, and business where other parts of the country, like the Southern United States, face climate conditions unsustainable for agriculture. Population dynamics are driven by many unrelated factors, but many of these factors indicate our region will see an increase in population, and an increase for housing, through the middle of the 20th century.

Added development pressure could stress watershed health as pervious surfaces and wetlands are developed and more impervious surface constructed. Communities are advised to take a proactive approach to planning, zoning, and land protection in anticipation of accelerated population growth.[[85]](#endnote-86) Protecting existing undeveloped land should be a priority for communities with limited fiscal capacity due to the high rate of economic benefit. The Trust for Public Land has found that land protection creates a $4 to 10 return on investment for every $1 spent on land protection.[[86]](#endnote-87)

In particular, the use of pervious pavements to reduce concentrated runoff during heavy precipitation events, as has been demonstrated throughout the watershed, are recommended. Even better is planning that reduced the amount of artificial pervious or impervious surface needed entirely. Actions that accomplish this at the community scale may be include putting in place proactive ordinances to reduce parking requirements, zoning for higher density in urbanized areas, and prioritizing sustainable transportation means like buses, trains, and bicycle routes. Maintaining existing natural infrastructure or utilizing green infrastructure options when possible is recommended.

3.5 Emerging Research

The scientific understanding of the cascading effects physical, ecological, built, and social systems of the planet continues to evolve rapidly. This advance of scientific knowledge is even more pronounced at regional, subregional, and watershed scales. As new information emerges, best practices will also need to readily adapt.

The causes of global climate change, as well as the projected trajectories of many fundamental climate characteristics of southeast Michigan, are clear, however. It is extremely unlikely that the trajectory of observed and contemporary changes in climate will deviate to such a degree to fundamentally alter watershed management priorities or planning objectives over the coming decades.

Several iterative datasets and comprehensive reports serve the Huron River watershed particularly well due to their tailored focus to our regional climate and other local factors. These resources are peer-reviewed and vetted at multiple levels and at every phase of collection and production. Some of these key resources, used to guide this and other Huron River watershed management plans are described below:

Data and climate summaries are periodically compiled by the Great Lakes Integrated Sciences and Assessments (GLISA) team at the University of Michigan and Michigan State University, most recently in 2019. The summary data and narratives rely on multiple datasets from numerous sources. More information can be found at <https://glisa.umich.edu>.

The Fourth National Climate Assessment, the most recent iteration of a report mandated by The Global Change Research Act of 1990, was written to help inform decision-makers, utility and natural resource managers, public health officials, emergency planners, and other stakeholders by providing a thorough examination of the effects of climate change on the United States. It provides chapters detailing effects by region and by type of impact. The supporting technical materials for this and previous iterations of the report also provide a sound, vetted summary of many complicated fields of study, many of which have implications for watershed management. More information can be found at <https://nca2018.globalchange.gov/chapter/front-matter-about/>. The Fifth National Climate Assessment is currently in development. Private consultation with key authors of several draft chapters indicate the findings of the Fifth Assessment will reaffirm the findings of the Fourth Assessment that are relevant to local watershed management planning.

The Midwest Technical Input Team to the Third National Climate Assessment, the previous iteration of the process outlined above, was the first such team to be led by experts from Michigan State University and the University of Michigan. While the scope of the Fourth National Climate Assessment followed a similar approach as the Third iteration and updated much of the relevant information, many of the references and key findings of the Midwest Technical Input Team provide relevant guidance for Michigan watersheds. More information can be found at: <http://glisa.umich.edu/resources/nca>

The Sixth Assessment Report from the United Nations Intergovernmental Panel on Climate Change was completed through 2021 and 2022. The Working Group I contribution to the Sixth Assessment Report, *Climate Change 2021: The Physical Science Basis* was released on 9 August 2021. The Working Group II contribution, *Climate Change 2022: Impacts, Adaptation and Vulnerability* was released on 28 February 2022. The Working Group III contribution, *Climate Change 2022: Mitigation of Climate Change* was released on 4 April 2022. Taken together, these three reports provide a comprehensive summary of the state of climate science and potential solutions. The reports focus on global analyses and global perspective but also inform actionable goals for local and statewide jurisdictions. <https://www.ipcc.ch/assessment-report/ar6/>

1. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896. [↑](#endnote-ref-2)
2. Baule, W. et al. Synthesis of the Third National Climate Assessment for the Great Lakes Region. 2015. Great Lakes Integrated Sciences and Assessments. Michigan State University and University of Michigan, East Lansing, MI and Ann Arbor, MI, USA. https://glisa.umich.edu/media/files/Great\_Lakes\_NCA\_Synthesis.pdf [↑](#endnote-ref-3)
3. Waters, C.N. et al., 2016: The Anthropocene is functionally and stratigraphically distinct from the Holocene. Science, 351(6269), aad2622–aad2622, doi:10.1126/science.aad2622. [↑](#endnote-ref-4)
4. Vose, Russell S.; Applequist, Scott; Squires, Mike; Durre, Imke; Menne, Matthew J.; Williams, Claude N., Jr.; Fenimore, Chris; Gleason, Karin; Arndt, Derek (2017): NOAA's Gridded Climate Divisional Dataset (CLIMDIV). Michigan Climate Division 10: Southeast Lower Michigan. NOAA National Centers for Environmental information. doi:10.7289/V5M32STR Data provided by the Great Lakes Integrated Sciences and Assessments center, 2019. [↑](#endnote-ref-5)
5. Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner, 2018: Our Changing Climate. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2 [↑](#endnote-ref-6)
6. Data and climate summaries compiled by the Great Lakes Integrated Science and Assessment team at the University of Michigan in 2019. https://glisa.umich.edu [↑](#endnote-ref-7)
7. Dynamical Downscaling for the Midwest and Great Lakes Basin.” Future projections are based on the dynamically downscaled data set for the Great Lakes region developed by experts at the University of Wisconsin-Madison. There are a total of six downscaled models that represent how a variety of different variables are projected to change (mid-century, 2040-2059, compared to the recent past, 1980-1999). The ranges are comprised of the lowest and highest values from all six dynamically downscaled data sets. The regional data are available for download at: http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php. [↑](#endnote-ref-8)
8. Winkler, J.A., Andresen, J.A., Hatfield, J.L., Bidwell, D., & Brown, D. (Eds.). (2014). Climate Change in the Midwest: A Synthesis Report for the National Climate Assessment. Washington, DC: Island Press [↑](#endnote-ref-9)
9. Frankson, R., K. Kunkel, S. Champion, and J. Runkle, 2017: Michigan State Climate Summary. NOAA Technical Report NESDIS 149-MI, 4 pp. [↑](#endnote-ref-10)
10. Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner, 2018: Our Changing Climate. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2 [↑](#endnote-ref-11)
11. Data and climate summaries compiled by the Great Lakes Integrated Science and Assessment team at the University of Michigan in 2019. https://glisa.umich.edu [↑](#endnote-ref-12)
12. National Oceanic and Atmospheric Administration National Centers for Environmental Information Global Historical Climatology Network Station Observations (GHCN). More information about this station located in Ann Arbor, MI from 1981-2010 is available at: https://glisa.umich.edu/station/c00200230 [↑](#endnote-ref-13)
13. Under the World Climate Research Programme (WCRP) the Working Group on Coupled Modelling (WGCM) established the Coupled Model Intercomparison Project (CMIP) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). CMIP provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyze GCMs in a systematic fashion, a process which serves to facilitate model improvement. Virtually the entire international climate modeling community has participated in this project since its inception in 1995. The Program for Climate Model Diagnosis and Intercomparison (PCMDI) archives much of the CMIP data and provides other support for CMIP. PCMDI's CMIP effort is funded by the Regional and Global Climate Modeling (RGCM) Program of the Climate and Environmental Sciences Division of the U.S. Department of Energy's Office of Science, Biological and Environmental Research (BER) program. [↑](#endnote-ref-14)
14. Dynamical Downscaling for the Midwest and Great Lakes Basin.” Future projections are based on the dynamically downscaled data set for the Great Lakes region developed by experts at the University of Wisconsin-Madison. There are a total of six downscaled models that represent how a variety of different variables are projected to change (mid-century, 2040-2059, compared to the recent past, 1980-1999). The ranges are comprised of the lowest and highest values from all six dynamically downscaled data sets. The regional data are available for download at: http://nelson.wisc.edu/ccr/resources/dynamical-downscaling/index.php. [↑](#endnote-ref-15)
15. Data and climate summaries compiled by the Great Lakes Integrated Science and Assessment team at the University of Michigan in 2019. https://glisa.umich.edu [↑](#endnote-ref-16)
16. Data and climate summaries compiled by the Great Lakes Integrated Science and Assessment team at the University of Michigan in 2019. https://glisa.umich.edu [↑](#endnote-ref-17)
17. National Oceanic and Atmospheric Administration (NOAA) ThreadEx Long-Term Station Extremes for America”. ThreadEx is a data set of extreme daily temperature and precipitation values for 270 locations in the United States. For each day of the year at each station, ThreadEx provides the top 3 record high and low daily maximum temperatures, the top 3 record high and low daily minimum temperatures, the top 3 daily precipitation totals, along with the years the records were set for the date (NCAR, 2013). ThreadEx data for the Detroit area from 1966 to 2016: http://threadex.rcc-acis.org/ [↑](#endnote-ref-18)
18. Data and climate summaries compiled by the Great Lakes Integrated Science and Assessment team at the University of Michigan in 2019. https://glisa.umich.edu [↑](#endnote-ref-19)
19. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, B. DeAngelo, S. Doherty, K. Hayhoe, R. Horton, J.P. Kossin, P.C. Taylor, A.M. Waple, and C.P. Weaver, 2017: Executive summary. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, doi: 10.7930/J0DJ5CTG. [↑](#endnote-ref-20)
20. Kirchmeier-Young and Zhang. 2020. Human influence has intensified extreme precipitation in North America. Proceedings of the National Academy of Sciences Jun 2020, 117 (24) 13308-13313; DOI: 10.1073/pnas.1921628117 [↑](#endnote-ref-21)
21. Walter A. Robinson (2021) Climate change and extreme weather: A review focusing on the continental United States, Journal of the Air & Waste Management Association, 71:10, 1186-1209, DOI: 10.1080/10962247.2021.1942319 [↑](#endnote-ref-22)
22. National Oceanic and Atmospheric Administration Hydrometeorological Design Studies Center Atlas 14 Precipitation Frequency Estimates. Data available at: hdsc.nws.noaa.gov/hdsc/pfds/pfds\_map\_cont.html   [↑](#endnote-ref-23)
23. F. Huff and J. Angel 1992. “Rainfall Frequency Atlas of Midwest.” Midwestern Climate Center and Illinois State Water Survey. NOAA National Weather Service. Champaign, Illinois. https://www.isws.illinois.edu/pubdoc/B/ISWSB-71.pdf [↑](#endnote-ref-24)
24. Shuang-Ye Wu (March 14th 2012). Projecting Changes in Extreme Precipitation in the Midwestern United States Using North American Regional Climate Change Assessment Program (NARCCAP) Regional Climate Models, Greenhouse Gases - Emission, Measurement and Management, Guoxiang Liu, IntechOpen, DOI: 10.5772/32667. [↑](#endnote-ref-25)
25. Wu, S. Changing characteristics of precipitation for the contiguous United States. Climatic Change 132, 677–692 (2015). https://doi.org/10.1007/s10584-015-1453-8 [↑](#endnote-ref-26)
26. Grubb, M., C. Okereke, J. Arima, V. Bosetti, Y. Chen, J. Edmonds, S. Gupta, A. Köberle, S. Kverndokk, A. Malik, L. Sulistiawati, 2022: Introduction and Framing. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.003 [↑](#endnote-ref-27)
27. Handler, S. et al. 2014. Michigan forest ecosystem vulnerability assessment and synthesis: a report from the Northwoods Climate Change Response Framework project. Gen. Tech. Rep. NRS-129. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 229 p. [↑](#endnote-ref-28)
28. Schwartz, M.D., R. Ahas, and A. Aasa. 2006. Onset of spring starting earlier across the Northern Hemisphere. Glob. Chang. Biol. 12:343–351. [↑](#endnote-ref-29)
29. Schwartz, M.D., T.R. Ault, and J.L. Betancourt. 2013. Spring onset variations and trends in the continental United States: Past and regional assessment using temperature-based indices. Int. J. Climatol. 33:2917–2922. [↑](#endnote-ref-30)
30. USGCRP (2014) Pryor, S. C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G. P. Robertson, 2014: Ch. 18: Midwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 418-440. [↑](#endnote-ref-31)
31. Angel, J., C. Swanston, B.M. Boustead, K.C. Conlon, K.R. Hall, J.L. Jorns, K.E. Kunkel, M.C. Lemos, B. Lofgren, T.A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 872–940. doi: 10.7930/NCA4.2018.CH21 [↑](#endnote-ref-32)
32. (2014) Pryor, S. C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G. P. Robertson, 2014: Ch. 18: Midwest. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 418-440. [↑](#endnote-ref-33)
33. Dukes JS, Pontius J, Orwig D et al (2009) Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? Can J For Res 39:231–248 [↑](#endnote-ref-34)
34. Ryan MG, Vose JM (2012) Effects of climatic variability and change. In: Vose JM, Peterson DL, Patel-Weynand

T (eds) Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis

 for the U.S. forest sector. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research

 Station, Portland, pp 7–95 [↑](#endnote-ref-35)
35. Weed AS, Ayres MP, Hicke JA (2013) Consequences of climate change for biotic disturbances in North

 American forests. Ecol Monogr 83:441–470 [↑](#endnote-ref-36)
36. Rustad L, Campbell J, Dukes JS, Huntington T, Fallon Lambert K, Mohan J, Rodenhouse N (2012) Changing climate,changing forests:the impacts of climate change on forests of the northeastern United States and easternCanada.U.S.

Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, p 48 [↑](#endnote-ref-37)
37. Harrington TC, McNew D, Yun HY (2017) Bur oak blight, a new disease on Quercus macrocarpa caused by

 Tubakia iowensis sp. nov. Mycologia 104(1):79–92 [↑](#endnote-ref-38)
38. Sturrock R, Frankel S, Brown A et al (2011) Climate change and forest diseases. Plant Pathol 60:133–149 [↑](#endnote-ref-39)
39. Weed AS, Ayres MP, Hicke JA (2013) Consequences of climate change for biotic disturbances in North

 American forests. Ecol Monogr 83:441–470 [↑](#endnote-ref-40)
40. Ryan MG, Vose JM (2012) Effects of climatic variability and change. In: Vose JM, Peterson DL, Patel-Weynand

 T (eds) Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis

 for the U.S. forest sector. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research

 Station, Portland, pp 7–95 [↑](#endnote-ref-41)
41. Hellmann JJ, Byers JE, Bierwagen BG, Dukes JS (2008) Five potential consequences of climate change for invasive species. Conserv Biol 22:534–543 [↑](#endnote-ref-42)
42. Brandt L, He H, Iverson L, et al. (2014) Central Hardwoods ecosystem vulnerability assessment and synthesis: a report from the Central Hardwoods Climate Change Response Framework project. U.S. Department of Agriculture, Forest Service, Northern Research Station. Newtown Square, p. 254 [↑](#endnote-ref-43)
43. Winkler, J.A., Andresen, J.A., Hatfield, J.L., Bidwell, D., & Brown, D. (Eds.). (2014). Climate Change in the Midwest: A Synthesis Report for the National Climate Assessment. Washington, DC: Island Press [↑](#endnote-ref-44)
44. National Audubon Society. 2009. Northward shifts in the abundance of North American birds in early winter: A response to warmer winter temperatures? [↑](#endnote-ref-45)
45. La Sorte, F.A., and F.R. Thompson III. 2007. Poleward shifts in winter ranges of North American birds. Ecology 88(7):1803–1812. [↑](#endnote-ref-46)
46. Krosby M, Theobald DM, Norheim R, McRae BH (2018) Identifying riparian climate corridors to inform climate adaptation planning. PLoS ONE 13(11): e0205156. https://doi.org/10.1371/journal.pone.0205156 [↑](#endnote-ref-47)
47. McGuire J L, Lawler J J, McRae B H, Nunez T A and Theobald D M ~ 2016 Achieving climate connectivity in a fragmented landscape PNAS 113 7195–200 [↑](#endnote-ref-48)
48. Keeley, A., et al. 2018. New concepts, models, and assessments of climate-wise connectivity Environmental Research Lette 13 073002 [↑](#endnote-ref-49)
49. Wisconsin Initiative on Climate Change Impacts first report, Wisconsin’s Changing Climate: Impacts and Adaptation, 2011 [↑](#endnote-ref-50)
50. Steen, P.J., Wiley, M.J. and Schaeffer, J.S. (2010), Predicting Future Changes in Muskegon River Watershed Game Fish Distributions under Future Land Cover Alteration and Climate Change Scenarios. Transactions of the American Fisheries Society, 139: 396-412. doi:10.1577/T09-007.1 [↑](#endnote-ref-51)
51. Alissa M. Ganser, Teresa J. Newton, and Roger J. Haro, "The effects of elevated water temperature on native juvenile mussels: implications for climate change," Freshwater Science 32, no. 4 (December 2013): 1168-1177. [↑](#endnote-ref-52)
52. Huron River Watershed Council. 2013. Climate Resilient Communities: Improving information access and communication among dam operations of the Huron River main stem. https://www.hrwc.org/wp-content/uploads/2013/03/Instream%20Flows.pdf [↑](#endnote-ref-53)
53. Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner, 2018: Our Changing Climate. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2 [↑](#endnote-ref-54)
54. Morelli, T., and Cartwright, J., 2018, Vernal pool threats: How might climate change alter vernal pool management considerations? Presented at Of Pools and People: Translating Vernal Pool Research into Desired Management Outcomes, Ashland, MA, October 25 2018. Supplemental maps of climate-change projections relevant to vernal pool hydroperiods. [↑](#endnote-ref-55)
55. Pimentel, D., and M. Burgess, 2013: Soil erosion threatens food production. Agriculture, 3 (3), 443–463. doi:10.3390/agriculture3030443 [↑](#endnote-ref-56)
56. Lal, R., and B. A. Stewart, Eds., 1990: Soil Degradation. Springer, New York, 345 pp. doi:10.1007/978-1-4612-3322-0 [↑](#endnote-ref-57)
57. Sharpley, A., 2016: Managing agricultural phosphorus to minimize water quality impacts. Scientia Agricola, 73, 1–8. doi:10.1590/0103-9016-2015-0107 [↑](#endnote-ref-58)
58. Issaka, S., and M. A. Ashraf, 2017: Impact of soil erosion and degradation on water quality: A review. Geology, Ecology, and Landscapes, 1 (1), 1–11. doi:10.1080/24749508.2017.1301053 [↑](#endnote-ref-59)
59. Yasarer, L. M. W., and B. S. M. Sturm, 2016: Potential impacts of climate change on reservoir services and management approaches. Lake and Reservoir Management, 32 (1), 13–26. doi:10.1080/10402381.2015.1107665 [↑](#endnote-ref-60)
60. USGCRP, 2018: Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report. U.S. Global Change Research Program, Washington, DC, 877 pp. [↑](#endnote-ref-61)
61. Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, and M.A. Grusak, 2018: Agriculture and Rural Communities. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 391–437. doi: 10.7930/NCA4.2018.CH10 [↑](#endnote-ref-62)
62. EPA, 2016: Climate Change Indicators: Heavy Precipitation. U.S. Environmental Protection Agency (EPA) [↑](#endnote-ref-63)
63. Maresch, W., M. R. Walbridge, and D. Kugler, 2008: Enhancing conservation on agricultural landscapes: A new direction for the Conservation Effects Assessment Project. Journal of Soil and Water Conservation, 63 (6), 198A–203A. doi:10.2489/jswc.63.6.198A [↑](#endnote-ref-64)
64. Hatfield, J.L., L.D. McMullen, and C.S. Jones. 2009. Nitrate-nitrogen patterns in the Raccoon River Basin related to agricultural practices. J. Soil Water Cons. 64:190-199 [↑](#endnote-ref-65)
65. Nearing, Mark & Jetten, V.G. & Baffaut, Claire & Cerdan, Olivier & Couturier, Alain & Hernandez, Mariano & Le Bissonnais, Yves & Nichols, Mary & Nunes, J.P. & Renschler, Chris & Souchère, Véronique & Oost, Kristof. (2005). Modeling Response of Soil Erosion and Runoff to Changes in Precipitation and Cover. Catena. 131-154. 10.1016/j.catena.2005.03.007. [↑](#endnote-ref-66)
66. National Oceanic and Atmospheric Administration Hydrometeorological Design Studies Center Atlas 14 Precipitation Frequency Estimates. Data available at: hdsc.nws.noaa.gov/hdsc/pfds/pfds\_map\_cont.html   [↑](#endnote-ref-67)
67. National Integrated Drought Information System. Current conditions. https://www.drought.gov/current-conditions. Accessed June 2021. [↑](#endnote-ref-68)
68. Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754. [↑](#endnote-ref-69)
69. Cameron, L., A. Ferguson, R. Walker, D. Brown, & L. Briley, 2015: Climate and health adaptation profile report: Building resilience against climate effects on Michigan’s health. Accessed at: www.michigan.gov/climateandhealth. [↑](#endnote-ref-70)
70. Ho, J.C., Michalak, A.M. & Pahlevan, N.: Widespread global increase in intense lake phytoplankton blooms since the 1980s. Nature 574, 667–670 (2019) doi:10.1038/s41586-019-1648-7 [↑](#endnote-ref-71)
71. Michalak, A.M., E. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgeman, J.D. Chaffin, K.H. Cho, R. Confesor, I. DaloÄŸlu, J. DePinto, M.A. Evans, G.L. Fahnenstiel, L. He, J.C. Ho, L. Jenkins, T. Johengen, K.C. Kuo, E. Laporte, X. Liu, M. McWilliams, M.R. Moore, D.J. Posselt, R.P. Richards, D. Scavia, A.L. Steiner, E. Verhamme8, D.M. Wright, M.A. ZagorskiÂ 2013 Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc. Nat. Acad. Sci. 110 (16) 6448-6452 [↑](#endnote-ref-72)
72. Watson SB, Miller C, Arhonditsis G, et al. The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. Harmful Algae. 2016;56:44-66. doi:10.1016/j.hal.2016.04.010 [↑](#endnote-ref-73)
73. Michalak, A.M., E. Anderson, D. Beletsky, S. Boland, N.S. Bosch, T.B. Bridgeman, J.D. Chaffin, K.H. Cho, R. Confesor, I. DaloÄŸlu, J. DePinto, M.A. Evans, G.L. Fahnenstiel, L. He, J.C. Ho, L. Jenkins, T. Johengen, K.C. Kuo, E. Laporte, X. Liu, M. McWilliams, M.R. Moore, D.J. Posselt, R.P. Richards, D. Scavia, A.L. Steiner, E. Verhamme8, D.M. Wright, M.A. ZagorskiÂ 2013 Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc. Nat. Acad. Sci. 110 (16) 6448-6452 [↑](#endnote-ref-74)
74. Watson SB, Miller C, Arhonditsis G, et al. The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. Harmful Algae. 2016;56:44-66. doi:10.1016/j.hal.2016.04.010 [↑](#endnote-ref-75)
75. EPA, 2016. Climate Change and Harmful Algal Blooms. https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms [↑](#endnote-ref-76)
76. Huron River Watershed Council. 2013. Climate Resilient Communities: Improving information access and communication among dam operations of the Huron River main stem. https://www.hrwc.org/wp-content/uploads/2013/03/Instream%20Flows.pdf [↑](#endnote-ref-77)
77. Maxwell, K., S. Julius, A. Grambsch, A. Kosmal, L. Larson, and N. Sonti, 2018: Built Environment, Urban Systems, and Cities. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11 [↑](#endnote-ref-78)
78. Kirchmeier-Young and Zhang. 2020. Human influence has intensified extreme precipitation in North America. Proceedings of the National Academy of Sciences Jun 2020, 117 (24) 13308-13313; DOI: 10.1073/pnas.1921628117 [↑](#endnote-ref-79)
79. Anderson, M.G., Barnett, A., Clark, M., Prince, J., Olivero Sheldon, A. and Vickery B. 2016. Resilient and Connected Landscapes for Terrestrial Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.http://easterndivision.s3.amazonaws.com/ Resilient\_and\_Connected\_Landscapes\_For\_Terrestial\_Conservation.pdf [↑](#endnote-ref-80)
80. Green Infrastructure Cost-Benefit Resources. EPA. 2016. https://www.epa.gov/green-infrastructure/green-infrastructure-cost-benefit-resources Accessed June 2020. [↑](#endnote-ref-81)
81. EPA. Soak Up the Rain. Rain Gardens and Green Infrastructure. https://www.epa.gov/soakuptherain/soak-rain-rain-gardens. Accessed 2019. [↑](#endnote-ref-82)
82. Huron River Watershed Council. 2013. Climate Resilient Communities: Improving information access and communication among dam operations of the Huron River main stem. https://www.hrwc.org/wp-content/uploads/2013/03/Instream%20Flows.pdf [↑](#endnote-ref-83)
83. Robinson C, Dilkina B, Moreno-Cruz J (2020) Modeling migration patterns in the USA under sea level rise. PLoS ONE 15(1): e0227436. https://doi.org/10.1371/journal.pone.0227436 [↑](#endnote-ref-84)
84. Nicholls, S., 2012: Outdoor Recreation and Tourism. In: U.S. National Climate Assessment Midwest Technical Input Report. J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown, coordinators.

Available from the Great Lakes Integrated Sciences and Assessments (GLISA) Center, http://glisa.msu.edu/docs/NCA/MTIT\_RecTourism.pdf [↑](#endnote-ref-85)
85. Winkler, J.A., Andresen, J.A., Hatfield, J.L., Bidwell, D., & Brown, D. (Eds.). (2014). Climate Change in the Midwest: A Synthesis Report for the National Climate Assessment. Washington, DC: Island Press [↑](#endnote-ref-86)
86. Economic Benefits and Fiscal Impact of Parks and Open Space: A Report by The Trust for Public Land. 2010. https://www.tpl.org/how-we-work/fund/conservation-economics [↑](#endnote-ref-87)