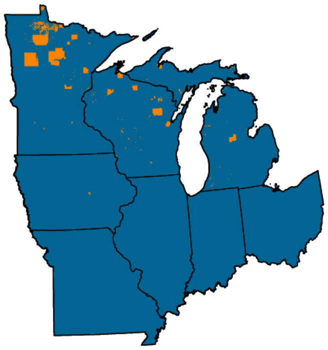
Fifth National Climate Assessment: Chapter 24

Midwest



Chapter 24. Midwest

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Introduction

The Midwest is diverse in landscapes, people, and culture. The region covers more than 328 million acres, with approximately 284 million acres covered by croplands and forests or designated as public land. It sustains vital ecosystems and wildlife and provides refuge and recreation for its residents, including 35 Federally Recognized Tribes and numerous other state-recognized and non-recognized Tribes. More than 40,000 natural lakes and thousands more human-made reservoirs and ponds dot the landscape. The Midwest borders four of the five Great Lakes; together, the five Great Lakes contain approximately 21% of the world's surface freshwater supply, and about 10% of the US population lives within the Great Lakes basin. There are more than 500,000 miles of rivers and streams flowing through the region, including the Mississippi, Missouri, and Ohio Rivers—critical lifelines enabling the exchange of goods and services throughout the country. The Midwest is linked by more than 2 million miles of roads, 160,000 bridges, 34,000 rail miles, and 3,000 airports. It has 41 cities with at least 100,000 residents, including 5 of the 30 most populated cities in the United States. All of the Midwest states except Illinois have lower urban populations than the national average, and 74.3% of the Midwest population lives in urban areas.[1]

The climate of the Midwest has warmed since the first half of the 20th century, and annual precipitation has increased (Figure 2.4). Sub-annual changes, such as the recent lack of warming during summer and rapid oscillations between extreme wet and dry periods (Figure 24.1), increase the complexity and uncertainty of future impacts. Nonetheless, these changes have impacted agriculture (KM 24.1), natural resources (KM 24.2), health and well-being (KM 24.3), the built environment and transportation (KM 24.4), and water quality and quantity (KM 24.5) in societally important and interconnected ways. Increasing temperatures and oscillations between extreme droughts and floods threaten field crops, specialty crops, and animal production across the Midwest,[2,3] which have direct and inequitable impacts on global food supply and security (KM 11.2). These rapid oscillations in hydrology will continue to transform aquatic and terrestrial ecosystems, many of which strongly influence individual and community health and the built environment. These observed and projected changes greatly limit access to natural areas, including those intimately tied to winter ice.[4] Not only does climate change threaten recreation and the economy of this region, but it also disrupts important identity connections between Indigenous Peoples and their ancestral lands (KM 16.1).[5] Individual and community health is at risk, with cascading impacts on social and cultural connections that highlight inequitable health disparities tied to race, ethnicity, age, and income (KMs 14.1, 15.2). Aging infrastructure creates uncertainty in the ability to meet current and future energy needs and withstand increasing volumes of water. Although rural landscapes dominate the Midwest, urban centers concentrate climate risks and socioeconomic inequities (KM 12.2). NOAA's Billion-Dollar Weather and Climate Disasters report (Figure 2.6) does not fully account for the burden felt by low-income populations of urban centers due to chronic, smaller-scale flooding events. Finally, projected increases in temperature and precipitation variability threaten the ability to maintain water quality and manage the Mississippi, Missouri, and Ohio Rivers in ways that maintain the flow of goods and services throughout the region and the country. The Great Lakes indicators, from fish consumption to invasive species, show diverse conditions. Many of the complex interactions between climate changes, the lakes, and their surrounding land and populations raise uncertainty in long-term projections of lake levels and trends in environmental and ecosystem metrics (Table 24.1),[6] and this uncertainty has important implications for international collaboration and adaptive management in the Great Lakes (Box 4.3).

Despite these many risks to the economy and identity of the Midwest, people are responding in ways that offer hope for the future. Researchers are identifying climate-smart agriculture practices that could help boost profitability and improve economic and environmental sustainability (Figure 24.4). There is growing recognition that undeveloped natural lands provide economic and social benefits by contributing to climate mitigation and adaptation (providing nature-based solutions through effective resource management) and that collaboration with Tribes on land issues improves climate outcomes for all residents. Within communities, people are engaging with one another to identify solutions to address structural, institutional, and systemic factors that contribute to inequities and climate injustice. Researchers and practitioners are collaborating to build transportation and energy networks that are resilient to climate change while also maintaining social cohesion in the process. For example, experimental port management in the Great Lakes is assuming the role of ecological restoration, which also improves the social health of the region (Figure 24.9). Communities like Milwaukee have developed public–private partnerships and increased green stormwater infrastructure. Finally, federal partners are working with state and local agencies to build tools and approaches to address climate-related challenges such as drought and harmful algal blooms.

Key Message 24.1

Climate-Smart Practices May Offset Complex Climate Interactions in Agriculture

Crop production is projected to change in complex ways (*likely*, *medium confidence*) due to increasing extreme precipitation events and transitions between wet and dry conditions (*likely*, *medium confidence*), as well as intensification of crop water loss (*likely*, *low confidence*). Changes in precipitation extremes, timing of snowmelt, and early-spring rainfall are expected to pose greater challenges for crop and animal agriculture, including increased pest and disease transmission, muddier pastures, and further degradation of water quality (*likely*, *high confidence*). Climate-smart agriculture and other adaptation techniques provide a potential path toward environmental and economic sustainability (*medium confidence*).

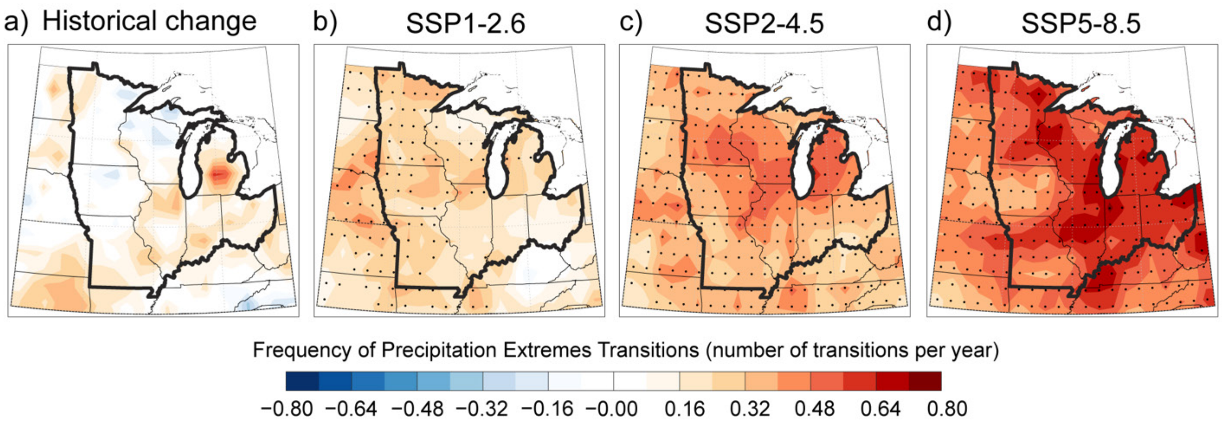
Risk

The Midwest is among the most intensive agricultural regions globally, producing more than 30% and 32% of the world's corn and soybeans, respectively; numerous specialty crops; and livestock in concentrated animal operations.[7,8] Climate change is already affecting Midwest agriculture, and projected climate changes increase these risks.

Impacts

Annual precipitation increased by 5%–15% across much of the Midwest during 1992–2021 (compared to the 1901–1960 average), with some areas experiencing reduced precipitation during summer (Figure 2.4).[9,10,11,12] These trends, particularly across the north-central region of the US, have been partly attributable to human influence.[13,14] Projections (under low [RCP2.6] to very high [RCP8.5] scenarios) suggest precipitation increases across the Midwest ranging from 8% to 20% by midcentury relative to the previous five decades, with individual model uncertainty regarding the degree, direction (wetter or drier), and regional spatial characteristics (KM 3.3).[10,12,15,16,17] Rapid transitions between precipitation extremes are expected to increase across all of the Midwest by late century (2071–2100) compared to historical conditions (Figure 24.1).[17,18] Amplified precipitation variability and more frequent wet–dry transitions increase the risks of transient drought and harm to crops, requiring changes in management systems to maintain food security.[19,20,21]

Change in Frequency of Transitions Between 1-Month Precipitation Extremes



The frequency of wet–dry and dry-wet transitions across the Midwest is projected to increase by late century (2071–2100).

Figure 24.1. Transitions between wet and dry periods are expected to become more frequent across the Midwest. Observed changes in transition frequency (from wet to dry or dry to wet) are based on the Standardized Precipitation Index (SPI), represented by the difference between the periods 1951–1980 and 1981–2010 (historical change, panel **a**). SPI is a common statistical index that quantifies the relative intensity of drought or wetness, and monthly SPI values are utilized to show transitions over short periods. Projected changes in transition frequency under low (SSP1-2.6; **b**), intermediate (SSP2-4.5; **c**), and very high (SSP5-8.5; **d**) scenarios are represented by the difference between the periods 2071–2100 and 1981–2010. The black boundary outlines the Midwest region. Black dots indicate grid cells where the model-projected transition frequency is significantly different from the historical climatology. Adapted from Chen and Ford 2023[18] [CC BY 4.0].

Although average corn and soybean yields increased in recent decades in the Midwest,[22] both excessive moisture (flooding) and extreme droughts significantly decreased corn yields in some locations and years by up to 37%.[2,23] Excessive spring moisture has delayed corn planting by up to a month,[24] while episodic droughts have reduced yields[2] despite increasing annual rainfall.[25]

Future projections suggest further changes in seasonality and increases in variability. Earlier snowmelt is expected to increase daily maximum spring streamflow.[26] Intermediate (RCP4.5) to very high (RCP8.5) scenarios show both an increase in the frequency of wet springs and decreasing summer precipitation and drier soils.[15,27,28] More intense precipitation during the early spring, when soils are largely uncovered and wetter, increases soil erosion[3] and leaching of nitrogen fertilizer.[10] Additionally, water quality concerns (KM 24.5) are compounded due to more frequent spring manure storage overflow and increased pressure on farmers to spread manure early.

Temperature increases directly affect crop development and physiology[29,30,31] and lead to increases in evapotranspiration and stress during dry conditions.[32] While daily minimum temperatures have increased, daytime maximum (summer) temperatures have cooled in some areas of the Midwest (1991–2021 compared to 1901–1960; see Figure 2.4). This is an important trend for the Midwest and differs from that of other regions (Figure 3.11). Often referred to as the "warming hole,"[33] this trend may be partly explained by the expansion of croplands and increased transpiration over parts of the Midwest and Northern Great Plains (KM 25.2).[34,35,36,37,38] Increased transpiration may have also induced observed summer rainfall increases over parts of the region.[34] These changes may have contributed to improved corn yields.[39,40,41] Projections across a range of scenarios (low [SSP1-2.6] to very high [SSP5-8.5]), however, show that rising temperatures will reduce corn and soybean productivity while maintaining wheat production by the end of the century.[31,42,43] Higher temperatures also increase atmospheric vapor pressure deficit (VPD), enhancing crop water loss. Without expansion of irrigation, projected increases in VPD are expected to limit corn yields.[44,45]

Irrigation in the Midwest affects climate as well. Across the Wisconsin Central Sands region, for instance, irrigated agriculture, compared to rainfed agriculture, has contributed to decreased maximum temperatures, increased minimum temperatures, increased VPD, and decreased evaporative demand.[46] This land-use change/microclimate complexity introduces uncertainty regarding future projections of temperatures and moisture across the Midwest (KM 6.2).

Animal production in the Midwest is also vulnerable to climate change. Increases in winter and spring precipitation and temperature are expected to result in muddier paddocks and pastures, which can decrease fetal growth during late gestation.[47,48,49] Perennial forage crops are under a greater risk of winter injury with climate change because of a greater frequency of above-freezing temperatures during winter.[23] However, there are potential gains in forage productivity with a warmer and wetter climate, longer growing seasons, and higher carbon dioxide concentrations, although with potential declines in quality.[50] Other important livestock impacts include feed shortages, loss of shade structures, nutritional restrictions, disease transmission, and biosecurity concerns (e.g., feral hogs and waterfowl may contaminate existing stocks as they seek higher ground).[51] Increasing temperatures and higher dewpoints place demands on livestock management and housing needs to limit productivity losses or mortality. Heat stress limits livestock production[51,52] and dairy quality.[53] Under intermediate (RCP4.5) and very high (RCP8.5) scenarios, more intense heat abatements (e.g., fans, misting, sprinklers, ventilation) could be necessary to sustain recent production increases,[54] and environmental impacts on dairy production will increase by 2050.[55]

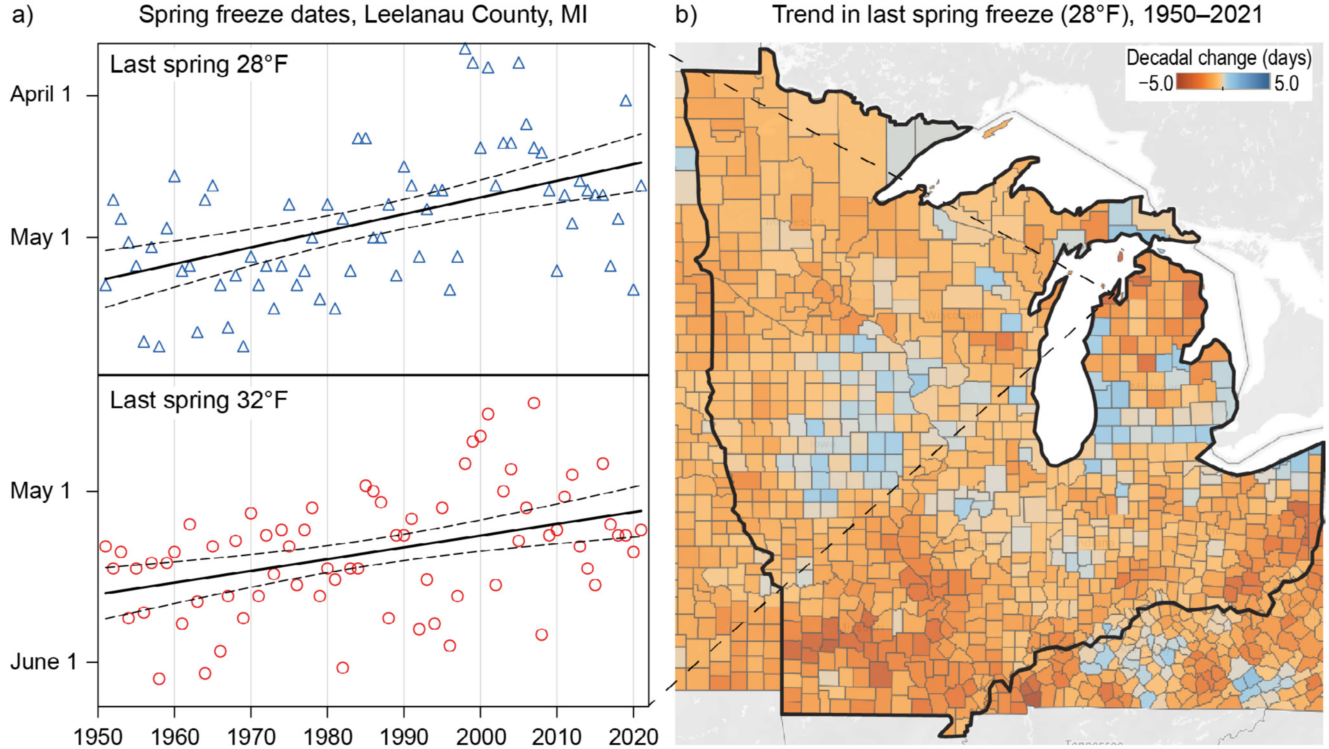
Specialty crops, such as tree fruit and vegetables (e.g., pumpkin and berries), represent a $7.1 billion industry (in 2022 dollars) and have higher potential market values and production-related risks than commodity crops due to their dependence on flavor and appearance.[56,57] Cold injury and damaging frosts during the spring are concerns for both perennial and annual crops (Figure 24.2), and excessive moisture has been associated with significant crop losses for growers throughout the year.[58] Early-season flowering followed by spring freezes (Figure 24.3) has resulted in premature phenological development of tree fruit crops, erratic flowering, and increased risk of freezing injury in April and May.[23,58] Current understanding of future impacts on specialty and horticultural crops across projected climate changes is limited. As temperatures increase, shifts in the timing and growing zones of crops have caused observed pollinator population declines that have translated directly into decreased crop production.[59,60,61] Projected temperature increases suggest continued challenges related to crop growing zones and timing.[62]

Freeze-Damaged Apple Blossoms

Early warmth and flowering followed by freezing temperatures in the spring poses risks to perennial and annual crops.

Figure 24.2. Apple blossoms are damaged by a freeze event on May 9, 2020, in Berrien County, Michigan. Photo credit: ©Dr. Mike Reinke, Michigan State University.

Trends in Last Freeze Dates for Spring



Last spring freezes are occurring earlier over most of the Midwest region.

Figure 24.3. (**a**) Trends (solid black lines) show that the last date in spring when minimum temperatures fall to either 28°F or 32°F in Leelanau County, Michigan, are occurring earlier in the year. For example, the last 28°F temperature commonly occurred after May 1 during the 1950s–1970s, with earlier dates noted since the 1980s. Note the large variability in dates. The statistical significance of the trends (dashed black lines; based on a 95% confidence interval) shows the range of values of the trend line based on the observed dates. In all cases, these confirm there is a trend toward earlier last freeze dates. Panel (**b**) shows change in the number of days per decade of the last spring freeze (28°F) over the period 1950–2021. The black boundary outlines the Midwest region. Orange shading indicates trends toward earlier last spring freeze dates, blue shading indicates trends towards later last spring freeze dates, and gray shading indicates no trend. Adapted with permission from the Midwestern Regional Climate Center's Freeze Date Tool (https://mrcc.purdue.edu/freeze/freezedatetool). Map base layer on right is ©Mapbox ©OpenStreetMap.

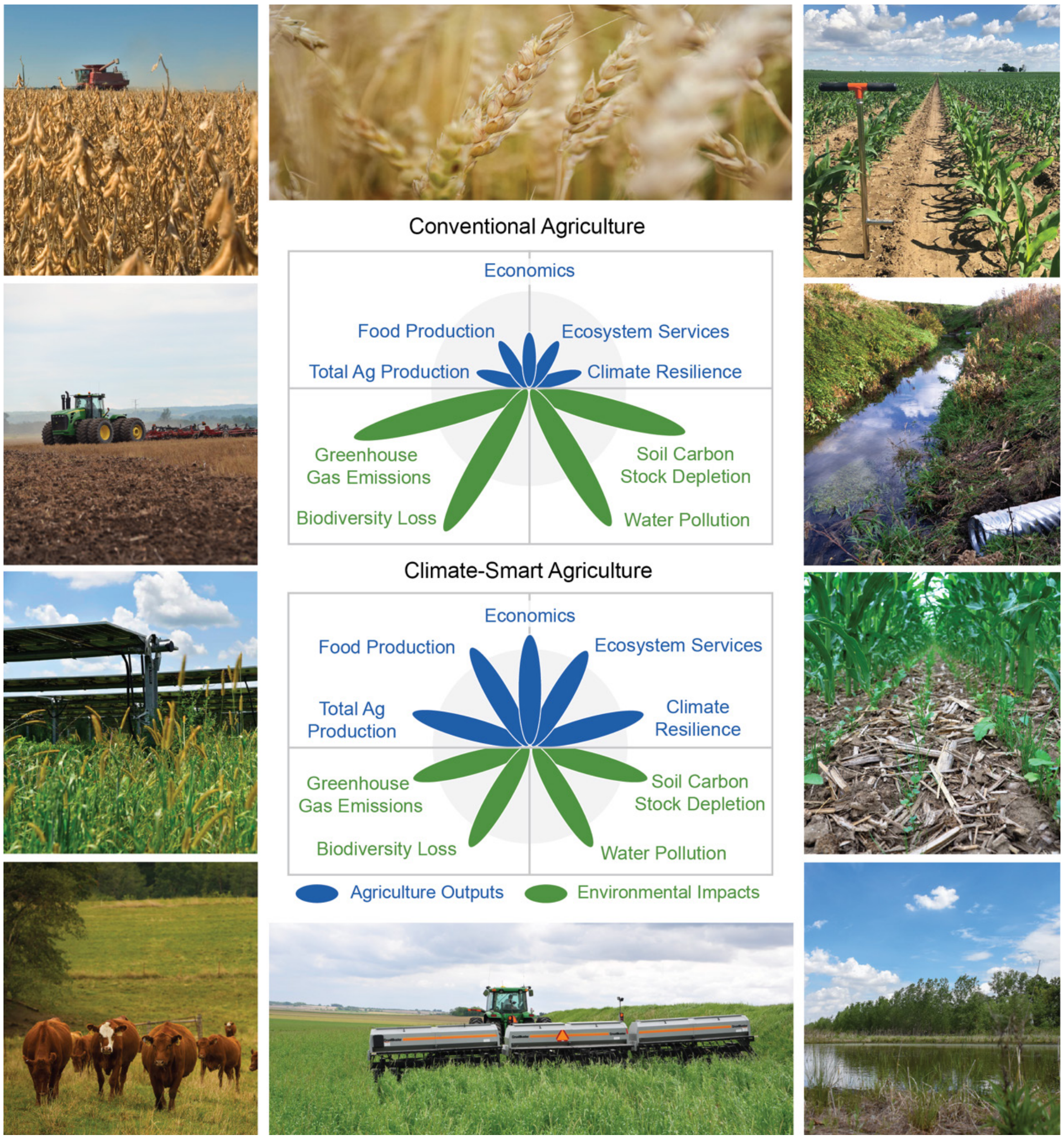
Evidence suggests that pest distributions have shifted northward since the early 20th century, and projections indicate that increasing temperatures will allow pests (e.g., brown marmorated stink bug, corn earworm, Japanese beetle, Mexican bean beetle, and potato leafhopper) to continue expanding northward across the Midwest.[63,64,65,66,67,68] Warming winters lead to insect population expansion throughout the Great Lakes (e.g., Kiefer et al. 2021[69]), while hotter, drier conditions exacerbate yield loss from weed competition.[70] Higher dew points (humidity) increase disease risk for numerous crops, including soybean and apples.[21,71,72]

Most Midwestern row crops are insured, providing growers with some economic security against weather- and climate-related risks.[73] However, US crop insurance losses continue to rise, with an estimated $31.9 billion (in 2022 dollars) attributed to climate change over the last three decades.[74] Drought payments represent the largest percentage of indemnities, although wetness losses are increasing.[75] Evidence suggests an overall decline in drought across the region since 1895;[76] however, an increased occurrence of flash drought (rapid depletion of soil moisture), along with soil degradation[77] and more productive crops,[8] has resulted in moisture stress to crops and native vegetation.[78,79] Damages from droughts and other climate-related financial losses have implications on farmers' mental health as well (KM 24.3).

Climate-Smart Agriculture

According to the United Nations Food and Agriculture Organization, “climate-smart agriculture defines an agriculture that sustainably increases productivity [and] resilience (adaptation), reduces/removes GHGs (mitigation), and enhances the achievement of national food security and development goals.”[80] Climate-smart strategies include, but are not limited to, the use of cover crops, reduced- or no-tillage operations, improved nutrient and manure management, wetland and grassland management, agroforestry, bioenergy crops, on-site carbon sequestration, and agrivoltaics (the integration of agricultural production activities and solar energy generation; Figure 24.4). However, there are uncertainties about the climate benefits and detriments of these techniques, particularly in field settings.[81] Cover crops can improve soil health, reduce erosion, and increase soil organic carbon. Five percent of agricultural fields in the Midwest were cover-cropped in 2017, up from 2.6% in 2012.[82] A reduction in yields for cash crops may deter further adoption of cover crops, and recent analyses suggest that non-legume cover crop adoption reduced maize yields by 3.9% to 5.5% in the Midwest.[82,83] Billions of dollars of investment to encourage producers to test various climate-smart practices have come from federal programs and legislation. Precision agriculture, which maximizes the efficiency of input application (e.g., fertilizers, herbicides) allows for homogeneously managed zones within the same field.[84,85] Such approaches have the potential to increase production efficiency; increase resilience to climate-related risks, particularly the loss of nitrogen fertilizer;[86,87] and yield co-benefits for Midwestern ecosystems (KM 24.2). Corn remains the major bioenergy crop in the US, providing ethanol as a biofuel.[88] Whether corn ethanol is a climate-smart practice is heavily debated.[88] Second-generation biofuels from cellulosic biomass feedstocks, including dedicated energy crops (grown specifically for energy and not food production); agricultural crop residues (materials left on land after crop harvest); and wood residues have greater potential to reduce greenhouse gas emissions, with limited adverse impacts on food crop prices and indirect land-use changes compared to corn ethanol.[89,90,91] Additional techniques concerning animal agriculture and greenhouse gas emissions are explored in KM 11.1.

Environmental Impacts from Conventional Versus Climate-Smart Practices



Climate-smart agricultural strategies may have adaptation and mitigation advantages that balance agricultural needs and environmental impacts.

Figure 24.4. The figure shows examples of conventional and climate-smart production methods: (**clockwise from top center**) wheat field in Brownsburg, Indiana; spring corn under fair skies in southwest Ohio with infield soil sampling probe; outlet from water control structure to agricultural drainage ditch; inter-seeded annual ryegrass, clovers, and radishes growing in young corn in Carroll County, Iowa; macrotopograhic feature (ridge and swale) on a wetland restoration easement in Starke County, Indiana; planting green: no-till drilling soybeans into standing cereal rye in Washington County, Iowa; Forage Systems Research Center in Missouri works to improve the quality of forage grass, promotes management-intensive grazing, rotational grazing, cattle management, and the economics of beef and forage; an example of agrivoltaics—combining solar energy production on agricultural production lands; farmer tilling fields: traditional practice to break up soil in preparation for planting; farmer harvesting soybean with combine. The center diagrams compare the agricultural needs (blue ovals and text) with environmental impacts (green ovals and text) for both conventional and climate-smart agriculture. As shown, there is an imbalance between the agricultural needs and environmental impacts of conventional agriculture (represented by the blue and green ovals); whereas climate-smart agriculture may provide more balance between the two. Adapted with permission from Foley et al. 2011.[92] Photo credits: (top left; left, second from top) United Soybean Board [CC BY 2.0]; (top center) Carly Whitmore, NRCS; (top right) ©Elizabeth Hawkins; (right, second and third from top; bottom left) NRCS/SWCS photo by Lynn Betts [CC BY 2.0]; (bottom right) Carly Whitmore, NRCS; (bottom center) Kyle Spradley [CC BY 2.0]; (left, third from top) ©Tony Mancuso.

Key Message 24.2

Adaptation May Ease Disruptions to Ecosystems and Their Services

Ecosystems are already being affected by changes in extreme weather and other climate-related changes, with negative impacts on a wide range of species (*likely*, *high confidence*). Increasing incidence of flooding and drought is expected to further alter aquatic ecosystems (*likely*, *medium confidence*), while terrestrial ecosystems are being reshaped by rising temperatures and decreasing snow and ice cover (*very likely*, *high confidence*). Loss of ecosystem services is undermining human well-being, causing the loss of economic, cultural, and health benefits (*medium confidence*). In response, communities are adapting their cultural practices and the ways they manage the landscape, preserving and protecting ecosystems and the services they provide (*low confidence*).

Risk

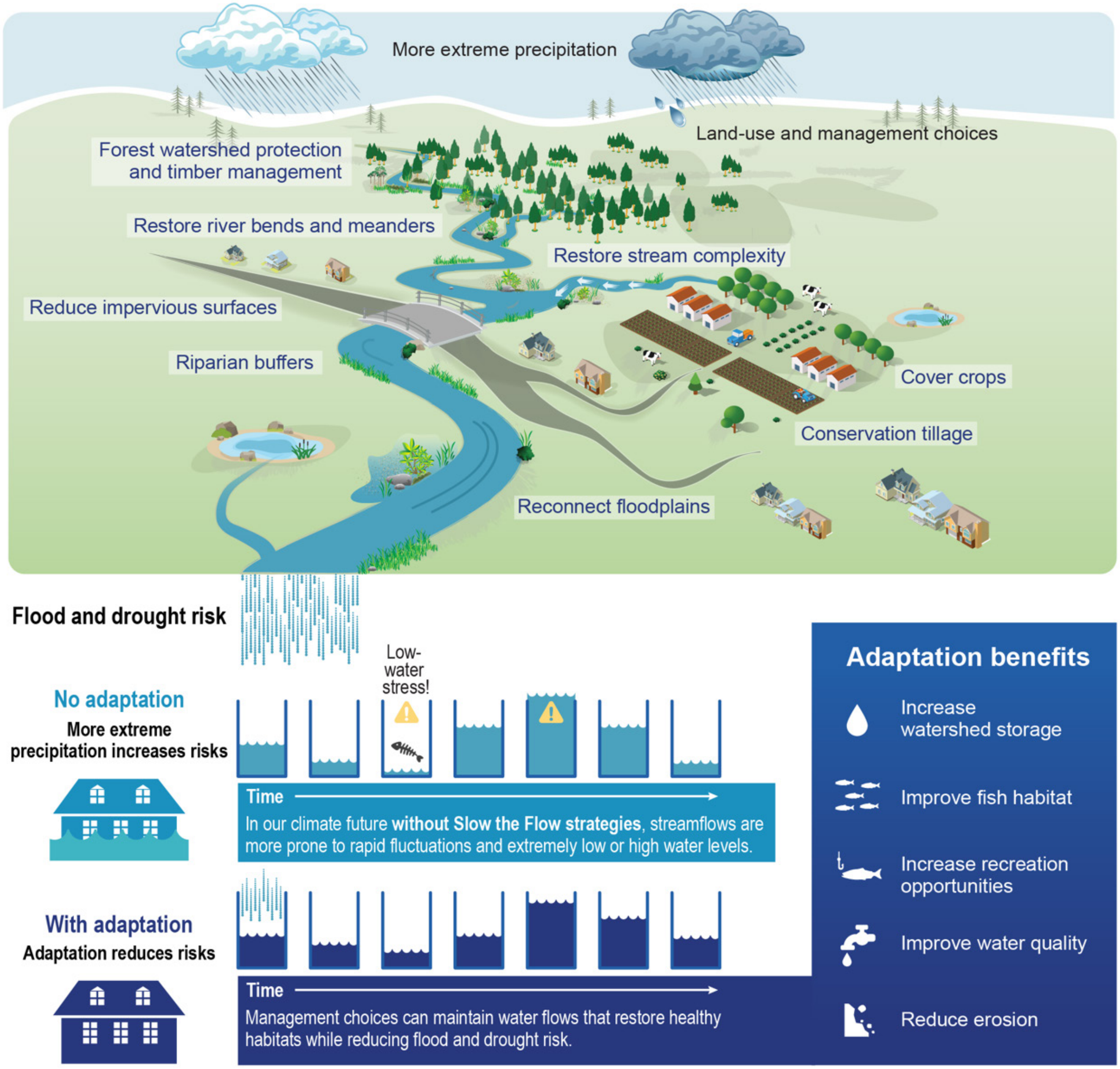
The Midwest is home to many communities and cultures that appreciate and rely on fish, wildlife, waters, and lands. Indigenous communities throughout the Midwest recognize natural resources as persons and extended family (a kin-centric viewpoint) and at times may use terminology such as relatives or beings to refer to them.[93] These relatives support intergenerational continuity, heritage, and spiritual practice. Fishing, hunting, and wildlife viewing are common recreational activities and contribute billions of dollars to the regional economy.[94] Exposure to natural environments enhances human well-being and health,[95] while limited access to natural resources contributes to health inequality.[96]

Impacts

Midwestern aquatic ecosystems are being harmed by rising temperatures and increased precipitation.[97] Climate change intersects with invasive species, land-use change, and human consumption to affect nutrient pollution, water quality, and water levels.[98,99,100,101] For example, invasive species and habitat degradation are negatively affecting walleye growth, survival, and abundance.[98,102,103,104] Mass fish die-offs due to extreme summer heat are projected to double by midcentury (under a very high scenario [RCP8.5]) in northern temperate lakes.[105] Indeed, the Fond du Lac Band of Lake Superior Chippewa has documented an increase in lethal stream temperatures and a decline in brook trout harvest.[5]

Extreme precipitation events degrade riparian ecosystems, erode river and stream banks, disperse contaminants, disrupt plant and animal cycles, and spread invasive species; however, there may be benefits to flooding, including increases in connectivity for aquatic organisms, habitat complexity, and size of the floodplain.[106] Reduced snowmelt is projected to shift spring peak flow earlier in the year.[107,108] Rapid transitions in hydrology (Figure 24.5) and increasing temperatures are projected to cause widespread changes in stream conditions, shifting habitats for invertebrates and fishes.[109] While broad declines in brook and brown trout populations are projected, streams with enhanced groundwater sources have demonstrated resilience to warming and the ability to maintain a viable fishery.[110] Climate-driven changes in heavy rainfall are magnified by land use, with pronounced negative effects in urban[111] and agricultural watersheds.[26]

Extreme Precipitation Impacts



Extreme precipitation events have adverse impacts on aquatic and terrestrial ecosystems, human health, infrastructure, and economies. Conservation and management strategies can help moderate these impacts.

Figure 24.5. Extreme precipitation events can degrade aquatic ecosystems, threaten human health and safety, damage infrastructure and communities, and yield billions of dollars in economic damage. The conservation and management of natural lands can reduce these negative effects—reducing erosion and flood risk, improving water quality, increasing carbon sequestration, and reducing the economic cost of flooding. This conceptual drawing, showing a Midwestern landscape with an extreme storm on the horizon and water flowing into streams and rivers, illustrates how land management choices affect downstream flooding, infrastructure, and ecosystem services. Landscape features and land management practices that slow the flow of water across the surface can improve habitat and water quality, reduce flood and drought risks, and have a variety of other benefits. Adapted with permission from Palmer et al. 2020.[112]

As in the Northern Great Plains (KM 25.4), agricultural expansion threatens Midwestern grasslands[113] via habitat loss and land fragmentation, which exacerbates the vulnerability of grassland wildlife.[114,115] In Indiana, high temperatures and drought contributed to the local extirpation of the endangered Karner blue butterfly,[116] and portions of the Midwest may become inhospitable for the monarch butterfly due to climate change.[117] While the composition of grassland communities is changing in response to climate change, land use, and management,[118] the adoption of mowing and prescribed burning may offset global and regional drivers to retain biodiversity in these threatened ecosystems.[119,120]

Increasing temperatures are projected to increase wildfire risks to Midwestern forests.[121,122,123] Flash droughts, characterized by sudden onset and rapid intensification,[124,125] have increased in frequency since 1980—although it is unclear whether current frequencies reflect a departure from the past (i.e., before the instrumental record began[126]). Flash droughts not only impact crops (KM 24.1) but also induce significant water stress in thin-soiled forests, inciting pathogen infection that increases tree mortality.[127] Additionally, climate change combined with river management for navigation strains the health of floodplain forests that are important hotspots of ecological activity.[128,129]

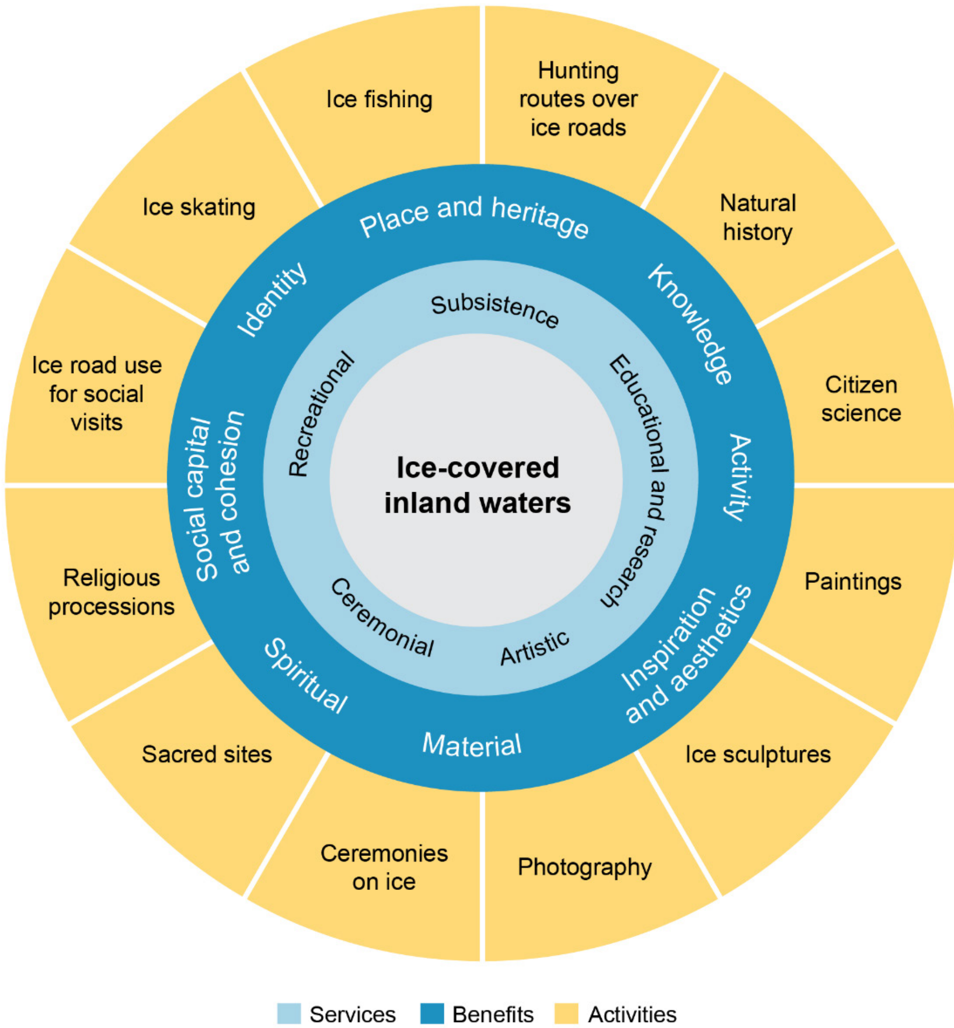
The threat of invasive species is amplified by climate change.[130,131] However, invasive species can be perceived in different ways: many Indigenous communities have holistic views of invasives, or non-local beings, who encompass both positive and negative attributes. For example, dandelions and common plantain are used medicinally in Anishinaabe communities. Understanding the gifts and teachings that beings have can change our interactions and resource management.[93,132]

Warming has shortened the length of persistent cold conditions and decreased snow cover in the Upper Midwest.[133,134] Snow supports the survival of boreal wildlife, providing insulation from cold conditions.[135] Some types of wildlife, such as moose, are threatened by warming winter conditions;[133] declining moose populations have been recorded in the 1854 Ceded Territory over the last three decades.[136,137] This loss, in turn, has cascading impacts on cultural practices, human well-being, subsistence harvesting, and tourism.[133,138,139]

Climate change accelerates the loss of beings, access, and connection to the land for Indigenous Peoples (Ch. 16).[133,140,141,142,143] Wild rice is one of the most vulnerable culturally significant species to Midwest Tribes,[5,144] and harvest rates have decreased due to warming and altered hydrology,[136,145] potentially leading to a loss of cultural identity.[5,146] Sugar maple is also culturally and economically important to Indigenous communities.[133,145,147] Warming winters have altered the timing and length of maple sugaring.[136,145] Seasonal changes and shifting habitats can impact Traditional Knowledge, language, physical health, and mental well-being by altering the timing of cultural ceremonies, availability of beings needed for the ceremonies, and potential loss of culturally significant relatives (KMs 8.2, 16.1).[145,148]

Nature-based recreation is transitioning, affecting opportunity, economy, and safety (KM 8.3). For example, climate change limits the availability of fish such as walleye and trout, sometimes leading to reduced catch limits[104] and food insecurity.[149] Ice cover, an important feature of northern lake systems, is declining in response to rising winter air temperatures,[150] with the most abrupt changes beginning in the 1990s.[4] Loss of ice cover is projected to continue through the end of the century, with greater losses under high scenarios,[150] threatening some cultural activities and services (Figure 24.6).[151] Winter drownings have also increased along with temperatures, which have decreased ice cover.[152]

Ecological Services of Ice-Covered Inland Waters



Rising winter temperatures are decreasing inland lake ice cover and the associated ecosystem services, benefits, and activities it provides.

Figure 24.6. Ice-covered inland waters provide humans with important cultural ecosystem services (light blue ring), benefits (dark blue ring), and activities (yellow ring) that are central to people's well-being, culture, and identity across the Midwest. Adapted from Knoll et al. 2019[151] [CC BY 4.0].

Nature-Based Solutions for Adaptation and Mitigation

Land managers are actively managing Midwestern forests to adapt to climate change[153] by reducing stressors, restoring native species diversity, increasing structural diversity (e.g., variation in age structure), and shifting forest composition to species better adapted to future climate conditions.[153,154] Additional studies can inform the introduction of species adapted to future climate to achieve desired forest management outcomes.[155]

Fish managers have ways to reduce the effects of increased water temperatures, novel invasive species, and other climate-driven changes.[97] They have combined socioeconomic and ecological data to prioritize lakes and identify suitable management techniques.[156] Current management interventions include acquisitions and easements, reducing runoff, protecting in-lake habitats, managing invasive species, changing harvest regulations, and adjusting stocking priorities.[156] Improvements in lake modeling and forecasting of harmful algal blooms, as well as better information about invasive species and resilient fisheries, have the potential to improve adaptation efforts.[157]

Climate adaptation and mitigation can be achieved in part through nature-based solutions, including the protection and management of natural lands. These approaches have the additional advantage of providing social, ecosystem, and economic benefits.[158,159] Since 1980, the Midwest has incurred $49–$109 billion (CPI-adjusted to 2022 dollars) in economic damages due to flooding,[160] with losses projected to increase with further climate change.[161] Natural floodplains can reduce flood damages and yield benefit-to-cost ratios of up to 5 to 1.[162] Moreover, a targeted 10% increase of wetland area within the Mississippi River basin could decrease nitrogen loading to the Gulf of Mexico by more than 40%.[163] Additionally, climate-smart strategies on agricultural lands (Figure 24.4)[164] can yield co-benefits for Midwestern ecosystems.

There is also growing enthusiasm for natural climate solutions, which are specifically designed to increase carbon storage or decrease greenhouse gas emissions through conservation, restoration, and improved land management.[165,166,167,168] Some Midwestern forests are already being managed to bolster carbon storage,[169] and there is much room for expansion of these practices in the region (KMs 7.2, 8.3). Ongoing changes in the climate and atmosphere are expected to accelerate growth of the region's grasslands, which, depending on how they are managed, could increase their carbon storage.[170] Extensive peatlands in the region historically sequestered carbon, but much of this carbon has already been released by draining wetland areas.[171,172]

The long-term mitigation potential of Midwestern ecosystems has large sources of uncertainty related to climate-driven risk factors such as fire, drought, and pests;[165] offsets from increased soil microbial respiration;[173] and warming-induced losses of carbon stored in peatlands.[174]

Tribal Nations have made considerable progress in adaptation, including collaboration on guidance, vulnerability assessments, and implementation (KM 21.4; Ch. 16).[132,144,175] Adaptation strategies vary among Tribal Nations and their values. For example, one being might be a suitable substitute for another, such as birch trees instead of sugar maples for syrup tapping; however, beings that are tied tightly to a Tribal Nation's cultural identity (e.g., wild rice) cannot be substituted.[145] Therefore, adaptation strategies for those beings could mean collaborating and building relationships with Tribes and agencies outside of traditional harvesting lands and jurisdictional boundaries.[132,145] Inclusion of cultural knowledge and language can strengthen adaptation planning and implementation.[132,141,143,144] Guidance for incorporating this information and Tribal input by non-Tribal entities can inform respectful and reciprocal collaboration.[132,176,177]

Key Message 24.3

Climate Adaptation and Mitigation Strategies Improve Individual and Community Health

Climate change has wide-ranging effects on lives and livelihoods (*very likely*, *very high confidence*), healthcare systems (*high confidence*), and community cohesion (*high confidence*). These diverse impacts will require integrated, innovative response from collaborations between public health and other sectors, such as emergency management, agriculture, and urban planning. Because of historical and systemic biases, communities of color are especially vulnerable to these negative impacts (*very likely*, *very high confidence*). Mitigation and adaptation strategies, such as expanded use of green infrastructure, heat-health early warning systems, and improved stormwater management systems, when developed in collaboration with affected communities, have the potential to improve individual and community health (*high confidence*).

Risk

The health of Midwestern populations is at risk from increased extreme heat, precipitation, drought, and flooding, along with reductions in air quality and increased incidence of vector- and waterborne illnesses (Ch. 15). Physical injury and illness resulting from climate-related hazards may also influence mental health and can reduce quality of life and community function as traditional forms of connection and culture are lost or diminished.[178,179]

An individual's exposure and sensitivity to climate change are influenced by preexisting health conditions, age and gender, race and ethnicity, access to resources, and the level of local adaptive capacity.[179,180,181,182] Therefore, climate change impacts on health are not distributed equally across populations. Historical policies and systemic racism have created conditions that leave lower-income individuals and people of color more vulnerable to climate-related hazards (KMs 15.2, 16.1).[179,182,183,184] Environmental and social conditions such as old or deteriorating housing stock, inadequate tree cover, poor or degraded stormwater infrastructure, increased exposure to air pollution, limited transportation access, and lack of preventive healthcare services amplify climate-related hazards in the Midwest.[181,183,185]

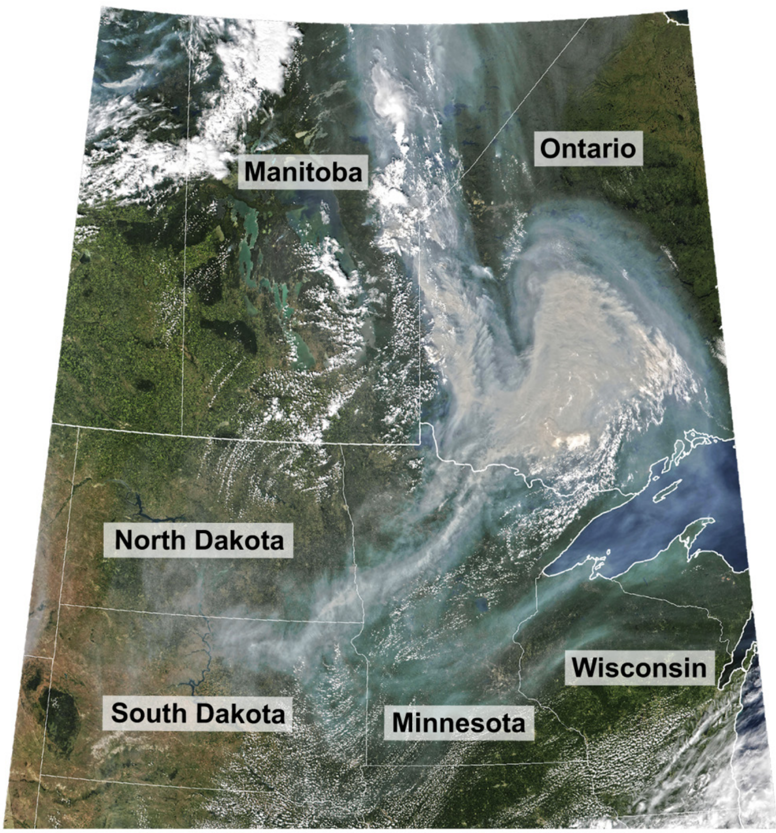
Impacts

Rising temperatures can increase the production of ground-level ozone and particulate matter (KM 14.1). Exposure to these air pollutants can cause or worsen cardiovascular and respiratory illnesses and lead to premature death.[186,187] Future warming under a very high scenario (RCP8.5) is projected to increase exposure to ground-level ozone by midcentury, with higher ozone-attributable death rates in counties in the Midwest and Great Plains than in the rest of the United States.[188] This association may be impacted by population factors, such as density and baseline death rates.[188] Mitigation efforts that reduce ozone can yield large reductions in associated healthcare costs.[189]

Projected increases in extreme heat events across the Midwest amplify the risk of heat-related and respiratory illnesses. A July 2012 extreme heat event in Wisconsin was associated with approximately $290.3 million (in 2022 dollars) in damages due to loss of life, hospitalizations, lost wages, and other health-related costs.[190] By the end of the century, approximately 1,200 deaths related to extreme heat would be avoided under an intermediate scenario (RCP4.5) compared to a very high scenario (RCP8.5).[191]

While many of the worst wildfires occur in the western US, there are scattered areas of high wildfire risk throughout the Upper Midwest (Focus on Western Wildfires).[192] Wildfire smoke from both local and distant sources (Figure 24.7) poses a threat to human health by aggravating cardiovascular and respiratory conditions such as heart arrhythmias and asthma.[89,193] A study of hospital admissions across the US between 2006 and 2015 found that an increase of 10 micrograms per cubic meter in wildfire-related particulate matter in a hospital's zip code was associated with a nearly 3% increase in probability of an intensive-care-unit admission.[194] Compared to other US census areas, this association was most consistent across Midwestern zip codes. This may be due to the larger population in this region compared to other study regions or the lack of personal protective behaviors.[194] Based on very high (RCP8.5) and intermediate (RCP4.5) future climate projections, many Midwest counties will experience increased exposure to wildfire smoke.[195]

Impacts from Wildfire Smoke in the Midwest



Wildfire smoke from both local and distant sources threatens human health.

Figure 24.7. This satellite image shows wildfire smoke from Canada moving down over the northern Midwest on July 11, 2021. Satellite image credit: Joshua Stevens, NASA Earth Observatory, using VIIRS data from NASA EOSDIS LANCE, GIBS/Worldview, and the Joint Polar Satellite System (JPSS).

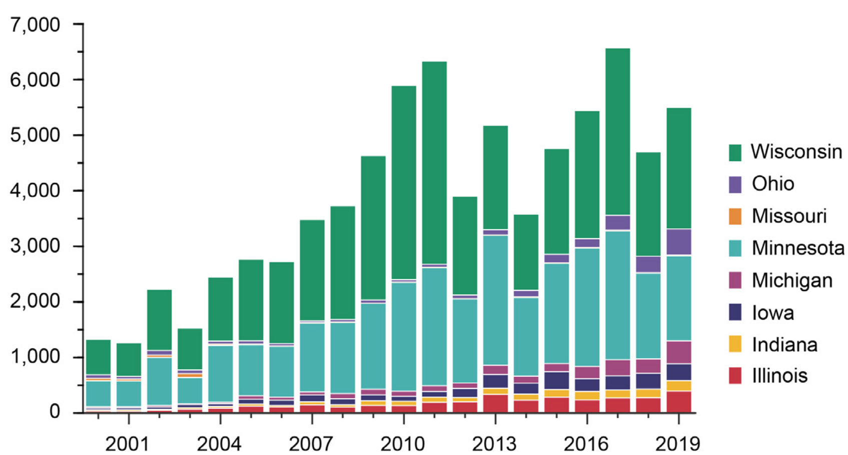
Increasing spring and fall temperatures are leading to rising pollen counts, which can worsen allergies, asthma, and other respiratory conditions (KM 14.4).[196,197] By 2050, increased oak pollen is projected to lead to a 7% annual increase in asthma-related emergency room visits for the Midwest under a very high scenario (RCP8.5) compared to 2% under an intermediate scenario (RCP4.5).[198] Notably, when sensitive individuals are simultaneously exposed to allergens and air pollutants, respiratory reactions can become more severe.[199] Black, Hispanic, and Indigenous populations tend to be disproportionately exposed to air pollution[181] and have the highest rates of asthma and asthma-related deaths and hospitalizations in the United States.[200]

The amount of precipitation falling in the most intense 1% of events increased significantly (45%) in the Midwest between 1958 and 2021 (Figure 2.8a). Under a global warming level of 3.6°F (2°C), extreme precipitation intensity is projected to increase 10%–15%, and perhaps more than 20% in some areas (Figure 2.12). Public health concerns related to flooding in the Midwest include drowning and injury, exposure to mold or waterborne pathogens, economic losses and fiscal strain, employment loss, mental stress, disruption of essential health services, and displacement from the community.[179,184,201,202]

Increases in extreme rainfall are stressing stormwater systems across urban and rural landscapes in the Midwest (KM 24.5).[164,201] Resulting sewage overflow threatens surface water and water distribution networks and increases exposure to waterborne pathogens.[201] By midcentury, precipitation changes are projected to increase the rate of gastrointestinal illness among children due to contaminated drinking water.[203] Under a very high scenario (RCP8.5), some Midwest households that rely on private wells for drinking water, most of which are outside of urban areas, are projected to be at higher risk for nitrate contamination from heavy rainfall and flooding.[204]

Rising temperatures, particularly in winter, and increasing precipitation contribute to the geographic spread of disease-carrying vectors (e.g., ticks and mosquitoes) into and across the Midwest.[205,206] Lyme disease, caused by the bacterium *Borrelia burgdorferi*, is the most prevalent vector-borne disease in the United States and is now endemic to the Midwest (Figure 24.8).[207] Health costs related to Lyme disease are substantial. One study estimated that in 2012, the health-related costs of treating Lyme disease in Michigan, which at the time was not a high-incidence state, was approximately $9 million (in 2022 dollars).[190] The tick species *Amblyomma americanum*, linked to ehrlichiosis and other serious diseases, has already been reported in the Upper Midwest, and projections indicate considerable potential expansion throughout this century.[208]

Midwest Region Lyme Disease Case Counts by State (2000–2019)



Lyme disease incidence has increased across the Midwest.

Figure 24.8. The graph shows annual reports of Lyme disease incidence across the Midwest between 2000 and 2019. Factors such as rising temperatures, increased precipitation, warmer winters and land-use change have contributed to an increase in the incidence of Lyme disease across the region. Figure credit: University of Minnesota Climate Adaptation Partnership, NOAA NCEI, and CISESS NC.

Milder winter temperatures and changes in precipitation patterns are also increasing the risk of mosquito-borne arboviruses such as dengue, chikungunya, Zika, yellow fever, and West Nile virus.[209] By 2050, areas like the Ohio Valley are projected to have approximately 99–201 annual cases of West Nile virus under an intermediate scenario (RCP4.5) or 112–231 annual cases under a very high scenario (RCP8.5).[210]

Stress associated with experiencing climate-related disasters is impacting the mental health of people living in the Midwest[179,211] and is expected to increase as the frequency of extreme events rises. The trauma caused by a disaster, such as losing one's home, job, or livelihood or being displaced from one's community, can contribute to chronic depression, anxiety, and post-traumatic stress disorder.[212,213] In addition, people can suffer a loss of social connections, bear witness to people being harmed and landscapes destroyed, and confront an uncertain future, any of which can trigger or intensify adverse mental health conditions.[178,214] Farmers and others dependent on agriculture for their livelihood are particularly at risk.[212,215,216] Many rural Midwesterners already experience obstacles to utilizing healthcare services,[217] including mental health services.[218,219]

Climate Resilience for Healthier Outcomes

Without efforts to reduce emissions and promote climate resilience, the Midwest will experience an increase in climate-related deaths, injury, and disease and a decrease in mental wellness.[220,221] Furthermore, because these health outcomes are linked to key social and environmental determinants of health, they are expected to disrupt community well-being, with costs and consequences for livelihood, social and cultural connections, education, transportation, and access to essential services.[178,182,221,222] Health disparities tied to race, ethnicity, age, and income are linked to an inequitable distribution of these climate-related health outcomes at individual and population levels.[179,184]

Actions and investments to reduce climate-related health and community impacts such as increased tree cover, weatherization programs, improved stormwater management, heat-health early warning systems, and culturally relevant climate education and climate services (Box 24.1) can yield multiple benefits for individual and community health while helping to advance more equitable climate adaptation.[182,223,224,225,226,227] Sufficient data, technical services, and tools on climate-related health risks, racial and socioeconomic disparities, and socioenvironmental determinants of health would help increase the effective management of emerging and anticipated climate and health-related risks.[182,204,227] For example, the CDC has advanced a framework for cross-sector collaboration that identifies a broad range of resources to reduce climate-related health risks.

Leadership efforts by the emergency management sector in the Midwest to address climate threats to individual and community health highlight the important role for this sector in adaptation planning.[220,228,229] The increased frequency of extreme events is expanding the need for more resources to support disaster preparedness and response, especially for vulnerable communities.[182,228,230]

Box 24.1. Midwest Educational Resources

The Midwest has a rich and expanding body of formal and informal climate education and services available to educators and resource managers of all ages and backgrounds. These efforts help build a climate-informed and responsive society and connect to impacts as well as adaptation and mitigation activities discussed throughout this chapter. Built on the National Research Council (NRC) Framework for K–12 Science Education,[231] educators from across the country created the Next Generation of Science Standards (NGSS), which includes contemporary climate science.[232] Incorporation of these standards varies across the Midwest. Illinois, Iowa, and Michigan have adopted the NGSS, while others have developed their own standards based on the NRC framework.[233] In response, educators have created new climate curriculums and activities for students across K–12 (e.g., Muhich and Rood 2022[234]). Recent federal investments, such as one establishing the Midwest Climate Adaptation Science Center,[235] augment climate research and outreach across the region, connecting with more communities and developing a stronger climate adaptation and community of practice. Since the publication of the Fourth National Climate Assessment in 2018, coordinated efforts have increased among extension professionals, who help translate climate research into practice to help rural and urban communities prepare for and respond to climate change. These and many other university, Tribal, and private entities are collaborating to expand the breadth and reach of climate education and services across the Midwest.

Key Message 24.4

Green Infrastructure and Investment Solutions Can Address Costly Climate Change Impacts

Increases in temperatures and extreme precipitation events are already challenging aging infrastructure and are expected to impair surface transportation, water navigation, and the electrical grid (*likely*, *medium confidence*). Shifts in the timing and intensity of rainfall are expected to disrupt transportation along major rivers and increase chronic flooding (*likely*, *high confidence*). Green infrastructure and public and private investments may mitigate losses, provide relief from heat, and offer other ways to adapt the built environment to a changing climate (*medium confidence*).

Risk

Midwest infrastructure, including dams, bridges, roads, wastewater facilities, and energy generation and distribution systems, need repair,[236] with estimated costs for upgrading these systems totaling $7,547 (in 2022 dollars) on average per capita across the Midwest. Projected changes in precipitation and temperatures increase the risk of failure and cost. Although the Midwest has had numerous state-level and federally declared flood disasters, the risk of loss due to recurrent, underreported inland and urban flooding events increases as the frequency of intense precipitation events rises. Fluctuating water levels make efficient navigation of goods and services through the region's rivers and the Great Lakes more challenging.

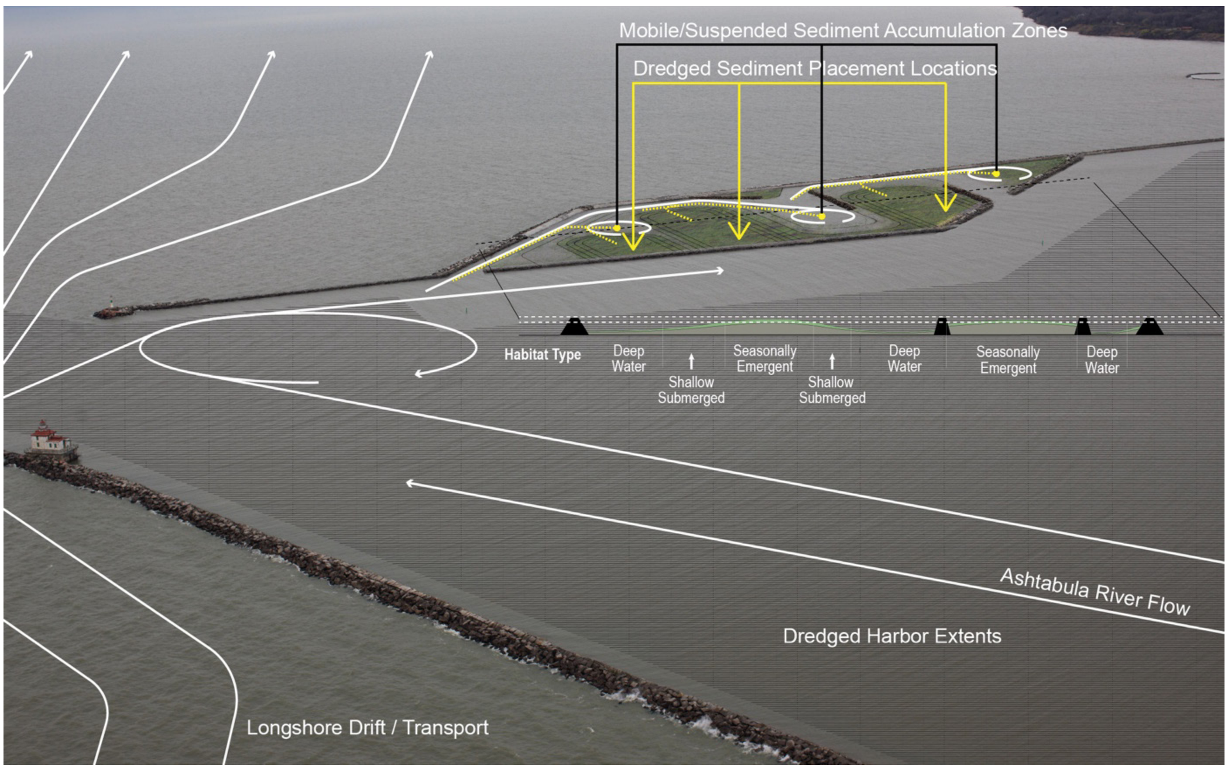
Impacts

Interest in the impacts of climate change on infrastructure has grown significantly over the last decade.[237] Although improvements have been made, recent grades based on capacity, condition, funding, future need, operations and maintenance, public safety, resilience, and innovation across Midwestern states vary from a C to a D+.[236] Significant repairs are needed in surface transportation, wastewater and stormwater, dams, ports, and the energy grid. Projected increases in temperature and more intense precipitation under a very high scenario (RCP8.5) are expected to increase costs associated with rail and roads (amounting to hundreds of billions of dollars annually by 2090), with significant reductions to these estimates under an intermediate scenario (RCP4.5).[238] For instance, projected rises in temperature are expected to increase the width of cracks caused by deicing salts in reinforced-concrete bridges.[239]

The commercial transport of goods and services along the major rivers (Mississippi, Missouri, and Ohio Rivers; KM 24.5), largely controlled by a system of locks and dams, is at risk from increased precipitation extremes. High-flow events reduce traffic on the river systems, which may be limited to daytime operation only or cease altogether. During low-flow events, channels are reduced and potentially need dredging. These hydrologic extremes increase costs and lead to delays in the delivery of commodities like food and fertilizer. Along the main stem of the Ohio River, increases in the spring (March) maximum and decreases in the fall (October) minimum flow discharge are projected for 2070–2099 under high (SRES [Special Report on Emissions Scenarios] A1B) and very high (SRES A2) scenarios, with up to a 35% change expected relative to 1952–2011.[240] Without coordinated adjustments to monitoring, water releases, and communications along the river, significant disruptions to traffic flow and volume of goods transported are expected.

Water transport is the most carbon- and fuel-efficient means of transport, especially compared to rail and truck.[241] Fluctuating Great Lakes water levels, coupled with diverse ecological and geophysical conditions, create unique coastal environments that necessitate funding and construction strategies that are closely tied to local ecological, economic, and social conditions. The period 1998–2013 saw some of the lowest water levels on the Great Lakes in recorded history, whereas the 2020s have seen some of the highest on record.[242] Great Lakes ports (Figure 24.9) are located at the vital intersections of ecological, cultural, and infrastructural systems, and port operations attempt to serve these overlapping, and at times conflicting, value systems.[243,244,245] In some cases, ports are taking on the work of ecological restoration as well as protection, property management, and urban industrial remediation—the types of efforts that can promote industrial opportunities, urban well-being, and ecological health. A good example of this is Toledo's More Than a Port initiative.[246] Another example is the multiyear Healthy Port Futures initiative, supported by the Great Lakes Protection Fund. This project reimagines how ports can function to enhance the ecological and social health of the surrounding community and ecosystem through sediment management, as well as through the ways it informs the design and restoration of public landscapes in critical nearshore habitats across the region.

Beneficial Use Wetland Creation for Healthy Ports



Innovative design of coastal infrastructure, such as the Ashtabula Port, allows the built environment to deliver social and environmental services.

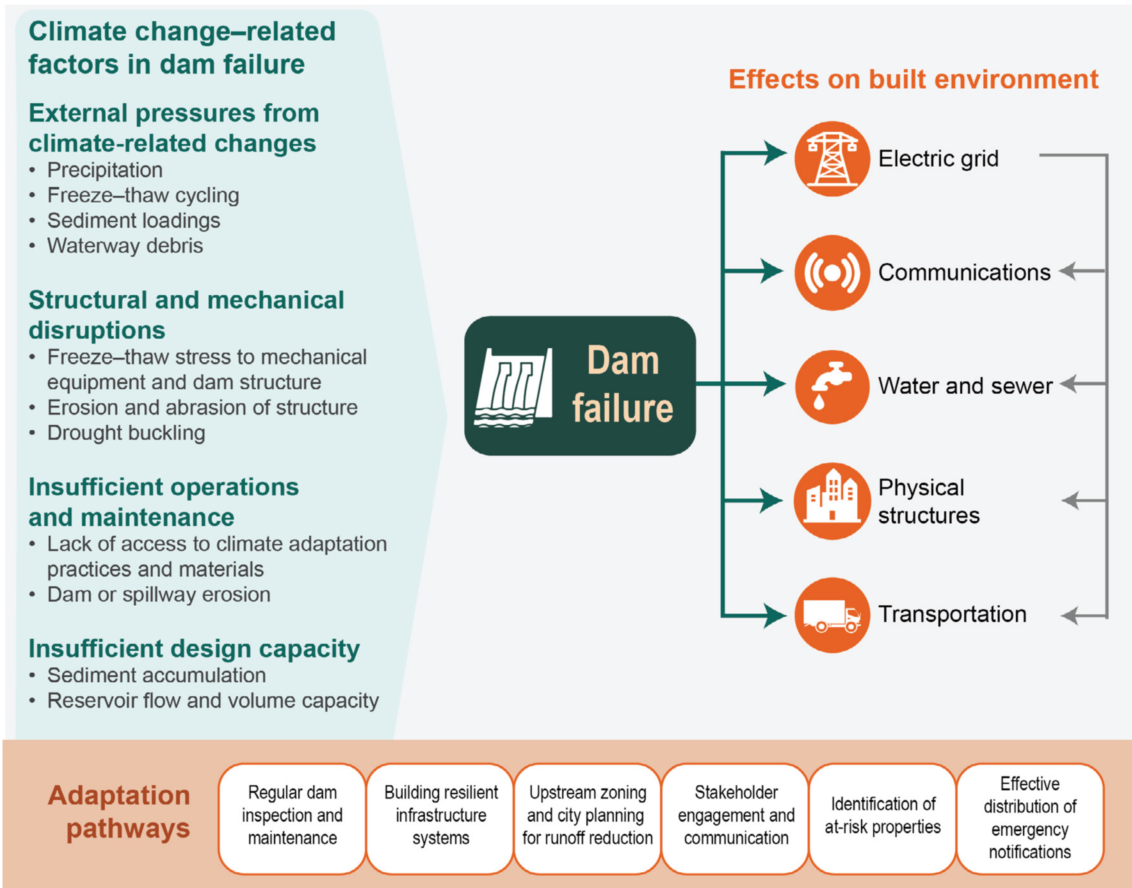
Figure 24.9. The image shows an overview of the harbor in Ashtabula, Ohio, the site of a wetland creation project by the US Army Corps of Engineers with support from Healthy Port Futures. This project, which works with the flow on the Ashtabula River into Lake Erie, was one of the first attempts in the Great Lakes to establish a partially open wetland system with reused dredge material. This design permits an occasional, ecologically necessary disturbance that will promote wetland complexity while also allowing for an important hydrological connection to the nearshore. The figure highlights areas of material placement (solid yellow lines) and sediment movement and accumulation (solid white lines, including sediment transported naturally along the shore). Sediment that accumulates in the wetland channels is placed in the dredged sediment placement locations (dashed yellow lines) every two to three years. This way, the project can employ an adaptive management approach and respond to successes and challenges that may arise. The project will create diverse habitat types including deep water, shallow submerged areas, seasonally emergent areas, and the adjacent open water areas (habits indicated by the light beige and green shading). The built project differs slightly from what is shown here. Adapted from Burkholder et al. 2022.[247]

An aging energy grid, combined with the extent and timing of a transition to different sources of energy generation, creates uncertainty about the impact of climate change on the grid itself. Increases in air temperature, rainfall, and the intensity and frequency of wildfires and storms are expected to disrupt grid efficiency and function, including maximum capacities and outage rates of transmission lines, transformers, and substations.[248] Climate change will reduce US transmission capacity by roughly 2%–8% during peak demand periods by 2100 across a range of scenarios (low [RCP2.6] to very high [RCP8.5]). Average summertime transmission line capacity reductions could range from 2%–6% under the same scenarios by the midcentury, with the Midwest seeing the largest reductions.[249] Transmission infrastructure failures, including those caused by mechanical failures and unplanned surges in electrical current, are projected to occur more frequently.[248] Given the strong push toward renewable energy and electrification of all systems, including transportation, it is uncertain whether the current grid will be able to handle the ongoing and anticipated changes in energy generation and distribution.

Renewable energy production in the Midwest has grown by more than 275% over the last decade,[250] reducing carbon emissions from the energy sector, although less so than in other regions. The growth of investment in renewable energy is contributing to the Midwest's economy. In Iowa, public interest coupled with public and private investment has advanced the state to the second-highest wind energy–producing state in the country and leading the Nation in megawatt capacity per capita. In Adair County, Iowa, investments by MidAmerican Energy Company have led to the installation of two large wind farms that are cumulatively expected to produce 550 megawatts of capacity to the grid and provide well-paying jobs.[251] However, the extent of growth in solar and wind power across the Midwest is constricted by a patchwork of state and local land-use laws and ordinances banning or regulating the siting of solar and wind power generation projects.[252]

Illinois, Iowa, Missouri, Wisconsin, and Minnesota are at high risk for increased riverine flood damage.[253] Of nearly 92,000 dams inventoried by the US Army Corps of Engineers, the average dam age is 61 years, an age when many dams require expensive repairs, and 75% are classified as high hazard potential. Climate-forced external pressures interact in complex ways, leading to effects on the built environment (Figure 24.10). Increased occurrence of extreme precipitation events stresses aging infrastructure and exacerbates the risk dams pose;[254] since 2018, 30 dam failures or near failures have occurred across the Midwest.

Climate Change–Related Factors in Dam Failure



Climate change–related factors contribute to dam failure, with cascading impacts on the built environment.

Figure 24.10. The graphic shows contributing causes for dam failure related to climate change, first-order effects of dam failure on the built environment, and adaptation pathways. Dam systems may experience climate change–related impacts independently or in parallel, and these impacts can have cascading effects. Damage to transportation, power, water, and communication infrastructure can limit a community's ability to access health services. Damage to infrastructure, land, and the built environment can negatively impact local businesses and the economy. Adaptation pathways provide a basis for communities to address dam risk from a variety of system viewpoints. Figure credit: MITRE, University of Pennsylvania, American Society of Adaptation Professionals, and The Ohio State University.

Increases in extreme rainfall events (Figure 2.8) negatively impact property, public health and safety, and transportation systems. Urban and rural communities are at risk from projected increases in frequency and intensity of extreme rainfall events. Even when events are not categorized as state or federal disasters, communities and households experience property damage from basement flooding, health impacts from sewer overflows, and traffic disruptions from storm damage.[179,255] Increases in state and federally declared disasters are expected to become more frequent. NOAA's Billion-Dollar Weather and Climate Disasters tracking data now offer a detailed analysis of disasters reaching this cost impact, but smaller events are difficult to assess.[160]

Moving away from disaster-struck areas is more difficult for people with low income than it is for wealthier populations.[256,257,258] Billion-dollar disasters and smaller-scale disasters alike have led to individual property damage and, in some cases, complete loss. A history of repairing buildings after repeated disasters has led to cases where structures have been rebuilt more than 30 times at a cost of nearly 100 times the value of the property.[259] Between January 1989 and August 2019, more than 18,000 structures experienced chronic losses in Ohio, Iowa, Illinois, and Missouri.[260] Repetitive losses are trending upward due to increases in extreme storms and flooding across the region. Some Midwest communities are facing relocation due to projected increases in heavy precipitation and increased flood risk. Managed retreat, or community relocation—moving an entire community out of harm's way—is often discussed as a coastal adaptation measure, but it has applied to the Midwest for decades. Examples, including the town of Valmeyer, Illinois, and the relocation of the Bad River Band of Lake Superior Chippewa in Odanah, Wisconsin, offer lessons on the benefits and drawbacks of flood-induced relocation. Equitable and effective relocation benefits from the coordination of dozens of jurisdictions and substantial funding and often takes years to achieve.[259] These relocation efforts can disrupt social relationships and institutions.[261] As described in Box 20.1, successful and equitable relocation programs require strong community engagement and an open recognition of the multiple drivers of migration, including environmental, economic, and governance conditions.

Innovative Finance and Investments

Recent federal funding from the Infrastructure Investment and Jobs Act is pushing funding to state and local governments to support long-delayed infrastructure upgrades and repairs. As of March 2023, more than $36 billion (in 2022 dollars) in project funding has been invested or announced for infrastructure projects in the Midwest, with an average 15.5% of funding directed toward climate, energy, and environment projects.[262] Along with this infusion of public dollars, the infrastructure investment landscape is changing, with private investment, environmental impact bonds (EIBs), and other financing tools being used in the region. An EIB is a financing tool that allows private investors to provide up-front capital for a pilot project or to scale up an existing project, with the goal of achieving a set of environmental outcomes. Some localities have combined innovative infrastructure approaches, including green infrastructure, with new funding models like EIBs or public–private partnerships. An innovative finance and construction approach being used by the Milwaukee Metropolitan Sewer District (MMSD) is an example of proactive climate adaptation. The MMSD reduced the annual number of combined sewer overflow events from 50–60 in the early 1990s to 2.3 in 2019. Using a community-based public–private partnership, the MMSD is now looking to add an additional 20 million gallons of green stormwater infrastructure (GSI) capture capacity beyond the current capacity of 40 million gallons. The project will allow for public and private investment to support local business and achieve massive green infrastructure benefits by 2026.[263] Other municipalities are implementing GSI, and it is estimated that private investments across Ohio, Wisconsin, Minnesota, Illinois, and Indiana can support more than a billion dollars of GSI.[264] Aside from leveraging private investment, some municipalities are combining funding from multiple public sources, including from different agencies and at different scales of government (federal and state) to fully fund projects. In the case of the Bee Branch Watershed Flood Mitigation Project in Dubuque, Iowa, eight federal and three state funding sources have been applied to the $250 million (dollar year not reported) project.[265]

Careful placement and design of green infrastructure provides benefits beyond flood reduction, such as reducing the urban heat island effect and providing relief to city residents during heatwaves. Green infrastructure such as increased vegetation, stormwater capture systems such as bioswales (vegetative areas that concentrate and move stormwater while filtering for debris and pollution) and detention ponds, and open green spaces can significantly lower temperatures and channel natural airflow, which enhances the cooling effect from the green infrastructure.[266]

Key Message 24.5

Managing Extremes Is Necessary to Minimize Impacts on Water Quality and Quantity

Climate-related changes to water quantity and quality are increasing the risks to ecosystem health, adequate food production, surface water and groundwater uses, and recreation (*high confidence*). Projected increases in droughts, floods, and runoff events across the Mississippi River basin and the Great Lakes will adversely impact ecosystems through increased erosion, harmful algal blooms, and expansion of invasive species (*likely*, *high confidence*). Federal and state agencies and nongovernmental organizations are cooperating on adaptation efforts related to streamflow, water quality, and other water issues (*high confidence*).

Risk

Climate change is affecting the quality and quantity of water in the Midwest, as well as management practices related to the health of human and natural systems.[267] Across both the Mississippi River and Great Lakes basins, climate change has impacted streams, rivers, and lakes—all vital to urban, rural, and Tribal communities. Drinking water sources, private wells, and agricultural irrigation sources are at risk. Observed changes in hydrology include increases in the variability of lake levels, evaporation, and water temperatures, along with more intense precipitation,[268] including lake-effect snow, and shorter duration of snow and ice cover. These changes impact food production, businesses, industries, tourism, and recreation. Ecologically sensitive aquatic systems in the Great Lakes are at risk due to changes in lake temperatures and invasive species (KM 24.2).[269]

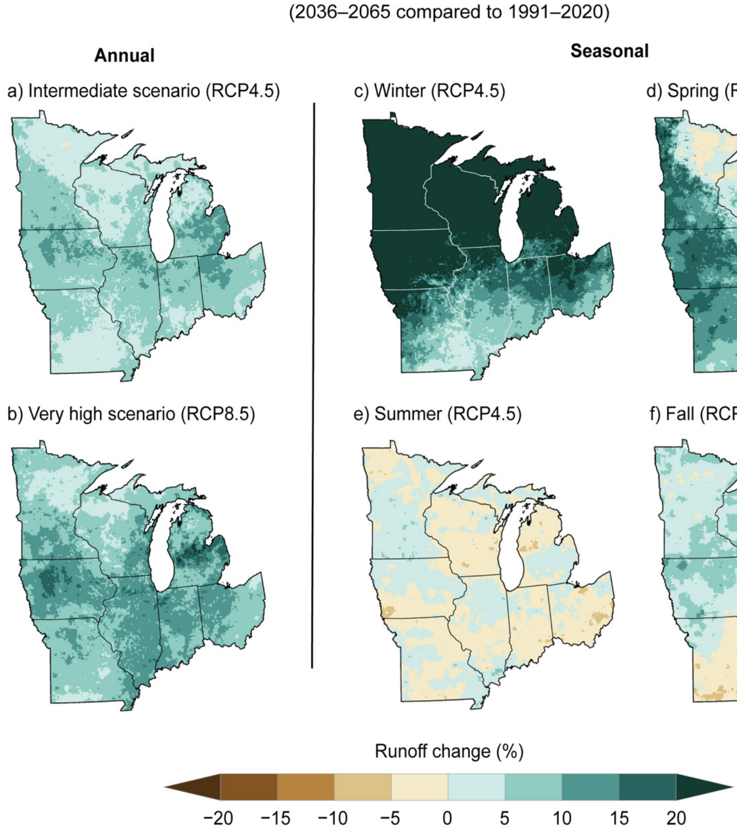
Impacts

Mississippi River System

The Ohio River, upper Mississippi River, and lower Missouri River are susceptible to floods and droughts based on projected changes in precipitation, evapotranspiration, and soil moisture (Ch. 4). Precipitation has increased in recent decades (Ch. 2) with more extreme variability and rapid shifts between wet and dry periods (Figure 24.1). Projections across a range of scenarios (low [SSP1-2.6], intermediate [SSP2-4.5], and very high [SSP5-8.5]) indicate future increases in annual precipitation of 0.3% to 1.5% per decade in the eastern Midwest and 0.2% to 0.5% in the western Midwest.[15] Winter and spring precipitation is expected to increase, while summer and autumn precipitation is projected to be more variable.[15]

Cumulative runoff has increased in recent decades[240] and is projected to continue increasing through midcentury (Figure 24.11), leading to increased riverine flooding in the Ohio, upper Mississippi, and parts of the Missouri River basins. Prolonged periods of increased cumulative runoff have adversely impacted ecosystems and commerce and are projected to continue to do so.[240] Observed decreases in the length of winter have reduced snowfall across the Midwest,[270] with negative impacts for snow-dependent winter tourism for the Midwest and Great Lakes (KM 24.2).[178] By the end of the century, projections indicate reductions in snowstorm frequency and size and snow-water equivalent totals;[271] shorter snow seasons; and fewer intense snowfall events.[272]

Projected Changes in Cumulative Seasonal and Annual Runoff



Projected changes in cumulative local runoff will lead to increased flooding susceptibility in winter and spring, with increased flash drought potential in summer.

Figure 24.11. The maps show projected changes in the annual approximate cumulative gridded local runoff generation (referred to as cumulative runoff) for intermediate (RCP4.5) and very high (RCP8.5) scenarios (**a**, **b**) and seasonal approximate cumulative runoff for an intermediate (RCP4.5) scenario (**c**–**f**). The cumulative runoff is defined as the gridded cell-by-cell ability of the landscape to generate excess water for potential downstream river runoff using the Variable Infiltration Capacity (VIC) land-surface model. The cumulative runoff was developed using Coupled Model Intercomparison Project Phase 5–modeled scenarios and the VIC hydrology model. Cumulative runoff is projected to increase annually across the Midwest between 2036 and 2065 compared to 1991–2020 (shown in percent changes). Cumulative runoff increases are expected throughout the region in winter and across all but the northern Great Lakes in spring and southern Midwest in fall. Summer cumulative runoff is projected to be more variable. The result of the projected increases (and in summer, both increases and decreases) in cumulative runoff will be increased stresses to ecosystems, the built environment, natural and water resources, and agriculture. Figure credit: NOAA NWS, NOAA NCEI, and CISESS NC.

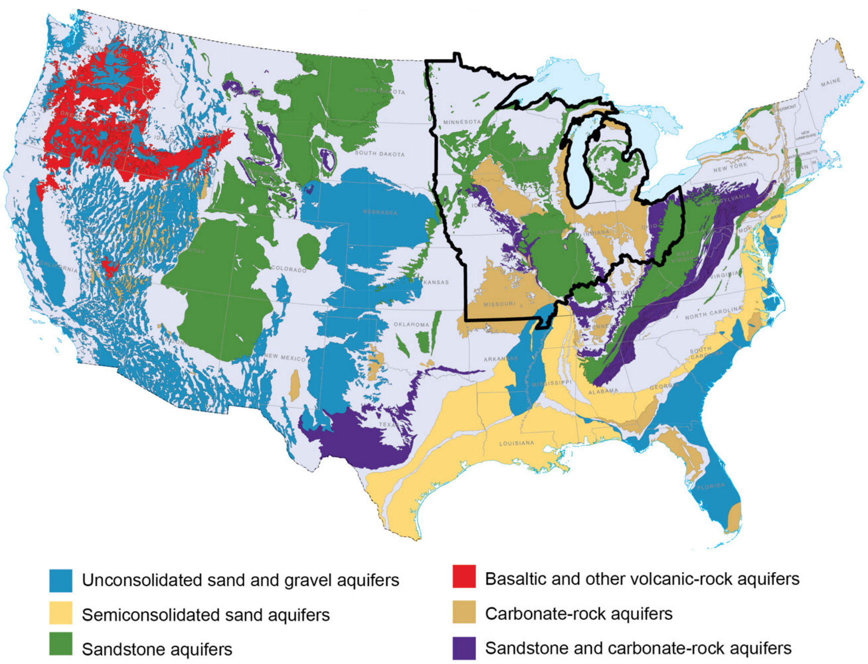
Midwest droughts develop in response to precipitation deficits or extremely high temperatures and evapotranspiration (KM 4.1). In recent decades, evapotranspiration has become, and is expected to continue to be, the dominant driver of drought,[273,274] especially across the eastern Midwest.[275] Precipitation deficiencies remain the primary driver of increased drought in the southwestern Midwest.[276]

Groundwater storage is important for water resource management, including wastewater permitting, water supply, and fisheries. Groundwater recharge is projected to be variable in the Midwest,[277] with water imbalances[28] resulting from precipitation and evapotranspiration changes. Failure of private wells is expected to increase during droughts as water tables drop with increased irrigation and water usage.

Vulnerability to water shortages and water quality depend, in part, on the primary source for water use and drinking water for any given location (aquifers/deep groundwater versus surface/shallow groundwater;

Figure 24.12). Thus, drought occurrences will have different impacts based on the source. For surface water, decreases in summer runoff (Figure 24.11) can reduce water quality and streamflows.[278] Aquifers, on the other hand, are more resilient to rapid hydrological transitions but are still impacted by longer-term drought conditions.[278] Precipitation is projected to increase in all seasons, while runoff is projected to increase in the cool season but become more variable in the warm season (Figure 24.11). The combination of warming temperatures and more variable summer runoff suggests an increased risk of drought for people, crops, livestock, and ecosystems across the region.[240] At the same time, increased precipitation and runoff events (Figure 24.11; KM 4.1) are expected to increase nuisance flooding (KM. 24.4) and sewage spills and resulting odor releases, as well as deteriorate water quality due to increased uncontrolled discharges. Stormwater runoff increases are expected to harm aging infrastructure and lead to higher costs for new systems (KM 24.4). Thus, urban and rural managers are implementing best practices for water quality across diverse landscapes, from agriculture (Figure 24.4) to forests (Figure 24.5) and the built environment (KM 24.4).[164]

Map of US Aquifers



Vulnerability to disruptions in water quality and quantity varies by location, depending on the primary source of water for drinking and other uses.

Figure 24.12. The USGS Ground Water Atlas of the United States provides a complete summary of the Nation's groundwater resources and includes the location, geography, geology, and hydrologic characteristics of the major US aquifers. Surface water and groundwater (aquifers) are the primary sources of water in the Midwest and Great Lakes. The areas highlighted in color represent groundwater aquifers, while areas in gray represent surface water as the main source. The black boundary outlines the Midwest region. Changes in rainfall and runoff patterns impact water availability and water tables differently across the Midwest, depending on whether the main source of water is surface- or aquifer-based. For more information on aquifers outside the contiguous US, visit the USGS Ground Water Atlas of the United States and Principal Aquifers of the United States. Adapted from USGS 2021.[279]

Harmful algal blooms (HABs) and their impacts to water quality, food production, recreation, tourism, and ecosystems continue to be a major concern across parts of the Midwest. Observed increases in precipitation[15,268] are resulting in, and are projected to continue to result in, increases of sediment and nutrient loads in the Mississippi River system. However, research has been inconsistent about whether HAB severity and magnitude in the Midwest have been increasing, remaining constant, or decreasing.[280,281]

Great Lakes

The Great Lakes are the largest freshwater ecosystem on Earth[282] and are among the fastest-warming lakes in the world.[283] The Great Lakes Water Quality Agreement between the United States and Canada established a suite of nine indicators to assess the ecosystem health of the Great Lakes (Table 24.1). While efforts to restore and protect the Great Lakes are ongoing, this ecosystem is at risk from shifts in seasonality (changes in the timing of the formation and destruction of temperature stratification) and from changes in ice cover, maximum summer temperatures, and oxygen levels, which have significant impacts on fisheries and habitats in the lakes.[282] Invasive species and threats to biodiversity are the greatest concerns of the Great Lakes.[282] Aquatic invasive species (KM 24.2) can degrade water quality by decreasing water clarity, concentrating toxins, and altering nutrient flows within the food web. Great Lakes water quality across a wide range of metrics currently ranges from fair to good.[282]

Table 24.1. State of the Great Lakes 2022 Assessment

CAPTION: The EPA and Environment and Climate Change Canada work jointly to meet the mission of the Great Lakes Water Quality Agreement. As part of this effort, the State of the Great Lakes Report is released every three years. The following table details the state of the Great Lakes using 10 Indicators. The assessments are basin-wide and typically vary between lakes. The metrics listed are synthesized to determine the status and trends of each indicator. The definitions for "poor," "fair," and "good" are quantitative, vary between indicators, and are documented in the report (ECCC and EPA, 2022).[282] Status assessments are not provided for the climate trends indicators. Adapted from ECCC and EPA 2022.[282]

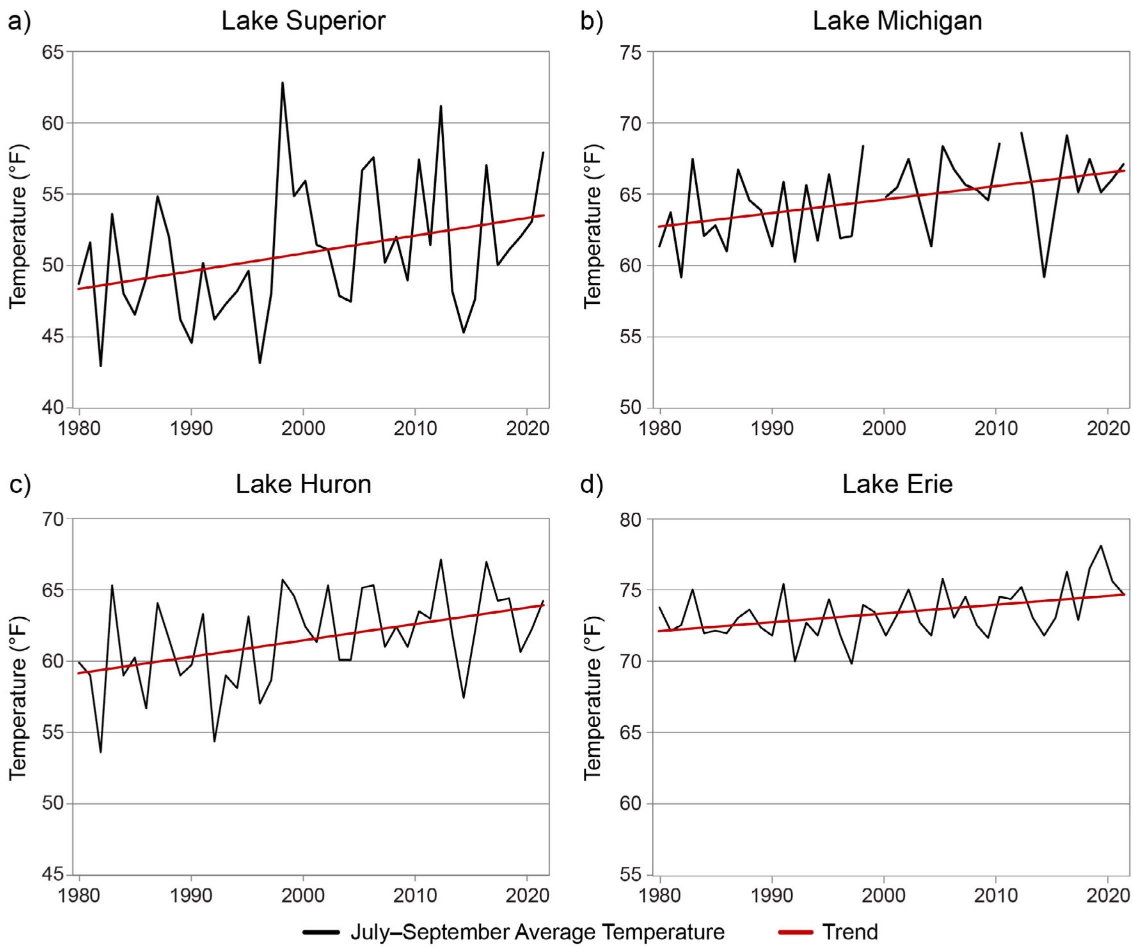
Great Lakes Indicator	Metric	Status	Trend
Drinking Water	US/Canadian drinking water standards (microbial, radiological, chemical)	Good	Unchanging
Beaches	*E. coli* assays	Good	Unchanging–improving
Fish Consumption	Polychlorinated biphenyls [PCBs] and mercury in fish flesh	Fair	Improving
Toxic Chemicals	Concentrations of compounds (PCBs, mercury, polybrominated diphenyl ethers, and others) in sediment, water, whole fish, and herring gull eggs	Fair	Unchanging–improving
Habitat and Species	Overall health and habitat conditions and availability of invertebrates, fish, amphibians, birds, plants, connectivity	Fair	Unchanging
Nutrients and Algae	Nutrient concentration, harmful algal blooms, *Cladophora*	Fair	Unchanging
Invasive Species	Rate of introduction	Good	Unchanging
Invasive Species	Aquatic invasive species impacts	Poor	Deteriorating–unchanging
Groundwater	Chloride/nitrate concentrations	Good	Undetermined
Watershed Impacts	Forest and land cover, hardened shorelines, tributary water quality, human population	Fair	Unchanging
Climate Trends	Lake levels	N/A	Unchanging–increasing
Climate Trends	Surface water temperature	N/A	Increasing
Climate Trends	Ice cover	N/A	Decreasing

The Great Lakes have witnessed significant water-level variability over the last several decades, with low water levels from 1998 to 2013 and high-water levels since 2015. This variability is due in part to changes in the seasonality and intensity of precipitation (including lake-effect snow), warmer lake temperatures, lake evaporation, and loss of ice cover.[284] The twin stressors of increases in precipitation and air temperature result in increased interannual variability in lake levels.[285] However, the complex interactions between lakes, land, and atmosphere make the system difficult to model, so that long-term projections of net basin supply and lake levels have high uncertainty.[6] These climate changes impede current water management practices for the Great Lakes, which are similar to those elsewhere in the Midwest, with the added challenge of transboundary water agreements with Canada (Ch. 4). For example, low water levels limit power production from hydropower facilities and pose risks to shipping[286] and ports (KM 24.4), while high water levels lead to shoreline erosion, loss of coastal habitat[287] and flooded communities. Shorelines are also at risk from high-wind events during high-water-level episodes.[288]

Great Lakes water and air temperatures have been rising since 1980[282] (Figure 24.13). Summer surface water temperatures recorded by offshore buoys have shown nearly uniform increases across the upper Great Lakes (Superior, Michigan, and Huron). Lake Erie shows slower warming rates, while there are not enough data from Ontario to make a determination. Increases in lake surface temperatures are expected on all five lakes.[289] Although uncertainty remains on the seasonal and spatial variability, increased temperatures are expected to result in loss of suitable fish habitat.[290] How the surface warming will affect the rest of the water column and the overall impact on the ecosystem is not as well characterized. Coupled with increasing water temperatures is a decrease in winter ice cover,[291] which is observed on all five lakes and has cascading impacts on ecosystems and culture (KM 24.2; Figure 24.6).

Great Lakes Summer Surface Water Temperature Trends

(1980–2021)



Summer surface water temperatures have been increasing for Lakes Superior, Michigan, Huron, and Erie since the late 1970s.

Figure 24.13. The graphs show summer (July–September) surface water temperatures for the period 1980–2021 observed from buoys in the offshore waters of Lakes Superior, Michigan, Huron, and Erie. The upper lakes (Superior, Michigan, and Huron; **a**–**c**) show similar trends toward warmer temperatures against a background of strong interannual variability, while Lake Erie (**d**) shows a weaker but still positive trend. To facilitate comparison of trends, a temperature range of 25°F is used for the vertical axis on all four charts, with actual temperatures varying across the different lakes. Figure credit: University of Minnesota Duluth, NOAA NCEI, and CISESS NC

HABs occurring in portions of all five of the Great Lakes, including western Lake Erie and parts of Lake Superior, are affecting people through poor water quality and advisories against swimming and beachgoing. HABs also negatively impact habitats and fisheries. Projected increases in cumulative annual runoff (Figure 24.11), which elevate the risk of nonpoint-source pollution (natural and human-made pollutants that are carried from many sources by precipitation and runoff) and warming trends across the Great Lakes (Figure 24.13), are expected to promote the growth of HABs through midcentury. Although the direction of change of HABs across the Midwest is inconsistent,[280,281] recent trends in western Lake Erie show a significant increase in the extent and severity of HAB events over the last 20 years.[282]

Managing Hydrologic Complexity and Extremes

Federal, state, and local governments and institutions are working with communities on initiatives to adapt to and/or lessen the impacts of climate change. For example, the US Army Corps of Engineers has partnered with federal agencies, nongovernmental organizations, and institutions on the Ohio River Basin Climate Change project.[240] The goal was to create a comprehensive plan to address changing streamflows and identify adaptations needed to deal with water quantity, quality, and management challenges related to regulations, recreation, navigation, and aquatic habitats (e.g., fisheries). A similar study with NOAA and the University of Minnesota for the upper Mississippi River basin kicked off in 2022. Additionally, a number of climate resilience partnerships throughout the Midwest and Great Lakes have been completed.[292]

As part of the National Integrated Drought Information System, the Midwest Drought Early Warning System was established in 2016 to advance drought monitoring, forecasting, and preparedness in the region and to improve regional capacity to respond to drought.[293,294]

To adapt to extreme runoff, strong private and public partnerships can help formulate best management practices for reducing nutrient and sediment loads into streams and rivers. NOAA is accomplishing this through the Runoff Risk Decision Support project.[295] NOAA is working with state departments of agriculture in parts of the Midwest and Great Lakes, including Minnesota, Wisconsin, Michigan, and Ohio, as well as New York. The NOAA Runoff Risk Decision Support tool provides the agriculture community with timely forecast information on when to apply fertilizers. Most fertilizer applications are executed in the Midwest and Great Lakes during the winter into spring just before planting season, which is also peak runoff season. A significant percentage of total nutrient and sediment losses typically occur from a small number of runoff events each year.[296,297] The information provided by this tool allows farmers to make better-informed decisions on when to apply manure and fertilizer. The correct application of manure and fertilizer will reduce the risk of chemicals entering into river systems. The reduction of excess chemicals, including nitrogen and phosphorus, entering into waterways is important, since high nutrient and sediment loads contribute to impactful environmental HAB and hypoxia (low oxygen level) events.[297] The Mississippi River/Gulf of Mexico Hypoxia Task Force and the US/Canada Great Lakes Water Quality Agreement highlight the need for nutrient load reductions in the Mississippi and Great Lakes watershed systems, due to increasing impacts on both the public health system and ecosystems.[298]

Traceable Accounts

Process Description

The Midwest chapter authors were identified and recruited in August and September of 2021. The goal was to construct the team with at least one author from each of the Midwest states, with attention to geography, interconnected systems, level of expertise, gender, and diversity. The selection of authors was based on Federal Registry Notice comments, USGCRP (US Global Change Research Program) Research Gaps Summary for the Midwest, and author nominations, as well as discussions and nominations by the chapter lead, coordinating lead author, agency chapter lead, and National Coordination Office point of contact. Authors were added iteratively, with those who accepted early providing additional suggestions for subsequent nominations. All but two of the invited authors agreed to participate.

Regular virtual meetings were held during the fall of 2021, with the Zero Order Draft finalized in December 2021. The Midwest chapter hosted a virtual public engagement workshop on January 24, 2022. The key topics selected were well received, with ample discussion and feedback. Authors considered the comments along with inputs provided in the public call for technical material and incorporated the available recent scientific literature in developing the Key Messages for the First Order Draft. Author consensus was built through routine meetings and based on feedback from the NOAA Technical Support Unit (TSU); federal agencies; the National Academies of Sciences, Engineering, and Medicine; and public comment review periods. This iterative process occurred between the Second and Fourth Order Drafts, from the winter of 2022 to the spring of 2023.

Key Message 24.1

Climate-Smart Practices May Offset Complex Climate Interactions in Agriculture

Description of Evidence Base

There is strong evidence that increasing extreme precipitation events, changing seasonality, and rapid transitions between hydrologic conditions are negatively impacting soil conditions and challenging traditional row crop agricultural production in the Midwest, with uncertainty remaining due to local climate influences and limitations with downscaled climate data.[12,18] Studies link the loss of soil and applied nutrients to increasing rainfall, with cascading impacts including financial loss and increased water quality issues. Numerous studies point to future decreases in corn production, in combination with episodic drought, and increases in the production of some crops like wheat due to cooler-season changes including warmer springs and greater rainfall (e.g., Li et al. 2019[2]). Impacts on animal agriculture in the region remain an understudied topic, although some studies have shown impacts are already occurring (e.g., Crist et al. 2020[51]). Many of these projected impact studies rely heavily on a very high scenario (e.g., RCP8.5), which limits the assessment of the full range of uncertainty.

Reports and studies strongly demonstrate the economic importance of specialty crops to the Midwest and their vulnerability to climate change.[56] Most studies to date focus on the impact of spring-freeze injury, although a limited number of studies address other impacts such as excessive moisture, disease, and pest pressure. Evidence suggests a wide range of future outcomes to specialty crops based on species and location of cropping systems within the Midwest. Studies on the direct impacts of rising temperature and altered precipitation patterns on specialty crops across the Midwest remain limited. The evidence base for the impacts of climate change on important pollinators and insect species distributions is growing.

An increasing number of studies address agriculture's impact on climate, particularly the intensification of cropping systems and potential impacts from increased irrigation.[46] Impacts on atmospheric moisture and feedback loops within the system are ongoing.

Studies have linked, at least in part, climate change to crop insurance losses across the US and the Midwest.[75] These losses are related to drought and excess moisture. Building resilience to these hazards is part of a climate-smart approach. Studies to evaluate specific benefits and other impacts from varying climate-smart techniques are evolving.

Major Uncertainties and Research Gaps

Current climate trends are, in some ways, counter to projected climate conditions and differ from other regions of the country. For example, summer daytime warming trends (daily maxima) and drought are not occurring as projected by previous model simulations. Historical changes have been much more seasonally dependent, with the largest increases in temperature occurring during the cooler seasons rather than the summer. A high degree of uncertainty also exists in individual model-projected changes in the intensity and seasonality of future precipitation, as well as the attribution of these complexities to anthropogenic sources. While model consensus strongly points to overall increases in annual temperature, additional investigations on the interactions between agriculture and its impact on climate in the region would help resolve seasonal discrepancies. Reductions in model and scenario uncertainty would improve local impact assessments and decision-making.

More detailed information about projected changes in other climate parameters (e.g., vapor pressure deficit, soil moisture, extremes, and severe events) and impacts on specific crops would be needed for a broader understanding of the potential impacts on agricultural production and increased confidence in the findings. This includes studies beyond corn, soybean, and wheat, including other cash and specialty crops (e.g., apples, pumpkins, cucumbers). Detailed information on secondary climate change impacts (i.e., increased insect, disease, and weed pressure on production) is less well understood as well. Analyses of historical changes in the distributions of agricultural pests are limited, as are model projections of their future distributions.

With respect to social equity and justice concerns for agriculture in the Midwest, identifying and increasing engagement with BIPOC (Black, Indigenous, and People of Color) communities and low-resourced communities across the Midwest could increase the sharing of information and bring resources to these communities to enhance their climate adaptation and mitigation activities already underway. This would lead to a more informed and full assessment of the impacts, adaptation, and mitigation agricultural activities already taking place within these communities. There have been recent federal investments, for example, that have infused support into National Institute of Food and Agriculture programs that bring social and physical scientists together to help fill in this knowledge gap. Work from these new projects could be sought for future National Climate Assessment reports.

Research activities on the ability for climate-smart practices to help agriculture adapt to changing climate conditions and lessen future issues are increasing. However, further investigation of the potential trade-offs between strategies and a diverse set of outcomes based on crop, cover, soil type, and local changes in climate would be needed to increase confidence in their use and whether they reach desired outcomes. Research does support some climate-smart practices, but widespread implementation and interaction of various practices is poorly understood.

Description of Confidence and Likelihood

Based on numerous studies and converging evidence, there is *high confidence* and it is *likely* that climate change is negatively impacting agriculture in various ways. Examinations of historical extreme precipitation events and rapid transitions between hydrological states through novel analysis techniques show that these phenomena are *likely* increasing in number, and projections show that they are *likely* to continue throughout the 21st century. The team focused on the challenges, including poor field conditions and potential crop losses, that are *likely* to accompany these changes in the hydrological conditions. Although crop impacts are *likely* based on similar results across scales and methods, uncertainty in specific impacts by species (crop, insect, etc.) leads to *medium confidence* in future outcomes of row and, especially, specialty crops. Other *likely* changes, including snowmelt timing and extreme precipitation events in spring, will lead to additional impacts on animal agriculture in the region, and attention was given to dairy production as a major component of animal agriculture in the Midwest (*high confidence*). Climate-smart adaptation techniques provide a potential path toward environmental and economic sustainability, but the limited converging evidence and adoption to date lead to overall *medium confidence* in their ability to mitigate future agricultural challenges.

Key Message 24.2

Adaptation May Ease Disruptions to Ecosystems and Their Services

Description of Evidence Base

Strong convergent evidence from many sources in the published and gray literature shows that climate change is impacting natural resources in the Midwest and that these impacts will further intensify with advancing climatic change. However, the amount of evidence varies by ecosystem, the particular type of environmental change, and geographic location within the Midwest.

Strong convergent evidence from published studies shows that Midwestern aquatic ecosystems are responding to increasing temperatures and to changes in extreme weather.[97,99] There is a moderate amount of evidence demonstrating that these systems are responding to increasing precipitation. Several studies show that flooding and drought pose increasing risk to aquatic ecosystems, specifically by altering structure and community dynamics.

The evidence from published studies demonstrating that terrestrial ecosystems are being altered by climate change is strong overall (e.g., Contosta et al. 2019[133]), although the amount of evidence for any given ecosystem type being affected by any given environmental change is variable. Evidence supports the finding that impacts have been more pronounced in more northerly parts of the Midwest. Overall, there is unequivocal evidence that Midwestern ecosystems have been and will continue to be affected by landscape change, and many studies link changes in the functioning of these systems to rising temperatures and reduced snow and ice cover.[133,151] There is strong evidence that these climatic factors have been changing in the Midwest.

Major Uncertainties and Research Gaps

Much of the uncertainty concerning Midwestern natural resource responses to climate change is linked to the varying responses across species, ecosystems, and geographic location. Many species and some ecosystems are subjects of few or no direct studies; some variables have been studied in only one location within the Midwest; and species interact in complex ways that could potentially lessen or reverse direct effects of climate change in some cases—all of which increase the uncertainties of projected climate change responses.

Assessing projected responses to climate change can be challenging because of scale mismatches with climate model output. For example, streams are much smaller than climate model grids and as such require offline downscaling. Although this has been done, it has not covered the breadth of Shared Socioeconomic Pathway (SSP) scenarios.

There is significant uncertainty concerning how widely human communities are adapting their cultural practices to climate change and whether adaptation strategies have documented benefits. Case studies are available,[145] but more information is needed across the full spectrum of Midwestern communities.

Description of Confidence and Likelihood

Broad evidence from published studies indicates it is *likely* that climate change is impacting natural resources in the Midwest (*high confidence*). Published studies show that flooding and drought *likely* pose increasing risk to aquatic ecosystems by altering structure and community dynamics, although agreement on the precise magnitudes of effects is less clear (*medium confidence*). Numerous studies show that rising temperatures, altered winter conditions, and landscape changes are *very likely* altering terrestrial ecosystems and limiting their adaptive capacity (*high confidence*). This is particularly pronounced in northern ecosystems. Emerging evidence shows that losses of ecosystem services are undermining human well-being, causing the loss of economic, cultural, and health benefits (*medium confidence*). Owing to the site- and ecosystem-specific nature of the evidence, it is difficult to make broad generalizations across the Midwest. People are adapting management and cultural practices in response to climate change, particularly for inland lakes and forest systems; many of these practices have co-benefits for ecosystem services, including mitigation of climatic changes (*low confidence*). The authors assess with *low confidence* because of noted knowledge gaps across the Midwest concerning both community actions and documented responses.

Key Message 24.3

Climate Adaptation and Mitigation Strategies Improve Individual and Community Health

Description of Evidence Base

There is strong evidence that increasing temperatures and changes in historical precipitation patterns are occurring across the Midwest and will *likely* continue through the end of the century. The level of air contaminants, such as particulate matter, ozone, and pollen, are positively associated with rising temperatures, and there are numerous studies describing the link between exposure to these contaminants and increased morbidity and mortality.[186,187]

Exposure to climate-related events, such as extreme heat and flooding, has been shown to impact the health and well-being of Midwest communities, as well as degrade social and environmental determinants of health.[178,179] The occurrence of extreme heat and precipitation events is projected to rise across the Midwest. However, there are few in-depth qualitative assessments that capture and report person- or community-specific information from those impacted, particularly the short- and long-term effects of experiencing a climate-related hazard. Increases in intense rainfall have been linked to increased exposure to waterborne contaminants in both public and private drinking water systems in the Midwest.[201,204] Studies using climate projection data have shown that climate-related seasonal precipitation changes will increase the rates of gastrointestinal illness in children.[203]

There is strong evidence that rising temperatures are contributing to the expansion of disease-carrying vectors like ticks and mosquitoes into and across the Midwest.[207] Modeling using climate projections predicts that the range of many established and newly invasive species will increase throughout the century, increasing the risk of various zoonotic diseases like Lyme disease and West Nile virus.[208]

Climate change is associated with negative impacts on mental health.[211] However, there are few studies, particularly based on Midwest populations, that link robust measures of climate change or climate-related events with clinically validated psychiatric diagnoses.

There is a substantial increase in the number of climate assessments conducted for Midwest states and cities that emphasize the need to address systemic injustice and historical racism and prioritize equity in climate resilience decision-making.[32,299,300] Many of these reports also acknowledge the need to involve disproportionately impacted communities in the design and implementation of resilience strategies. These assessments are not part of the peer-reviewed literature and thus were not considered as part of the evidence base for this section. However, it is notable that many Midwest climate assessments have not only included but also prioritized these issues as part of their climate resilience planning.

Major Uncertainties and Research Gaps

While there are many studies linking climate change to impacts on health and community well-being, only a small number of these studies have been conducted directly or solely on Midwest populations. Furthermore, to capture the breadth of potential impacts, these studies could consider a range of scenarios, not just the highest or worst-case scenarios.

There is a gap in research characterizing how climate-related health impacts differ based on local population-specific characteristics and shared realities, particularly across the urban–rural gradient and multiple Tribal Nations and as a result of increasing immigration. This is particularly true for specific health outcomes (e.g., mental health) and health determinants (e.g., livelihood). Such information would be useful for developing targeted, effective intervention strategies that address existing inequities and historical racism.

The literature currently lacks studies specific to the Midwest that attempt to quantify the cost burden associated with climate impacts on health and key health determinants like livelihood or housing security. Thus, there is uncertainty about how much climate change impacts are costing Midwest communities in terms of injury, disease, job loss, property damage, healthcare utilization, and more.

Certain emerging topics for climate and health in the Midwest, including climate-driven migration and concerns for people with disabilities, were not covered due to a lack of literature specific to the Midwest region. Thus, it is uncertain what the attending health impacts may be related to these topics and how they may be distributed throughout a community.

Description of Confidence and Likelihood

There is *high confidence* and it is *very likely* that climate change will impact the health and well-being of individuals and communities in the Midwest across a wide range of exposure pathways. Literature shows that these pathways include extreme events, such as flooding, drought, heatwaves, and wildfires, that all pose an increasing risk to physical and mental health by direct exposure. Studies show that indirect exposure through degrading air and drinking water quality threatens livelihoods and strains essential health and emergency-related services. An individual's exposure and sensitivity to climate change is *very likely* influenced by preexisting health conditions, income, race and ethnicity, age, and access to resources (*high confidence*). Evidence illustrates that health disparities tied to racism and income inequality are *likely* linked to an inequitable distribution of climate-related health outcomes. Actions and investments to reduce climate-related health and community impacts can yield multiple health benefits while helping to advance more equitable climate adaptation (*high confidence*).

Key Message 24.4

Green Infrastructure and Investment Solutions Can Address Costly Climate Change Impacts

Description of Evidence Base

Based on numerous independent analyses, much of the infrastructure of the Midwest is aging, and repairing this infrastructure will come at a significant cost (e.g., American Society of Civil Engineers Report Card for America's Infrastructure).[248] These costs require new forms of financing, data, and expertise, much of which is just emerging. The infrastructure deficit in the Midwest is articulated through academic literature and practitioner resources and research,[236,248] all demonstrating that the infrastructure of the Midwest is aging and that repairing it will come at a significant cost. These costs require new forms of financing, data, and expertise, much of which are just emerging.[236] There is strong evidence showing that increasing storm damages to infrastructure across the Midwest disproportionately impact people with low income and BIPOC populations.[258] Numerous studies of social vulnerability and adaptive capacity demonstrate that individuals with lower vulnerability and higher adaptive capacity are better able to prepare for and recover from disaster.

Major Uncertainties and Research Gaps

Storm damages not captured through disaster declarations are difficult to identify, and midsize disasters are difficult to quantify. One method for quantifying these midsize disasters could be to report on the total times states in the Midwest declare a state of emergency in response to a weather- or climate-related event. There is a gap in aggregated and standardized reporting of state-declared disaster events and related losses. Another approach could be to calculate insurance losses as reported by private insurance companies with holdings in the region. State-level data and private insurance datasets are accessible but require analysis and synthesis to be usable by decision-makers. The US Billion-Dollar Weather and Climate Disasters report, developed by NOAA's National Centers for Environmental Information, has become a common way to understand the increasing cost incurred by climate change and related extreme events. However, many smaller-scale yet damaging storm events occur annually and lead to damage or destroyed infrastructure, loss of life, and harm to the health and well-being of people in the Midwest. One measure of these events is through the National Flood Insurance Program database. Tracking these events and the related economic impact could enable more effective and equitable distribution of resources before and following extreme storms.

Climate migration is an area of uncertainty, yet information is highly sought within academic and public spheres. Literature and resources on community relocation within the region exist, but literature and evidence on climate-induced migration of people moving into the region is not currently available.

Description of Confidence and Likelihood

There is strong evidence that climate change *likely* threatens built infrastructure, especially if a heavy dependence on conventional road transportation continues. Uncertainty about the modes of transportation that will exist in the future and uncertain trends toward electrification result in an assignment of *medium confidence*. More certain are the impacts from increased precipitation extremes and transitions between wet and dry conditions on riverine and Great Lakes environments (*likely*, *high confidence*). The emergence of new investments offers alternative methods toward development, but volatility in the economy leaves some uncertainty whether more communities and local businesses will embrace these tools (*medium confidence*).

Key Message 24.5

Managing Extremes Is Necessary to Minimize Impacts on Water Quality and Quantity

Description of Evidence Base

There is strong evidence that the Midwest and Great Lakes water is and will continue to be impacted by climate change, with associated adverse effects for both human society and ecosystems.[267] The evidence for change is supported by the trends in temperature, precipitation, runoff, and evapotranspiration.[268] Further, reasonably good climate-based scenario model performance in the past provides confidence in those predictions going forward.

The evidence and research were more consistent for water quantity and water management than for water quality.[280,281] This is due, in part, to the more complex nature of water quality. The biggest areas for lack of agreement were in harmful algal blooms (HABs) and how global climate scenario-based models deal with the regional representation of the Great Lakes.

Major Uncertainties and Research Gaps

The lack of robust model simulations of how the Great Lakes physically operate is a major gap and uncertainty. Climate processes in the Great Lakes region are difficult to simulate due to the complexity of lake–land–atmosphere interactions.[6] Even the most sophisticated climate models for the Great Lakes region have deficient physical representations of the key hydrological components that make up a lake's net basin supply (i.e., precipitation, evaporation, and runoff).[6] Therefore, high levels of uncertainty are associated with future lake-level projections that are based on simulated changes to these hydrological components. However, higher variability in future water levels is anticipated, which will impact the entire ecosystem (KM 24.2), ports (KM 24.4), and coastlines.[284,301] Better physical representation of the Great Lakes would enhance confidence in how increases in the water temperatures of the lakes (both surface and deep lake) could impact the ecosystem.

HAB research across the Midwest and Great Lakes is conflicting and limited.[280,281] While research has been more conclusive in the Great Lakes with increasing HAB severity, research has been inconclusive in the Midwest as to whether HAB severity has been increasing, remaining constant, or decreasing. Connections to agricultural tiling and septic systems and their impacts on water bodies are additional knowledge and data gaps.

Temperature, precipitation, and runoff research is much more comprehensive in the Midwest than streamflow research.[268] There is limited available work on large basin–scale streamflow to assess climate impacts. The Ohio River Basin Climate Change project, by the US Army Corps of Engineers and NOAA,[240] is one of the US's largest and most comprehensive climate change–related projects on water quantity, quality, and management for streamflows on medium- to larger-scale systems. A similar Midwest project by NOAA's North Central River Forecast Center and the University of Minnesota is underway for the upper Mississippi River basin. More large-scale hydrologic projects, including in the Missouri River basin and Great Lakes, would aid in understanding large-scale streamflow changes and projected impacts. The absence of more such projects limits the ability to have higher confidence in some areas of water quantity, quality, and management. Combining Coupled Model Intercomparison Project Phase 5 with the Variable Infiltration Capacity hydrology modeling is a step in the right direction.

Description of Confidence and Likelihood

Confidence and likelihood were assigned based on the consistency of the information in trends and research combined with strengths and weaknesses in the climate scenario models. For the Midwest and Great Lakes, there is consistent information to support *high confidence* for air temperatures, precipitation, and runoff trends and projections and the impacts to water quantity, water quality, water management practices, ecosystem health, food production, and recreation.[15] Based on literature and projections, it is *likely* and there is *high confidence* that increases in runoff (in all seasons but summer, where some decreases are projected), drought, and flooding will adversely affect ecosystems through increased erosion and the expansion of invasive species. This applies to enhanced erosion and expansion of invasive species. For harmful algal blooms (HABs), the literature and projections support *high confidence* for continued HABs in the Great Lakes. For the Midwest, confidence is lower that increased temperatures and precipitation and runoff will continue to lead to variable changes in HAB events (increasing, decreasing, or remaining unchanged). This will *likely* result in continued adverse impacts to water quality and ecosystems. There are numerous examples where federal and state agencies along with nongovernmental organizations are collaborating on adaptation efforts related to water in the Midwest (*high confidence*).

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