

CHAPTER 6

POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE FOR THE MIDWESTERN UNITED STATES

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Acknowledgments

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CHAPTER SUMMARY

Regional Context

The Midwest is characterized by farming, manufacturing, and forestry. The Great Lakes form the world's largest freshwater lake system, providing a major recreation area as well as a regional water transportation system and access to the Atlantic Ocean via the St. Lawrence Seaway. The region encompasses the headwaters and upper basin of the Mississippi River and most of the length of the Ohio River, both critical water sources and means of industrial transportation providing an outlet to the Gulf of Mexico. The Midwest contains some of the richest farmland in the world and produces most of the nation's corn and soybeans. It also has important metropolitan centers, including Chicago and Detroit. The largest urban areas in the region are found along the Great Lakes and major rivers. The "North Woods" are a large source of forestry products and have the advantage of being situated near the Great Lakes, providing for easy transportation.

Climate of the Past Century

Over the 20th century, the northern portion of the Midwest, including the upper Great Lakes, has warmed by almost 4°F, while the southern portion along the Ohio River valley has cooled by about 1°F.

Annual precipitation has increased, up to 20% in some areas, with much of this coming from more heavy precipitation events.

Climate of the Coming Century

During the 21st century, it is highly likely that temperatures will increase throughout the region, likely at a rate faster than that observed in the 20th century, with models projecting a warming trend of 5 to 10°F over 100 years.

Precipitation is likely to continue its upward trend, with 10 to 30% increases across much of the region. Increases in the frequency and intensity of heavy precipitation events are likely to continue in the 21st century.

Despite the increase in precipitation, rising air temperatures and other meteorological factors are likely to lead to a substantial increase in evaporation, causing a soil moisture deficit, reduction in lake and river levels, and more drought-like conditions in many areas.

Key Findings

- A reduction in lake and river levels is likely to occur as higher temperatures drive increased evaporation, with implications for transportation, power generation, and water supply.
 - Agriculture as a whole in this region is likely to be able to adapt and increase yields with the help of biotechnology and other developments.
 - For both humans and other animals, a reduction in extremely low temperatures is likely to reduce cold-weather stress and mortality due to exposure to extreme cold, while an increase in extremely high temperatures is likely to decrease comfort and increase the likelihood of heat stress and mortality in summer.
 - Preventative measures such as adequate storm-water discharge capacity and water treatment could help offset the likely increased incidence of water-borne diseases due to an increase in heavy precipitation events. As temperatures increase there is also a chance of more pest-borne diseases, such as St. Louis encephalitis.
 - Changes in seasonal recreational opportunities are likely, with an expansion of warm weather activities during spring and fall, and a reduction during summer due to excessively hot days.
- Cold weather activities are likely to decline as warmer weather encroaches on the winter season.
- Boreal forest acreage is likely to be reduced under projected changes in climate. There is also a chance that the remaining forestlands would be more susceptible to pests, diseases, and forest fires.
 - Major changes in freshwater ecosystems are likely, such as a shift in fish composition from cold water species, such as trout, to warm water species, such as bass and catfish.
 - Higher water temperatures are likely to create an environment more susceptible to invasions by non-native species.
 - The current extent of wetlands is likely to decrease due to declining lake levels.
 - Changes in bird populations and other native wildlife have already been linked to increases in temperature and more changes are likely in the future.
 - Eutrophication of lakes is likely to increase as runoff of excess nutrients due to heavy precipitation events increases and warmer lake temperatures stimulate algae growth.

POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE FOR THE MIDWESTERN UNITED STATES

PHYSICAL SETTING AND UNIQUE ATTRIBUTES

The Midwest region is dominated by the Great Lakes, two major river systems, and large tracts of both forests and agricultural lands. The landscape of most of this region was scoured by a series of continental glaciers resulting in thousands of lakes, wetlands, and huge expanses of relatively flat land. The last of these glaciers retreated about 10,000 years ago and glacial meltwater carved many important river valleys. As the glaciers retreated, the lands that were once covered by ice up to two miles deep developed some of the richest and most productive agricultural soils in the world. In addition to the Great Lakes, they also formed tens of thousands of small- to moderate-size lakes, which have become a

characteristic of the region, the “land of 10,000 lakes,” as Minnesota license plates proclaim (Lew, 1998).

The Great Lakes are one of the world’s largest inland lake systems, containing 20% of the world’s freshwater reserve (Botts and Krushelnicki, 1987). They also provide a regional water transportation system and access to the Atlantic Ocean via the St. Lawrence Seaway. This is a vital competitive advantage for transporting manufactured goods and agricultural products produced in this region. This region also contains the headwaters and upper basin of the Mississippi River and most of the length of the Ohio River, both critical water sources and means of industrial transportation providing an outlet to the Gulf of Mexico.

The Midwest region is comprised of the area north of the Ohio River, including the Great Lakes region, and west to the states adjacent to the Mississippi River (Figure 1). It contains 12% of the US land area and 22% of its population. This area covers a wide range of ecosystems with some extensive urban/suburban development. The region can be divided into three subregions: the rolling forested landscapes of southern Missouri, Illinois, Indiana, and Ohio; the relatively flat farmland in the northern portions of these states as well as in Iowa; and the heavy evergreen and deciduous forests of Wisconsin, Minnesota, and Michigan. Native vegetation ranges from mixed deciduous forests in the south to the so-called Prairie Peninsula, (a region of tall grass prairie in southwestern Minnesota, Iowa, and large portions of Missouri, Illinois, and southern Wisconsin), giving way to the deciduous and coniferous forests in the northern Great Lakes. The flora of the region are accustomed to periodic extreme droughts, flooding, late-spring or early-autumn frost, low minimum temperature, high maximum temperature, and severe storms.



Figure 1. Map of Midwest region.

SOCIOECONOMIC CONTEXT

The Midwest is a combination of the Manufacturing and Corn Belts, a region of manufacturing and agricultural production on which the entire country depends. Shaped by surface water systems and other emerging transportation networks, it developed rapidly in the latter half of the 19th century with the arrival of both large numbers of settlers from eastern US and immigrants from Europe. It has relatively high population density, and numerous pockets of national excellence such as the Mayo Clinic in Minnesota. The region provides more than 40% of the nation's industrial output and is responsible for 30% of the nation's foreign agricultural exports.

Historically, the Midwest's image as the heart of the Manufacturing Belt has been closely associated with the automobile age, and its prosperity has traditionally been tied to the fortunes of the automobile industry. Other heavy industry has been important as well, including the production of chemicals, steel, paper, and medical products. Due to foreign competition, an aging industrial infrastructure, and environmental issues, the Manufacturing Belt declined in competitiveness during the 1970s, coming to be referred to as the Rust Belt. However, the region responded with vigorous industrial restructuring related to modern technologies and components such as electronics, and also to services and financial industries. Meanwhile, continued improvements in farming methods and seed stock from new research and development has pushed the yields of corn, soybeans, fruits, vegetables, and other crops up to previously inconceivable levels. This revitalized economic base is expected to lead to continued economic and demographic growth (see Figures 2 and 3), but still lagging behind the rest of the country (with the notable exception of Minnesota).

ECOLOGICAL CONTEXT

Land use in the Midwest region is dominated by managed ecosystems such as farmland. However, the natural land cover of the region is characterized by three prominent environmental gradients. First, a southwest to northeast gradient from prairie to forest in Minnesota is largely a function of water availability. Second, a south to north gradient from Eastern deciduous (oak-hickory) to Northern mixed hardwood forests (beech, maple, hemlock) in Michigan and Wisconsin is a prominent landscape feature. These patterns correspond to climatic and soil gradients and a steep south-north land-use gradi-

Midwest Population Estimates and Projections

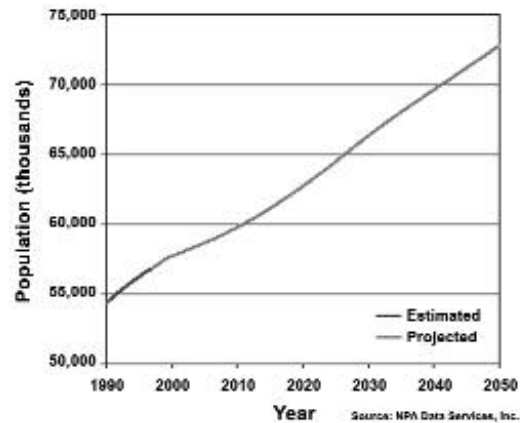


Figure 2. Population trend estimate for the Midwest region using the baseline assumptions from the NPA Data Services estimates. Under this scenario, the population of the Midwest is expected to increase by about 30% by 2050.

Midwest Industry Income

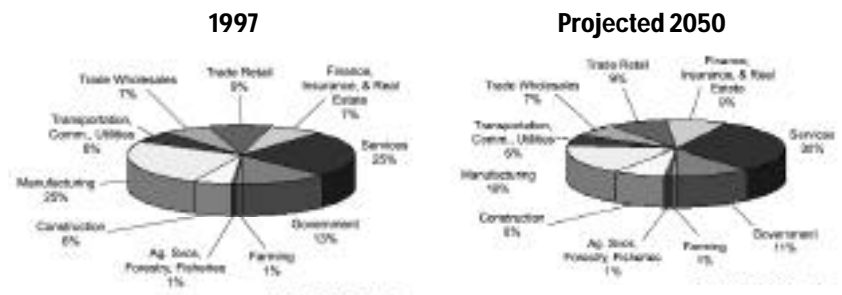


Figure 3. Percentage of economy by sector for (a) 1997, and (b) 2050, estimated from the NPA Data Services using baseline assumptions (NPA 1999b). Under these estimates, by 2050 the manufacturing percentage of the economy decreases by 7%, and the service sector increases by 5%. See Color Plate Appendix

ent from predominantly agriculture to predominantly forested. Third, the region is at the southern margin of the boreal forest (spruce-fir) and northern portions of the region include boreal species as locally dominant, especially on wetter sites.

In 1992, the Upper Great Lakes region (Michigan, Minnesota, and Wisconsin) was about 42% (over 50 million acres) forestland. Over 90% of the forestland is used for commercial forestry, and more than half of the commercial forest land is owned by the non-industrial private sector. The forestry sector employs about 200,000 people and produces over \$24 billion dollars a year in forest products. Expectations in the industry are for sustained or increased output of forest products, particularly given increasing demand for forest products, decreasing supply from the Pacific Northwest, and

the already high production from the neighboring southern and southeastern regions of the US. The second and third-growth forests of the Upper Great Lakes are maturing, and recent forest inventories report substantial increase in the amount of forested land and in stocking on those lands. The majority of Americans, including those in the region, express a desire for increased emphasis on non-commodity values in forest management (e.g., recreation, aesthetics, and biodiversity). This desire often conflicts with the dependence of rural landowners on forests for employment and community development. While both standing volume and demand for forest products continue to increase in the Upper Great Lakes, the amount of land available for timber production continues to decrease due to conversion to urban and industrial uses, and development of seasonal and retirement homes.

Two trends in land use should be considered and are very likely to continue for the short term. Declines in the amount of farmland in Michigan, Minnesota, and Wisconsin (a 5% decline between 1998 and 1997) was observed in the Census of Agriculture. Forest cover increased by 3% between 1980 and 1993 according to the USDA Forest Service forest inventory, and urban sprawl has accelerated, both replacing important agricultural land use. Although the pressures causing these changes are still in place (declining agricultural productivity and increasing demand for recreational and aesthetic uses of land), it seems unlikely that the trends can continue long term. Increasing development and declining rates of agricultural abandonment are likely to lead to declines in forest area in the longer term (Warbach and Norberg, 1995). Furthermore, large-scale management of forests on private lands is becoming increasingly difficult as ownership is becoming increasingly fragmented among many more and smaller parcels (Norgaard, 1994; Brown and Vasievich, 1996). Between 1960 and 1990, average private parcel sizes declined by an average of 1.2% per year across the region. While this "parcelization" associated with recreational and seasonal home development doesn't necessarily result in forest clearing, it does affect the management of forests and, therefore, the ability of foresters and thus forests to respond to changing climatic conditions.

Given the substantial potential expansion of the temperate deciduous forests and savannas (oak and hickory dominant) it is important to consider two limiting factors. First, between two-thirds and three-quarters of these two communities are under active human management for agriculture and/or develop-

ment. This can affect the availability of seed sources and, therefore, slow the migration of species northward. This delay can contribute to dieback as communities make the transition from one type to another. Second, the northern forests are strongly influenced not only by climate, but also by the soils present, with conifers tending to dominate on the sandy soils, such as found in the north of the region, especially in lower Michigan. Sandy soils are more prone to drought conditions. Although vegetation models consider this influence, the scale of the variation in soil effects is much finer than can be represented in the models. Therefore, soil effects contribute to uncertainties in projections.

CLIMATE VARIABILITY AND CHANGE

The climate of this region is typical of an interior continental climate, although the Great Lakes exert a strong influence on nearby areas for both precipitation and temperature. Total annual precipitation varies from a low of about 25 inches in western Minnesota and Iowa to more than 40 inches per year along the Ohio River. Rainfall in most of the region is highly seasonal, with most falling in the summer. Only in the Ohio River Valley is precipitation more consistent throughout the year. Temperatures range widely from winter to summer, year-to-year, and even decade-to-decade, with reduced variability in areas adjacent to the Great Lakes.

Annual mean temperature trends in this region over the 20th century indicate that the northern portion, including the upper Great Lakes, is warming at a rate of almost 4°F/100 years (2°C), but the southern portion along the Ohio River valley has a slight cooling trend of around 1°F/100 years (0.6°C). By the end of the 21st century, the projected changes in mean annual temperature for much of the Midwest are between 5 and 10°F (3-6°C) with about twice the rate of temperature increase in the Canadian climate model scenario than in the Hadley scenario. In both scenarios, the mean daily minimum temperature rises more than the maximum temperature, often by a degree or two F by the end of the 21st century, a characteristic also observed during the 20th century.

The decrease in the annual mean temperatures over the 20th century along the Ohio River is also associated with a reduction in the number of days in the late 20th century exceeding 90°F (32°C). Decreases

of up to 14 days per year exceeding 90°F in the Ohio Valley have been observed, owing in part to the extreme heat in the first half of the century associated with the intense droughts during the 1930s. This is in contrast to the projected increase in the probability of temperatures exceeding 90°F during the 21st century. For example, in Cincinnati, the probability of more than half the days in July having temperatures at or above 90°F increases from 1 in 20 now, to 1 in 2 by 2030 in the Canadian climate scenario and to 1 in 10 for the Hadley scenario.

Changes in extreme temperature can be even more dramatic. For example, the Canadian scenario suggests that for places like Chicago, the probability of three consecutive days with nighttime temperatures remaining above 80°F (27°C) and daytime temperatures exceeding 100°F (38°C) increases from about a once in 50 years occurrence today, to approximately once every 10 years by the decade of the 2030s. By the decade of the 2090s this probability increases to one year in two or 50% for any given year. Analysis of the historical data shows no change during the 20th century in the number of days below freezing for the southern portion of the region, and only slight decreases of around 2 days per 100 years around the Great Lakes. Again, this is expected to change considerably by the end of the 21st century. For example, in southern Wisconsin, the Canadian scenario projects an increase in the number of wintertime nights remaining above freezing from the current 5 nights per winter to 15 of the nights by the end of the 21st century.

The length of the snow season over the last 50 years increased by about 6 days per year in the northern Great Lakes area, but decreased by as much as 16 days in the Ohio River valley and adjacent areas. Both climate scenarios project a decrease of up to 50% in the length of the snow cover season by the end of the 21st century. Although it is possible that during the next few decades lake-effect snows might initially increase with a reduction in lake ice cover, it is highly likely that by the end of the 21st century, a reduction in the conditions favorable for lake-effect snows would cause the frequency of lake-effect snows to decrease (Kunkel et al., 2000). Therefore, it is likely that by the end of this century, sustained snow cover (more than 30 continuous days of snow cover) could disappear from the entire southern half of the region.

Observed trends for annual precipitation over the 20th century show moderate to strong increases

almost everywhere in the region, often exceeding 20% per century. On an annual basis, precipitation is projected to increase by 20 to 40% by the end of the 21st century in the upper Midwest and decrease by up to 20% along the Ohio River in the Canadian scenario. However, these changes are not uniform throughout the year. For the Hadley scenario, increases in precipitation occur everywhere in the Midwest with increases of 20 to 40% common. However, the magnitude of precipitation increases in the Hadley scenario is unusual compared to other 2xCO₂ equilibrium models run over the past several years in that it does produce more precipitation at the end of the 21st century (Quinn, et al., 1999).

Observed changes in soil moisture calculated from the Palmer Drought Severity Index indicate moderate to very strong increases in wetness in the eastern portions of the region. In contrast, even with the temperature increases there is a strong enough increase in precipitation to outweigh increased evaporation in the Hadley scenario which leads to small positive changes of soil moisture content by 2100. In the Canadian scenario however, despite the increase in annual precipitation, a reduction in summer precipitation coupled with the larger increase in temperature relative to the Hadley scenario leads to increased evaporation and reduced soil moisture content, especially during summer. The frequency and intensity of droughts increase in the Canadian scenario, but decrease slightly in the Hadley scenario by 2100.

Changes in variability related to the changes in extremes are of particular interest. The interannual variability of the annual mean temperature decreases slightly for both model scenarios by the end of the 21st century, but the magnitude of this decrease is very small compared to the increase in the mean. As a result, new record high extremes of temperature are common in both climate scenarios throughout the 21st century (Karl and Knight, 1998; National Climatic Data Center, 1999).

The interannual (year-to-year) variability of precipitation in both scenarios shows no significant changes, even by the end of the 21st century. But an increase in the mean annual precipitation would likely be accompanied by even greater changes in heavy daily precipitation events (Groisman et al., 1999a). Both climate scenarios show increases in precipitation for the Midwest region, and analysis indicates that this increase is occurring due to increases in the highest daily precipitation amounts (Figure 4). However, in the Canadian scenario, even with projected increases in precipitation, the increased evaporation due to

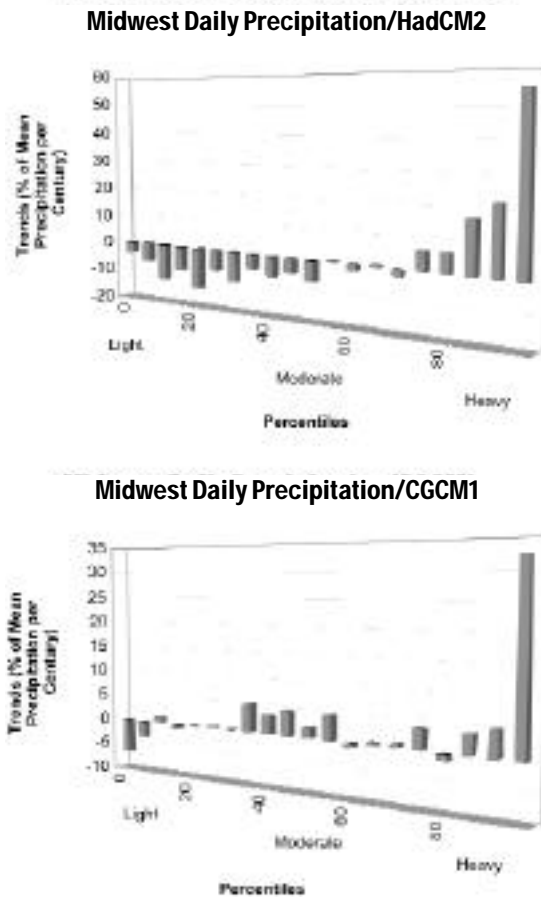


Figure 4. Annual trends in daily precipitation by percentile for the (a) CGCM1 (Canadian model) and (b) HadCM2 (Hadley model) scenarios. Notice the largest trend is in the heaviest daily precipitation amount for both model simulations indicating that most of the increase in annual precipitation is due to an increase in precipitation on days already receiving large amounts (analysis based on method in Karl and Knight, 1998). See Color Plate Appendix

rising temperatures would result in both decreased runoff and increased direct lake evaporation, resulting in decreased lake levels (see water resources section below).

KEY ISSUES

1. Water Resources
2. Agricultural Ecosystems
3. Natural and Semi-natural Ecosystems
4. Quality of Life

The key issues discussed here were chosen to be representative of those issues that are potentially affected directly by climate change, in either positive or negative ways. Moreover, they are issues of key economic and/or environmental importance. It is clear that secondary and even tertiary effects due

to climate change among the various sectors are possible, however these types of effects are very difficult to quantify and are not considered here.

1. Water Resources

Some climate model scenarios project a reduction in available water with increasing atmospheric CO₂ even with increased precipitation, due to enhanced evaporation with increased temperatures outweighing the precipitation increase (Meehl et al., 2000). Decreased lake levels and river flow would pose special problems for the region, affecting commerce and recreation and altering entire ecosystems. Understanding potential impacts of climate change on water resources is a key element in understanding impacts on a variety of other sectors. Issues with the region's many lakes including the Great Lakes, and the river systems including the Ohio and Mississippi basins, are critical to the region's economy and ecosystems. These issues include water levels, water temperature, ice cover, and water quality.

Lake levels. For the Great Lakes, the potential impacts related to the various scenarios of climate change span a wide range. The Canadian climate scenario projects a reduction in the levels of the Great Lakes by as much as 4 to 5 feet because of decreases in the net basin supply of water caused by reduced land surface runoff and increased evaporation of lake water. These reductions are projected to occur in spite of the projected increases in total precipitation. Should these changes occur, they would be 3 to 6 times larger than the seasonal variation of Lake levels, which normally reach a minimum during winter and a maximum in late summer, unlike many smaller lakes which reach their minimum in late summer. The reduction in water levels projected by the Canadian scenario would result in a 20-40% decrease in outflow in the St. Lawrence River. The Hadley scenario, with its smaller temperature increases and greater precipitation increases, leads to smaller changes (a slight increase of 1 foot) in Lake levels during the 21st century (see box, Quinn et al., 1999). However, Chao (1999) presents Great Lakes level changes calculated using a number of both transient and equilibrium climate change simulations. For each lake the results show lake level declines ranging from less than 1 foot (0.3 meter) to more than 5 feet (1.8 meters) (see Figure 5). The differences in the results from various model projections illustrate the difficulty in planning long-term adaptation strategies because they require consideration of a broad range of possibilities.

The Drought of 1988

Along with the droughts of the 1930s, the 1988 Midwest drought was one of the worst in the previous 100 years and brought home the socioeconomic impacts of these types of short-period climate fluctuations. Major impacts occurred in most sectors of the economy including agriculture, recreation, and transportation. The National Climatic Data Center (1999) lists this drought and associated heat waves as one of the most expensive natural disasters in US history, with costs of over \$30 billion.

One of the unforeseen impacts was on river-borne transportation on the lower Mississippi River. The drought reduced water levels in the Mississippi River to the point that barge traffic was restricted, causing bulk commodity shipping to be shifted to more expensive rail transport. A controversial proposed response was to increase the diversion of Lake Michigan water into the Mississippi River system via the Chicago River. The diversion is limited to 3,200 cubic feet per second (cfs) by a US Supreme Court decision and the proposed increase was to 10,000 cfs. However, a number of factors led to a decision not to implement this increased diversion. First, it was determined to be too politically controversial, particularly because Great Lake water levels were rapidly falling from their record levels of the previous few years and the increased diversion could accelerate this fall. Furthermore, hydrologic studies indicated that the increased diversion would be insufficient to improve conditions anyway.

As with many such impacts, there were winners and losers. Losers included producers such as farmers, petroleum companies, the coal industry, and others who had to pay more to ship their products. In addition to the river-based shipping industry itself, other losers were consumers of the commodities normally shipped via river traffic that had to pay more due to higher shipping costs. There were also negative ecological impacts due to low water levels including fish kills, wetland damage, and salt-water intrusion up the lower Mississippi River past New Orleans. The major winners economically were the alternative shippers such as the rail and trucking industries.

If reductions in runoff as large as those projected by the Canadian climate scenario occur, this would have a substantial effect on all the major rivers of the region. During the 1988 drought, hundreds of millions of dollars were lost due to transportation inefficiencies (Changnon, 1989). On an annual basis, over \$3 billion in business revenue and personal income, and 60,000 jobs relate to the movement of goods on the Great Lakes-St. Lawrence transportation system (Allardice and Thorp, 1995). Low water levels often lead to gouged ship hulls or damaged propellers. Dredging operations can be used to offset these problems. In addition to the added cost of dredging, another risk is the possibility of re-suspending human-made inert toxins and heavy metals lying within the lake bottom sediments, significantly impacting water quality. Such "surprises" are often difficult to anticipate. There is the potential that the competitive advantage this region has had due to reliable and efficient transportation of goods in and out of the area could be lost.

This event illustrated the high likelihood for future controversy if droughts of this magnitude become more frequent due to climate change. Clearly if this occurs the barge industry would be severely impact-

ed by a change in shipping patterns favoring railroads and trucking.

Lake ice cover. Some offsetting changes related to the water transportation problem are projected in both the Hadley and Canadian climate scenarios. For example, with water temperature increases there would be a longer ice-free season (see box) resulting in a one to two month extension of the shipping season by the end of the 21st century. This could translate into hundreds of millions of dollars of additional business revenue, however the ship-

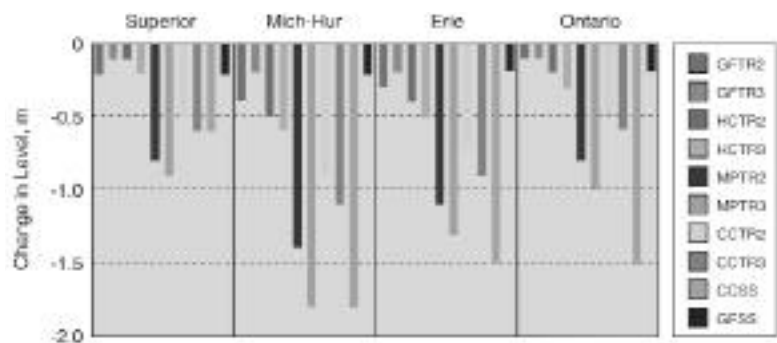


Figure 5. Change in water level for each of the Great Lakes under a number of climate change scenarios, from Chao (1999). See Color Plate Appendix

ping cost per ton would likely increase for reasons previously discussed due to low water levels (Chao, 1999, see Figure 6).

Improved understanding of Great Lakes ice cover, its climatic variability, and the ensuing economic and ecological impacts is needed for the development of strategies for adaptation to potential climate change. Reduced ice cover duration over the 21st century, as recent studies suggest (see box, Quinn et al., 1999), would have feedbacks on lake evaporation, lake levels, and even lake-effect snowfall (by possibly affecting the seasonality of lake effect snowstorms). Ecosystem services that could possibly be lost with a reduction of lake ice include: 1) storage of airborne atmospheric particulates until their rapid release in the spring, 2) enhancing overwinter survival of fish and fish eggs, and 3) protecting the shore against erosion.

For the thousands of smaller lakes in the region, ice cover is projected to form every year only in lakes in Minnesota, upper Michigan, and Wisconsin by the end of the 21st century (Fang and Stefan, 1998), but shortened by nearly half of its normal duration. These changes could eliminate fish winterkill in most shallow lakes, but possibly can endanger traditional recreational users of these lakes because of reduced ice thickness.

Storm-water routing and flood plains. Despite the lower water levels as temperatures increase, it is likely that a continuation of the increase in heavy precipitation events would occur as the climate warms (IPCC, 1996; Groisman et al., 1999a; Groisman et al., 1999b; Karl and Knight, 1998). Parts of the region, including Indiana and much of the area around Chicago are already at a high risk related to the number of residents living in the 500-year flood plain. The addition and expansion of impervious surfaces such as pavement can compound the

difficulties related to flash flooding events, taxing existing storm water routing infrastructure. Already states like Illinois have updated their 100- and 500-year rainfall return periods in recognition of the changing climate (Angel and Huff 1997).

Furthermore, Olsen et al. (1999) found evidence for increased flood risk over the most recent decades in the lower part of the Missouri basin, and on the Mississippi River at St. Louis.

With a warmer climate that is drier due to enhanced evaporation, but also experiencing an increase in heavy precipitation events, it is likely that there would be changes in eutrophication incidence in lakes. Increased surface water temperature reduces vertical mixing of nutrient rich water between the hypolimnion (the colder bottom layer in a thermally stratified lake) and the epilimnion (the warmer, top layer) resulting in a reduction in the intensity of summer algae blooms. However, heavier rain events with associated greater runoff would likely increase eutrophication because heavy rain events are most important in transporting nutrients such as fertilizer from the watershed to the lake (Stephan et al., 1993). Also under this scenario it is likely that groundwater could also be affected through a reduction in water tables due to both increased irrigation and a reduction in recharge with enhanced evaporation; there would also be an increased risk of well-head contamination during flooding events (Rose et al., 1999).

2. Agricultural Ecosystems

Agriculture in this region is vitally important to the nation and the world. With continued intensive application of technological advances, the impact of projected climate changes on agricultural yields would likely increase the high productivity of the region. Larger impacts could be related to changes in growing conditions abroad affecting crop prices.

Under climate change scenarios, a longer growing season would likely translate into increased farm production. Although only 4% of the farms in the Upper Great Lakes region have irrigation capabilities, even non-irrigated crops are likely to increase yields with an increased growing season length. Increasing irrigation capabilities would allow farmers to take advantage of the increased growing season length and push yields even higher. Although soil-types and farming practices in the Great Lakes region are more suitable for current crop types than those grown further south, these limitations are likely to be outweighed by increases in growing season length and warmer summer temperatures (Andresen

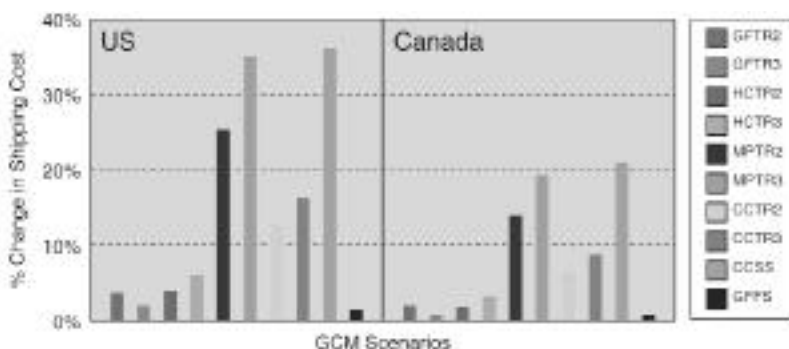


Figure 6. Change in shipping costs under a number of climate change scenarios, from Chao (1999). See Color Plate Appendix

Great Lakes Water Diversion

In 1900, the city of Chicago built the Chicago Sanitary and Ship Canal to keep sewage from contaminating the Chicago water supply intakes in Lake Michigan. The flow of water down the Chicago River was reversed. Sizeable amounts of water were diverted from Lake Michigan. This diversion launched a series of continuing legal controversies involving Illinois as a defendant against claims by the federal government, various Lake States, and Canada (which wanted the diversion stopped or drastically reduced). During the past 96 years, extended dry periods lowered the lake levels. Using these dry periods as surrogates for future conditions, their effects on the past controversies were examined as analogs for what might occur as a result of climate change. The results suggest that changing socioeconomic factors, including population growth, will likely cause increased water use, with Chicago seeking additional water from the Great Lakes. New priorities for water use will emerge as in the past. Future reductions in available water could lead to increased diversions from the Great Lakes to serve interests in and outside the basin. Lower lake levels in the future could lead to conflicts related to existing and proposed diversions, and these conflicts would be exacerbated by the consequences of global warming. Costs of coping with the new water levels could also be significant. Should Lake Michigan levels drop as much as 5 feet by the end of the 21st century as predicted by the Canadian climate scenario, it is possible that a lowering of the level of the Canal would be needed. To lower the canal by 4 feet, at least 30 miles of the canal would need to be dredged, and 15-17 miles would be rock excavation at huge financial costs (Injerd, 1998). A warmer climate, even with modest increases in precipitation, will likely lead to a drier climatic regime and will tax the economy and challenge existing laws and institutions for dealing with Great Lakes water issues.

Great Lakes Physical Impacts

Hydrologic impact analyses for the Great Lakes were developed for 20-year periods centered about 2030, 2050, and 2090 using the Canadian and Hadley climate scenarios. These scenarios were used with the Great Lakes Environmental Research Laboratory's Advanced Hydrologic Prediction suite of models (Quinn et al., 1999) and freezing degree-day ice cover models to assess impacts to Great Lakes water supplies, lake levels, ice cover, and tributary river flows for the 121 Great Lakes major tributary basins. Relative changes in hydrologic factors predicted by the two scenarios compared to the 1961-90 base period are summarized below.

1. Increases in precipitation are offset by increases in evaporation with higher temperatures in the Canadian climate scenario resulting in decreases in Lake levels of between 4 and 5 feet by the year 2090. The Hadley scenario shows modest increases in Lake levels, generally less than 1 foot, largely due to smaller increases of temperature accompanying the increase in precipitation.
 2. The Canadian climate scenario leads to a decrease in mean annual outflow from each lake of -20 to -30% by 2090, whereas the Hadley scenario produces a modest increase in outflow of between 2 and 7%.
 3. Both scenarios produce increases in water surface temperatures between 4.5°F (2.5°C) and 9°F (5°C).
 4. Ice cover duration for Lakes Superior and Erie show decreases ranging from 29 to 65 days depending on the model scenario used.
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et al., 1999). Figure 7 shows the projected changes in the climate of Illinois during the 21st century using the two climate scenarios. For the Hadley climate scenario, farming conditions during the summer will be like those in West Virginia by 2030 and like the eastern part of North Carolina by the end of the 21st century. In contrast, the much drier Canadian scenario projects Illinois' climate to be

similar to that of Missouri and Arkansas by 2030 and eastern Texas and Oklahoma by the end of the 21st century. Simulation results by Izauralde et al. (1999) suggest that the Corn Belt in general, is likely to experience an increase in corn yields due to both the CO₂ fertilization effect, and decreased plant stress due to low temperatures. In particular, results from the Hadley scenario show a simulated warm-

Summer Climate Shifts

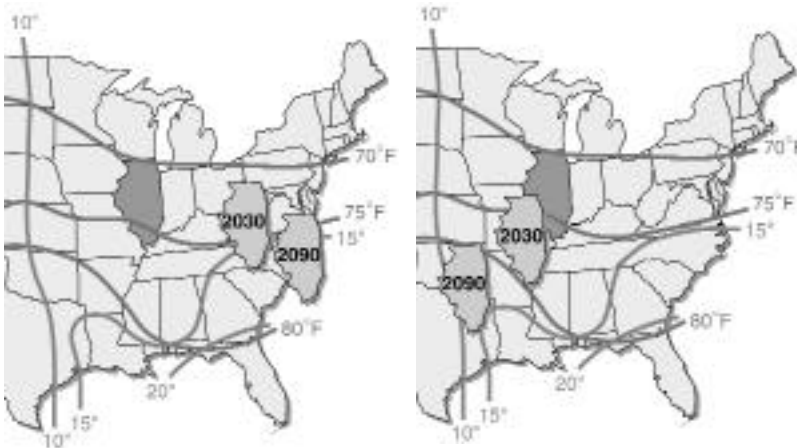


Figure 7. Illustration of how the summer climate of Illinois would shift under the (a) CGCM1 (Canadian model) scenario, and (b) HadCM2 (Hadley model) scenarios. For example, under the CGCM1 Canadian scenario, the summer climate of Illinois would become more like the current climate of southern Missouri in 2030 and more like Oklahoma's current climate in 2090.

Midwest Soybean Yield and Precipitation

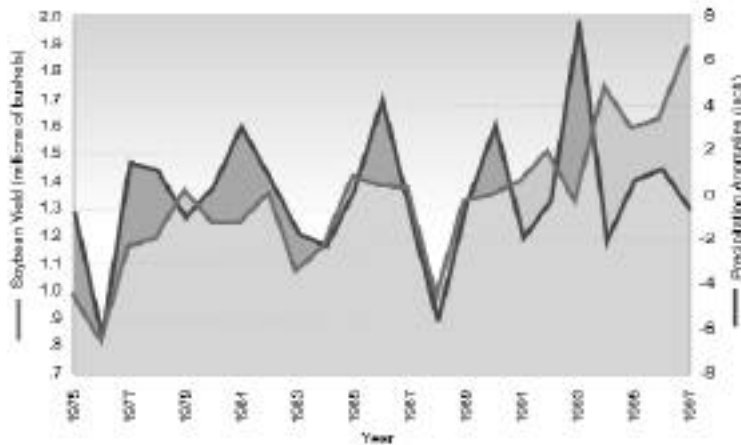


Figure 8. The relationship between Midwest soybean yield and precipitation is shown here. Soybean yields in thousands of bushels are shown as the differences from the average yield in recent decades. Precipitation is the difference from the 1961-90 average precipitation. Note that lower yields result from both extreme wet and extreme dry conditions. Soybean yields from National Agricultural Statistics Service, USDA

ing in minimum temperatures of over 3°C (5.5°F) by the end of this century that helps contribute to simulated corn yield increases (Izaurre et al.,1999).

The year-to-year variability found in corn and soybean yields is primarily driven by growing season weather conditions. The climate variability of the Midwest since 1960 has been rather small and yields in most years have been within 10 to 15% of a run-

ning 5-year mean. Occasionally, severe drought, heat, or flooding can cause larger yield reductions, such as in 1983, 1988, and 1993. It is possible that severe drought will pose the biggest threat to future crop production. Severe droughts, such as in 1988, can cut production by 30% or more, and heavy flooding events can have a similar effect (see Figure 8). If more droughts or wet spells do become more common, adaptations in farming practices and crop selection would be necessary to offset yield reductions due to these types of climate events.

Dairy productivity is also directly affected by temperature. For example, optimal ranges for dairy cattle are between 40 and 75°F (4 and 24°C); dairy cattle are sensitive to heat stress and high humidity (Wolfe, 1997). As the climate warms, it is likely additional measures such as artificial cooling methods will be necessary to ensure that the productivity of livestock is not reduced by extremes of heat. On the other hand, with warmer winters it is likely that productivity will be enhanced by a reduction in cold stress. It is uncertain whether enhanced productivity with the reduction in cold stress will offset the costs of dealing with increased heat stress.

The types of grasses, including crops that grow in the Midwest, are a mixture of C3 and C4 type grasses. The C4 grasses include warm weather crops, such as corn, and the weedy grasses, such as crabgrass and many other creeping perennials. The C3 grasses, which dominate in the northern portions of the region, include cultivated grasses such as wheat and ryegrass that thrive in cooler growing season conditions. Total biomass transient climate change experiments, examining the response of grasslands to gradual changes in climate, show that total biomass in grassland regions of the western Midwest that are initially dominated by C3 perennial grasses would be replaced by C4 perennial grasses (Coffin and Lauenroth, 1996). The change in grass types is strongly determined by increased temperature throughout the year. Because many weedy creeping perennials are C4-like, this could pose problems for agricultural areas in the western and northern Midwest where the current dominant natural vegetation is C3 grasses. Agriculture has contributed to pollution in lakes and rivers of the region including bioaccumulation of fertilizers and pesticides in fish. The use of herbicides is likely to increase as temperatures increase and the dominant grass type becomes the C4 grasses (Allardice and Thorpe, 1995). Conflicting priorities between agricultural yields and water quality are likely to be exacerbated.

Soils in the Midwest region contain significant amounts of carbon and the management of the vegetation above the soil strongly influences the carbon that is removed from and is stored in those soils. Land management activities that influence soil carbon include deforestation and afforestation, biomass burning, cultivation crop residue management, application of inorganic fertilizer and organic manures, and the various farming systems (Lal et al., 1998). On agricultural lands, soil management practices such as conservation tillage, mulch farming, water management, soil fertility management, liming, and acidity management have been shown to increase the carbon stored in agricultural soils. However, the climate change effects on soil, particularly soil carbon storage, are difficult to predict. For example, in agricultural areas where crop residue is available and incorporated into the soil system, there tends to be a build up of soil carbon. This is especially evident in the productive soybean/corn rotations where nitrogen fixation by the beans and the additional residue input from corn rapidly builds soil carbon.

Adaptation Options

Agriculture has exhibited a capacity to adapt to moderate differences in growing season climate. It is likely that agriculture would be able to adapt under the moderate climate change scenarios produced by many GCMs. There are several adjustment possibilities that are already used and could be employed in the future to adapt to climate change. Some of these possibilities are farm practices (e.g., earlier planting and harvests, changed planting densities, integrated pest management, conservation tillage) and development of new varieties and farming technologies. There are already examples of individual farmers getting the benefit of double cropping (planting a second crop after the first is harvested) as the growing season has noticeably increased in just the past few years, but these are isolated cases at present. The

potential for double cropping soybeans with a warmer climate was examined using the two Assessment scenarios. If only temperature is considered, simulation results using both the Canadian and Hadley scenarios indicate that the potential exists for double cropping even in the northern parts of the region. However, the limiting factor appears to be a lack of adequate soil moisture. If a second crop of soybeans is grown, particularly in more northern sites, adequate yields would likely be dependent on the use of irrigation (Garrity and Andresen, 1999).

If extreme climate conditions like the droughts of the 1930s or 1988 become more common, then additional adaptation measures would be necessary. Some possibilities include shifting the mix of crops, increasing irrigation, and removing marginal lands from production. Hybrid strains of corn, for example, have been developed that allow the corn to be grown under a wide range of conditions. If climate conditions in the Midwest become unsuitable for the current hybrids to be grown, one adaptation mechanism would be a switch to a hybrid more suited to future climate conditions. Furthermore, there is evidence that carbon dioxide fertilization by itself can enhance crop production. Studies indicate that this effect, coupled with a warmer climate, outweighs poor soil quality in the northern parts of the region and could allow corn and soybean crops to be grown in areas where they are not currently found (Andresen et al., 1999).

3. Natural and Semi-natural Ecosystems

Both natural and semi-natural ecological systems on land and in water will be affected by the sustained warming projected by the climate models. Water-based ecosystems are currently under multiple

Agriculture and Drought

The agricultural impacts of the drought of 1988 illustrate potential impacts of one possible future climate scenario, one that is warmer and much drier. The temperature and precipitation conditions in 1988 were similar to conditions in the 1930s. Overall grain production was down by 31%, with corn production down by 45%. The supply of grain was adequate to meet demand because of large surpluses from previous years; however, the drought reduced surpluses by 60%. Interestingly, overall farm income was not reduced because grain prices increased substantially (35% for corn, 45% for soybeans); however, these overall figures mask large losses in the heart of the drought region where yield reductions were much larger than the national average. The reduced production caused slightly higher domestic food prices, estimated at a 1% increase in 1988 and a 2% rise in 1989 (in 1989, the drought persisted in some areas and surpluses were much reduced following 1988). In summary, the drought of 1988 demonstrated that the agribusiness sector remains vulnerable to severe climatic anomalies, despite decades of advances in agricultural technology.

stresses such as eutrophication, acid precipitation, toxic chemicals, and the spread of exotic organisms. Climate change will interact with these existing stresses, often in not very well understood ways.

Forest types in the Midwest range from the deciduous forests of Missouri, southern Illinois, Indiana, and Ohio, to coniferous forests in northern Minnesota, Wisconsin, and Michigan. The upper Midwest has a unique combination of soil and climate that allows for abundant coniferous tree growth. For example, Michigan is second only to Oregon in Christmas tree production. It is possible that regional climate change will displace boreal forest acreage, and make current forestlands more susceptible to pests and disease. A decrease in soil water content as projected by the Canadian scenario would increase the potential for more drought and excessive wet periods, increasing forest fire potential. Higher temperatures could also increase growth rates of marginal forestlands that are currently temperature limited, but can also reduce stands of aspen, the major hardwood harvested in the northern Midwest. The southern transition zone of the boreal forest is susceptible to expansion of temperate deciduous forests, which in turn would have to compete with other land use pressures. This could have major impacts on the boreal forest industry, such as Christmas tree production.

Oak/hickory forests in the southern Midwest are also a major resource for the forestry industry. Oak decline or oak dieback is caused by a complex interaction of environmental stresses. Trees weakened by environmental stresses such as drought, flooding, or insect defoliation could then be invaded and killed by insects or diseases that could not successfully attack a healthy tree (Wargo et al., 1983). Although commonly called oak decline, this problem is not confined to oak or other deciduous trees (see box). Because the initial stresses leading to this problem are either drought or excess wetness, the Canadian scenario's combination of temperature and precipitation change would likely reduce soil moisture leading to more drought-like conditions and increasing the likelihood of this kind of decline in both deciduous and coniferous species.

Forests

Another area of concern is the urban forest. These are tracts of forest-type land in urban settings such as parks or trees lining streets and are particularly important for large urban areas such as Chicago and Detroit. Besides beauty, these urban forests provide practical benefits such as shade, wind breaks, habitat for urban wildlife, and help in mitigating water, air,

and noise pollution, and in reducing storm water runoff. Furthermore, urban forests help reduce urban air temperatures through increased shade and evapotranspiration, which reduces air conditioning needs and summer-time energy demand (McPherson et al., 1997). The more than 70 million acres of urban forests in the US are dwindling (American Forests, 1998, Wong, 1999). With almost 80% of the US population living in urban areas, the health of these small pockets of forest is a growing concern (Sadof and Raupp, 1999). Because of their urban environment, these forests are already stressed beyond what a comparable rural forest would be in the same region, and climate changes that could affect the health of rural forests would likely be magnified in the urban setting. Encouraging the planting of appropriate tree species in urban areas wherever possible would be beneficial.

Fragmentation of large forest tracts in the region is another major stress on the forest industry, and this could become an even greater problem if scenarios of vegetation change are correct. Competing land use, particularly between forest and agriculture, could become a major problem, possibly significantly reducing the current extent of forestland. Forest fragmentation also severely affects wildlife, by reducing protective cover and natural migration stopover habitat. Furthermore, there is concern that natural responses to climate change are likely to be nonlinear, with an apparent resistance to change up to a certain threshold, beyond which time a rapid or catastrophic transition could occur (Moll, 1998).

Model simulations under both the Hadley and Canadian climate scenarios project the disappearance of the boreal forest from the region, and a consistent and substantial reduction in the amount of area covered by both the temperate continental coniferous forest and cool temperate mixed forest types as well. This suggests that the northern hardwood forests that sustain the regions forest products industry are likely to undergo substantial conversion to temperate deciduous forest and temperate deciduous savannas. The results for the grasslands are mixed, depending on the moisture projections in the climate scenarios and the assumptions about water use in vegetation models. The fact is, however, that very little natural grassland remains and the fate of the grasslands has more to do with agricultural policies and economic conditions than climate (Brown, 1999).

Fish and Wildlife

Wildlife impacts are a critical issue. For example, since the mid-20th century songbird populations have declined in the Midwest for a variety of reasons

including habitat destruction and fragmentation (Robinson, 1997). However, bird populations, like other wildlife, are particularly susceptible to extreme climate events. Periods of excessive wetness and particularly drought affect both habitat and food supplies, resulting in diminished reproduction and a decline in populations the next year. Furthermore, the locations of the climate extremes affecting migratory Midwest bird populations could very well be outside the borders of the US, for example in Central America, where the birds spend the winter (Robinson, 1997).

Climate changes could have large and unpredictable impacts on aquatic ecosystems. Along with concerns regarding changes in water availability and ice cover, changes to other characteristics such as water temperatures are a concern. For example, Great Lakes surface water temperatures are likely to increase by as much as 5°C by the end of the 21st century (see box). Water temperature increases in deep inland lakes can lead to a decrease in dissolved oxygen content and primary productivity, and a decline in cold-water fish populations. A rise in water temperature would change the thermal habitats for warm-, cool-, and cold-water fish. The thermal habitat for warm- and cool-water fishes would likely increase in size, but could be eliminated for cold-water fish in lakes less than 13 meters (43 feet) deep (especially those in eutrophic states) and in many streams (Magnusson, 1997). Species such as brown and rainbow trout are at risk (EPA, 1995; 1997) as well as other cold water fish found in shallow lakes. Furthermore, Chao (1999) used a number of GCM-based scenarios of climate change to examine changes in cold water habitat in Lake Erie, (defined as a well-oxygenated hypolimnion), and found reductions of 50 to 80% depending on the scenario.

Wetlands

Because Great Lakes' water levels have an unusual seasonal cycle (related to winter precipitation being locked up as snow/ice cover with frozen soils), reduced ice cover and higher temperatures are likely to affect the winter Great Lakes ecosystem by changing the annual cycle. The annual and interannual water level fluctuations act as a perturbation to wetland biophysical systems and maintain a more productive intermediate stage of wetland development. Changes in the annual cycle could be compounded due to substantially lower water levels, which would lead to more pressure on wetlands. Projected lake-level changes would likely affect wetland distributions, resulting in a displacement or loss of current wetlands (Mortsch, 1998). These wetlands serve a variety of important functions including waterfowl habitat, fish breeding areas, and natural improvement of water quality. Wetlands particularly at risk are those in areas where the topography inhibits successful wetland migration, such as areas with irregular topography.

Invasive Species

Invasive species are another current stress that could be exacerbated under climate change. For example, the zebra mussel has become a major problem in the Great Lakes system. Zebra mussels are small, fingernail-sized mussels native to the Caspian Sea region of Asia. It is believed that they were transported to the Great Lakes via ballast water from a transoceanic vessel. The ballast water, taken on in a freshwater European port, was subsequently discharged into Lake St. Clair near Detroit, where the mussel was discovered in 1988. Since that time, it has spread rapidly to all of the Great Lakes and waterways in many US states, as well as Ontario and Quebec. Hydroelectric power plants, municipal drinking water facilities, and other water-

Drought, Insects, and the Decline of Forest Species

In the late 1930s, many hemlock trees showed signs of deterioration in the Menominee Indian Reservation in east-central Wisconsin. Hemlock is an important forest tree at Menominee, which is located about 30 miles (50 km) north of the southwestern range limit of the tree. By the late 1930s, the hemlock borer, ordinarily not a problem, reached epidemic proportions. Careful examination by Secret et al. (1941) revealed that extensive root damage had occurred during the drought years 1930-1937. Borer attacks in 1938 were successful only on trees that had 10% or less of their root system still alive. In 1939, attacks were successful only on trees with less than half of the main lateral roots alive. Obviously hemlock borer attacks were successful only on trees that were already heavily damaged by unfavorable climatic conditions. The 1930s droughts were ultimately responsible for the loss of trees near the range limit, but insect attack was the proximate cause of death of trees already weakened by drought. The implication of this example is that unfavorable climatic conditions may not kill trees outright, but by stressing the trees, climate can contribute to death by insect attack.

using industries are most heavily impacted by zebra mussel populations. Mussels colonize the surfaces of pipes, diminishing the flow rate through water intake pipes. Unless preventive measures are taken, larval zebra mussels colonize the interior parts of turbines and other equipment, leading to costly repairs. On the other hand, zebra mussels do act to improve water quality through their natural filtration of nutrients.

Temperature can limit the extent of zebra mussel colonization and has likely kept populations in Lake Superior small. Each mature female produces several hundred thousand eggs during the breeding season, which occurs when the water temperature is above 54°F (12°C). The longer this period, the more successful colonization is likely to be. Adults are unable to survive prolonged exposure to temperatures above 90°F (32°C) and they can tolerate temperatures as low as 32°F (0°C), provided they do not freeze. With warmer summer water temperatures in northern lakes, such as Lake Superior, the small current infestation is likely to become as widespread as it is in the lakes in warmer parts of the region.

4. Quality of Life

The Great Lakes and surrounding region is the industrial heartland of the United States. It is a leader in automobile, paper products, medicine, chemical, and pharmaceutical production. Recreation is also an important part of the regional economy. Although most of these industries are not directly vulnerable to climate change, severe indirect effects are possible. For example, changes in governmental policy designed to address climate change issues have the potential to dramatically impact certain industries (e.g., the automobile industry) affecting the overall economic health of the region.

Human Health

It is possible that human health will be affected by climate change in the Midwest in a number of ways. Although our understanding of the relationship between cold weather and mortality is weaker than the relationship between heat and mortality, milder winters are likely to have beneficial effects on cold-related mortality. For example, Changnon (1999) argues that 850 lives were saved across the US during the record warm winter of 1997-1998. But, even with generally milder winters, temperatures are still expected to go below 0°F every other year even out to the end of the 21st century in places like Chicago. On the other hand, increases in dangerously high day and nighttime

temperatures (at or above 100°F during the day and 80°F during the night) are likely to increase in frequency, with 3-day consecutive heat waves occurring every other year by the end of the 21st century. If heat waves do increase in frequency and severity this would likely lead to more temperature-related mortality and morbidity. This is particularly true in most large Midwest cities that experience these kinds of events relatively infrequently and where the population is not accustomed to these events (Kalkstein and Smoyer, 1993). Studies have shown that during the first heat wave of a season, most heat-related deaths begin to occur on the second or third day of the heat wave (Kalkstein and Greene, 1997). With a diverse population that ranges from crowded urban settings to dispersed farming communities, impacts are likely to vary considerably among different social and demographic groups. For example, under current climate change scenarios, more frequent extremely hot days are likely to occur more often in urban areas where the "heat island effect" reduces nighttime cooling. The recent susceptibility to heat-related mortality in places like Chicago has been attributed to factors such as a growing elderly lower income population that cannot afford or would not use air conditioning (Kunkel et al., 1999). However, recent adaptation and responses to potentially deadly heat waves, such as enhanced warning and educational programs, have been markedly improved and would likely help reduce severity of the impact on human mortality in the future. Other concerns for both urban and rural areas of the region include a possible increase in respiratory disease due to excess air pollution. Poor dispersion and high temperatures are closely related to elevated levels of ozone and other air pollutants, potentially compounding the health effects of extremely high temperatures (Karl, 1979, see Figure 9).

Indirect effects of climate variability on infectious diseases are another possible area of health impact, but whether any change in disease rates might occur is uncertain and highly specific to each disease. An increase in heavy precipitation events could also increase the potential for water-borne disease outbreaks similar to the one in Milwaukee during the 1993 flood (Rose et al., 1999, see sidebar story). Increases in water-borne infections such as *Cryptosporidiosis* are possible if heavy precipitation events become more frequent resulting in greater cattle- and human-derived *Cryptosporidium* contamination of surface water in combined sewer and storm water drainage systems. The water-associated disease known as "Swimmers itch" could become more prevalent if lakes are more often contaminated

by larval *Schistosoma* from birds or mammals, and swimming becomes more frequent with hotter days. Various vector-borne diseases caused by infectious agents transmitted by mosquitoes or ticks might also be effected, but the complex and multiple impacts of climate on transmission make prediction difficult. For example, increases in temperature and precipitation extremes can affect mosquito ecology and potentially the transmission of viral agents such as Lacrosse or St. Louis encephalitis, however climate predictors of encephalitis outbreaks in the US are still unclear (see Human Health, Chapter 15).

For most of the health effects discussed above, there appears to be considerable opportunity for adaptation, either through increased prevention and/or greater education. The development of better educational and monitoring programs and increased support for public health systems would help reduce weather-related mortality from heat waves or increases in vector-borne diseases.

Recreation

Recreation is clearly sensitive to climate change. Ice fishing and snowmobiling are favorite pastimes in the upper Midwest, and higher winter temperatures coupled with a possible reduction in lake-effect snows are a direct threat to these activities. Reductions in lake-ice cover would significantly reduce the length of the season for recreational activities dependent on ice cover. Changes in the seasonal characteristics of precipitation resulting in more winter precipitation falling as rain than snow and increased numbers of days above freezing would affect both snowmobiling and skiing opportunities.

Temperature and Stagnation

(Analysis Period: 1948 to 1998, Summer)

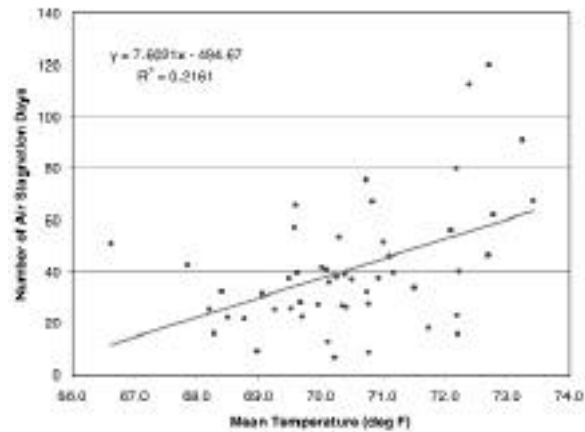


Figure 9. Relationship between average summer air temperature and the number of air stagnation days for the Midwest showing that as the mean summer temperature increases, the number of air stagnation days also increases (air stagnation data from Wang and Angell, 1999).

Reductions in cold-season recreational opportunities would likely be offset by increases in opportunities for more warm-season recreational activities such as golfing and boating in the fall and spring seasons as the length of the warm season increases. But as the climate continues to warm, the number of desirable days for outdoor summer activities is likely to be reduced. Clearly, habits and preferences for outdoor recreation options will need to change, and commercial interests will need to keep abreast of these changes.

1993 Midwest Flooding and Water-borne Disease

The heavy rainfall and major flooding on the upper Mississippi River basin in the spring and summer of 1993 was an exceptional and unprecedented event in modern times. By any measure this was a climate anomaly unseen in the modern historical record for this region. The flooding resulted from pre-existing conditions that created circumstances ripe for flooding, and day after day of heavy rainfall over the basin.

One unforeseen impact of the flooding was an outbreak of water-borne *Cryptosporidiosis* in the city of Milwaukee in the early spring of 1993. Unusually heavy spring rainfall and snowmelt washed fecal material from agricultural non-point sources into streams. This fecal material is often infected with *Cryptosporidium* oocysts. The streams emptied their infected load into Lake Michigan near the intakes for the Milwaukee water supply that made its way into the water treatment system. Engineering malfunctions combined with the massive flooding resulted in an outbreak of water-borne *Cryptosporidiosis* that infected over 400,000 people and caused over 100 deaths. As a result of this outbreak, the Milwaukee water system was forced to extend the water intake pipes much further from the shoreline, and improve water treatment controls.

ADDITIONAL ISSUES

A number of additional consequences are also likely to be of importance for the Midwestern US:

- Warmer winters are likely to result in savings in winter heating bills, potentially offsetting increased cooling bills during summer. Fewer lake-effect snows would reduce transportation problems, and could reduce building costs.
- Great Lakes issues include impacts on water supply intake pipes due to reduced water levels, and increased temperatures resulting in reduced water cooling efficiencies for power plants.
- Erosion of agricultural soil is currently a major problem, which could be exacerbated by the potential for increased heavy downpours.
- Quality of cool season vegetable crops could be reduced with brief high temperature events at critical stages in crop development.
- With climate changes and changes in natural ecosystems, there are concerns for proper management of game and wildlife and their respective habitat resources in order to maintain current levels of hunting and other outdoor recreational activities that contribute to the regional economy.
- Climate impacts on agriculture will have secondary impacts on local economies and land use, resulting in winners and losers, and potentially large community changes.
- With a drier climate, freshwater ecosystems may be more susceptible to the effects of such current problems as acid rain increasing surface water acidity, and the effects of increased development of dams for reservoirs.
- Exotic species will likely continue to invade this region and some native species will start or continue to decline. The climate change effects on these kinds of biological changes are unknown.

ADAPTATION STRATEGIES

Perhaps the most important approach to adapting to the potential effects of climate change is to develop and maintain flexibility in vulnerable activities and sectors. This would include, for example, developing water resource policies that are flexible enough to adapt to the potential for either an increase or decrease in available surface and ground water. Other strategies include: improving forecasts and warnings of extreme precipitation events and the related impacts; as well as designing large infrastructure projects to provide increased capability to cope with climate extremes. This might include rethink-

ing the construction of dams and levees on river systems, or the development of new hydroelectric generation facilities in the face of potential changes in lake levels and river flow (Smith, 1997).

On the other hand, a number of activities and sectors will likely be able to adapt easily with no outside intervention. Agriculture and many types of businesses and industries have benefited and will continue to benefit from consistent technological advances and will easily adapt as conditions change. Advances in plant genetics suggest that most cropping activities will be able to cope with most foreseeable climate shifts. Furthermore, the turnover rate in most large capital items, such as manufacturing facilities, is rapid enough that these types of facilities will have turned over or been remodeled at least once, if not two or more times by the year 2050 (Ausubel, 1991).

Another critical adaptation strategy is to develop a public education program regarding the potential risks and consequences associated with rapid climate change. For example, the potential for increasing fire danger associated with warmer and drier conditions should be communicated to homeowners in high fire-risk ecosystems. The increased potential for flooding with increases in the frequency of heavy rain events should be communicated to flood plain landowners. With better information, the residents of the region would be better prepared to respond to a less certain climate.

CRUCIAL UNKNOWNNS AND RESEARCH NEEDS

1. Perhaps one of the most important unknowns with regard to future climate is reconciling projections of temperature and precipitation change from various climate models. Both model scenarios used here project warming and increased precipitation. However, in the Canadian scenario, warming was great enough to increase evaporation to the point that decreased soil moisture becomes a critical issue. Since some climate model simulations even project a decrease in precipitation for the region, this could severely impact water levels in both the Great Lakes and Mississippi/Ohio River systems, ground water, and soil moisture levels. However, other simulations project increases with only modest effects on water levels, which leaves this question an important one for future research.

2. Another crucial unknown is how extreme weather events might change. If precipitation variability increases, even with no change in average annual amount, this would have large implications for drought and wet-spell occurrence. It is clear that extreme events such as droughts and heat waves, flooding, and severe winter storms all can have dramatic effects on agriculture, transportation, human health, etc. This is perhaps one of the most difficult but critical issues to address as far as future climate is concerned, particularly since relatively little is known about past changes in extreme events, and the current generation of climate models still does not resolve many of these types of events well.
3. Also at issue are effects of CO₂ fertilization on crops, forests, and other flora and the ability of farmers to adapt to a changing, but uncertain, future climate in an economically competitive world agricultural market. For example, significant increases in growing season temperatures will require shifts to new varieties that are more heat tolerant, do not mature too quickly, and have a higher temperature optimum for photosynthesis. This may be achieved through plant genetics, but it is uncertain as to how the public in the US and abroad will react to these new genetically modified food sources. Moreover, new crop types may require abandoning traditional crops and this may be difficult to accomplish. For example, an apple grower may need to change varieties, taking years to grow new trees.

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