CLIMATE CHANGE IMPACTS ON IOWA 2010

January 1, 2011

Report to the Governor and the Iowa General Assembly

The Complete Report and Executive Summary are posted at:
www.energy.iowa.gov and at www.iowadnr.gov/iccac/

Iowa Climate Change Impacts Committee

(July 2009 – December 2010)

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CONTENTS

Iowa Climate Change Impacts Committee

Meeting Attendees :

Nathaniel Baer	Iowa Environmental Council
Joe Bolkcom	University of Iowa
Aaron Brees	Iowa Department of Natural Resources
Amy Christensen	Iowa Utilities Board
Gordon Dunn	Iowa Utilities Board
Mark Douglas	Iowa Utility Association
Jennifer Easler	Iowa Office of the Consumer Advocate
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Kevin Nordmeyer	Iowa Energy Center
Kerri Johannsen	Iowa Office of Energy Independence
David Miller	Iowa Division of Homeland Security and Emergency Management
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Marnie Stein	Iowa Department of Natural Resources
Monica Stone	Iowa Office of Energy Independence
Greg Watkins	Iowa Utilities Board

Note: Attendance at meetings does not imply that the attendees or their agencies participated in the drafting of the report and does not imply that the attendees or their agencies express any position regarding the statements made in the report.

Policy Recommendations

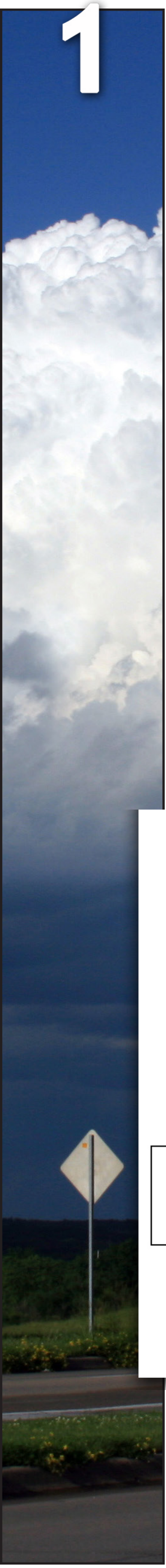
Climate change is already affecting the way Iowans live and work. Without action to mitigate these effects, our future responses will become more complex and costly. The following policy recommendations are offered as initial steps to help safeguard our state's economy, environment, and residents.

Iowa policy-makers should:

- Consider the rising financial and human impacts of Iowa's recent climate trends – for example, the increasing annual precipitation and more extreme rain events that can result in more intense summertime floods – in policy and appropriations decisions.
- Take strong steps to protect Iowa's soil, water quality, and long-term agricultural productivity in the face of climate change. (See example on the right.)
- Increase investments in state programs that enhance wildlife habitat and management and restore public and private lands. Changes in climate will have a direct impact on both game and non-game species.
- Designate the Iowa Department of Public Health to report annually on the consequences of changing climate on the health of Iowa citizens.
- Advocate for federal highway construction standards that consider the effects of climate change, and encourage the Iowa Department of Transportation to explore the use of interim designs that take into account trends in Iowa's climate.
- Authorize the Iowa Insurance Division to periodically issue reports of findings and policy recommendations concerning the risks and anticipated costs of property insurance related to climate-related claims and payouts.
- Fund ongoing research that further delineates changes in our climate and their effects on Iowa and Iowans.

These recommended activities will help Iowa *adapt* to climate change. However, halting ongoing climate-change manifestations depends on *reducing greenhouse gas emissions*. For methods on doing so, see the *Iowa Climate Change Advisory Council's Final Report* to the state legislature, released December 2008.

These recommendations are supported and explained by information in this report. For example, the 2010 unprecedented heat and drought in Russia affected Iowa through reducing world grain supplies, which increased commodity prices. Higher prices typically create pressures to farm increasingly marginal land, but doing so aggravates soil loss and water degradation. Thus climate changes elsewhere can result in further degradation of Iowa's soils and water quality. Loss of soil and water quality are also aggravated by Iowa's climate trends toward greater precipitation and more frequent extreme rain events.



Introduction: Impacts of Climate Change on Iowa 2010

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Climate refers to the long-term course or condition of weather, usually over a time scale of decades and longer. It has been documented that our global climate is changing (IPCC 2007, Copenhagen Diagnosis 2009), and Iowa is no exception. In Iowa, statistically significant changes in our precipitation, streamflow, nighttime minimum temperatures, winter average temperatures, and dew-point humidity readings have occurred during the past few decades.

Iowans are already living with warmer winters, longer growing seasons, warmer nights, higher dew-point temperatures, increased humidity, greater annual streamflows, and more frequent severe precipitation events (Fig. 1-1) than were prevalent during the past 50 years. Some of the impacts of these changes could be construed as positive, and some are negative, particularly the tendency for greater precipitation events and flooding. In the near-term, we may expect these trends to continue as long as climate change is prolonged and exacerbated by increasing greenhouse gas emissions globally from the use of fossil fuels and fertilizers, the clearing of land, and agricultural and industrial emissions.

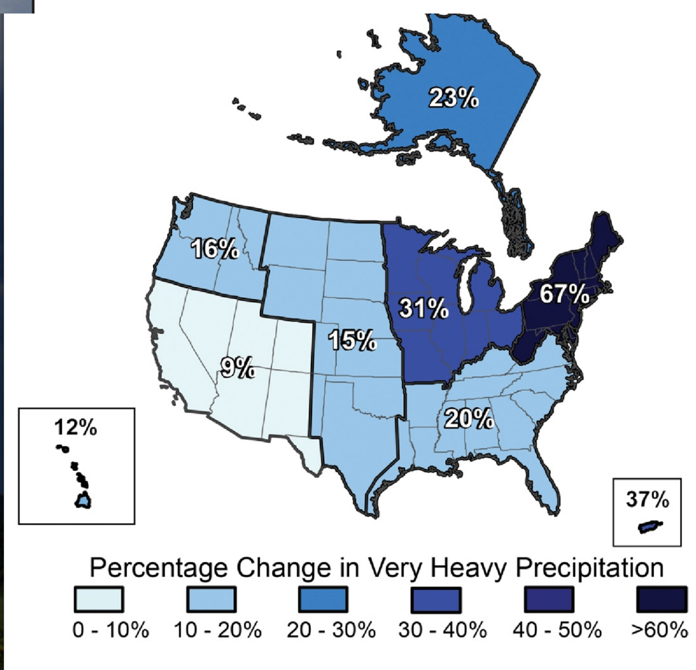


Figure 1-1. **Increase in very heavy precipitation in the US.** Climate change has regional implications for Iowa and the Midwest. Shown here is the increase in very heavy precipitation in different regions of the US from 1958 to 2007. Very heavy precipitation is defined as the heaviest 1% of all events. (Karl et al. 2009)

This report documents the impacts of changing climate on Iowa during the past 50 years. It seeks to answer the question, "What are the impacts of climate change in Iowa that have been observed already?" And, "What are the effects on public health, our flora and fauna, agriculture, and the general economy of Iowa?"

Charge

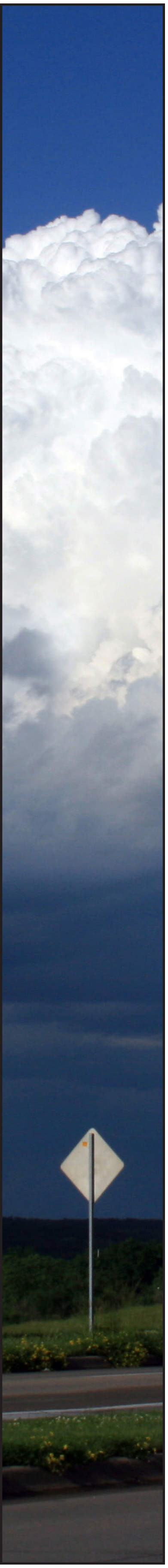
Following a report in December 2008 from the Iowa Climate Change Advisory Council, the Iowa Legislature requested additional information on the ramifications of climate change for Iowans, and it enacted a new bill in 2009 (Sec. 27, Section 473.7, Code 2009 amended). The amendment set in motion a review of climate change impacts and policies for the State of Iowa. It reads as follows:

Conduct a study on activities related to energy production and use which contribute to global climate change in conjunction with institutions under the control of the state board of regents. The study shall take the form of a climate change impacts review, to include the following:

a. *Performance of an initial review of available climate change impacts studies relevant to this state.*
b. *Preparation of a summary of available data on recent changes in relevant climate conditions.*
c. *Identification of climate change impacts issues which require further research and an estimate of their cost.*
d. *Identification of important public policy issues relevant to climate change impacts.*

In the course of the review, the institutions shall meet at least twice with the Iowa climate change advisory council established in section 455B.851. The office shall submit a report, based upon input from the institutions, containing its findings and recommendations to the governor and general assembly by January 1, 2011.

The committee conducting the review was formed under the auspices of the Iowa Office of Energy Independence (OEI) and the chairmanship of Robert Mulqueen, now with the Iowa Department of Economic Development (IDED). The committee has come to be known as the "Iowa Climate Change Impacts Committee." The author of the authorizing house file that set up the committee was State Representative Donovan Olson (Boone), chair of the House Environmental Protection Committee.



The Iowa Climate Change Impacts Committee has drawn upon the expertise of faculty and staff from all three Regents' institutions (Iowa State University, the University of Iowa, and the University of Northern Iowa) and from other specialists in Iowa government. The authors of the chapters and attendees at the meetings are listed in the front materials of this document. Responsibilities among the members were divided into six chapters including: Introduction; Climate Changes in Iowa; Agriculture; Flora and Fauna; Public Health; and Economy, Infrastructure, and Emergency Services. This is the final report of the committee.

Background

The report of the Iowa Climate Change Impacts Committee, *Climate Change Impacts on Iowa 2010*, follows on the heels of findings by the Iowa Climate Change Advisory Council (ICCAC), which arose from action by the Iowa Legislature. The Iowa General Assembly enacted Senate File 485 in 2007 and House File 2571 in 2008 to create the ICCAC. ICCAC consists of 23 voting members appointed by the governor who serve staggered terms for up to three years, and also includes four non-voting ex-officio members from the General Assembly. ICCAC conducted most of its business during the period from October 2007 through December 2008, concluding with a final report to the governor and legislature on December 23, 2008. That report included: 1) an Iowa Greenhouse Gas (GHG) Emissions Inventory and Forecast; 2) 56 policy options for Iowa to reduce its GHGs including cost estimates for each option; and 3) scenarios whereby Iowa could achieve GHG reductions of 50% or 90% by 2050, using 2005 emissions as a baseline. The total net cost associated with 37 of the options was $4.8 billion between 2009 and 2020, and the weighted-average cost-effectiveness of the options was estimated to be $8.80 per ton of carbon dioxide equivalents (tCO_2e) reduced. Some options were projected to yield net savings, while others required significant investment and costs.

Progress has been made on some of the options contained in the ICCAC final report including weatherization of homes, increased use of wind power, biomass utilization for combined heat and power, and improved fuel efficiency of light cars and trucks. But more work needs to be done to reverse the general trend of increasing Iowa GHG emissions during the past two decades, and the ICCAC 2008 report continues to be a good reference for energy-saving, cost-effective ideas.

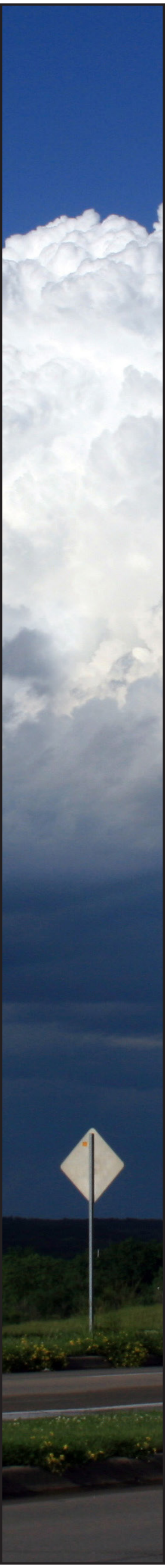
Iowa Climate Change Impacts Committee

The Iowa Climate Change Impacts Committee has met ten times since its inception in the spring of 2009. The first meeting was held in July 2009. Early on, the committee surveyed important publications on impacts of climate change. Generally, ICCAC had completed its work with data published through 2005 or, in a few cases, 2007. Therefore, one task of the current committee was to focus on more recent information specifically related to climate change impacts in Iowa. This introduction lists the major reports that were drawn upon by the committee members (see the following section and References Cited). As required by Iowa Code 2009, the committee met twice with ICCAC in meetings hosted by the Iowa Department of Natural Resources (IDNR) Air Quality Bureau, to receive ICCAC's suggestions for the report. These meetings occurred on November 24, 2009, and November 8, 2010.

The IDNR has been charged with inventorying and issuing annual reports on Iowa's GHG emissions, efforts that were required by legislation from the Iowa General Assembly in 2007. The legislation, Senate File 485, requires that the IDNR submit a report by September 1 of each year to the governor and the general assembly regarding GHG emissions in the state during the previous calendar year and forecasting trends in such emissions. The most recent report was filed on August 31, 2010 (IDNR 2010).

IDNR's report is not comprehensive because it only includes *major sources* of fossil fuel combustion and industrial processes, as defined by federal law. It also includes emissions data from ethanol production facilities in Iowa (both dry mill and wet mill). It does not include emissions from agricultural practices, waste treatment, landfills, or biogenic (natural) emissions. The IDNR emissions inventory shows that major sources of fossil fuel combustion decreased from 56.61 million tons of carbon dioxide equivalents (MMtCO_2e) in 2008 to 51.44 MMtCO_2e in 2009, most likely due to the recession, and total GHG emissions decreased 8%. This decline is set against a backdrop of steadily increasing emissions that were rising at approximately 1% per year from 1990 to 2008 (ICCAC 2008). Emissions from fossil fuel combustion at ethanol production facilities increased 35% at dry mill plants, fermentation emissions increased 41% at dry mill plants and 12% at wet mill plants, and the volume of ethanol produced increased 32%. Although emissions from ethanol production are still a small part of Iowa's overall GHG emissions (less than 10%), they are rising quite rapidly.

Overall, Iowa's emissions are expected to rise again following the economic recession. Iowa's emissions are presently in the range of 1/100th of the nation's total, and it is certainly true that steep reductions of GHG emissions in Iowa alone would not be sufficient to reverse global climate change. But it is also true that Iowa is a state with a relatively high rate of emissions per capita, and that Iowa is a state that can benefit economically from energy efficiency and renewable energy resources.



In 2005, Iowa's GHG emissions from electricity production comprised 31% of the state's total, and emissions due to electricity usage have been among the fastest growing sectors contributing to the overall increase in GHG emissions in Iowa (ICCAC 2008). It stands to reason that greater use of renewable energy sources (wind, solar, and biomass) would decrease Iowa's emissions significantly. In fact, growth in emissions would have been much greater during the past ten years if it were not for the tremendous growth of wind energy from approximately 1000 megawatts to 4000 megawatts. Wind energy now supplies more than 15% of the state's electricity needs.

Recent Literature

Several new references, which were published after ICCAC drafted its 2008 report, have been helpful in this assessment of climate change impacts in Iowa. *Global Climate Change Impacts in the United States* (Karl et al. 2009) states clearly that very heavy precipitation has increased significantly (31%) in Iowa and the Upper Midwest in just the past 50 years (1958-2007), using data from the National Oceanic and Atmospheric Administration (NOAA) (see Fig. 1-1).

One of the series of 21 synthesis and assessment reports produced under the auspices of the US Global Change Research Program, *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* (Backlund et al. 2008), was also very helpful in assessing climate change impacts on Iowa. One of the most interesting reports in terms of documenting changes in the Midwest is *Weather and Climate Extremes in a Changing Climate* (Karl et al. 2008). From these reports and other references, it is clear that climate change is already occurring in Iowa.

An analysis of NOAA's 2010 temperature data appeared recently (NOAA 2010). The National Resources Defense Council (NRDC 2010) has shown that this past summer, nighttime low temperatures were the hottest ever recorded at nearly one in every four weather stations in NOAA's historic climatology network, an unprecedented event in a record of more than 100 years. While summer average temperatures were much higher than normal, their anomalies were small compared to the warming of nighttime minimum temperatures. This is consistent with what is known about climate change. As the earth is beginning to warm, there is more moisture in the air and more clouds, which cause nighttime temperatures to increase much more than daytime temperatures. During the day, clouds increase the albedo (reflectance) of the earth's surface and exert less of a warming effect. But during the night, the increased cloud cover prevents back-radiation from escaping the atmosphere and the nights remain exceptionally humid and warm. Thus, Iowa is one of the states experiencing the largest increase in nighttime minimum temperatures, which in turn affect Iowa's elderly residents, flora and fauna, and agriculture.

Global Context

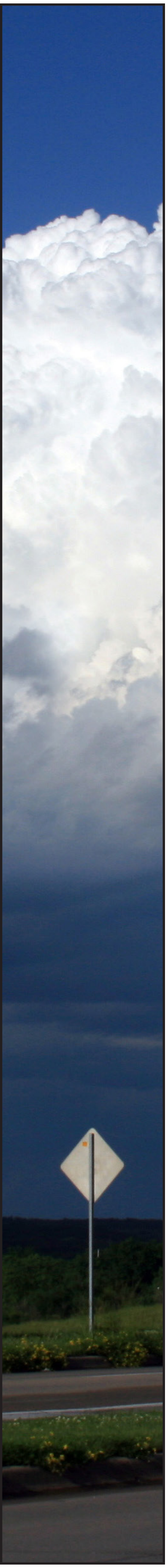
Climate Change Impacts on Iowa 2010 has sought to highlight the latest literature documenting impacts in Iowa caused by a changing climate. In doing so, several themes have become readily apparent, including the theme of our globe's interconnectedness. Iowa does not find itself in a vacuum. Climate is changing the world over, and changes in distant locations may reverberate around the world. The global context of climate change means that even regions with little change can be significantly affected (positively or negatively) by the changing climate of their trading partners or competitors.

In 2010, when unprecedented drought conditions and fires erupted in Russia, wheat and corn crops were decimated there and prices increased dramatically on commodity exchanges worldwide. These events drove corn prices above $5 per bushel, increasing the income of Iowa corn farmers significantly. Thus, in this instance, Iowa benefitted from climate events in other locations, but at other times Iowa may be devastated when severe drought or intense precipitation visit here.

Water is a central theme that runs throughout this entire report. The effects of climate change on precipitation – its frequency, patterns, and severity – are likely to be among the greatest impacts on arid areas, poor countries, and agricultural economies. Water is a basic need, and its availability is crucial to human well-being. Too little clean water creates problems of access to drinking water and causes diseases such as cholera. Too much generates floods, soil erosion, and other disease.

Another theme states that climate *extremes* cause the greatest impacts on people and the planet. It is not so much the average change in temperature and precipitation that matters. Rather, the variability of climate and its extremes cause damage to the people, economy, flora and fauna, and agriculture of Iowa.

Iowans cannot reverse global climate change by themselves. However, Iowa is among the states with the largest GHG emissions per capita, and Iowa is also among the states that could benefit the most economically by mitigating climate change through the use of energy efficiency and renewable sources of energy. These facts support the concept that for the good of our economy, health, and the environment, we should mitigate GHG emissions, while simultaneously seeking ways to adapt to current and future climate change. While this report relates most to how Iowans might adapt to climate



change, ultimately *mitigation* efforts will be needed worldwide to reverse the trends discussed within.

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Climate Changes in Iowa

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Introduction

Climate change is much more than simply a rise in temperature. Other climate factors, specifically the frequency of extreme precipitation events, rise in humidity, and length of the growing season, are having much more impact on Iowa than changes in annual mean temperature. We know from geological records that the climate of Iowa, like other regions of the Midwest and even the entire planet, has always been changing, although at slower rate than today. Current climate changes in Iowa are linked, in very complex and sometimes yet unknown ways, to global climate change. Independent evidence of a warming global climate comes from temperature trends at both the surface and in the upper atmosphere, trends in the melting of continental glaciers and arctic and sea ice, rising ocean temperatures, and increases in atmospheric moisture. Biological evidence consistent with climate trends points to a decline of coral resulting from warmer ocean water, earlier blooming of widely observed plants such as lilacs, altered seasonal migration patterns, and changes in plant hardiness zones (Jackson and Berendzen 2011).

A vast number of scientific studies using physically based methods for analysis and simulation of climate processes show that past climate changes over the globe have not been uniform and will not be uniform in the future. Although global averages pose overall constraints on climate changes, the regional changes that have high impact on communities and economic activities will be quite diverse.

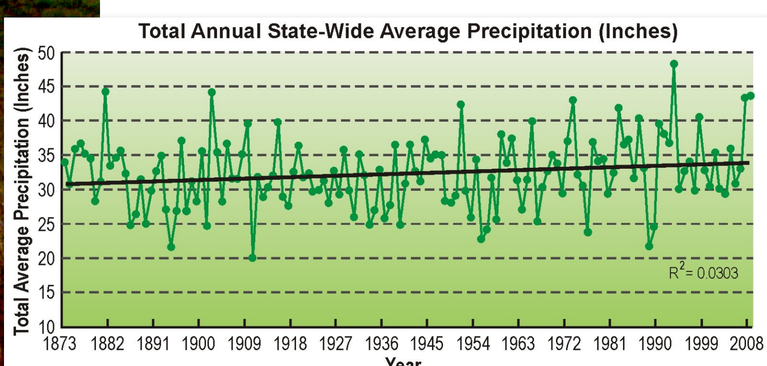


Figure 2-1. **Iowa annual state-wide precipitation in inches from 1873-2008.** Note that the state has had an 8% increase in annual average precipitation over this 136-year period. (Data from Iowa Climatology Bureau 2010.)

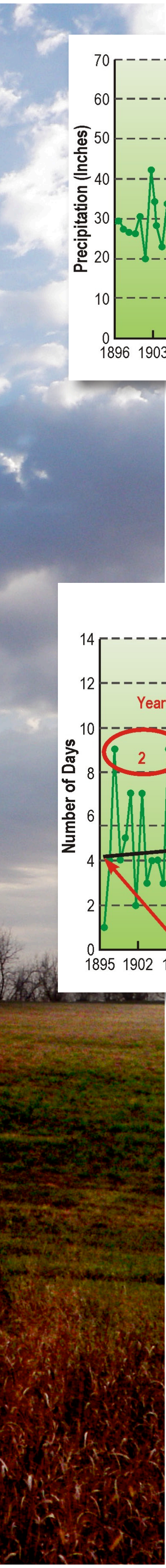
The following paragraphs provide examples of recent trends and variability of a few climate factors in Iowa and projections of their future changes. These trends and projections are based primarily on my analyses of Iowa's past climate, global modeling studies reported by the Intergovernmental Panel on Climate Change (IPCC 2007), and the reports of the US Climate Change Science Program (e.g., Backlund et al. 2008).

Changes in Storms and Precipitation

Climatological patterns of precipitation for Iowa consist of an east-west gradient, with drier conditions to the west and wetter to the east, and a somewhat wetter pattern to the south and slightly drier to the north. These continental patterns generally are created by transport of Pacific Ocean moisture from the west (including the North American Monsoon in the southwest) and Gulf of Mexico moisture in the east (including hurricane-derived precipitation in the south and southeast). Because Iowa sits in the transition zone among these competing sources of moisture, its changes in precipitation will be strongly influenced by changes in the continental-scale processes that control its moisture supply.

Precipitation in Iowa has gradually increased over the last 100 years, although year-to-year variability is high (Fig. 2-1). Eastern Iowa (Fig. 2-2) has a higher upward trend than the statewide average. A notable trend, however, is that there has been a change in "seasonality": most of the precipitation increase has come in the first half of the year, and less in the second half, leading to wetter springs and drier autumns. Trends toward more precipitation and changed seasonality, as well as higher increases in eastern Iowa, are projected to continue (IPCC 2007). The central US also has been experiencing more variability of summer precipitation (Karl et al. 2008), with more intense rain events and hence more episodes of higher runoff (see Fig. 1-1). Records for Iowa also show a higher tendency for more intense rain events, as shown in Fig. 2-3 for Cedar Rapids, which has experienced a five-fold increase in number of years having eight or more days with daily total precipitation exceeding 1.25 inches (3.0 cm). Des Moines also has experienced an increase in days with total precipitation exceeding 1.25 inches (Fig. 2-4).

Growing evidence points to stronger summer storm systems in the Midwest, although no studies have been done on recent trends in severe storms, lightning, hail, or tornadoes for Iowa, in part because trends in extreme events such as tornadoes are difficult to quantify. With summer temperatures becoming warmer (more heat energy) and humidity levels increasing (more moisture), both in summer and winter, it is plausible to speculate that this rise in the ingredients needed for severe weather will increase the likelihood of these extreme events. However, more studies are needed to explore this relationship.



Cedar Rapids Data

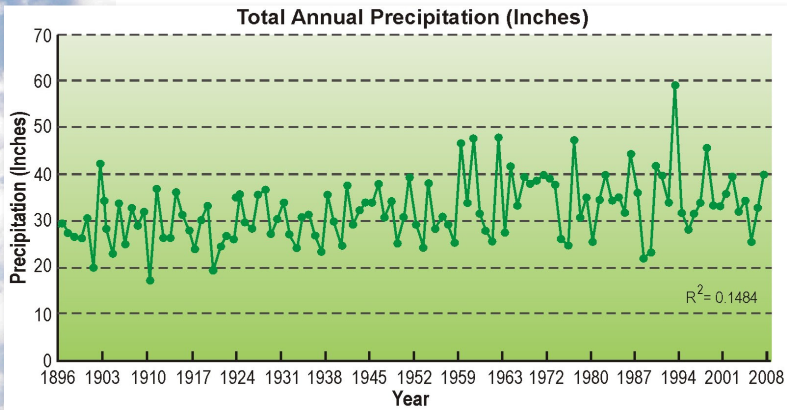


Figure 2-2. **Cedar Rapids precipitation records for the period 1896-2008.** Over this 113-year period, this city (with its 32% increase) and eastern Iowa in general have had a steeper upward trend in precipitation than the state as a whole. (Data from Iowa Climatology Bureau 2010.)

Cedar Rapids Data

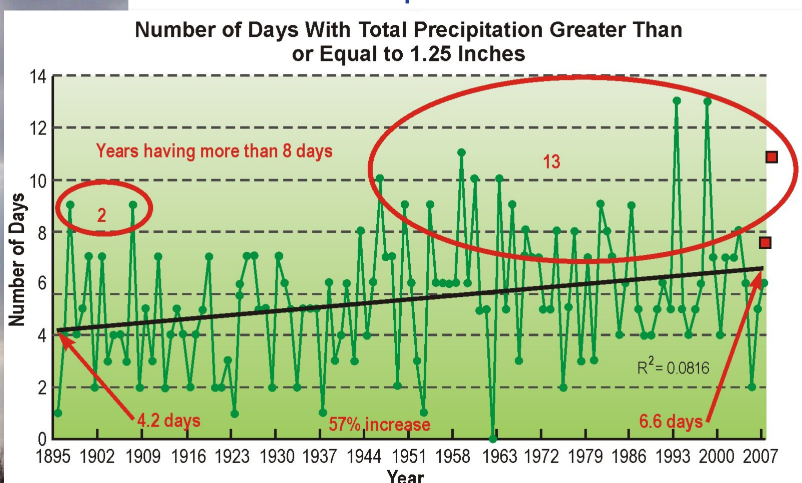


Figure 2-3. **Annual number of days when daily total precipitation exceeded 1.25 inches (3 cm) in Cedar Rapids.** Note the increase in number of years having more than 8 days with daily total precipitation exceeding 1.25 inches. (Data from Iowa Climatology Bureau 2010.)

Pinning down causal effects for changes in storms and patterns of precipitation is more complex than tracing such causes for changes in temperature. Global climate models are not in good agreement on future trends of precipitation for Iowa and the Midwest. It is generally agreed that the western US will dry substantially in the future, and regions to the north and east of Iowa will become wetter. To our south, a drying trend is most likely.

Iowa's future precipitation regime therefore will depend on how these dominating patterns are altered by global climate change. For instance, a strengthening of the drying pattern to the west could routinely push drier air eastward to include Iowa. However, a strengthened northward flow of moisture from the Gulf of Mexico, without an eastward shift in its path, might lead to wetter conditions in Iowa. It is plausible, therefore, that Iowa might experience a wider swing in extremes in precipitation from year to year.

Temperature Changes

Iowa's annual average temperature has increased since 1873 at a rather modest rate (Fig. 2-5), but seasonal and day-night changes are proportionately larger and have higher impacts. Temperatures have increased six times more in winter (0.18°F/decade) than in summer (0.03°F/decade), and nighttime temperatures have been increasing more than daytime temperatures.

Since 1970, daily minimum temperatures have increased both in summer and winter (Fig. 2-6), and while daily maximum temperatures have risen in winter, they have actually declined substantially in summer. Iowa (and the central US) has experienced a declining number of extreme high summer temperatures, a feature of summer climate that seems counter to global and continental trends. Des Moines has had only six days with a temperature of 100°F or above in the past 22 years, in contrast to the individual years of 1988, 1983, and 1977, in which 10, 13, and 8 days of temperatures 100°F or above, respectively, were recorded. A NOAA study (NRDC 2010) of the summer of 2010 has shown that none of the 23 Iowa stations in the NOAA Historical Climatology Network reported 2010 to be among the five hottest summers, but four reported 2010 having the highest average nighttime temperatures on record. And 16 stations had average *nighttime* temperatures among the five hottest on record.

It is important to recognize the roles that increased summer precipitation and soil moisture have had on suppressing surface heating, and thus daytime summer maximum temperatures (Fig. 2-6d). If Iowa were to experience a severe drought, as has occurred frequently in the past, the slow and steady rise in statewide annual mean temperature, now masked in summer by moist surface conditions, could lead to an abrupt switch to extreme summer heat comparable to the summers of 1983 or 1988.

Iowa now has a statewide average of five more frost-free days per year than 50 years ago, and 8 to 9 more than at the beginning of the 20th century (Fig. 2-7). This provides Iowa with a longer growing season, earlier seasonal snowmelt, and longer ice-free period on lakes and streams. The daily accumulation of Growing Degree Days (GDD) is used to estimate the seasonal physiological development of crops. (GDD is calculated by subtracting 50 from the daily average temperature in °F.) The annual number of GDDs in Iowa has varied from location to location across the state over the last 116 years, with increases in Cedar Rapids and Des Moines and a

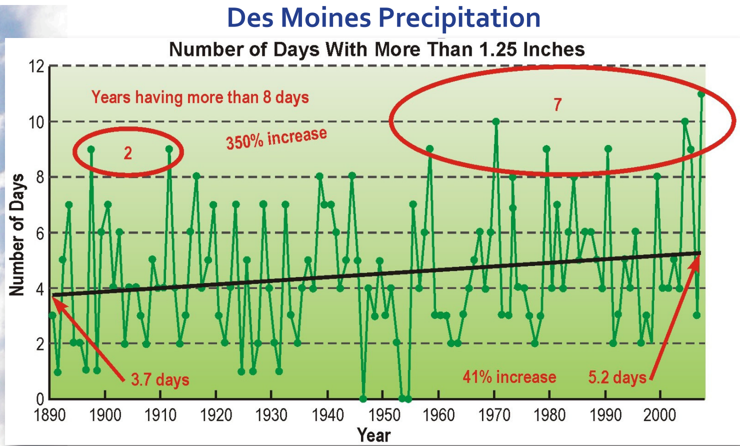


Figure 2-4. **Annual number of days when daily total precipitation exceeded 1.25 inches (3 cm) in Des Moines.** Note the increase in number of years having more than 8 days with daily total precipitation exceeding 1.25 inches. (Data from Iowa Climatology Bureau 2010.)

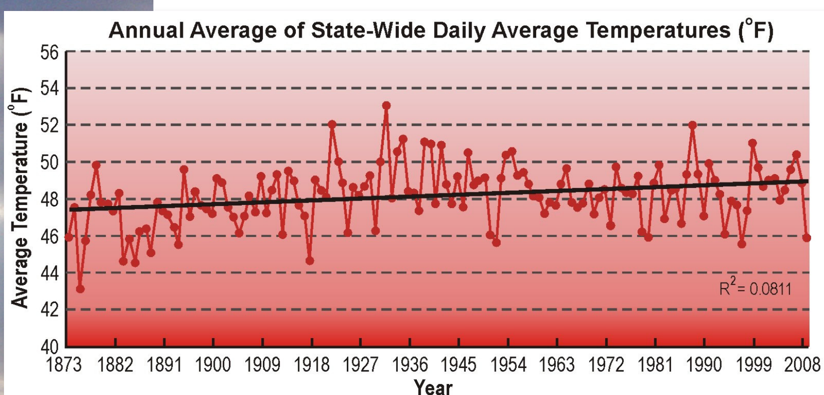


Figure 2-5. **Annual average of state-wide daily average temperatures (°F) from 1873-2008.** Note the increase in the first half of the 20th century and little change since then. Seasonal and day-night changes are proportionately larger and have greater impacts – with winter and nighttime temperatures increasing more than summer and daytime temperatures. (Data from Iowa Climatology Bureau 2010.)

decrease in Waterloo. The most recent 40 years (Fig. 2-8) also show site-specific trends, with slight increases in Cedar Rapids and Des Moines and slight decreases in Ottumwa and Mason City. The Iowa annual average total Heating Degree Days (HDDs), widely used as a measure of cold-season demand for space heating, has shown a significant decline since 1893 (Fig. 2-9). (The number of HDDs is calculated by subtracting the daily average temperature from 65°F and accumulating these values (positive values only) over the heating season.)

Global and regional climate models predict that Iowa's annual average temperatures can be expected to continue to increase as they have in recent years (IPCC 2007). These models – which 20 years ago correctly projected polar regions to warm more than equatorial regions, minimum daily temperatures to rise more than maximum temperatures, and US winter temperatures to increase more than summer temperatures – indicate that the current trends likely will continue. Rates of temperature increases in the near future will be more like the trends of the last 30 years than those of the last 136 years. However, year-to-year variation around the averages of the last 10 years will be high, and decadal averages will not likely return to those that were recorded before 1970.

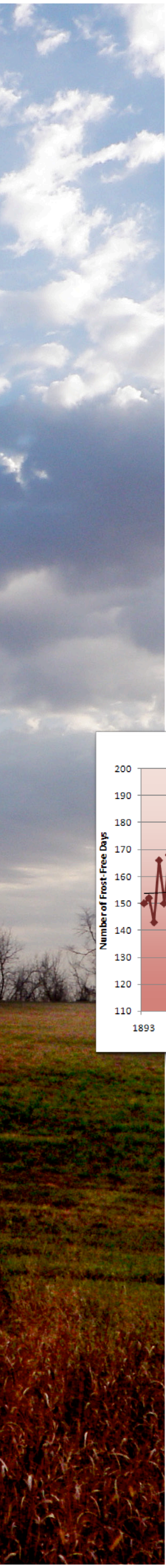
Changes in Humidity

The humidity level in Iowa has risen substantially in the last 35 years, as is shown by the measurements of the temperature at which condensation begins (the "dew-point" temperature; see Fig. 2-10). The closer the dew-point temperature is to the air temperature, the higher the relative humidity will be. The summertime dew-point temperature increase of about 3.5°F, as measured in Des Moines in the last 35 years, means that the atmosphere has about 13% more moisture (Fig. 2-10). Higher amounts of atmospheric moisture also provide more water to fuel the convective thunderstorms that provide abundant summer precipitation in our region. Higher winter temperatures bring higher probability of rain and lower probability of snow, which may increase the recharging of winter soil moisture.

Changes in Streamflow and Flooding

In recent years, levels of streamflow have risen in part because of changes in precipitation, leaving areas having relatively modest topographic variation prone to flooding. Iowa's soils can absorb about 1.25 inches of precipitation in a one-day rain event, but rainfall in excess of this amount initiates runoff and increases streamflow. It is easy to understand that a 5-inch rainfall will contribute about 1 inch more water to runoff, and eventually to streamflow, than would a 4-inch rainfall. Our studies of streamflow (Jha et al. 2004) under climate change show that a predicted 21% increase in precipitation in a future scenario (the 2040s) climate leads to a 50% increase in streamflow in the Upper Mississippi River basin over a 50-year period. From the recent increase in the number of days with extreme precipitation at single stations (Figs. 2-3 and 2-4), we can logically conclude that enhanced streamflow and the potential for flooding are also rising.

For a given amount of rainfall, summertime precipitation has a higher probability of creating flood events than does springtime precipitation. This increased probability can be explained by the seasonal change in alignment of storm tracks passing over the state. Springtime (March-May) storms tend to track SW-NE across the state, but summer storms have a more west-to-east orientation, occasionally shifting to a NW-SE track in late summer (Fig. 2-11) (Takle 1995). Tracks of storm cells align more closely with river basins in central and eastern Iowa in summertime than they do in spring. Thus, summertime storms



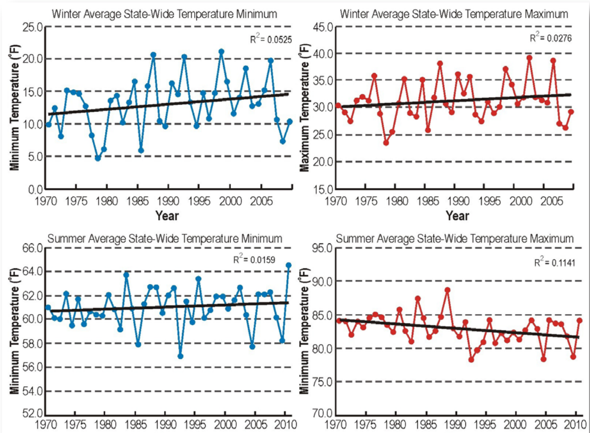


Figure 2-6. **Iowa state-wide temperature trends over the most recent forty years for (a) winter daily minimum temperature, (b) winter daily maximum temperature, (c) summer daily minimum temperature, and (d) summer daily maximum temperature.** Note the decline in maximum summer temperatures, a trend that is counter to continental trends. In recent years, increasing precipitation and soil moisture have suppressed Iowa's summer daily-maximum temperatures, but a future drought could abruptly return extreme summer heat. (Data from Iowa Climatology Bureau 2010.)

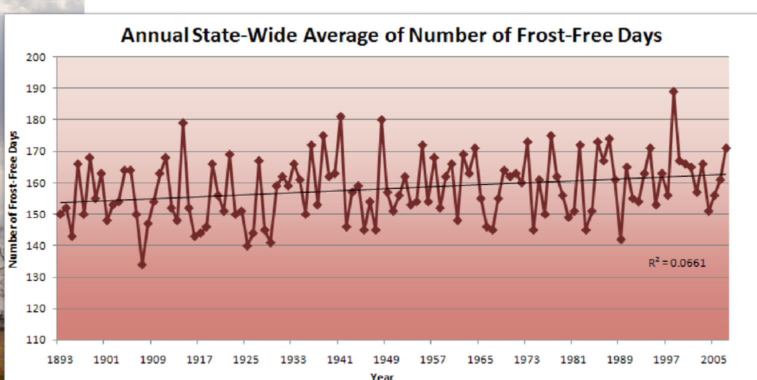


Figure 2-7. **Annual state-wide average of number of frost-free days from 1893-2008.** The number of frost-free days has increased by 8-9 days over this 116-year period. This allows the growing season to begin earlier in spring and last later into the fall. (Data from Iowa Climatology Bureau 2010.)

have the potential to dump much larger amounts of rain in a given river basin – and also have a greater probability of causing flooding. Iowa's recent rise in the number of large summertime rainfall events (those exceeding 1.25 inches, see Figs. 2-3 and 2-4) further increases the probability of summertime floods.

Higher winter and spring temperatures seem to be causing earlier and more protracted snowmelt, leading to a reduced probability of spring flooding, while changes outlined in the previous paragraph have led to increased summer flooding. This seems to be the new norm for seasonal flood occurrence in the state.

Change in Soil Moisture

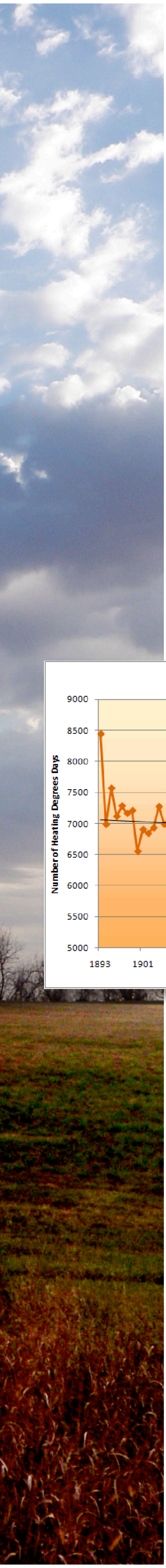
Soil moisture has not been widely measured over long periods of time to assess trends. However, it is clear that in Iowa, soil moisture has increased dramatically over the last 30 years (Rogovska and Cruse 2011). This is amply demonstrated by the increase in subsurface drainage tile that has been installed in recent years and continues to be installed here, to cope with increased precipitation and excessive soil moisture. It has been speculated but not definitively shown that the large amounts of subsurface water transpired to lower atmosphere by current agricultural crops are strong contributors to the recent increase in summertime atmospheric moisture and related impacts such as greater soil moisture (Changnon et al. 2003).

The IPCC (2007) report suggests that over the 21st century, there will be a weak decline in soil moisture in Iowa, primarily due to higher temperatures. However, inter-annual variation likely will be more significant than long-term trends. Iowa soils generally are deep with good water-holding capacity, so soil moisture is related to total seasonal precipitation and is less sensitive to the exact timing of precipitation than if Iowa had sandy or shallow soils. Variations in soils, slope, and subsurface geological conditions are complicating factors that also influence soil moisture variability.

Changes in Other Atmospheric Conditions

Surface wind speeds (at the standard measurement height of 32 ft) over Iowa and the US have been declining over the last 30 years (Pryor et al. 2009). Reduced surface wind speeds have a negative impact on agriculture (less ventilation of crops and hence more heat stress during intense heat, longer dew periods allowing growth of pathogens,, etc.) and human health (more intense heat waves, build-up of urban air pollutant concentrations, etc.). This trend in surface winds does not necessarily mean that wind speeds at heights of wind turbine generators (250-300 ft) will be declining, since factors such as land use have lesser impact at 250 ft than at 32 ft. Inter-annual variability of wind speed at turbine heights is much more important than long-term trends to the wind power industry.

Surface solar radiation in the Mississippi River basin has declined for the period 1948-2004, due primarily to increased cloud cover (Qian et al. 2007). These authors use a model to estimate hydrological properties not routinely measured, and they find that evapotranspiration has been increasing. Simulations of a future climate based on increased greenhouse gas concentrations (Pan et al. 2004) show that the decline in surface solar radiation is likely to continue.



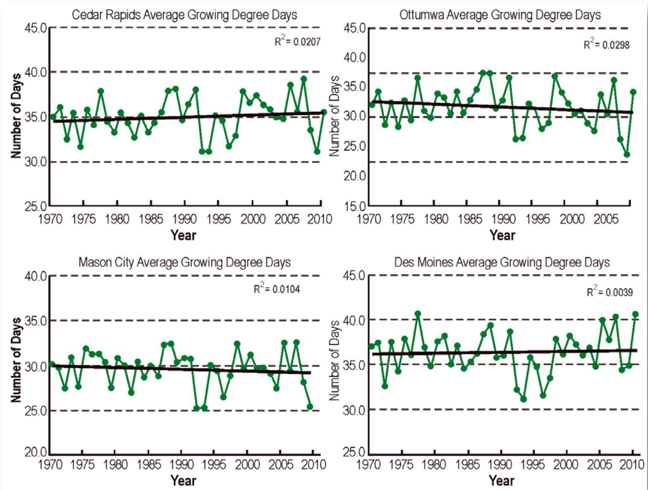


Figure 2-8. **Annual average number of growing degree days calculated for (a) Cedar Rapids, (b) Ottumwa, (c) Mason City, and (d) Des Moines from 1971-2010.** Rising summer temperature minimums have offset declining temperature maximums (see Fig 2-6 c and d) to produce little change in both daily mean temperature and GDD. (Data from Iowa Climatology Bureau 2010.)

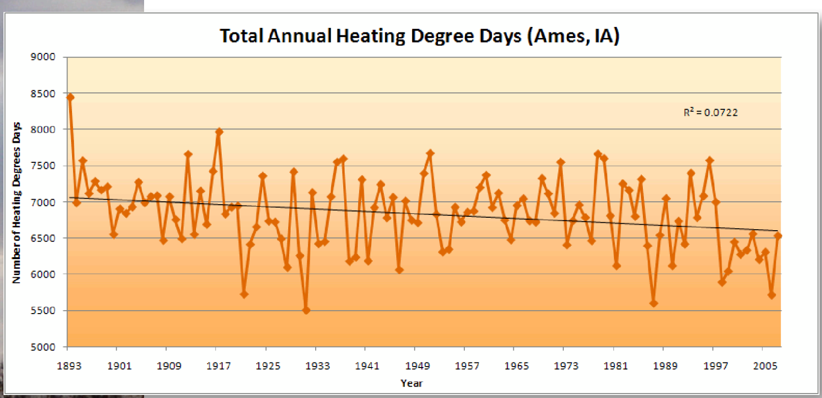


Figure 2-9. **Annual total heating degree days for Ames for 1893-2008.** The substantial rise in winter temperatures has significantly reduced HDDs, and with it Iowa's space-heating requirements. (Data from Iowa Climatology Bureau 2010.)

Ozone in the lowest five miles of the atmosphere (troposphere) is produced by both natural and anthropogenic causes (reactions of emitted hydrocarbons and oxides of nitrogen under ultraviolet light). Being distinctly different in concentration from stratospheric ozone (which is produced naturally and destroyed by human emissions of long-lived chlorine-containing compounds), tropospheric ozone has a negative impact on agriculture and human health (Rogovska and Cruse 2011, Osterberg and Thorne 2011). Annual increases in temperature – and population growth – suggest that there will be future increases in anthropogenic production of tropospheric ozone. Agricultural crops, particularly soybeans, as well as horticultural crops are negatively affected by tropospheric ozone.

Research Gaps

Of all natural hazards, floods, water-logged soils, and droughts have the highest impact on Iowa's economy. More research is needed to better understand why Iowa's precipitation extremes are increasing and whether these increases will continue. Improvements in seasonal climate predictions would enable Iowa decision-makers to better prepare for these extremes and to reduce their economic impact when they do occur.

Conclusions

Many changes of Iowa's climate over the last 30 years have had major economic impacts, some positive and some negative. Most notable are the annual rise in temperature, increase in extreme precipitation, and increase in humidity. The first climate projection for Iowa based on a global climate model was published nearly 20 years ago (Takle and Zhong 1992). This model correctly projected most, but not all, climate changes in the intervening two decades and demonstrated the utility of climate models for adapting to the major impacts of climate change.

The Iowa legislature has taken the first step in assessing climate changes in Iowa. Other states have demonstrated the usefulness of factoring climate change into long-term decisions on infrastructure and resource management. Iowa's universities have the research capacity to provide guidance to urban, regional, and state agencies and to the private sector. Iowa legislators and administrators who work with the state's researchers will be better able to address climate-change trends and their impacts on the economy of the state and welfare of its people.

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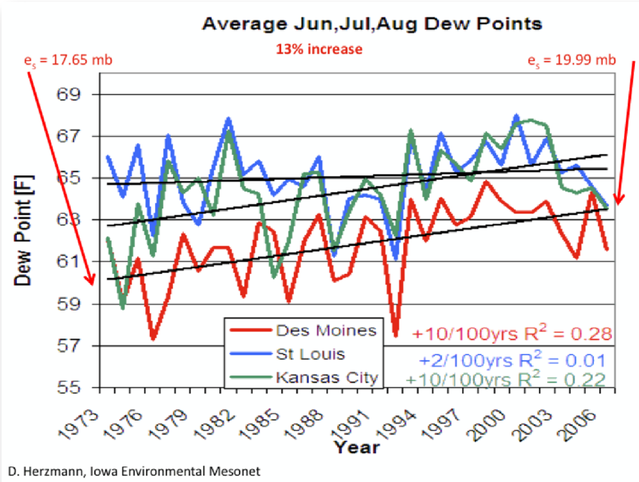

Figure 2-10. **Thirty-five year trends in summer dew-point temperature for three Midwestern cities.** Dew-point temperature is an indication of the moisture content of the air. The rise in summertime dew-point temperature for Des Moines over this 35-year period translates into a 13% increase in atmospheric moisture near the earth's surface. Winter dew-point temperature also has risen in Des Moines, but not as much as in summer. (Iowa Environmental Mesonet 2010)

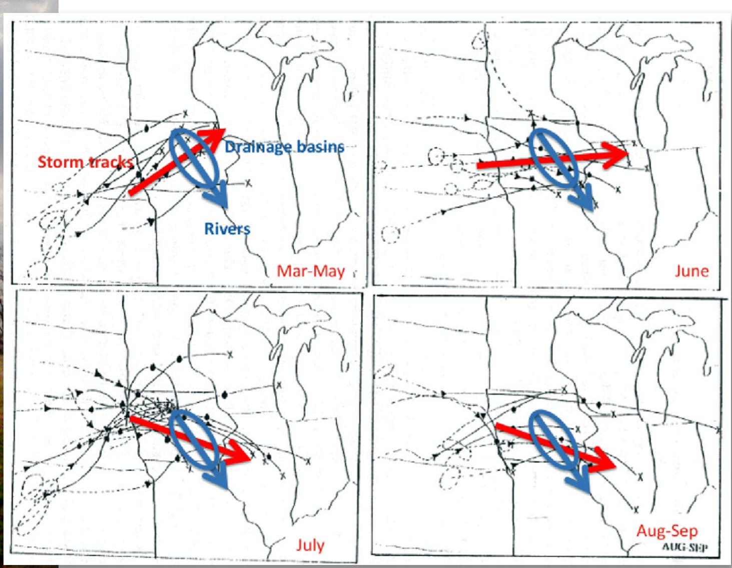

Figure 2-11. **Tracks of storms (shown by black lines) producing heavy rains across Iowa for 1978, 1981-83, and 1985-87.** Note that spring storm tracks (March-May) tend to be oriented from SW-NE (red arrows), while summer storm tracks (June-September) tend to be more E-W or even NW-SE (Takle 1995). Most rivers (blue arrows) in central and eastern Iowa flow from NW to SE, and their drainage basins (blue ovals) are more closely parallel to the late-summertime storm tracks. Thus, mid- to late-summer storms tend to deposit more rain in a given river basin than do springtime storms, which are perpendicular to these river basins and pass over them rapidly. (Sources: Augustine and Howard 1988, 1991)

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3

Climate Change Consequences for Agriculture in Iowa

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Introduction

Many recent climate trends such as increases in the number of frost-free days, annual and springtime precipitation, the frequency of intense precipitation events, and dew-point temperature, as well as decreased fall precipitation, have relevance to Iowa agriculture. Some of the changes are favorable to agriculture, but others are not. Farmers have responded to these changes by planting corn and soybean earlier to take advantage of the longer growing season, installing more subsurface tiles to drain excess soil water faster, and purchasing larger combine heads to facilitate harvest in the fewer hours without dew. Increased soil erosion rates are requiring many farmers to adopt additional conservation practices aimed at improving soil and water quality. Higher monthly rainfall and increased transpiration from crops coupled with reduced winds have created favorable conditions for survival and spread of many unwanted pests and pathogens. Increased use of pesticides and other chemicals, used in response to these pests and pathogens, is likely to raise the level of chemicals and contaminants in our water and food.

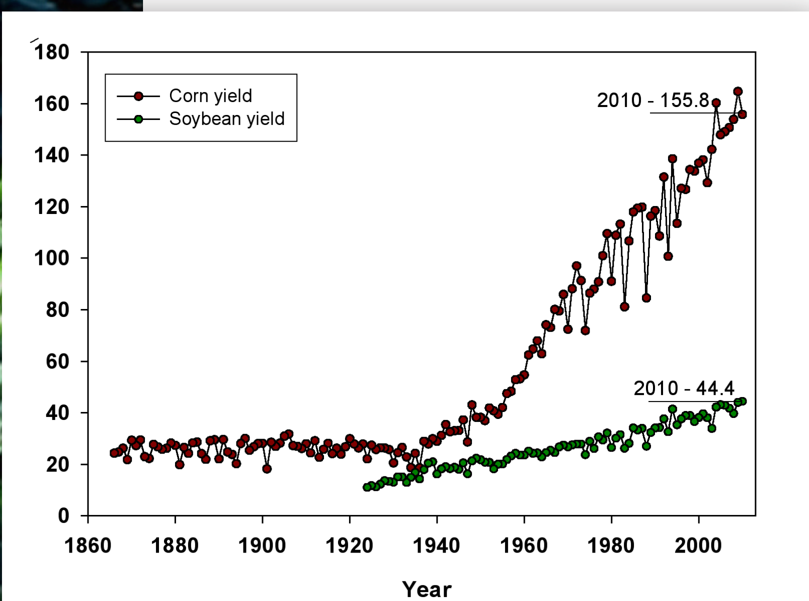


Figure 3-1. **Average yield of corn and soybeans in the US**. Corn yields have increased since 1940 on average 2.5 bu/year, and soybeans have increased on average 0.6 bu/year. These increases are traced partially to favorable climate. Variability about this trend also is caused by climatic or weather phenomena. (USDA NASS 2010)

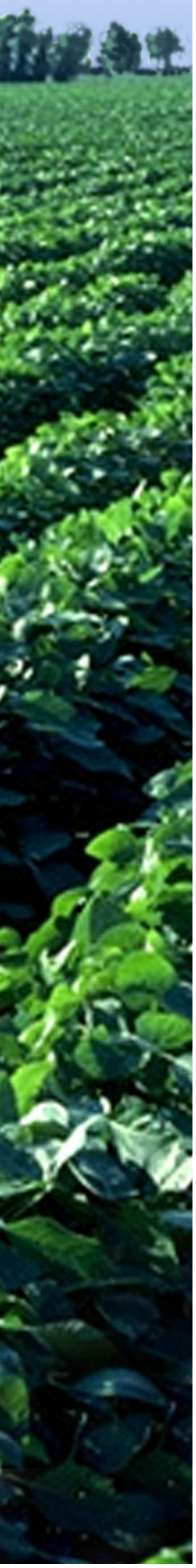
Crop Production and Yield

Corn and soybean yields have been rising steadily since the 1940s (Fig. 3-1), with the average yearly increase in the last decade being 2.5 and 0.6 bu/acre, respectively (USDA NASS 2010). Improved management and genetics, higher fertility, and reduced drought stress have all been partially credited for this yield increase. Despite great improvements in yield potential, crop production remains highly dependent on climate in conjunction with other variables. The overall effect of climate change on crop productivity in Iowa remains unclear, as positive climatic events could be overridden by the impacts of poor management or genetics, or favorable management and genetics could override negative climate events. Regardless of these interactions, it is certain that climate changes will affect future crop production.

Greenhouse and growth chamber studies suggest increases in atmospheric carbon dioxide (CO_2) will generally have a substantial positive effect on crop yields by increasing plant photosynthesis and biomass accumulation. Field research, however, indicates conclusions from such controlled conditions overestimate the "fertilization" effect of CO_2 on crop yields (Schimel 2006). Despite earlier reports of substantial effects, field experiments found no increase in corn yield and an estimate of only 14% increase in soybean yield (Long et al. 2006). Increasing CO_2 concentrations change the competitive advantage of different plant types.

Greater precipitation during the growing season, as we have been experiencing in Iowa (Takle 2011), has been associated with increased yields; however, excessive precipitation early in the growing season adversely affects crop productivity. Waterlogged soil conditions during early plant growth often result in shallower root systems that are more prone to diseases, nutrient deficiencies, and drought stress later in the season (Stolzy and Sojka 1984). An Iowa study indicated that waterlogged conditions are responsible for an average 32% loss in crop yields, and 100% crop production loss is expected in four out of 10 years on poorly drained areas (Kanwar et al. 1984). The maximum crop damage is observed when flooding occurs at the early stages of growth (Bhan 1977, Chaudhary et al. 1975). These data reinforce the common understanding that a dry spring followed by a wet summer is much better for yields than a wet spring followed by a dry summer.

Frequent or excessive early season rainfall also can delay planting beyond the optimum for crop production, as happened in 2008 (Pope 2008). Shortened growing seasons pose a substantial risk of yield reduction.



According to De Bruin and Pedersen (2008), delaying soybean planting in Iowa from late April to late May or June results in a 12 to 41% yield reduction. Switching to early maturity varieties does not negate yield loss and in many cases might not be an option, because seeds are often prepaid well in advance of planting.

An increase in temperature, especially during nighttime, reduces corn yield by shortening the time in which grain is accumulating dry matter (the grain fill period). According to Takle (2011), Iowa's nighttime temperatures have been increasing more rapidly than daytime temperatures. In 2010, corn yield forecasts dropped from the previously projected 179 to 169 bu/acre due to warm temperatures during the grain fill period (Elmore 2010).

Crop Management

Changes in precipitation patterns and an increase in temperatures are affecting nitrogen (N) management for crop production. Increased rainfall in early to late spring forces crop producers to delay in-season fertilization, which often results in a yield penalty (Balkcom et al. 2003). Moreover, excessively wet soils are prone to N losses via denitrification, with an estimated 4 to 5% loss of N per day when soils are saturated (Sawyer 2008). Application of N in the fall when soil temperatures fall below 50°F is a common practice in Iowa. According to Iowa Environmental Mesonet observations (2010), soil temperatures in Ames, Iowa, historically are almost certain to drop below 50°F by October 2. However, on October 24, 2010, most of Iowa still had soil temperatures into the mid to high 50s, which resulted in delaying N application that fall. The first fall day when the average soil temperatures are below 50°F is occurring later and later in the season (Fig. 3-2), a change that delays the time of fall N application.

Excessive rainfall can force farmers to delay planting, as was mentioned in the previous section, or to replant damaged acres, a practice often recommended if flood damage occurred during the early vegetative stages (Pedersen 2008). In contrast, crops affected by floodwaters later in the season, when replanting is not an option, are often lost. In recent years, many crops along rivers and in potholes have been lost along with substantial amounts of applied nitrogen fertilizer.

The current changes in precipitation, temperature, wind speeds, solar radiation, dew-point temperatures, and cloud cover imply less ventilation of crops and longer dew periods. Soybean plants in particular readily absorb moisture, making harvest problematic. One adaptive approach to these conditions involves farmers purchasing larger harvesting equipment to speed harvest, compensating for the reduced daily time suitable for soybean harvest.

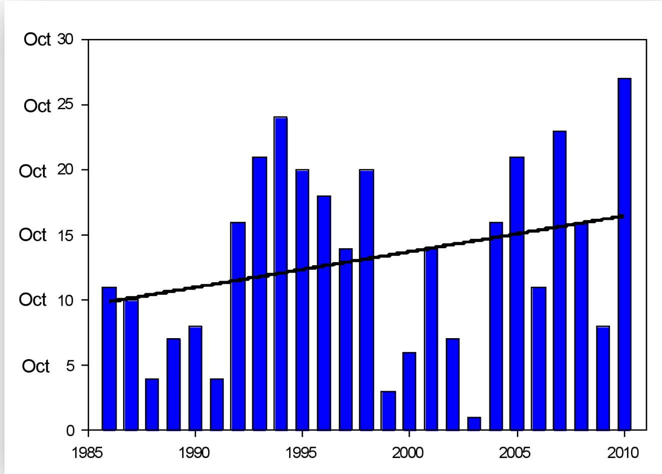


Figure 3-2. **Iowa's fall soil temperatures**: First day of the fall season when the average 4-inch soil temperature was below 50°F. With current warming temperatures, this date is occurring later in the season, a change that is delaying fall nitrogen application. (Iowa Environmental Mesonet 2010)

Soils

The recent extreme weather events involving greater intensity and amount of rainfall (Takle 2011) have increased the erosive power of Iowa's precipitation, resulting in significant erosion of topsoil. According to the USDA's National Resource Inventory report, Iowa's average erosion rate is estimated to be 5 tons per acre per year. Best science indicates soil renewal rates are closer to 0.5 tons/acre/year (Montgomery 2007). Iowa Department of Agriculture and Land Stewardship showed that an estimated 2.3 million acres – about 10 percent of Iowa's cropland – had that year suffered severe erosion damage, which is defined as an annual erosion rate of 20 tons or more of soil per acre. In some areas, erosion rates exceeded 50 tons per acre per year (Fig. 3-3) (Iowa Daily Erosion Project 2010). The impact of climate change on the erosive force of precipitation in the US is expected to increase by as much as 58% (Nearing 2001). Moreover, today's soil erosion rates are expected to increase exponentially as precipitation continues to rise; consider for example that a 20% increase in precipitation has been shown to increase erosion rates by an estimated 37% (Lee et al. 1996).

Crop Health and Use of Pesticides

Iowa's current increases in temperature, soil wetness, and humidity can favor the development and establishment of plant diseases, leading to more severe disease epidemics. A prime example is the wet soil conditions of the 2010 growing season, which are often cited as the cause for the widespread epidemic

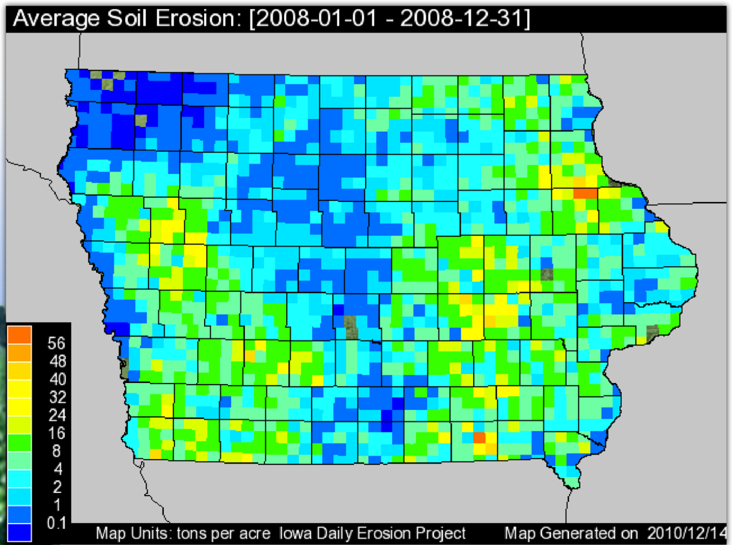


Figure 3-3. **Average soil loss in Iowa in 2008**. The increased intensity and amount of rainfall during this flood year resulted in a soil loss of more than 50 tons per acre in some townships (orange). This contrasts with the "tolerable average" of 5 tons/acre/year (blue shades). The rise in the intensity and amount of rainfall have increased the erosive power of Iowa's precipitation. (Iowa Daily Erosion Project 2010)

of soybean sudden death syndrome that year. This syndrome has the potential of reducing yields by up to 100%. 2010 was the worst year for soybean sudden death syndrome since it was discovered here in 1994 (Yang 2010). Soybean Asian rust is present in the southern US but has not yet been observed in Iowa. However, warmer winters and wetter summers, with extended periods of summer warmth and leaf wetness, raise concern among plant pathologists about possible spread of this disease to Iowa (NCSRP 2005). Overall, the increasing risks of plant disease resulting from increased precipitation have led to more frequent use of foliar fungicides in the past several years in Iowa (Yang et al. 2008).

With increasing temperatures and soil moisture, weeds are posing more problems and are proving more difficult to control. In 2008, weed pressure was exacerbated due to heavy rains and saturated soils that reduced the efficacy of pre-emergent herbicides and reduced development of crop canopy, allowing weeds to thrive (Hartzler 2008). Weeds are more genetically diverse than crops, and therefore in the face of climate changes are more likely than crops to show enhanced growth and reproductive stability. The southern US, with its higher average annual temperatures and greater precipitation, has much greater estimated crop loss due to weeds (when herbicides are not used) than more northerly regions (Bridges 1992). With warming temperatures and elevated CO_2 concentrations, many weeds are migrating northward (Backlund et al. 2008). The efficacy of herbicides is expected to further decrease with rising CO_2 levels (Ziska and Goins 2006). The growing weed problem cannot be solved by using standard methods of weed control alone, such as tillage or repeated in-season cultivation, because these may not be as effective as herbicides and will lead to greater rates of soil erosion. Current rainfall patterns also make mechanical cultivation more difficult.

With increasing temperatures, harmful invasive species might pose new agricultural challenges, since many invasive weeds and plant pathogens can now overwinter in regions that were previously too cold for them.

Water Quality

The increased rainfall frequency and intensity now experienced in the Midwest (Karl et al. 2009) produce more pollution and sediment due to increased surface water runoff and subsurface drainage (IPCC 2007). Currently, nitrate loss via tile drains is one of the biggest concerns for water quality. Long-term monitoring of agriculturally-related drainage in Gilmore City, IA, showed that nitrate loss is greatest in years with higher precipitation and hence greater tile flow (Fig. 3-4). Depending on the rainfall, the annual nitrate loss varied from 1 to 67 lb of nitrate-N per acre (Lawlor et al. 2008). Due to increases in the amount of precipitation, the number of acres that are artificially drained is likely to increase, exacerbating problems of nutrient-related water-quality issues.

Runoff of nutrients such as phosphorous and nitrogen, pesticides and herbicides, and various manure-derived

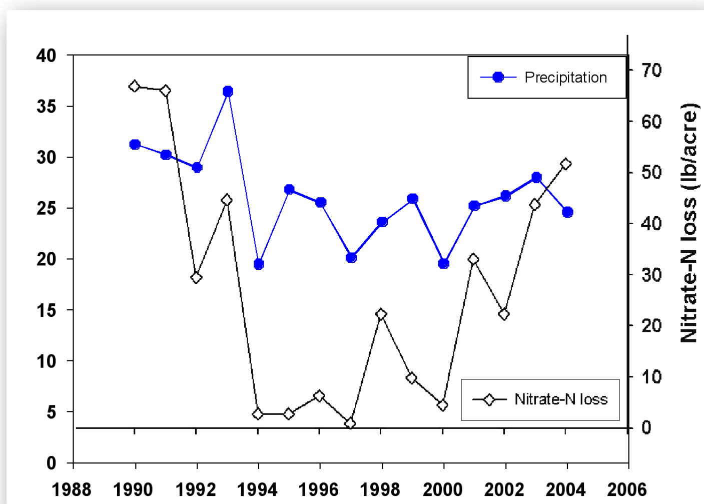


Figure 3-4. **Comparison of annual precipitation and nitrate-N loss via tile drainage**. Nitrate loss via tile drainage (bottom line) is greatest in years with higher precipitation (top line), and Iowa's precipitation and rainfall intensity have been increasing. (Adapted from Lawlor et al. 2008)

pathogens and antibiotics poses a threat to water quality in Iowa and downstream. Following the 1993 Midwestern floods, the Gulf of Mexico's dead zone doubled in size because of increased nutrient runoff that year (Epstein 1998).

Animal Production

Despite the fact that Iowa ranks first in hog and fifth in cattle production nationwide (USDA NASS 2008), there is a lack of information about the effects of climate change on animal production in Iowa. Nevertheless, our general knowledge and principles pertaining to livestock and extreme weather events are applicable to Iowa's changing climate conditions.

High temperatures have been shown to reduce summer milk production, impair immunological and digestive functions of animals, and increase mortality rates among dairy cattle (Klinedinst et al. 1993, Nienaber and Hahn 2007, Mader 2003). On days when the ambient temperature exceeds 90°F, the risk of sow mortality doubles (Carlton 2004). In 1992, 1995, 1997, 1999, 2005, and 2006, the loss of cattle during extended heat episodes exceeded 100 head for some Midwestern farms (Backlund et al. 2008). In 1995, livestock-related economic losses due to heat stress were estimated to be $31 million in Iowa alone (Hahn et al. 2001).

In general, domestic livestock can adapt to gradual changes in environmental conditions; however, extended periods of exposure to extreme conditions greatly reduce productivity and are potentially life-threatening. During adverse heat events, management alternatives, such as the use of bedding in winter or sprinklers in summer, need to be considered (Mader at al. 2009).

Research Gaps

There are many uncertainties associated with predictions and assumptions about the effect of climate change on agriculture. These uncertainties beg to be addressed by research. Most studies to date have only considered the average climate change rather than extreme climate events. However extremes, not averages, will delineate successes and failures. Currently, scientists have insufficient understanding about CO_2 fertilization effects on crops. Attempts to study these effects are often hindered by failure to consider other interactive factors such as pests, diseases, weed pressure, adaptation measures, and technological improvements. The same is true when studying other factors.

There is a need to develop strategies to help crops cope with climate variability through plant breeding, and through selection for increased tolerance to water stress and improved nutrient use efficiency, and through tolerance to temperature extremes during grain fill periods. More advanced soil and water conservation technologies must be developed.

Conclusions

Recent weather events and climatic trends are stressing agriculturally related resources. Increased rainfall, and frequency of much heavier-than-normal rainfall events, result in disproportionately negative impacts on soil and water resources and on crop production. Increasing dew-point temperatures and reduced wind flow have potential near-term crop-disease impacts. Subsurface drainage is increasingly necessary to maintain acceptable crop yields. Elevated precipitation and early season rainfall increasingly delay planting, increase nitrate nitrogen losses, and affect nitrogen fertilizer application timing. Climate extremes, not the averages, frequently control productivity of crops and livestock.

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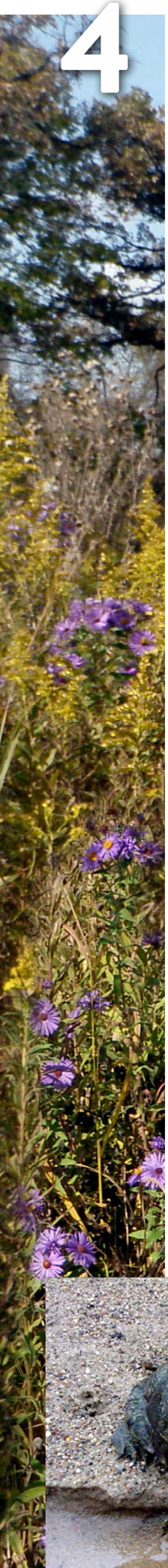

4

Climate Change Consequences for Iowa's Flora and Fauna

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Introduction

In a stable climate, we know what to expect. We know when to expect the leaves to turn color in the fall, the first killing frost and spring thaw, the first robin, summer thunderstorms, and the arrival of certain weeds and pests in our gardens. Farmers know when to plant and harvest, and which crop varieties are best for their county. With current and future changes to Iowa's climate (Takle 2011), cultivated and wild plants ("flora") and game and non-game animals as well as insects and other smaller organisms ("fauna") will all be affected. This report describes the challenge of predicting what will happen because of climate change, and summarizes the available published research that is most relevant to our region. Changes in the interactions among species, the timing of life cycles, and shifts in the range of species to the north are already being felt in the Midwest and around the globe (Backlund et al. 2008; Parmesan 2006; Walther et al. 2002).

Iowa's endangered wood turtle is a good example of a species that is in decline, due in part to changes in the timing of flooding events (Figs. 4-1 and 4-2). The wood turtle is a semi-aquatic species that inhabits much of the northeastern United States and southeastern Canada and is in decline over most of its range (Spradling et al. 2010). Its distribution is limited to areas with the appropriate combination of aquatic and terrestrial habitats. In Iowa, the wood turtle has a patchy, discontinuous distribution along the north Cedar River and its major tributaries (Christiansen and Bailey 1997). Its distribution here is limited by the availability of sandy nest sites on islands, sandbars, and shorelines (Spradling et al. 2010).

Figure 4-1. **A nesting wood turtle**. The Iowa numbers of this state-endangered species are declining in part because of increased flooding during the summer egg incubation period. (Photo credit: Dr. Jeff Tamplin, UNI)

The estimated census population size in Iowa is 77 turtles (Spradling et al. 2010), which is one of the lowest reported for a wood turtle population to date. Recruitment in the Iowa population (1.6%) is also among the lowest reported for the species (Spradling et al. 2010). These are essentially ghost populations that consist of older adults that are not being replaced by juveniles. The apparently poorer recruitment in Iowa likely is due to the destruction of wood turtle nests by predation and flooding. Over the past 50 years, the upper Midwest region has experienced increased rainfall, decreased late summer droughts, and an increase in days with very heavy precipitation (Karl et al. 2009, Takle 2011). Flooding in Iowa now occurs commonly during the turtle's egg incubation period (Walde et al. 2007). The majority of observed nesting sites in Iowa now are subjected to frequent and repeated flooding events throughout the egg incubation period, causing them to be either in saturated substrates or fully underwater (Spradling et al. 2010).

The Long View

The flora and fauna of the Upper Midwest have changed constantly in the last 2.6 million years, as glaciers repeatedly advanced and retreated and global temperatures fluctuated by as much as 18° F (Lowe and Walker 1997). Animal and plant species moved to more favorable regions, some new species evolved, and others went extinct (Berendzen et al. 2010). Human-caused climate change will have the same general effect, except that the changes will be faster and they will be unidirectional (representative of warmer climates) rather than cyclical (Takle 2011). Animals and plants living now will have a more difficult time moving to suitable habitat due to the fragmentation of habitats by our extensive fields, roads, and cities (Walther et al. 2002).

The following groups of Iowa's wild species are most vulnerable to the effects of today's changing climate:

1) Species restricted to cold microclimates such as fens, cold air slopes, and cold-water streams
2) Rare, threatened, or endangered species
3) Specialists that rely on one species of pollinator or host for their survival
4) Declining species, including grassland nesting birds and neotropical migrant birds in general
5) Species that need large blocks of undisturbed forest or prairie
6) Turtles that rely on incubation temperature to determine the sex of the offspring; the sex ratio of their offspring (and thus future reproductive potential) are disturbed by rising temperatures
7) Turtles and amphibians vulnerable to mid-summer flooding (such as the wood turtle)

Figure 4-2. **Typical Iowa nesting site of the wood turtle**. West Fork of the Cedar River, Butler County, Iowa. These types of sites are quite vulnerable to flooding. (Photo credit: Dr. Jeff Tamplin, UNI)

Changes in Interactions Among Species

While we can predict how individual species tolerate certain temperatures, it becomes impossible to predict the outcome of every interaction between every animal, plant, insect, and microbe. There are many examples of changing interactions among species due to climate change. While there are no studies specifically from Iowa, we can draw upon studies from other locations to get a sense of how climate change affects interactions among animals and plants.

Worldwide, 32.5% of all known amphibian species are threatened with extinction, and many are declining for unknown reasons (Stuart et al. 2004). Many scientists are investigating causation by a fungal disease that may be more deadly or spread faster with changes in climate (Burrowes et al. 2004).

The yellow-bellied marmot (a relative of our woodchuck) lives at high elevations in the Rocky Mountains of western North America. It is now emerging from hibernation on average 28 days earlier than it did in 1975. Today, it often emerges before its food plants are available (Inouye et al. 2000).

Due to a longer growing season consistent with predictions of climate change, the mountain pine beetle in the Rocky Mountains only needs one year to reproduce instead of two, increasing the spread of the deadly tree fungus it harbors. Its range is expanding to higher latitudes and northern latitudes (Kurz et al. 2008).

The Timing of Life Cycles

Phenology is the timing of major life events such as bud burst in trees, flowering times, breeding period in animals, or fall and spring migration of birds and butterflies. These processes are closely associated with seasonal changes and climatic events and are thus vulnerable to changes in climate (Backlund et al. 2008; Parmesan 2006; Walther et al. 2002).

To our knowledge, only one scientific study of climate change impacts on animals or plants has been conducted in the Upper Midwest. A study initiated by Aldo Leopold in the 1930s carefully documented the first spring sighting of 55 species of animals and plants near Baraboo, Wisconsin (Bradley et al. 1999). Records were kept for about 20 years, and the same site also was resurveyed in the 1980s and 1990s. Birds such as Canada geese, red-winged blackbirds, house wrens, and robins were arriving earlier in the spring. Many species of early-blooming flowers such as *Hepatica*, columbine, and shooting star were blooming earlier. Overall, eighteen of the 55 species were showing up or flowering earlier; only one was arriving later. On average, spring in Baraboo began 7.3 days earlier in the 1990s than in the 1930s, and March temperatures were 5° F warmer in the 1990s. The authors were able to correlate these changes with records of earlier spring ice melt in nearby lakes. Earlier spring ice melt is a good indicator of overall warmer temperatures in a region (Bradley et al. 1999).

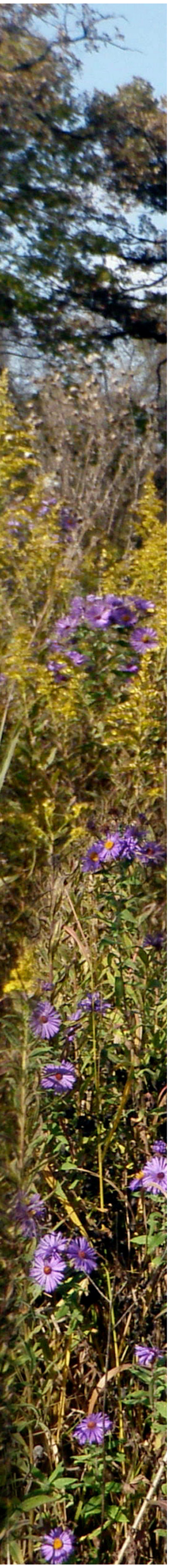
Beyond this one regional study, we must rely on studies conducted in terrestrial ecosystems across North America. Lilac bushes have been studied across the United States since they are widespread and easily observed. Mean flowering date has advanced from 2 to 5 days between 1959 and 1993 across the United States, and from 2 to 8 days across the northeastern United States during the same general period (Schwartz and Reiter 2000, Wolfe et al. 2004). Lilacs are a familiar shrub around homes in Iowa; their changes represent how all plants, wild as well as domestic, will have to respond to climate change in various ways.

Studies from other parts of the world can provide insight as well. Scientists have reviewed 1,598 studies of all kinds of animals and plants from all over the world. Fifty-nine percent showed changes in their timing of important events, such as earlier spring migration or nesting of birds (Parmesan 2006). In the longest-running studies on the timing of life cycles, spanning hundreds of years, the recent nature of climate warming is particularly evident. In Japan, the timing of cherry blossoms has been recorded since the year 1400. Blossom time was stable until 1952, then began to advance earlier each spring (Menzel and Dose 2005). Similarly, grape harvest dates in Europe going back 500 years show significantly earlier harvests during the last 50 years (Menzel 2005).

Shifts in the Ranges of Species to the North

Animals and plants in our hemisphere are expected to move north in latitude or upward in elevation in order to adapt to warmer temperatures (Backlund et al. 2008, Parmesan 2006, Walther et al. 2002). This has been observed in our cultivated garden plants as well as among some wild species.

In 2006, the Arbor Day Foundation updated its Hardiness Zone maps based on data from 5,000 weather stations



across the US. Northern Iowa moved from a solid "4" in the 1990 map to a "5," indicating that a wider variety of trees may now survive our winter temperatures (Arbor Day Foundation 2006). In the study of 1,598 animals and plants from all over the world mentioned above, 41% were moving to cooler regions: the average was 6.1 km north (or 6 meters higher in elevation) every ten years. Very few were moving south or to lower elevations.

A recent study by the Wisconsin Department of Natural Resources modeled the effects of climate warming on the distribution of 50 species of stream fishes in Wisconsin (Lyons et al. 2010). Water temperature is a key factor in determining the geographical range of fish; changes of only a few degrees can result in major shifts in abundance and survival. With a warming climate, 23 of the species were predicted to decline in distribution and abundance in the future, 23 were predicted to increase, and four had no change (Lyons et al. 2010). All three cold-water species in Wisconsin, including the game fish brook and brown trout, 16 cool-water species, and four warm-water species, were predicted to decline. All species predicted to increase in distribution and abundance were warm-water species, including game fish such as the largemouth bass. The effects of a warming climate on Wisconsin's stream fishes will be most dramatic in small, geographically isolated headwater streams in the north, which are now dominated by cold and cool-water species (Lyons et al. 2010).

The Humpty-Dumpty Effect

While we can't predict exactly what changes will take place with climate change, past experience has taught us that these changes may be impossible to reverse. Natural systems tend to be very resilient, so we are sometimes lulled into a false sense of complacency. For instance, the impacts of damming a river on fish and wildlife are often not fully appreciated for 50 years. Again, forests can remain stable for years and then suddenly convert to a shrubland. This can be thought of as the "Humpty Dumpty Effect" because it is virtually impossible for ecosystems to return to the previous system. Game birds or fish that we enjoy today, our common backyard companions like the American robin, could be replaced by entirely new species in what seems like the blink of an eye.

How will we know for sure that such changes are because of climate change? We won't. The effects of old and familiar challenges to our natural systems may be difficult to differentiate from those of new, climate-related stressors. Climate change also may interact with other stressors to accelerate ongoing changes in ecosystems.

Interacting stressors may explain why some carefully managed game species (quail and pheasant) are struggling while others (wild turkey) are doing very well. Meanwhile, native species like the white tailed deer and Canada goose have gone from rare to overly-common in some places. In contrast, other native plants and animals already face dire challenges to their survival due to habitat loss and degradation, competition with nonnative species, and new pests and diseases.

We are likely to see the current concerns about our flora and fauna amplified by temperature extremes, freak storms, and flooding. Treasured natural areas may be radically changed by localized weather events such as high winds or an historic flood. We have seen this recently with the unprecedented high water levels of the Cedar River at the Nature Conservancy's Swamp White Oak Preserve in southeastern Iowa.

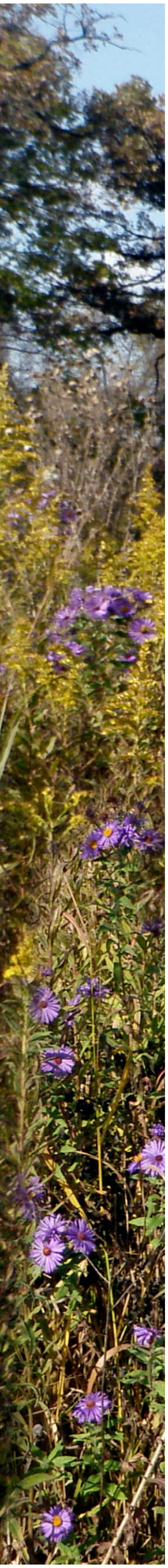
Game Species

Climate change may differentially affect certain fish and waterfowl that are important to Iowa's sporting industry. For example, fish of coldwater streams, including brook, rainbow, and brown trout species, smallmouth bass, and other coldwater fish, could be vulnerable to rising temperatures. Not only are these species dependent on cool groundwater, but they also are sensitive to sedimentation. With more intense rainstorms, sediment from eroding fields will increase (Eaton and Scheller 1996; Chu et al. 2005).

Ducks and other migratory waterfowl that nest in the prairie pothole wetlands of United States and Canada may decline (Johnson et al. 2010). Summer drought predicted for the western portion of the Prairie Pothole Region (Takle 2011) could reduce waterfowl populations across their entire range. In response, the higher-rainfall portions of the pothole region in Iowa and eastern Minnesota may take on greater importance for protecting duck populations (Johnson et al. 2010).

Impacts on white tailed deer, turkey, pheasant, and quail populations are unknown. Much depends on the amount of habitat in the landscape. With changing climate, Iowa wildlife will need still more room to roam. Acquiring more habitat for climate adaptation will benefit pheasants and quail along with many other non-game species. Pheasant-friendly farming practices such as pasture and hay production will not only expand habitat and enable south-north migration, but also will improve a watershed's ability to absorb water and deliver it to streams more slowly (Schilling and Libra 2003).

Given the potential for greater streamflows due to increased rainfall, it also makes sense to give rivers more room to flood. Game fish and other animals can survive these floods if we give them room. Greater wetland capacity and wider stream corridors will also reduce downstream flooding and sedimentation, while improving fish and wildlife habitat in normal years.



Research Gaps

Few climate impact studies exist for the flora and fauna of the Great Plains and Upper Midwestern US. We need to understand the impact of climate on the changes of the interactions among species, timing of life cycles, migration, range shifts, invasive species, and pests and diseases. Given the changes already seen in storm intensity and streamflow, more work is needed on plant and animal responses to these weather factors.

The Iowa Department of Natural Resources is planning vulnerability assessments for certain groups of animals. These preliminary efforts are very important and should be fully supported.

Conclusions

Uncertainty, novelty, and risk, as well as unknown opportunities will force Iowans to continually adjust and adapt rapidly to climate change in ways we have not experienced before. Changes of only 0.9º F have already had measureable affects on the world's ecosystems. Projected changes of 3.6º to 9º F or even more, along with changes in the amount and timing of precipitation, will create a very different kind of natural world than the one we now inhabit.

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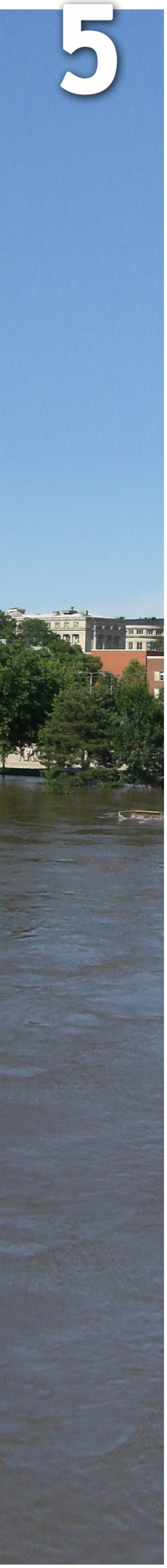

5

Climate Change Consequences for Public Health in Iowa

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Introduction

Investigations of the past two decades indicate that the health effects of climate change can be serious. The World Health Organization estimated that in 2002, 2.4% of worldwide diarrhea cases, 6% of malaria cases, 7% of dengue fever cases, and 170,000 deaths (0.3% of worldwide deaths) were attributed to climate change (Beggs and Bambrick 2005, WHO 2002). A major 2010 study included a range of diseases in its listing of potential effects of climate change, ranging from obvious illnesses such as asthma and vector-borne disease to less obvious cancer and neurological disease (Portier 2010).

While the complicated interactions of climate change might eventually affect all or most health issues, the data are scanty for any limited geographic area such as Iowa or the Midwestern US. Thus, in this chapter, we use a shorter list of five possible health effects developed for the nation as a whole (Karl et al. 2009) in our consideration of the effects of climate change on the health of Iowans.

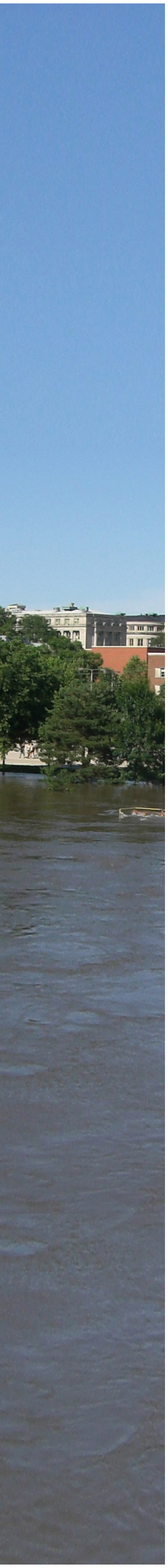
Extreme Precipitation Events, Rising Humidity, and Associated Disease

Global temperature and precipitation data measured around the world or estimated by proxy methods since the year 1600 provide clear evidence that the temperature is rising, and that the pace of this increase has accelerated in the last 30 years. A warmer world means higher humidity levels owing to the greater water-holding capacity of warmer air. As described in Chapter 2 of this report, data from Iowa exhibit a trend toward a warmer and more humid regional climate with precipitation coming more frequently in extreme events. Since 1980, a growing number of weather disasters have resulted in loses of over a billion dollars (in 2007 dollars, adjusted for inflation): there were 12 such events in the US in the 1980s, 38 in the 1990s, and 46 from 2000 to 2009 (NCDC 2010). Of these, 39% involved flooding, including the largest disaster, Hurricane Katrina and its ensuing floods. Floods are also a growing problem in Iowa, where the 2008 floods presented one of the most devastating natural disasters in our state's history.

Figure 5-1. **A Cedar Rapids home damaged by the 2008 flood**. Residents returning to muck out and gut their homes after such events are faced with extensive mold growth, chemical and microbial pollutants, and other potential health hazards. With current rises in precipitation and streamflow, floodplain residents may be increasingly exposed to such hazards. (Photo credit: Linn County Public Health Dept.)

Floods create many health hazards in addition to deaths caused by rising waters. They mobilize chemical pollutants from contaminated soils, hazardous waste sites, storage basins, and other such reservoirs and introduce them into the moving waters. Pollutants include pesticides, fertilizers, gasoline, and industrial chemicals. Floodwaters on the Ohio River in Kentucky resurrected leaking 55-gallon drums of toxic waste that had been buried at a dumpsite for a generation. Some of these drums contained toxic chemicals that had been banned since the 1970s. Microbial pathogens from livestock production facilities and sewage treatment plants are also mobilized by floods. During Iowa's 2008 flood, the Cedar Rapids wastewater treatment plant was discharging raw sewage into the floodwaters. When the floodwaters receded and residents returned to "muck out and gut" their homes, they were faced with extensive mold growth and with the multiple hazards that the floodwaters had carried in, including both chemical and microbial pollutants (Fig. 5-1).

Molds are saprophytic fungi – the great recyclers of organic matter. Thus wet wood, fabric, paper, and wallboard are consumed by molds. Exposure to these molds during cleanout or demolition produces disease. Air sampling performed in New Orleans homes after Hurricane Katrina demonstrated extremely high concentrations of molds, bacteria, and a bacterial cell wall component called endotoxin that is a known trigger of asthma (Chew et al. 2006, Rao et al. 2007). Concentrations of airborne mold spores were over 1,000 times higher than levels considered acceptable, and were



so high that standard particle masks were ineffective for respiratory protection (Tillett 2006). In 2008, homeowners in Cedar Rapids and Iowa City typically returned to their homes 3 to 7 days after the flood to begin the cleanup (Thorne 2010a). They were faced with houses filled with mold and with the monumental task of removing moldy materials. As in the 2005 Gulf Coast flooding, in the aftermath of the 2008 Iowa flood there was an increased burden of respiratory diseases including allergic rhinitis, asthma, toxic alveolitis, and reports of a condition known colloquially as "the flood crud." The flood crud left victims suffering malaise, fatigue, and cough, often for many weeks (Thorne 2010a).

Another health hazard associated with floods is carbon monoxide poisoning. When flood cleanup begins, affected buildings are often without power, requiring use of gasoline- or diesel-powered generators and pressure washers. Indoor use of these machines and inadequate ventilation send workers to the hospital with carbon monoxide overexposure. This scenario played out in Cedar Rapids in June and July of 2008 (Thorne 2010b).

Even without flooding, Iowa's rising atmospheric humidity is problematic (Takle 2011). Higher summertime humidity has the potential to produce higher indoor moisture levels which give rise to problems of mold and house dust mites in homes. Levels of mold and house dust mite allergens have been shown to be positively associated with indoor relative humidities above 60%. An indoor relative humidity of 70% at 75°F will reach the dew-point, condense on a 65°F basement wall or floor, and give rise to mold. Spores emanating from such growth are distributed throughout the house and can produce allergies and asthma.

Illness and Death Associated with Extreme Heat and Heat Waves

Extreme heat and heat waves are deadly, especially to the most vulnerable (McMichael et al. 1996, Patz et al. 2000, Balbus and Wilson 2000). One of the best early examples of what might be in store for humans from a warmer climate took place in Chicago. "[A]fter a 5-day heat wave in 1995 in which maximum temperatures in Chicago ranged from 93 to 104°F, the number of deaths increased 85% over the number recorded during the same period of the preceding year. At least 700 excess deaths (deaths beyond those expected for that period in that population) were recorded, most of which were directly attributed to heat" (Patz et al. 2000).

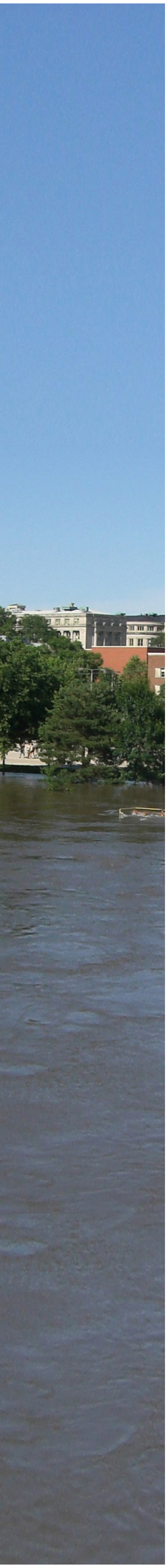
Most of the excessive morbidity and mortality from heat waves is expected to take place in regions where extremely high temperatures occur infrequently or irregularly (Patz et al. 2000), and government services have not prepared for addressing these emergencies. A well known heat wave killed thousands in France in 2003, especially the elderly, but by 2006, the French public health system had responded by establishing a response system that was shown to be effective (Fouillet et al. 2008). However, Russia's heat wave in 2010 demonstrates that public health lessons must be learned by each country. The death rate in Moscow doubled during that summer heat wave, putting the city's morgues at near-capacity (BBC 2010). Heat and drought also led to massive wildfires that produced choking smog and extremely high levels of toxic air pollutants.

Less dramatic heat events also are associated with increased mortality. A recent study using data from 43 US cities gathered over 19 years demonstrates that mortality rises with rising heat and longer duration of the heat, and depends on seasonal timing (Anderson and Bell 2010). Longer and hotter heat waves lead to higher mortality, and heat events occurring earlier in the summer season are harder on the population. This study has implications for Iowa, since heat-related mortality was more pronounced in the Northeast and Midwest than in the southern US.

How can we expect Iowa to fare on this health issue? Extreme heat causes more deaths in the US than any other type of weather-related event (Karl et al. 2009). A higher proportion of elderly in the population heightens a region's vulnerability to extreme heat, a factor that could bode ill for Iowa (Portier 2010). In recent times, frequent heavy rains and high levels of soil moisture have suppressed the daytime summer maximum temperatures in Iowa (Takle 2011). A severe drought could unmask the overall warming that is evident from trends in other seasons. It is noteworthy that the extreme events in Russia in 2010 did not follow any trend of increasingly hot summers; they came out of the blue, or rather out of the brown sky caused by the summer's forest fire smoke. That country had displayed no discernible historic trend of ever-hotter Julys, and yet Russia's heat in July 2010 exceeded that of any July on record over the last 130 years (Hoerling 2010). This example demonstrates the risks and uncertainties of climate-change events, one of the themes carried throughout these chapters.

Warming, Air Quality, and Respiratory Problems

Ground-level ozone and particulate matter are ambient air pollutants with well-established adverse health effects. More people reside in counties in violation of National Ambient Air Quality Standards for these pollutants than for any others. Both ozone and particulate matter are expected to increase with climate change in Iowa, producing new risks of respiratory disease. As seen in Russia in 2010 and almost annually in Southern California, heat waves are often accompanied



by extreme levels of air pollution from wildfires. But even in the absence of wildfires, the combination of higher levels of primary air pollutants (e.g. nitrogen oxides, fine particulate matter) with increasing temperatures in urban heat islands gives rise to enhanced exposures to secondary air pollutants, especially ozone. Ozone is most hazardous to the young and the old and those with underlying respiratory diseases and asthma. Ozone may act synergistically with other pollutants. It is estimated that each 2°F increase in temperature is associated with a 2- to 3-parts-per-billion increase in ozone (Bloomer et al. 2009). Thus, heat effects are coupled with high ozone exposures that increase the burden of morbidity and mortality, especially among vulnerable populations. Where energy is produced through combustion of coal or oil, increased demands for air conditioning and cooling further exacerbate photochemical smog and other air-quality problems.

Pollen Production and Allergies

Climate change is modifying, both spacially and temporily, the growth of flora. Evidence is mounting both for northward shifts in the range of certain plants in the northern hemisphere and for extended growing seasons (Rogovska and Cruse 2011, Takle 2011). Experiments growing allergen-producing plants like ragweed in chambers with elevated CO_2 concentrations and higher temperatures demonstrate increased biomass, higher yields of pollen, and higher allergen content in the pollen grains of these plants (Shea et al. 2008, Beggs 2004, Wayne et al. 2002). The northward movement of plant species, longer allergy seasons, and higher allergen exposures all point to a higher prevalence of allergic rhinitis and allergic asthma in coming years. This is not good news for allergy sufferers and suggests the potential for higher medical costs associated with this climate-change-induced shift.

Diseases Transferred by Food, Water, and Insects

Studies in the US as a whole have established an association between the incidence of vector-borne diseases and the occurrence of heavy rainfalls or periods of high humidity, and also have associated waterborne and foodborne diseases with changes in heat, humidity, and rainfall. Although no Iowa-specific studies have been performed yet, these associations would be expected to apply here as well as elsewhere.

The numbers of pathogens such as *Salmonella*, *Cryptosporidium*, and *Giardia* are enhanced by higher temperatures or heavy downpours (Karl et al. 2009). Vectors such as mosquitoes, ticks, and rodents can be affected by climate change and more easily pass on such diseases as West Nile virus, equine encephalitis, Lyme disease, and hantavirus (Karl et al. 2009).

To take just one example, a recent study of West Nile virus looked at more than 16,000 reported human cases from across the US. The study found associations with the incidence of reported infections and increasing temperature and also with heavy (but not low) levels of rainfall (Soverow et al. 2009).

A recent study from Iowa State University researchers documented the arrival of a new species of mosquito in the state (Dunphy et al. 2009). *Aedes japonicus japonicus* was discovered in traps set as part of a statewide mosquito and mosquito-borne virus surveillance program. The new mosquito has the potential to transmit both the West Nile virus and the Lacrosse virus, so the researchers consider the appearance of the new mosquito to be a health concern for Iowans.

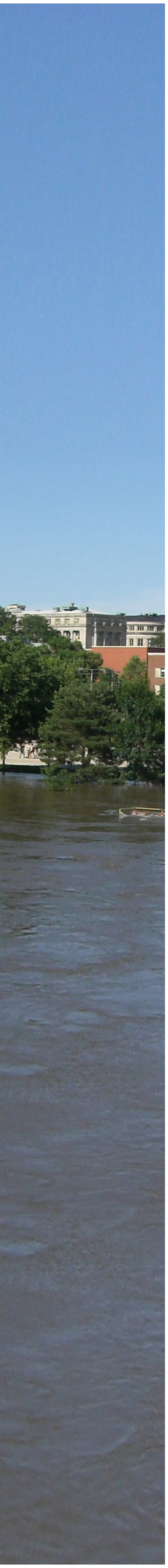
Migration of exotic disease vectors can create problems, but so can common native plants and animals. For example, researchers have shown that when poison ivy is exposed to higher levels of the greenhouse gas CO_2, the poison ivy plant becomes larger and more robust and produces "a more noxious form of its rash-causing chemical" (Fountain 2006).

Research Gaps

As this chapter has demonstrated, Iowa data on the relationship of health and climate change are limited, and there is presently no one at the Iowa Department of Public Health (IDPH) investigating links between climate-change data and public-health data. While knowledge should improve because of a recent Centers for Disease Control and Prevention grant awarded to the IDPH (Sharp 2010), specific studies in Iowa will always be few, and studies from larger geographic areas must be relied upon. Furthermore, the number of studies anywhere is not extensive. More studies at all geographical scales are needed.

Conclusions

Humans adapt to many climates, but do not adapt very well to extreme events. While warmer winters might produce fewer injuries, nearly every other anticipated change coming from a warmer, wetter world is bad for human health. Health is adversely affected when extreme heat leads to fatalities in our cities or when humid conditions contaminate indoor air with mold spores. More frequent extreme weather events will increase exposures to molds and toxic agents and add significantly to stress. Some health effects from our changing climate have already begun to appear. Others appear to loom ahead, depending on the choices we make to mitigate and adapt to the changing climate.



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Climate Change Consequences for Iowa's Economy, Infrastructure, and Emergency Services

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Iowa's climate is changing, and that means Iowa's economy is changing. If climate change is "the mother of all externalities: larger, more complex, and more uncertain than any other environmental problem" (Tol 2009), there will be unarguable consequences for all aspects of economic activity in Iowa. Our society has a market-based economic system for allocating scarce but desired private and public goods and services involving producers, consumers, financial and risk management institutions, and governments. All are affected by a changing climate. While there are no Iowa-specific published economic impact projections attributable to climate change, one may infer likely consequences for the state based both on national and global economic impact research (Deschenes and Greenstone 2004, Jorgensen 2004, Ross et al. 2008, Tol 2009, Stern 2007), as well as from Iowa-specific evaluations of Iowa's climate in particular (Takle 2011), its agricultural base (Rogovska and Cruse 2011), and other resource-related evaluations (Jackson and Berendzen 2011).

Agricultural Productivity and Food Costs

Iowa consistently ranks third in the U.S. in agricultural sales, behind California and Texas. Climate change consequences for agriculture have been researched for many years (e.g., Adams et al. 1990, Sinclair and Rawlins 1993). A growing body of research indicates grain and animal production in Midwestern states may be both positively and negatively affected economically by changing climate conditions over time (Karl et al. 2009, McCarl 2009). Temperature and rainfall are critical factors in crop productivity, range suitability, soil stabilization, and animal health. In the medium term, assumed in this paper to include the 2010 through 2030 period, climate change in Iowa is expected to produce a longer growing season, warmer growing season temperatures, and a wetter climate. Unless we have abrupt temperature increases and other mitigating variables, "wetter is better" (Jorgenson 2004), and warmer weather yielding more rainfall and higher summer humidity levels favors increased corn production, Iowa's dominant cash crop.

Research in controlled environments (Adams et al. 1990) indicates that higher CO_2 levels boost yields on soybeans; however, Rogovska and Cruse (2011) note that lower gains were realized in field trials, so incremental boosts in production are likely not as great as previously assumed; Warmer temperatures also affect ozone levels, which may further offset higher CO_2 level yields (Long et al. 2006). Higher CO_2 levels also promote weed virulence, plant pathogens, and fungi, and result in insect pest population increases (Rogovska and Cruse 2011, McCarl 2009), all of which undermine yields and increase producer costs.

There are other cost-generating concerns associated with climate change in Iowa. There is mounting evidence that Iowa agriculture may have to cope with changes in seasonal rainfall patterns, making spring planting more difficult. There is also accumulating concern that large precipitation events are becoming more severe, which in turn would increase the probabilities of crop and livestock peril and soil damage, and the requirement for remedial drainage engineering (Takle 2010).

Research indicates that by mid-century, Iowa temperatures are expected to increase enough to begin to inhibit plant growth, causing yield declines and reduced overall agricultural outputs (Karl et al. 2009, Tol 2009). Higher temperatures also affect animal health, animal appetites, reproduction, and range health (McCarl 2009). As southern Iowa contains much more pasture than the northern two-thirds of the state, southern portions of Iowa would realize range and pasture-related productivity offsets before the remainder of the state.

If climate change in the Midwest and in Iowa enhances crop productivity and delivers incremental increases in grain supplies in the medium term, reduced input costs into animal feeding and food processing during this time period would be expected. During the same period, consumers would be expected to realize stable to declining prices for key foodstuffs containing significant content from Midwestern producers (Jorgenson et al. 2004); however, large fractions of our food requirements are produced in southern and western areas of the US, which are anticipated to have yield-reducing outcomes from climate change due to warmer and drier conditions in those areas (Karl et al. 2009, McCarl 2009). Those changes would alter the supply and increase the cost of those commodities, potentially offsetting medium-term food price savings from Midwestern commodities.

Agriculture, like all industries and households, must compete for water, land, investments, labor, and operating capital (Schimmelpfennig et al. 1996). Longer-term climate changes, those that are expected after 2030, would likely shift interstate and intra-state crop and livestock production as incrementally warmer and ultimately drier climates force producers to optimize the use of all natural, labor, and capital resources at their disposal. The nature and location of those shifts, however, is still the subject of speculation (FAO 2007, Rose and McCarl 2008, Nelson et al. 2009).

Iowa's Insurance Industry

Iowa's nationally prominent insurance industry warrants special concern as it will be directly influenced by both Iowa's and the nation's climate change consequences. In 2008, climate change was identified as the number one issue confronting insurance companies (Ernst and Young 2008), and Ross et al. (2007) noted that climate change liability "… exposures have already begun to materialize." Every aspect of the insurance industry that underwrites property losses for all manner of businesses, crop and livestock coverage, liabilities associated with pollution, business continuity and other interruptions, as well as life and health coverage, are affected by climate change (Mills 2005, Ross et al. 2007). For this industry to remain profitable, it must determine the magnitudes of accumulating risks, devise strategies for spreading those risks, price financial instruments appropriately to assist all manner of businesses and households to purchase peril-mitigating policies, and, importantly, foster strategies for risk reduction (The Geneva Association 2009).

Iowa has a mix of major insurance companies, with specializations ranging from those appropriate to Midwestern agricultural production, such as crop and livestock peril, to completely diversified insurance services covering life, health, and all forms of property insurance nationwide. The industry at large is considered to be deeply within a period of transition as it learns to cope with the consequences of a changing climate. As climate destabilization continues in Iowa and nationwide, Iowa-based insurers will continually modify their risk evaluations as more scientific evidence is gathered. This period of adjustment may create profitable opportunities for new and different insurance products, and it may also threaten profitability if firms are subjected to unanticipated liabilities or if they limit insurance coverage because uncertainty is so great that it precludes appropriate pricing.

Energy Use

Every Iowa industry and household is expected to trade-off higher cooling costs against lower heating costs as a consequence of a changing climate. This will result in average cost savings because the daily costs of heating are higher than cooling costs. The heating and cooling equipment investments required for these changes will be incremental in nature and should not result in meaningful shifts in trade activity.

If carbon legislation is enacted by the U.S. Congress, the price of all fossil fuels will increase. This would increase the prices paid for all consumer goods. These changes will be widely felt in the prices paid for electricity, which in Iowa is predominantly coal-fired at present, and for natural gas. Since Iowa's electricity use peaks in the summer, warmer temperatures coupled with carbon production price penalties will lead to higher electricity prices during those periods. On the other hand, natural gas costs will decline because of lower heating requirements.

Households

Given the wide array of scientific research on a changing climate, it is reasonable to conclude that longer periods of warmer weather coupled with shorter and less-cold winters will alter the mix of retail goods, wholesale goods, and services demanded by household consumers. Incidences of household activity limited or prevented by abnormal snow, cold, or ice will decline. Increases in out-of-doors productivity would be expected, as well as more opportunities for warmer-weather recreational and occupational choices in early spring or late fall. Conversely, labor productivity and recreational choices may be constrained during periods of sustained high temperatures.

Climate change may also influence household health and health costs (Karl et al. 2009, Osterberg and Thorne 2011). Iowans could realize more heat-related stresses, respiratory and coronary disease linked to higher levels of allergens, infectious and waterborne diseases, food poisonings, and physical injuries due to extreme weather events. Increased morbidity decreases worker productivity, lowers incomes, and increases household costs, especially medical costs. Iowa has an older median population than the nation, and this population's vulnerabilities to illnesses are likely to be exacerbated by heat and overall air quality changes due to a changing climate.

Government Services and Infrastructure

Iowa governments will see cost savings, shifting services, and cost increases because of a changing climate. Iowa's state and local governments are an essential element in the successful operation of commerce and the well-being of households. As in the private sector, climate change should increase the efficiency of local and state government operations across many service categories because public facility heating costs will be lowered by progressively warmer winters. Earlier warmth in the springtime and later warmth in autumn may require additional spending on cooling equipment in older schools. Snow removal costs will decline significantly over time for both local and state governments. Infrastructure stress due to extreme cold temperatures, such as water-main breaks, will give way to stresses associated with warmer temperatures, such as roadway buckling.

The increased weather volatility that Iowa is now experiencing has been shown to be particularly damaging to public infrastructure (Takle 2010, Swenson and Eathington 2010). Serious flooding in 1993, 2008, and 2010, as notorious examples, resulted in extensive damage to water supply and waste treatment systems in Des Moines, Mason City, and Cedar Rapids and massive

damage to state university property in both Iowa City and Ames. Serious weather events have washed out roadways and bridges, disrupted freshwater supplies, and interfered with multimodal transportation systems.

The costs of harsh weather events have proven to be monumental in Iowa of late (Swenson and Eathington 2010). Figure 6-1 displays the distribution of losses following the severe weather events of 2008 in Iowa. Those occurrences resulted in $848 million in federal appropriations to clean public space after the disaster and to repair or replace damaged infrastructure. If indeed "the dice have been loaded toward a higher probability of extreme flooding events," it could become increasingly important for Iowa to take broad and proactive measures to "enhance Iowa's flood resilience (Takle 2010)," to protect its cities and to reduce future losses. Local and state governments will increasingly require civil engineering innovations to deal with greater ranges of infrastructure-damaging occurrences, as well as withstand increased occurrence frequencies. In response, governments will likely begin to implement more stringent design standards for critical infrastructure, to include hardening that infrastructure to withstand previously unthought-of occurrences. All of these actions will increase taxpayer costs or shift costs away from other public service areas.

Disaster Services

A changing Iowa climate will create greater demands for disaster-response services. These services include monitoring disaster potentials, identifying vulnerabilities, and procuring governmental resources for recovery and humanitarian assistance, as well as disaster preparedness and training and disaster response and coordination.

Enhanced emergency management training and technical assistance in response to a changing climate and a changing range of disaster consequences are likely to be developed. Coordination with local agencies, other state agencies to include the Iowa National Guard, and federal operations such as NOAA and the U.S. Army Corps of Engineers will incrementally increase over time. Communications systems will evolve, due in part to increasing demand for early-warning systems and to increases in functionality. Disaster assistance in Iowa is currently coordinated extensively with local and state human services counseling and behavioral response resources. If climate change yields greater consequences for households and communities, those services will expand. It is conceivable that local and state governmental emergency services costs will necessarily increase to adequately fund these changes.

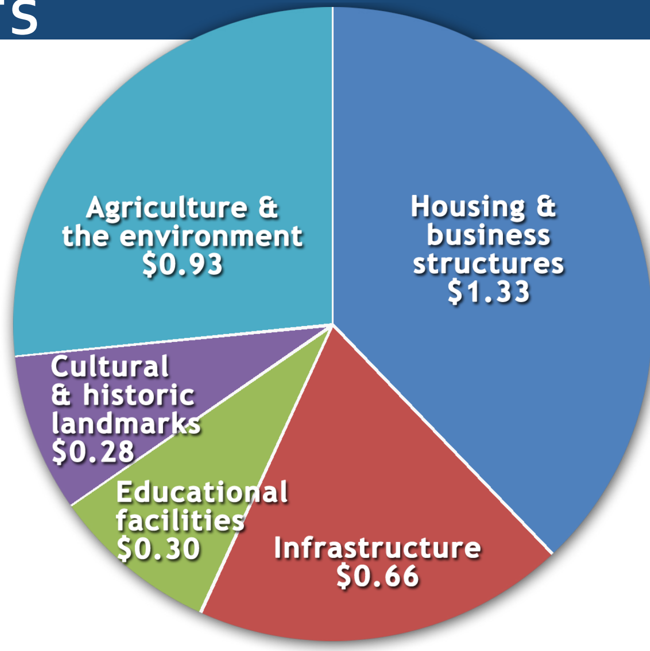

Figure 6-1. **Distribution of weather-related losses in Iowa in 2008 (amount in billions of dollars).** The consequences of weather-related events are costly to home owners, businesses, agricultural productivity, and public services and essential infrastructure. Climate change could increase the frequency of these types of losses. (Rebuild Iowa Advisory Commission 2008.)

Research Gaps

Iowa-specific research further clarifying the state's grain and oilseed crop gains and risks, along with research focusing on different forms of livestock production, will need to be underwritten by both the private and the public sectors to better identify climate change consequences for Iowa agribusiness and consumers. The Iowa Insurance Division is the key regulatory agency exercising insurance company oversight, and it could be a potential leader in sponsoring or guiding additional and on-going investigations of the risks the state's insurance industry faces over both the medium and the longer term due to climate change. The precise consequences of a changing climate on Iowa's households can be described in a broad sense, but additional economic research related to epidemiology, recreation, workforce participation, mobility, and social well-being will need to be conducted to better understand both the benefits and offsets that climate change will bring to the average household. Finally, there are many research topics affecting public service delivery, ranging from materials science and civil engineering, and disaster preparedness and response, to public health and sanitation issues, expected to arise as a consequence of a changing climate. These need to be evaluated in order for Iowa's public sector to address arising issues in both timely and effective manners.

Conclusions

There will be mixed agricultural productivity and food cost consequences for Iowa farmers, manufacturers, and consumers as a consequence of climate change. Iowa's insurance sector is important for the state and for the nation, and both state and national climate changes will affect the industry's profitability and stability in Iowa. Iowa's households are resilient, and they adapt to all manner of changing social and environmental circumstances. Climate change, however, will affect all manner of household activity including participation in the labor force, recreation, personal comfort, and health. All levels of government in Iowa will need to adapt to climate change, as well. The roles of governments given the changing climate are only beginning to be identified. It is increasingly evident that there will be incremental changes in service provision, critical infrastructure investments, disaster services, and emergency responses.

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7

Findings on the Impacts of Climate Change in Iowa

Climate Changes in Iowa

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Iowa's changing climate is already affecting the state's economy and the welfare of its people. Current state climate changes are linked, in very complex and sometimes yet unknown ways, to global climate change. Some changes, such as the increased frequency of precipitation extremes that lead to flooding, have seriously affected the state in a negative way. Others, such as more favorable summer growing conditions, have benefitted the state's economy. *Floods*, *water-logged soils*, and *droughts* have the highest impact on Iowa's economy.

Iowa has experienced significant changes in precipitation, including:

- a long-term upward trend in precipitation (see Fig. 2-1),
- an increase in extreme heavy precipitation in summer in the last 40 years, consistent with regional changes (see Figs. 1-1, 2-3, 2-4), and a shift in seasonal distribution: more precipitation now comes in the first half of the year, and less in the second half; and
- a larger precipitation increase in eastern Iowa than in western Iowa.

All of these trends are projected to continue well into the future.

Iowa has experienced a long-term upward trend in temperature (see Fig. 2-5). Again, details are most significant:

- Long-term winter temperatures have increased six times more than summer temperatures.
- Nighttime temperatures have increased more than daytime temperatures since 1970.
- Since 1970, daily minimum temperatures have increased in summer and winter; daily maximum temperatures have risen in winter, but declined substantially in summer (see Fig. 2-6).

Iowa (and the central US) has been experiencing fewer extreme high summer temperatures in the last 40 years, which seems counter to global and continental trends. This is likely due to increased summer precipitation and moist soils, which suppress surface heating and daytime summer maximum temperatures. If severe drought were to return, the current slow and steady rise in annual mean temperature could abruptly produce extreme summer heat, comparable to that of 1983 and 1988.

Temperature changes are manifest in multiple ways:

- Iowa has gained an average of 8-9 more frost-free days than 100 years ago (see Fig. 2-7). This is providing a longer growing season, earlier seasonal snowmelt, and longer ice-free period on lakes and streams.
- The number of heating-degree days has declined significantly since 1893 (see Fig. 2-9), decreasing winter space-heating requirements.
- Trends in annual growing degree days are variable across the state; some locations show increases, other decreases (see Fig. 2-8).

Global and regional climate models, which in past decades correctly predicted current trends for Iowa, now predict that Iowa's annual average temperatures will continue to increase. In the near future, rates of increase will be more like those of the last 30 years than those of the last 136 years. However, year-to-year variation around the averages of the last 10 years will be high. Decadal averages are unlikely to return to those recorded before 1970.

Iowa's humidity has risen substantially especially in summertime, which now has 13% more atmospheric moisture than 35 years ago as indicated by a 3.5°F rise in dew-point temperature. (see Fig. 2-10). Greater atmospheric moisture provides more water to fuel convective thunderstorms that provide abundant summer precipitation.

In recent years, Iowa's streamflow levels have risen in part because of changes in precipitation. Rainfall in excess of 1.25 inches/day initiates runoff and increases streamflow. The recent increase in extreme precipitation and projections of global and regional climate models point to continued enhanced streamflow and the potential for more frequent and greater flooding in coming years.

Summertime seems to be the new seasonal flood norm in Iowa. For a given amount of rainfall, summertime precipitation can create more flooding than springtime precipitation because of seasonal changes in alignment of storm tracks. Also, Iowa's recent rise in the number of large summertime rainfall events (those exceeding 1.25 inches) increases the probability of summertime floods. Higher winter and spring temperatures seem to be melting snow earlier and more slowly, reducing springtime flooding.

The Iowa legislature has taken the first steps in assessing climate changes in Iowa. Other states have demonstrated the usefulness of factoring climate change into long-term decisions on infrastructure and resource management. While more research is needed, Iowa's universities have the research capacity to improve seasonal climate predictions, deciphering for example why Iowa's precipitation extremes are increasing and whether these increases will continue. This type of understanding can guide government agencies and the private sector to better prepare for climate extremes and reduce climate impacts on Iowa's economy and the welfare of Iowa's citizens.

Agriculture in Iowa

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Recent climate trends have relevance to Iowa agriculture. Some of the observed trends are favorable to agriculture, but others are not. Farmers have responded to climate trends by planting corn and soybean earlier to take advantage of the longer growing season, installing more subsurface tiles to drain excess soil water faster, and purchasing larger combine heads to facilitate harvest in the fewer hours without dew.

Corn and soybean yields have been rising steadily since the 1940s (see Fig. 3-1). Improved management and genetics, higher fertility, and reduced drought stress have all been partially credited for this yield increase. However, crop production remains highly dependent on climate in conjunction with other variables. For example, higher monthly rainfall and increased transpiration from crops coupled with reduced winds have created favorable conditions for survival and spread of many unwanted pests and pathogens. A changing climate will impact future production through a variety of mechanisms.

Increase precipitation is having a variety of impacts including:

- Delayed planting and associated yield loss, especially critical in poorly drained soils.
- Increased replanting of damaged croplands.
- Increased soil erosion (see Fig. 3-3) and water runoff.
- Increased tile drainage, leading to greater nitrate-nitrogen loss and water quality degradation (see Fig. 3-4).
- Increased challenges associated with manure applications that are timely, nutrient-use efficient, and environmentally benign.

Combined increases in precipitation, humidity, and temperature are causing:

- Delayed nitrogen application and increased nitrogen losses.
- Enhanced development and establishment of crop pathogens and diseases.
- More weed problems and simultaneous reduction in herbicide efficacy.
- Greater use of agricultural pesticides and associated water quality issues.
- Potential reduction in productivity and lifespan of domestic livestock.

Higher nighttime temperatures are contributing to shortening of the corn grain-filling period and the lowering of potential corn grain yields.

We must remember that climate extremes, not averages, have the greater impact on crop and livestock productivity.

Iowa's Plants and Animals

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Changes in Iowa's climate will force native plants and animals, including fish and game species, to adapt or move. Several results of a warming climate are already reported in the Midwest and around the globe:

- Plants, from backyard lilacs to forest wildflowers, are leafing out and flowering sooner.
- Birds are arriving earlier in the spring.
- Particular animals are now being sighted farther north than in the past.

Some native animals and plants could disappear from Iowa. For example, the wood turtle nests on river sand bars in mid-summer (see Figs. 4-1, 4-2). Historically, this was a safe time to nest, but today's more intense mid-summer flooding is now washing out or drowning out most nests, accentuating declines of this state-endangered species.

Climate change will stress interactions among animals, plants, and their environment. As the stresses mount, even common backyard companions like the American robin could be rapidly replaced by entirely new species. Game animals will be affected as well. For example:

- *Coldwater game fish* such as *trout* and *smallmouth bass* depend on cool groundwater and clear,sediment-free streams. They could be vulnerable to rising temperatures and, with more intense rainstorms, to increased sediment from eroding fields.
- *Ducks* nest in the prairie pothole wetlands of United States and Canada. Their populations may drop due to future drought in the west and loss of habitat to agriculture in the east. More wetland habitat in the eastern pothole region could compensate for losses due to western drought.

Specific impacts of climate change on game populations or state parks are virtually impossible to predict. However, in general, scientists expect major, irreversible alterations of native flora and fauna in the next 100 years, even with the most conservative climate-change projections. The Iowa Department of Natural Resources is planning vulnerability assessments for certain groups of animals, studies that are crucial to understanding future changes and should be fully funded.

Public Health in Iowa

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Climate change has had major effects on global health. Iowa is likely to see similar effects from a changing climate, including:

- *death and illness from extreme heat waves* which disproportionately affect the elderly,
- *pulmonary and cardiac problems* from increasing air pollutants (especially ozone and fine particulates) enhanced by higher temperatures,
- increases in *infectious diseases* transmitted by new species of insects that require a warmer, wetter climate, and
- an increased prevalence of *allergic rhinitis* and *allergic asthma*.

Allergic diseases are expected to become more widespread and more severe due to a northward expansion of the range of certain allergenic plants and climate-associated increases in pollen loads from both native and invading species. In addition, Iowa's higher humidities and rise in extreme precipitation events will worsen mold exposures, thereby increasing the ranks of allergic individuals and expanding medical costs.

Iowa's increased floods pose multiple health hazards (see Fig. 5-1) in addition to death from the rising water. These include:

- mobilization of hazardous chemicals into flood waters,
- dissemination of microbial pathogens from livestock facilities and sewage treatment plants,
- carbon monoxide poisonings from use of gasoline-operated tools after floods, and
- molds contaminating flooded homes and businesses.

These problems were manifest in Iowa's 2008 floods, when researchers identified flood-related ailments that left many sick for weeks. Extreme events such as this are happening with greater frequency and severity. They will challenge our public health practitioners to do more to prepare for these events and to protect us when they occur.

Iowa's Economy, Infrastructure, and Emergency Services

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Changing climate is affecting all aspects of Iowa's economy, and will continue to do so in a major way.

Changes in agriculture are expected to be the most prominent impacts. The current upward trend in crop productivity should continue until around 2030:

- A longer and warmer growing season and wetter climate should increase corn yields, and stabilize or lower feed and food costs of Midwestern commodities.
- Higher atmospheric CO_2 could increase soybean yields.

However, these same environmental factors could also increase weed virulence, fungi, and insect issues, raising farming costs and decreasing anticipated yield gains. In addition, seasonal rainfall changes will impact spring planting and increase weather-related crop and livestock perils.

By mid-century, warmer and drier conditions are expected to decrease crop yields and negatively influence livestock health, appetites, reproduction, and range health.

Iowa's prominent insurance industry is currently responding to changes in the climate. It is:

- Undergoing transition in order to address climate change consequences nationally and in Iowa.
- Developing risk-reducing products and services.
- Vulnerable to potential losses in areas where climate-change-related risks are yet to be identified.

As temperatures rise, Iowa consumers and state and local governments could realize *savings in heating costs*. Shifts in labor productivity and public service delivery costs will produce both economic gains and losses.

If climate change results in more serious weather events, then *in addition to losses from these events* (see Fig. 6-1), *disaster services and costs of mitigation and infrastructure maintenance will rise*. More costly civil engineering innovations and designs that withstand infrastructure-damaging weather occurrences will be required.

The economic ramifications of Iowa's changing climate will continue to unfold in coming decades, with declines in agricultural productivity anticipated from mid-century on as climate change produces warmer but drier conditions in Iowa. Consequences for the broader economy over that longer horizon are less certain.