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Climate Change in the Hawkeye State: Potential Impacts on Iowa Communities and Ecosystems

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Introduction

Iowa, located in the very heart of North America, is bound by the Mississippi River to the east and the Missouri to the west. Iowa lies in a transition zone where ecosystems of the Great Plains abut more easterly forests. With more than 97,000 farms, Iowa's landscape is still largely rural, and the state is an essential part of America's, and thus the world's, breadbasket. More than half of Iowa's three million residents, however, now live in urban and suburban areas and derive their income from manufacturing, services, retail or wholesale trade, and government jobs.

This summary highlights the potential impacts of climate change on Iowa's economy, people, and the places where they live, work, and enjoy the outdoors. A short summary version of this document can be obtained at www.ucsusa.org/iowa.

The overwhelming majority of climate scientists are now convinced that human activity, primarily burning fossil fuels to produce electricity and drive our cars, is changing our climate (IPCC 2001a). These activities emit gases, principally carbon dioxide (CO₂), that blanket the planet and trap heat. Already, we are seeing signs of climate change throughout the United States and the Midwestern region: for example, average annual air temperatures and average soil temperatures are increasing (despite some summer cooling) and winters are getting shorter (Hu and Feng 2003; Karl et al. 1996). Moreover, trends in measured precipitation point to a significant increase in the central United States between 1982 and 1999 (Mauget 2003). In recent decades, this increase in precipitation has also been associated with longer growing seasons (Changnon and Winstanley 1999). Finally, extreme rainfall events have become more frequent (Kunkel 2003a, b; Kunkel et al.

2003; Trenberth et al. 2003; Karl and Knight 1998; Karl et al. 1996).

Climate Analysis

To place future climate change within the context of Iowa's climate experienced over the last century, we combined the historical record of climate over the Midwest with the most up-to-date global climate model projections for a range of future emissions scenarios. Historical data from the Midwestern Regional Climate Center (Kunkel et al. 1998, 1990) include daily observations of temperature and precipitation from more than 300 stations dating back more than a century. These long-term records offer the best view of past climate in the region and how it has already changed.

Forecasts of future changes in human activities that affect climate are based on a consistent set of projections of population growth and related demographic changes, economic growth, energy supply and demand, land use, and technological progress. These projections are used as input to complex socioeconomic models that estimate emissions of heat-trapping greenhouse and other important gases resulting from human activities in a number of sectors, including agriculture, forestry, industry, and transportation, as well as the energy use in the commercial and residential sectors.

The reference standard for these projections is a set of emission scenarios developed by an interdisciplinary team of integrated assessment modelers under the auspices of the Intergovernmental Panel on Climate Change (see the Special Report on Emissions Scenarios [SRES], IPCC 2000). Our analysis considers one scenario from each of

the four basic SRES storylines—A1, A2, B2, and B1—each of which describe widely divergent futures.¹

These emission scenarios provide input to complex, three-dimensional global climate models (GCMs) that incorporate the latest understanding of the physical processes linking the atmosphere, oceans, and Earth's surface. Our analysis is based on two of the latest generation of GCMs: the Parallel Climate Model (PCM), recently developed at the U.S. National Center for Atmospheric Research (Washington et al. 2000), and the HadCM3 model, developed at the U.K. Meteorological Office's Hadley Centre for Climate Modeling (Gordon et al. 2000; Pope et al. 2000). These two state-of-the-art climate models vary in their sensitivity, i.e., in the response of the modeled climate system to a change in atmospheric concentrations of heat-trapping gases. PCM is a low-sensitivity model while HadCM3 is a mid-range sensitivity model.

Our analysis builds upon the work of Wuebbles and Hayhoe (in press). Further detail on the methodology and results, including figures, are available in technical appendices at < <http://www.ucsusa.org/iowa> >.

While today's GCMs are generally in good agreement concerning globally averaged climate projections, regional changes in climate are more difficult to predict because the extrapolation from global to local scales is not precise. Like the actual climate system, model-simulated climate variability and uncertainty increase as the area under consideration grows smaller. In addition, the model resolution required to complete the enormous number of

calculations required for a climate projection means that GCMs are limited in their ability to represent the smaller-scale features such as local topography and land-water contrasts that drive local climate. Regional climate prediction is complicated by emissions of short-lived aerosol species and precursors such as soot and SO₂ that vary widely over space and time, as well as by land use changes. In the future, studies such as ours will be enhanced through the use of regional climate models driven by output from global models running the IPCC scenarios, currently under development.

Despite the lack of higher resolution, our confidence in the projections of general trends across the state described here is reinforced in several ways. First, the detailed historical record provides insight regarding the plausible range of future change in the region and how the future compares with past trends. Our confidence in available climate projections can further be improved through comparison of results between reliable, well-tested models, such as HadCM3 and PCM, driven by the same emission scenarios. Furthermore, systematic model bias has been removed by comparison between observed and modeled climate for the reference period 1961–1990 and projected future change calibrated to the historical record. Finally, paleoclimatic studies provide additional circumstantial evidence for the significant impacts of an Iowa climate that was only slightly warmer and drier climate than today (e.g., Van Zant 1979).

C limate Projections

Using the climate analysis described above, we combined 100 years of historical data for Iowa with the most up-to-date general circulation models of the Earth's climate system. While uncertainties in these climate models remain, we project with reasonable confidence that, in general, Iowa's climate will grow considerably warmer and probably drier over this century, especially in summer. While this suggests a departure from the historical record of the last 25 years which generally indicates winter warming, most GCMs agree on this type of temperature increase for mid-continental regions.

• **Temperature.** By the end of the 21st century, maximum daily temperatures are projected to rise 5–14°F in winter and 9–22°F in summer. Daily minimum temperatures are projected to increase at least that much, suggesting that increases of average daily temperatures are roughly on the same order of magnitude. This dramatic warming is more than the warming seen since the last ice age, some 10,000 to 12,000 years ago. Extreme heat will also become more common, and the growing season could be three to seven weeks longer by the end of the century.

¹ The A1FI scenario is a fossil fuel-intensive scenario lying at the highest end of the range of human-related emissions throughout the next century. In this scenario, a rapid rate of temperature change is driven by a continued dependence on fossil fuels and rapid economic growth throughout the next century. The A2 and B2 scenarios span the middle range of the new SRES projections (which, globally, are above the old IS92a ("business-as-usual") scenario on which a number of earlier impact assessments were based). At the upper- mid range, A2 represents a very heterogeneous world where economic development is regionally-oriented and economic growth and technological change are relatively slow. By the end of the century, A2 emissions exceed those of the A1FI "high" scenario. In the lower-mid range, the emphasis in the B2 scenario is on local solutions to economic, social, and environmental sustainability with less rapid and more diverse technological change. Finally, the B1 scenario, which has lower emissions than the other scenarios by the end of the century, focuses on global solutions to economic, social, and environmental sustainability. Clean, efficient technologies are introduced in all sectors. Importantly, concentrations of heat-trapping gases, even in this lower-end scenario, are still significantly higher (reaching about 550 ppm, which is almost a doubling relative to pre-industrial concentrations of 280 ppm) than today's emission concentration of about 370 ppm CO₂.

• **Precipitation.** While annual average precipitation may not change much, seasonal precipitation in the state is likely to change, increasing from the current winter average of 3 inches by up to 30 percent and decreasing in summer from today's average of 12.6 inches by 10 to 35 percent by the end of the century. When summer rain does fall, it will likely come in intense downpours. For example, the frequency of heavy 24-hour rainstorms, which already nearly doubled over the past century (see also Trenberth et al. 2003), will continue to increase and by 2100 could be as much as double again. Multi-day intense rainstorms, with a slight increase in frequency since 1900, may also become more frequent, but projections for these storms are less conclusive at this time.

• **Soil moisture.** In the near term, moisture deficits are not expected to occur more frequently. By the end of the century, however, the combination of significant increases in summer temperature, more evaporation, more runoff from intense rainfall events, and the decline in summer precipitation could lead to drier soils and more droughts. Especially during crop development and grain infilling, expected soil moisture deficits could become problematic (see also Haskett et al. 2000). More rainfall in winter and spring, on the other hand, increase soil moisture, thus leaving projections for the annual moisture budget uncertain. In case of saturation of soils and floods in spring, planting dates could be delayed.

What the Climate Will Be Like

These changes will dramatically affect what the climate will be like. By 2030, Iowa summers may resemble those of Kansas in terms of average temperature and rainfall. By the end of the century, Iowa's summer climate will generally be more like that of current northwest Mississippi. Winters will also change, albeit less drastically. By century's end, they may be similar to current-day northern Kansas.

Potential Impacts of Climate Change

Agriculture

Iowa devotes the most land area of all U.S. states to agricultural production. In 2002, it ranked first nationwide in soybean, corn, and egg production. Livestock is very important as well, with the state being first in hogs, ninth in cattle and calf production, and twelfth in milk production

(IASS 2003a, b).² In addition, Iowa's agriculture produces biofuel, clothing and medicine for world markets. In 2001, Iowa's agricultural exports totaled \$3.25 billion, ranking Iowa third in the nation in total agricultural exports. It is estimated that one Iowa farm grows enough food and fiber to feed 279 people (Iowa Department for Agriculture and Land Stewardship 2003; Iowa Tourism Office 2003).

Climate exerts a significant influence on agricultural yields and profitability, yet scientists point out that population growth, market fluctuations, and access to resources including emerging technologies that might facilitate adaptation and increase productivity also influence farmer's options (Johnson et al. 1983; Adams et al. 1999a). Most previous studies, relying on older climate models and emission scenarios, suggested that while production patterns are likely to shift regionally, climate change is not likely to seriously disrupt this region's agricultural capacity over the next 100 years (Adams et al. 1999a; Reilly and Graham 2001; Reilly et al. 2001; IPCC 2001b). In particular, these studies concluded that overall U.S. capacity to grow food would not be reduced and that changing climate could deliver economic savings to the public, while likely increasing costs to farmers (Reilly et al. 2003, 2001).

More recent studies are less optimistic and highlight significant challenges to agriculture that need to be weighed against the positive impacts from a warmer climate. Applying the new climate projections to what is known about the influence of climate on crops and crop pests, Iowa's farmers may see the following impacts in the future:

• **CO₂ fertilization and crop yields.** Increased atmospheric CO₂ and (biologically, photochemically, and radiatively active forms of) nitrogen, higher temperatures, a longer growing season, greater water use efficiency, and improvements in soil organic matter (Brinkman and Sombroek 1996) could improve seed quality, and boost yields of some crops, such as soybean and wheat, and less so for corn. Ainsworth et al. (2002) suggest that soybean biomass could increase by 40 percent and soybean yield by 24 percent. Much of the predicted increase is attributable to the CO₂ fertilization effect, but uncertainty is high as such predictions depend strongly on the climate scenarios used (see also Mavromatis and Jones 1998). Reflecting this ambiguity, another recent study (using older models and milder, wetter climate scenarios) simulated corn yields under different conditions and concluded that yields could increase, decrease, or be unaltered in the Corn Belt by 2095, while soybean yield may decline (Izaurrealde et al. 2003). That study also suggested that by 2030, increasing corn yield in the Corn Belt and the Great Lakes states may

² Rank based on production in bushels (grains), pounds (milk), head (livestock), or absolute numbers (eggs).

not be sufficient to offset losses in the Plains, potentially resulting in lowered overall national production. Future studies using hotter and overall drier climate scenarios—such as the one used here—will show whether regional and/or national crop yield projections will have to be adjusted downward given the less favorable climate projections.

• **Extreme rainfall.** The incidence of extreme precipitation has increased notably in a belt extending from the Northeastern United States, via the southern portion of the Great Lakes, into the Northern Plains (Kunkel et al. 2003; USGS 1999). Over half of the total increase in precipitation is due to increases in the upper 10 percentiles of intensity. Despite this increase, the frequency of summer rain days has not increased in the central United States since 1910 (Karl and Knight 1998). Climate projections developed for this study suggest that trends in short, extreme rainfall events are likely to increase. Extreme events, such as severe storms and floods during the planting season, could depress productivity. The combination of flooding and high heat is particularly lethal to row crops (Rosenzweig et al. 2002; Schoper et al. 1986). Increased frequency and severity of flooding may also increase grain shipping costs due to delays in shipping on the Mississippi and Missouri rivers when barges cannot use the river ways.

• **Droughts and irrigation needs.** Studies using more moderate climate projections concluded that warmer and wetter conditions could increase the yield of rain-fed crops and potentially reduce the need for irrigation on crops requiring additional water (Izaurrealde et al. 2003; Reilly et al. 2003). But these models not only overestimate future summer precipitation (compared to the updated projections used in this study), but also the benefits of such projected average increases (Changnon and Hollinger 2003). Instead, changes in the *distribution* of rain and of temperature extremes, rather than in *average* traits, will determine agricultural outcomes. Consequently, hotter and drier conditions and potentially more frequent droughts during the early and main growing seasons are likely to disrupt production. The risk from drought stress is illustrated in the fact that four days of soil moisture stress can reduce corn yield by 50 percent (Rosenzweig et al. 2001; Schussler and Westgate 1991). Thus, currently rain-fed crops may require irrigation, an additional economic challenge to farmers. Moreover, heat stress during the pollination of corn (July) can have particularly negative impacts on yields (Carcova and Otegui 2001; Takle and Mearns 1995a, b).

• **Ground-level ozone.** Higher ground-level ozone concentrations (a likely outcome of higher nitrogen oxides emissions from fossil fuel combustion and fertilizer use) may counter positive impacts of a warmer climate (Fuhrer 2003; Long and Naidu 2002; Chernikova et al. 2000; Levy II et al. 1995). In particular, ozone damage is expected to cause losses in soybean yields and horticultural crops (Morgan et al. 2003; Benton et al. 2000).

• **Runoff and soil erosion.** In recent years, north-central Iowa has experienced an expansion of confined animal feeding operations (CAFOs), which accumulate large quantities of manure and, consequently, nutrients that pose risks to air and water quality (Jackson et al. 2000). Moreover, high present-day rates of fertilizer use on maize and the expansion of soybean cultivation have already contributed notably to eutrophication of the Mississippi River since 1950 (Donner et al. 2002; McIsaac et al. 2001). The risk of soil erosion and runoff of such agricultural wastes and chemicals is likely to increase if flooding and intense rainfall events with big runoff pulses become more frequent (Interlandi and Crockett 2003). More soil erosion would also raise farmers' costs to maintain soil fertility as well as downstream costs to restore or preserve safe drinking water standards (Lal 1998; Forster et al. 1987).

• **Agricultural pests and diseases.** The future of agricultural pests is complex, with a number of factors favoring their abundance and spread and other factors potentially constraining them. In general, warmer winters, longer freeze-free periods, and shifts in temperature and rainfall combine to create more favorable conditions for a number of pests. Extremely high temperatures or potential increases in natural enemies, such as insect-eating birds, would contain them.

- Milder winters, for example, result in enlarged pest populations of corn borer, aphids (which carry soybean mosaic virus), and leaf hoppers (Rosenzweig et al. 2001), and also in a northward shift of pests currently uncommon in Iowa.
- Day length and temperature influence the number of generations of some pests, such that higher temperatures accelerate the number of generations of multi-generational species including bean beetles. Very high temperatures, however, would limit insect life span (Rosenzweig et al. 2001).
- Pests, such as the western corn rootworm, which now have only one generation per year, may also be affected by indirect influences -- for example, the potential increase or decrease of natural enemies.
- Fluctuating temperatures during winter and spring would kill many insect pests as they come out of diapause/dormancy, especially in the near-to-mid term, where average winter temperature increases are still relatively small and frequent back-and-forth between below- and above-freezing temperatures likely (Rosenzweig et al. 2001).
- Studies relying on milder, wetter climate projections found that increased frequency of corn pests, such as grey leaf spot, crazy top and smut are common problems resulting from excess moisture

and warm, humid conditions (Scherm and Yang 1995; Yang and Scherm 1997; Yang et al. 1998; Rosenzweig et al. 2001). Other studies project that a warmer, wetter climate would result in expanded ranges of soybean sudden death syndrome (Scherm and Yang 1999; Hartman et al. 1995). These conditions could be met in the near term where warming and, thus, the drying effect of a warmer climate are still less extreme. As the region dries overall, insect pests common under drought conditions, such as soybean cyst nematode and aphid-borne viral diseases, are likely to increase (Rosenzweig et al. 2000).

• **Heat stress on crops.** Greater number of heat waves will reduce crop growth and quality, especially in already dry conditions (Wheeler et al. 2000). For example, soybeans and corn are particularly sensitive to excessive heat during early growth stages, and pollen viability decreases at high temperatures (Chinnusamy and Khanna-Chopra 2003; Liu et al. 2003; Carcova and Otegui 2001; Dupuis and Dumas 1990; Schoper et al. 1987). At present, soil moisture stress already limits soybean yield, explaining—in one study of 30 sites in Iowa—more than 48 percent of yield variability (Irmak et al. 2002).

• **Heat stress on livestock.** Warmer summer temperatures suppress appetite and decrease weight gain in livestock; warmer winters and less snow cover likely will reduce the quantity and quality of spring forage and, thus, milk quality (Adams et al. 1999). Extreme heat also decreases milk production. Other livestock production (e.g., hogs, chickens) will likely become more expensive as the need for cooling grows with higher temperatures (Smoyer-Tomic et al. 2003).

• **Winners and losers.** Recent studies acknowledge the distributional effects of climate change on agriculture. Overall (e.g., national summaries) hide that some regions or types of crops may win under climate change, while others lose—an outcome that becomes only apparent at finer local and regional scales (e.g., Adams et al. 2003; Tsvetsinskaya et al. 2003).

Water Supply and Pollution

Iowa depends heavily on groundwater, surface waters, and rainfall for agriculture, drinking, and industrial uses. Paleoclimatic studies have determined that in the only slightly warmer and drier climate of 6,000 years ago, water tables in northwest Iowa dropped significantly (Van Zant 1979). Whether or not the state's current population of about three million continues to grow (U.S. Census Bureau 2002), these paleostudies caution us to prepare for the potential impacts of a warmer climate on all freshwater users, especially in light of the far greater projected changes in rainfall, evaporation, and groundwater recharge rates in the future.

• **Water yield.** Water yield modeling studies relying on milder, wetter climate scenarios than those underlying this study suggest that mid-continental regions of the United States may become drier by 2030 (Rosenberg et al. 2003). A recent stream flow modeling study for the Upper Mississippi River Basin (UMRB), using milder and wetter climate projections based on a business-as-usual emissions scenario and a well-established regional climate model to downscale global projections, suggests annual average increases in stream flow (except in late fall) for the UMRB (Jha et al. 2003). A similar study for the Upper Missouri River Basin showed comparable results (Stone et al. 2001). Both Jha et al. (2003) and Sankarasubramanian and Vogel (2003) suggest that stream flow/watershed runoff increase disproportionately relative to the increase in precipitation, suggesting that winter and spring flooding become more likely even with only a small increase in precipitation. The newer (hotter and overall likely drier) climate projections used in this study are likely to shift these projections to an even more pronounced seasonal pattern: more stream flow in winter and spring, less in summer and fall.

• **Flood risk.** Increased heavy precipitation events will increase the risk for flood damage. For example, Pielke and Downton (2000) found that flood damage is related to the number of two-day heavy rainfall events and the number of wet days. Additional support for the connection between climate change and flood frequencies is provided by paleoflood records reconstructed from the Upper Mississippi and Lower Colorado River systems. These records show that small changes in climate—on the order of 1–2°C and a 10 to 20 percent increase in precipitation, well within the projected ranges for Iowa—resulted in important changes in the magnitude and recurrence frequencies of extreme floods in the region (Knox and Kundzewicz 1997; Knox 1993).

• **Flood-absorbing capacity of floodplains and wetlands.** Impacts from development and climate change combine to degrade the natural flood-absorbing capacities of wetlands and floodplains.

• **Soil erosion and runoff.** Increased flooding, especially during spring run-off when fields are still without or only minimal crop cover, will worsen soil erosion and runoff of agricultural chemicals and wastes into the water supply (Donner et al. 2002; Adams et al. 1999a, b). This could exacerbate existing water quality problems from nitrate pollution, pesticide residues, bacterial contamination, and other toxins entering ground- and surface water reservoirs (Iowa Water Quality Bureau 2001; Kolpin et al. 1997).

• **Public water supplies.** Major storm and flood events can also leave cities temporarily without public drinking water supplies, as in the 1993 Mississippi flood when the entire city of Des Moines was without its public water supply system for 20 days, affecting 250,000 people (MMWR 1993).

- **Groundwater recharge.** Reduced summer water levels are likely to diminish the recharge of groundwater, cause small streams to dry up, and reduce the area of wetlands, resulting in poorer water quality and less habitat for wildlife (LeBaugh et al. 1996; Poiani et al. 1995).

- **Demand on water supplies.** Experience shows that water consumption increases drastically during periods of extreme heat. Thus, as summer temperatures increase and heat waves become more common, additional demands on limited supplies may produce local shortages and water distribution conflicts (Palecki and Changnon 1999).

Human Health

Climate projections suggest that extreme heat periods are likely to become more common, as will severe rainfall events and flooding, especially if grounds are frozen or already saturated. Iowa has experienced a stark preview of this future scenario during the past decade or more with the big Mississippi River flood of 1993 (the state's costliest disaster ever); more record-breaking floods in 1998, 1999 and 2002; tornado outbreaks associated with the severe rainstorms and floods of 1999; intense heat waves in July 1995, July 1999, September 2000, and August 2003; and drought conditions in late summer of 2003 (Iowa Channel 2003; NOAA 2003; Office of the Governor 2003; American Red Cross 2002; Smith 2002; AP 2000; AP 1999; NOAA 1999; Palecki and Changnon 1999; USA Today 1999; CNN 1998). The climate analysis done for this study suggests that events such as these are likely to become more common in a warmer climate, confirming trends expected globally (IPCC 2001a, b).

- **Heat waves.** Health risks from winter cold-related mortality will decrease, while summer heat-related morbidity or mortality is likely to increase. The number of days above 90°F in Iowa is projected to increase two- to five-fold, with years later in the century experiencing 50 to 85 such days. Of even greater concern is the projected increase in extreme heat days (exceeding 97°F). By 2080–2100, Iowa could see more than 30 to 60 such days annually, which will require improved warning systems, more secure power supplies for cooling, and other medical preparation to avoid severe health impacts. More important for human health perhaps than the number of individual days exceeding certain temperature thresholds, however, are extended heat periods. Based on the climate projections developed for this study, heat waves will become more frequent: by the end of the 21st century, three-day heat events with temperatures over 90°F could occur as many as 15 to 25 times per year on average, where the lower end of that range is similar to the peak of the dustbowl era, while the upper end of that range is outside the range of historical experience. Heat events lasting 10 days could be as much as 10 times as frequent as today by 2100. Such extreme

heat periods are likely to be felt more strongly in cities, where the urban heat island effect can magnify regional high temperatures by several degrees. The most vulnerable populations include the elderly, children, and otherwise ill people (Palecki et al. 2001; Thornbrugh 2001; Palecki and Changnon 1999; Fouts and Piver 1995).

- **Air pollution.** Higher temperatures and more electricity generation for air conditioning could increase the formation of ground-level ozone, likely exacerbating asthma and other respiratory diseases, especially in children and the elderly (Fouts and Piver 1995). While federal air quality standards are currently met throughout the state (U.S. EPA 2003), ozone levels are already fairly high in eastern counties of the state (American Lung Association 2003) and could well exceed safe levels as temperatures and air pollution (especially the release of nitrogen oxides from fossil fuel combustion and fertilizers) continue to increase. Such increases are likely to increase the number of Iowans suffering from asthma (more than 200,000 in 1999), as well as the associated medical expenses (\$116 million in 1994) (Iowa Department of Public Health 2003).

- **Risks from floods.** Threats to public health during flood events, such as flood-related injuries, temporary loss or contamination of drinking water supplies, or closure of public sewer systems, as well as interruptions in public health services, could become more common.

- **Infectious diseases.** The occurrence of many infectious diseases is strongly seasonal, suggesting that climate plays a role in influencing transmission (Gubler et al. 2001). Some diseases carried by ticks, such as monocytic ehrlichiosis (transmitted via infected white-tailed deer) (Mueller-Anneling 2000), or by mosquitoes, such as West Nile fever and western equine encephalitis, are rapidly expanding across the state (CDC 2003; MMWR 1993). Lyme disease, also spread by ticks, is becoming a threat at least in eastern Iowa (CDC 2001). While this spread is attributed largely to land-use changes, future changes in rainfall or temperatures could encourage greater reproduction or survival of the disease-carrying vectors (Gubler et al. 2001). In fact, recent studies suggest a clear link between infectious diseases and climate. For example, the extreme weather conditions accompanying long-term climate change may be contributing to the spread of West Nile virus in the United States (Epstein 2001). Current evidence suggests that inter-annual and inter-decadal climate variability have a direct influence on the epidemiology of vectorborne diseases (Githeko et al. 2000). With more heavy rainstorms, waterborne diseases will also pose a higher risk to human health. As weather disasters are likely to increase, both noninfectious and infectious diseases may flourish (Yoganathan 2001). Waterborne disease outbreaks due to surface water contamination showed the strongest association with extreme precipitation during the month of the outbreak, while a two-month lag

applied to groundwater contamination events (Curriero et al. 2001).

Property and Infrastructure

Cities such as Des Moines, Cedar Rapids, Davenport, Sioux City, and smaller cities, especially along rivers, are particularly vulnerable to the risks of climate extremes, incurring direct economic losses or requiring costly adaptations.

- **Extreme events.** More frequent extreme weather events such as storms and floods, exacerbated by stream channeling, levee construction, and more paved surfaces (e.g., in Fremont County along the Nishnabotna and Missouri Rivers [U.S. EPA 2002]), result in greater runoff, increased risk of landslides, more property damage, heavier burdens on emergency management, increasing cleanup and rebuilding costs, and a greater financial toll on farms, businesses and homeowners (Middlemis-Brown 1996).

- **Demands on insurance sector.** Iowa's burgeoning insurance sector could become more vulnerable economically as weather-related hazardous events affect rural areas (farms and crops), cities (property and infrastructure), industry, and businesses (Center for Business and Economic Research 2001). In reviewing past trends in damages and losses from extremes such as flooding, hail, hurricanes, tornadoes, and severe thunderstorms, Changnon (2003) found that flooding was the only extreme to exhibit a net upward trend in adjusted losses from 1950 to 1997. Other studies have shown that growth in total weather-related damages over the past few decades is related to both increases in heavy precipitation events and societal factors, including population growth and increases in per capita wealth (Pielke and Downton 2000). In terms of future change, Choi and Fisher (2003) found that a 1 percent increase in annual precipitation could enlarge catastrophic losses by as much as 2.8 percent, with losses increasing primarily due to inflation, population growth and per capita increase in wealth. These results illustrate the importance of extreme events under a changing climate regime as well as the need for land use planning and hazards management that accounts for these trends.

- **Infrastructure damage and adjustments.** Storms, and flooding in particular, will require changes in infrastructure. Municipalities in Iowa will have to upgrade water-related infrastructure including levees, sewer pipes, and wastewater treatment plants in anticipation of more frequent extreme downpours (Kling et al. 2003). Those drawing water from domestic wells will also have to take precautions to avoid contamination during heavy storm and flood events (CDC 2002). Extended heat periods in the past have also caused damage to roads due to heaving. As such periods become more common, road repair costs are likely to increase (Palacki and Changnon 1999).

Forests, Prairies and Terrestrial Wildlife

The 2.1 million acres of hardwood forests remaining in southern and eastern Iowa are crucial for wildlife, water supply protection, erosion control, and recreation (IDNR 2002a; Walkowiak and Haanstad 2001; Jungst et al. 1998; U.S. EPA 1998). For example, riparian woodlands along streams and rivers provide shade and cooling for fish and aquatic life. Forests also provide habitat for the declining redheaded woodpecker and the federally protected Indiana bat. Moreover, Iowa's 42,000 acres of state forests provide numerous recreational opportunities (IDNR 2002b), including hiking, fishing, hunting, cross-country skiing, horse riding, and snowmobiling. Forests—already fragmented and diminished in extent by post-glacial climatic changes and more recent historic land use—are vulnerable to additional climate stresses (Norris et al. 2001). Habitat fragmentation has already resulted in low genetic variability in small isolated populations of balsam fir and reduced its ability to adapt to climate change (Shea and Furnier 2002).

- **Ecosystem shifts.** Almost all of the state's natural woodlands are home to Iowa's state tree, the oak. Wild turkeys, pheasants, quail, wood ducks, nuthatches, grackles, and some woodpeckers depend on acorns for some part of their diet. Modeling studies assuming similar hot-and-dry climate change scenarios for the American Midwest as used in this study suggest that many oak species may be gradually replaced by more drought-tolerant species, such as southern pine or bur oak (Bachelet et al. 2003, U.S. EPA 1998). Other rare tree species in Iowa, such as white pine, balsam fir, and yellow birch—which are at their southern limit in the state—are extremely vulnerable to climate change and may be lost from the state (Iverson et al. 1999).

- **Long-term forest health.** Increasing atmospheric CO₂ will likely spur forest growth in the short term. Elevated levels of nitrogen oxides (from fossil fuel combustion and fertilizers), however, also lead to higher concentrations of ground-level ozone. Together with the potential for more frequent droughts and a greater risk from insect pests and invasive species, long-term forest health could be at risk (Bachelet et al. 2003, Walkowiak and Haanstad 2001; Bezemer and Jones 1998; Lindroth 1996; Levy II et al. 1995).

- **Biodiversity and ecosystem interactions.** The impacts of higher CO₂ concentrations on wild flowering plants have been shown to vary substantially, with both inclines and declines being observed and modeled (Jablonski et al. 2002). The difficult-to-predict resulting changes in community-level species interactions include altered biodiversity, plant community dynamics, and ecosystem functioning (Körner 2000).

• **Isolated habitats and species losses.** Natural prairies and oak savannas, which once dominated the region, are now endangered ecosystems (U.S. EPA 1998). Only a few isolated segments of natural or restored tallgrass prairie remain in Iowa (U.S. FWS 2003a, b; Smith 1998).

Together with other human pressures on these habitats, increasing climate extremes or variability (e.g., droughts, floods) can have particularly devastating impacts on these isolated patches of native plant habitat, potentially leading to species extirpation (local loss of species) (IDNR 2002; Norris et al. 2001; Farrar 2001; Bernstein 1998; Lewis 1998).

• **Songbirds.** Many bird species have already reacted to the moderate warming that has occurred in the American Midwest over the past century, as evidenced in earlier arrival and breeding dates as well as range shifts (Root et al. 2003). Dynamic shifts in the state's avifauna have been observed over the past 25 years, likely due to a combination of factors, including land use, competition from invasive species, and climate change (Dinsmore 2001, 1998). One recent study found that as many as 36 songbird species, some of which are already on Iowa's endangered or threatened species list or are particularly hard-hit by the West Nile epidemic (CDC 2003; Price 2003; Iowa Natural Resources Commission 2002), could be lost from Iowa by the end of the century as a result of climate shifts. Ten species currently not at home in Iowa may become established in the state, leading to a potential net loss of 26 bird species in Iowa (Price 2003). Iowa's state bird, the American goldfinch, may contract its range to the northern part of the state (Price 2003).

• **Mammals.** Past declines of mammals typically coincided with the decline of forest and prairie habitat, while population increases reflected habitat restoration. Thus, the future of mammals in Iowa will be closely tied to how the combined pressures of land use change and climate warming will affect the availability of suitable habitat (Bowles et al. 1998). Some widely adaptable resident mammals such as raccoons, skunks, and the already prolific white-tailed deer may benefit from climate change, possibly exacerbating health threats, such as rabies, Lyme disease, or monocytic ehrlichiosis, which are transmitted by infected deer (Peterson 2002).

Recreation along Rivers, Streams and Wetlands

Iowa has more than 19,000 miles of fishable rivers and streams and more than 230 natural and man-made lakes that draw countless local anglers, birders, and hunters each year (IDNR 2001c). Wetland areas, while dramatically reduced since settlement, including the globally important Prairie Pothole region, which extends into north-central Iowa, still provide crucial stopover habitat for many waterfowl and migratory shorebirds of the western

hemisphere, as well as important recreational opportunities (U.S. FWS 2003a; Iowa State University-Department of Animal Ecology 1999; Bishop et al. 1998).

• **Warmer waters and fish.** Anglers on lakes will be affected by range shifts, loss of habitat, and increases or declines of their preferred catch. For example, Iowa's only cold-water fish, the trout, while currently stocked, may not survive in the state's warming waters. The Western mosquitofish—in the past limited in its range by cold Iowa winters—is already moving northward; other, more southerly fish species, such as the spotted gar, might migrate north in the Mississippi River (IDNR 2001a; Bernstein and Olson 2001).

• **Mercury and water pollution.** In 1999, Iowa ranked 17th in the nation in terms of mercury pollution from power plants (Corrigan 2003). Lower water levels in rivers coupled with warmer water temperatures may accelerate the accumulation of mercury and other contaminants in the aquatic food chain and ultimately in fish (Yediler and Jacobs 1995).

• **Wetlands and wetland restoration efforts.** Earlier spring runoff, more intense flooding, lower summer water levels, and extended droughts in a warmer climate generally spell growing challenges for Iowa's wetlands and the species that depend on them, unless they can adapt fast enough to the changing conditions (Garner 2003, personal communication). Already, development and agriculture have significantly reduced wetland habitat and resulted in amphibian and reptile declines throughout the state with several species on the state's endangered species list (Iowa Natural Resources Commission 2002; Christiansen 1998). Climate change could also hamper ongoing wetland restoration efforts. Loss of habitat or food resources for migratory birds, shorebirds, and waterfowl will affect Iowans' opportunities for birdwatching and hunting.

• **Invasive species.** Common invasive plants in lakes and wetland areas, such as Eurasian watermilfoil and purple loosestrife, already create pressures on native plant and animal communities. Climate change generally tends to favor such invasives, as their habitat requirements are frequently less specialized than those of native plants, they can disperse more rapidly, and they often have higher reproductive potential and success (Bernstein and Olson 2001; IDNR 2001b; Phillips 2001, 1998; Wiebe and Obrycki 2001; Galatowitsch et al. 1999).

• **Summer recreation.** The summer recreation season is likely to expand as temperatures warm further, but extreme heat, extreme downpours, elevated ozone levels, and possible increases in risk from insect- and waterborne diseases will affect those who enjoy the outdoors and may involve some restrictions and require behavioral adjustments.

C

limate Change Solutions

Climate change requires a comprehensive response (IPCC 2001b, c; Carmichael, Folk, and Schnoor 1995).³ Iowans can help reduce the potential impacts from climate change by pursuing three necessary and complementary strategies: (1) *Reducing heat-trapping gas emissions* to help curb the threat from a changing climate (mitigation of climate change); (2) *minimizing pressures on the environment* by improving air quality, protecting the quality and supply of water resources, protecting habitat, and limiting sprawl through more effective urban and rural planning (environmental protection and sustainability); and (3) *preparing for the unavoidable impacts* from global warming through adaptations in agriculture, better planning and emergency preparedness, strengthened public health response and warning systems, improved insurance coverage, and adjustments to flood control measures based on projected precipitation trends (adaptation to climate change).⁴ This three-pronged approach will require an ongoing, active dialogue between scientists and decision-makers in the private and public sector.

With foresight, planning, and a commitment to responsible management, Iowa can lead the Midwestern farm states in designing effective climate solutions. It is only fitting that the state that is first in the production of several farm crops also become first in stewardship of its rich environment and resources and reduce its carbon emissions to minimize the threats from climate change.

R

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³ For additional information on climate change solutions, see www.ucsusa.org/iowa.

⁴ The literature on each of these response options is vast, and a comprehensive discussion goes beyond the scope of this paper. We direct the reader to a small, introductory set of papers specific to the Midwest on mitigation in the energy sector (IA DNR 2003; IRENEW 2003; see also Fouts and Piver 1995, and the Solutions fact sheet produced by UCS, available at www.ucsusa.org/iowa), on adaptation (e.g., focus on agriculture, see Changnon 1995), and corporate and civic society sustainability strategies (e.g., Harkin 1995; Hansen and Paul 1995).

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