WORKSHOP PROCEEDINGS

Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond

Social Vulnerability and Risk

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ESS, LLC and
IPCC Working Group II
Technical Support Unit

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Abstract

Climate change is affecting natural and human environments, with greater impacts projected as temperature and precipitation patterns continue to change. But what does evolving climate change mean to people in communities with different lifestyles and infrastructure, and thus, different ways of experiencing climate? Impacts will differ among communities because climate-related weather changes will be manifested differently and because communities have strengths and limitations in their response. Using national and state assessments hides local circumstances by averaging over these differences. Therefore, assessments of climate change risks based on aggregate analyses may provide a false sense of limited and manageable impacts when, in fact, some communities may suffer high consequences. For example, a prolonged future heat wave may bring reports of disparate impacts: some areas will see higher mortality rates, especially in elderly populations, and significant losses of livestock, while others may only notice a disruption in summertime sports, such as baseball.

Introduction

A recent assessment (SAP 4.3) concluded it is very likely that temperature increases, increasing carbon dioxide levels, and altered patterns of precipitation are already affecting U.S. water resources, agriculture, land resources, biodiversity, and human health (Backlund et al., 2008); similar conclusions were reached by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a). The SAP 4.3 also concluded that it is very likely that climate change will continue to have significant effects on these resources over the next few decades and beyond. For example, Table 1 summarizes some of the regional vulnerabilities to specific climatic changes[1] (Gamble et al., 2008). However, the extent of impacts depends not only on the magnitude and degree of climate change (i.e. the exposure to climate change), but also on the vulnerability of the affected population, system, or sector.

This paper examines ways in which climate change may affect communities differently, depending on vulnerabilities and types of impacts, and then illustrates this with a future scenario – the impacts of an intensified U.S. Midwestern heat wave in 2015 on three cities.

Table 1. Summary of Regional Vulnerabilities to Climate-Related Impacts
(*Source: Gamble et al,.(2008)*

United States Census Regions	Climate-Related Impacts								
	Early Snowmelt	Degraded Air Quality	Urban Heat Island	Wildfires	Heat Waves	Drought	Tropical Storms	Extreme Rainfall with Flooding	Sea Level Rise
New England ME VT NH MA RI CT	•	•	•		•	•		•	•
Middle Atlantic NY PA NJ	•	•	•		•	•	•	•	•
East North Central WI MI IL IN OH	•	•	•		•	•		•	
West North Central ND MN SD IA NE KS MO	•		•		•	•		•	
South Atlantic WV VA MD MC SC GA FL DC		•	•	•	•	•	•	•	•
East South Central KY TN MS AL					•	•	•		•
West South Central TX OK AR LA		•	•	•	•	•	•	•	•
Mountain MT ID WY NV UT CO AZ NM	•	•	•	•	•	•			
Pacific AK CA WA OR HI	•	•	•	•	•	•	•	•	•

Vulnerability, Sensitivity, and Risk

Vulnerability is the susceptibility to harm, which can be defined in terms of population or location. The IPCC defines vulnerability to climate change as the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate variability and change (IPCC, 2007b). Vulnerability to climate change is described as a function of the character, magnitude, and rate of climate variation to which a system is exposed, its

[1] See the paper by MacCracken and Richardson in this volume for more detail.

sensitivity to that exposure, and its ability to avoid, prepare for, and effectively respond. When describing the vulnerability of a region, its characteristics, such as baseline climate, abundance of natural resources (e.g., access to freshwater), elevation, infrastructure, and other factors, can alter vulnerability. For example, coastal zones may be vulnerable to sea level rise or to typhoons. From a population perspective, vulnerability can be defined as the summation of all risk and protective factors that ultimately determine whether a subpopulation experiences adverse outcomes (Balbus and Malina, 2009).

Sensitivity can be defined as an individual's or subpopulation's increased responsiveness, primarily for biological reasons, to a particular exposure. Biological sensitivity may be related to developmental stage, pre-existing medical conditions, acquired factors (such as immunity), and genetic factors (Balbus and Malina, 2009). Socioeconomic factors also play a critical role in altering vulnerability and sensitivity, by interacting with biological factors that mediate risk (such as nutritional status) and/or lead to differences in the ability to adapt or respond to exposures or early phases of illness and injury. For example, adults who may be vulnerable during a heat wave include those over the age of 65, those with chronic diseases or taking certain medications, and other subpopulations. The proportion of these groups in a population is one determinant of a community's vulnerability. Table 2 lists groups particularly vulnerable to various climate-related exposures.

Table 2. Groups with Increased Vulnerability to Climate Change
(Source: Balbus and Malina, 2009)

Climate-Related Exposures	*Groups with Increased Vulnerability*
Heat stress	Elderly, chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers
Extreme weather events	Poor, pregnant women, chronic medical conditions, mobility and cognitive constraints
Ozone (air pollution)	Children, pre-existing heart or lung disease, diabetes, athletes, outdoor workers

A climate-related *risk* is the result of the interaction of a physically defined hazard (i.e. floods and other extreme weather events, increasing temperature, and other factors) with the properties of the exposed system (its vulnerability) (Lim et al., 2005). Risk also can be considered as the combination of an event, its likelihood, and its consequences (risk = the probability of a climate hazard multiplied by a given system's vulnerability). Therefore, system vulnerability is a critical determinant of the risk the region or subpopulation faces when exposed to a particular hazard. For example, Cuba, which has extensive programs for reducing vulnerability to hurricanes, faces less risk than neighboring countries with less extensive disaster risk reduction programs (Thompson and Gaviria, 2004). This also means that programs to decrease vulnerability will, in most cases, decrease risk.

Aggregated vs. Differentiated Impacts

Human systems include social, economic, and institutional structures and processes. Climate is one of many influences on these systems; other influencing factors include access to financial resources, urbanization, and shifts in demographics. Climate change will interact with these factors to stress U.S. populations and societies, and in some instances, could push stressed systems beyond sustainable thresholds. Because sensitivity to climate and climate change varies across populations and societies, and across temporal scales, there is substantial variability in susceptibility and capacities to adapt. Aggregating impacts across this variability may hide unacceptable risks, thus providing a false sense of the extent of potential harm associated with climate change.

An example from Hurricane Katrina illustrates the problem with aggregation. In 2005, Hurricane Katrina caused more than 1,500 deaths along the Gulf Coast. Katrina caused damage in several states, but the vast majority occurred in Mississippi and Louisiana, primarily from storm surge in Mississippi and levee failure in New Orleans. As shown in Table 3, the damage from Katrina was only 0.69 percent of U.S. GDP, but 33 percent of GDP in the two states most affected, Mississippi and Louisiana.

Table 3. Economic Damage from Hurricane Katrina

Region	2005 GDP (2008 $US)	Hurricane Katrina Damage (2008 $US) = $86.3B
U.S.	$12,422B	0.69 percent of 2005 GDP
Mississippi & Louisiana	$263.5B	33 percent of 2005 GDP

NOTE: Damage figure does not include second-order effects, such as from disrupted oil and gas supplies.
Source: Bureau of Economic Analysis, US Dept. Commerce (http://www.bea.gov/).

Further, victims were not evenly distributed across the populations. Many victims were members of vulnerable populations, such as hospital and nursing-home patients, older adults who required care within their homes, and individuals with disabilities (U.S. CHSGA, 2006). According to the Louisiana Department of Health and Hospitals, more than 45 percent of the state's identified victims were 75 years of age or older; 69 percent were above age 60 (LDHH, 2006). In Mississippi, 67 percent of the victims whose deaths were directly, indirectly, or possibly related to Katrina were 55 years of age or older (MSDH, 2005).

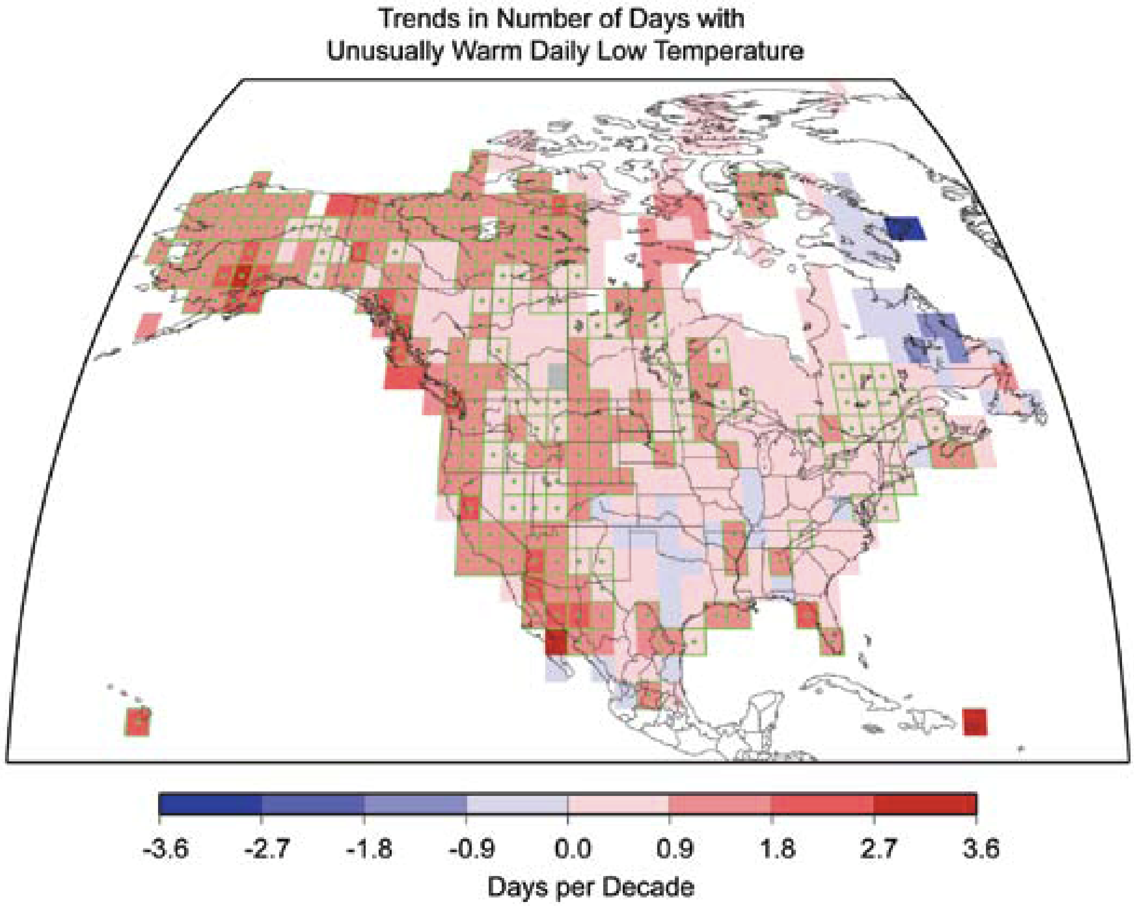
At hurricane evacuation centers in Louisiana, Mississippi, Arkansas, and Texas, chronic illness was the most commonly reported health problem, accounting for 33 percent (4,786) of 14,531 visits (CDC, 2006a). A quarter of the deaths indirectly related to the hurricane in Alabama were associated with preexisting cardiovascular disease (CDC, 2006b), and the storm prevented an estimated 100,000 diabetic evacuees across the region from obtaining appropriate care and medication (Cefalu et al., 2006). One study suggested that the hurricane had a negative effect on reproductive outcomes among pregnant women and infants, who experienced exposure to environmental toxins, limited access to safe food and water, psychological stress, and disrupted health care (Callaghan et al., 2007). Other vulnerable individuals included those without personal means of transportation and poor residents in Louisiana and Mississippi who were unable to evacuate in time (U.S. CHSGA, 2006).

Differential distributions of vulnerabilities and impacts need to be taken into account when planning programs to avoid, prepare for, and effectively respond to climate-related exposures. The costs and benefits of these programs can vary across populations and locations, depending on current activities, demographic structures, etc. For example, designing a heat wave early warning system for a particular location requires determining a threshold at which a heat wave is declared; this activity can be undertaken using various indicators of hot weather, but is basically similar across locations. The response activities will vary across populations depending on current activities and institutions. For example, once a heat wave is declared under the Philadelphia Hot Weather-Health Watch/Warning System, the city of Philadelphia and other agencies and organizations institute interventions that include encouraging friends, relatives, neighbors, and other volunteers ("buddies") to make daily visits to elderly persons during the hot weather (Kalkstein et al., 1996). These buddies are asked to ensure that the most susceptible individuals have sufficient fluids, proper ventilation, and other amenities to cope with the weather. This buddy system was built on an existing program to reduce rates of crime in at-risk neighborhoods. Such programs do not exist in many cities, so although it is an apparently effective model, different approaches may be needed when designing heat wave responses.

Case Study: Midwestern Heat Waves

Since 1950, the annual percentages of days exceeding the 90th, 95th, and 97.5th percentile thresholds for both maximum (hottest daytime highs) and minimum (warmest nighttime lows) temperature have increased when averaged over all of North America (Karl et al., 2008). The changes were greatest in the 90^{th} percentile, increasing from about 10 percent of the days to about 13 percent for maximum and almost 15 percent for minimum. These changes decreased as the threshold temperatures increased, indicating more rare events. The 97.5th percentile increased from about 3 percent of the days to 4 percent for maximum and 5 percent for minimum. There were important regional differences in the changes, as shown in Figure 1. The largest increases in the 90th percentile threshold temperature occurred in the western part of the continent, while some areas, such as eastern Canada, show declines of as many as ten days per year from 1950 to 2004. Since the record hot year of 1998, six of the past ten years (1998-2007) experienced annual average temperatures that fall in the hottest 10 percent of all years on record for the U.S. (Karl et al. 2008).

Figure 1: Trends in Number of Days with Unusually Warm Daily Low Temperatures
(Source: Karl et al., 2008)



Note: Trends in the number of days in a year when the daily low is unusually warm (i.e. in the top 10 percent of warm nights for the 1950-2004 period). Grid boxes with green squares are statistically significant at the p=0.05 level (Peterson et al., 2008). A trend of 1.8 days/decade translates to a trend of 9.9 days over the entire 55-year (1950-2004) period, meaning that ten days more a year will have unusually warm nights.

Heat waves are the leading cause of weather-related mortality in the United States (CDC). Over the period 1979–1999, 8,015 deaths in the United States were heat-related, 3,829 of which were due to weather conditions (Donoghue et al., 2003). As with other extreme events, the risk of heat waves is not evenly distributed. Populations in the Midwest have an increased risk for illness and death during heat waves, as evidenced during events occurring in the 1980s and 1990s. A heat wave in July 1980 caused a 57 percent increase in mortality in St. Louis and a 64 percent increase in Kansas City (Jones et al., 1982). The 1995 Chicago heat wave is perhaps the most widely known; it caused an estimated 696 excess deaths (Semenza et al., 1996; Whitman et al., 1997). A heat wave of similar magnitude in 1999 resulted in 119 deaths in Chicago (Palecki et al., 2001).

An analysis of future heat wave risk in the Midwest found that in coming decades, heat waves in the Midwest are likely to become more frequent, longer, and hotter than cities in the region have experienced in the past (Ebi and Meehl, 2007). This trend will result from a combination of general warming, which will raise temperatures more frequently above thresholds to which people have adapted, and more frequent and intense weather patterns that produce heat waves. Studies projecting future mortality from heat foresee a substantial increase in health risks from heat waves. Several factors contribute to increasing risk in Midwestern cities, including demographic shifts to more vulnerable populations and a built infrastructure originally designed to withstand the less severe heat extremes of the past. The elderly living in inner cities are particularly vulnerable to stronger heat waves; other groups, including children and the infirmed, are vulnerable as well. Adaptations of infrastructure and public health systems will be required to cope with increased heat stress in a warmer climate.

Throughout much of the Midwest, projections for 2090 (compared to 1975) forecast increases in nighttime minimum temperatures of more than 2 °C (3.6 °F) during the worst heat waves. Nighttime temperatures are important in determining the extent of health impacts during a heat wave, as limited nighttime cooling is associated with higher mortality (Kovats and Hajat, 2008). Table 4 summarizes projections of increases in heat wave frequency and intensity in Chicago, Cincinnati, and St. Louis in 2090 (Ebi and Meehl, 2007). These projections are well above present-day observations (i.e. more and longer-lived heat waves). On average, the frequency of heat waves for all three cities increased by 36 percent and the duration of individual heat waves increased by 27 percent. Combining these two effects implies an overall increase of about 70 percent in the annual number of heat wave days for the Midwestern region by the late 21st century. Moreover, as shown in Table 4, these extreme days will be hotter on average than at present.

Applying the magnitude of the 2003 European heat wave to five major U.S. cities (Detroit; New York; Philadelphia; St. Louis; and Washington, D.C.), Kalkstein et al. (2008) concluded that a heat wave of the same magnitude could increase excess heat-related deaths by more

Table 4. Projected Increases in Heat Wave Frequency and Duration in 2090 for Chicago, Cincinnati, and St. Louis *(Source: Ebi and Meehl, 2007)*

City	***Temperature Increase***	***Frequency Increase (Heat waves per Year)***	***Duration Increase (Days per Year)***
Chicago	4.0°F	24 percent	21 percent
		From 1.7 to 2.1	From 7.3 to 8.8
Cincinnati	4.3°F	50 percent	22 percent
		From 1.4 to 2.1	From 8.8 to 10.7
St. Louis	4.7°F	36 percent	38 percent
		From 1.4 to 1.9	From 10.3 to 14.2

Note: The table shows ensemble-average projections for each city. Because these are averages, they describe a typical summer in the late 21st century, not what an extreme year would look like.

than five times the average. New York City's total projected excess deaths exceeded the current national summer average for heat-related mortality, with the death rate approaching annual mortality rates for common causes of death, such as accidents.

Conclusions

The risk of adverse impacts due to climate change depends on exposure to a particular climatic event, its likelihood, and the consequences. The consequences of exposure depend on the geographic and socioeconomic vulnerability of the affected region and sector. Exposures and vulnerability vary over temporal and spatial scales, resulting in highly variable patterns of possible impacts. Aggregating over this variability can produce misleading assessments of the extent and magnitude of possible impacts. Societies will need to prepare for not just the average impacts, but for the tails of the distribution. A small or moderate average impact for a state or the nation can hide unacceptable impacts to some sectors and regions, with some populations experiencing limited adverse consequences, while others experience devastating impacts.

Illustration: News of 2015 Midwest Heat Wave

The societal impacts of model projections of the future can be difficult to imagine, particularly when dealing with changes in changes in events that are infrequent. For example, what does it mean for the population of Chicago to experience a given increase in the number of heat wave days per year? What strains would be placed on social systems and public health services?

To help make future events easier to visualize, we have created fictional news accounts based on projections of future heat wave occurrence in the U.S. Midwest. Our intent is not to create worst-case or nightmare scenarios such as those played out in popular movies, but rather to illustrate in a familiar format the impacts of the kinds of changes that can be reasonably expected based on current projections.

The scenario we have chosen is a prolonged heat wave in 2015 affecting the Midwest, including Cincinnati, Chicago, and St. Louis. We chose a year in the near future in order to make this fictional world easier to relate to than the more distant future and in order to examine the effects such a heat wave can have on an infrastructure that is no better adapted to climate extremes than today's.

We include a fictional story in the future *New York Times* as an overview of the scenario , a business story in the *Des Moines Register*, and a sports page story in the *Cincinnati Enquirer* as an illustration of the unexpected effects of climatic changes on particular sectors. References to climate trends are drawn from the references in this chapter, and references to events prior to 2009, such as prior heat waves, refer to actual events. We have based quantitative measures such as temperatures and economic damages, where possible, on estimates in the peer-reviewed literature (Ebi and Meehl, 2007 and references therein, St. Pierre 2003), published conference proceedings (Gaughan, 2009), and news accounts of past heat waves. Names of people are fictional.

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The New York Times August 10, 2015

Midwest Heat Wave Drags On, Death Reports Climb

By ERIKA ENGLEHAUPT

The heat wave that has scorched the Midwest continued to cause widespread problems yesterday, including more heat-related deaths and widespread power grid failures as air conditioners strained across the region.

The heat wave has ended its fourth consecutive week with temperatures regularly topping 100 degrees in many cities, making it the most widespread and intense heat wave on record for the Midwest, government scientists reported yesterday. The experts said that because the heat wave got an early start this year, it could set an additional record for the longest heat wave in U.S. history if conditions continue.

"Chicago looks more like Atlanta this year," John Carlo, senior scientist at the National Climatic Data Center in Asheville, N.C., said in announcing the latest temperature data at a briefing in Washington.

Other scientists pointed out the unusual conditions that have led to the heat wave. Domes of high atmospheric pressure have been getting larger in recent years, and this summer's high pressure event is keeping temperatures high both during the day and at night. Average temperatures in Cincinnati have been 8°F above normal for July, with nighttime temperatures at least 10°F higher than normal.

Temperatures have reached heat wave status in at least 15 states stretching from Texas in the south to Iowa in the north, and from Colorado to parts of the East Coast.

"Ten years ago, we were publishing model results showing that these atmospheric features would lead to more and longer heat waves," Mr. Carlo said. "But our models were for the middle of the century. This could be an early indication of formerly extreme conditions that are becoming more normal."

At least 4000 deaths have now been attributed to the heat wave, but officials say that number may rise significantly as a backlog of death certificates is issued. A survey of morgues in St. Louis found that more than 2500 excess deaths have occurred during the heat wave in that city alone. Most of these deaths are assumed to be related to the heat, with elderly people highest among the mortalities.

Morgues have been struggling to find places to store the bodies. In Cincinnati, the county coroner's office converted air-conditioned trailers to makeshift morgues only to have the electrical power fail yesterday afternoon, forcing the office to run the air conditioners on backup generators.

"We have been seeing a very high number of patients with cardiopulmonary problems," said Dr. John Wilkinson of Cincinnati General Hospital.

"I just don't feel good. I'm exhausted," said May Hopkins, 91, as she fanned herself on her front porch in west Cincinnati. Her neighborhood has few shade trees to help cool her house. Ms. Hopkins said she knows no one who can check on her during the day except the local Meals on Wheels program, which has found itself operating as a makeshift emergency service for the elderly and homebound.

A four-day blackout affected large parts of 5 states, caused by massive demands on the electrical grid coupled with damaging winds, hail, and lightning from thunderstorms. The lack of air conditioning and electric fans meant no relief from nighttime heat for many and may have raised the death toll.

Cincinnati Enquirer July 15, 2015

Braves Blast Reds in Heat Wave Meltdown

By ERIKA ENGLEHAUPT

Baseball officials are calling for new rules to help teams beat the heat after the Reds' disappointing 5-1 and 4-2 doubleheader losses to the Atlanta Braves yesterday.

The teams faced off in a sweltering series after a highly unusual postponement due to heat the previous afternoon. In the middle of a record-setting heat wave, temperatures in Cincinnati exceeded 100 degrees for three days prior to Thursday's game and did not dip below 80 degrees at night.

Last week, the Major League Baseball All-Star Game scheduled at Busch Stadium in St. Louis was cancelled because of high heat.

"Some teams have asked for a temperature threshold for starting a game, and we will consider that option," said baseball commissioner John Dupree after a string of slow-selling games. Umpires can call, suspend, or resume a game based on weather, but how hot is too hot is up to their judgment.

League officials say teams in the majors should play more twilight doubleheaders, with games starting after the worst afternoon heat is over. But owners say these games, which in the minor leagues typically allow fans to watch two games for the price of one ticket, would lose too much money for Major League Baseball.

The Reds played for a near-record low crowd of 13,450 yesterday. Many fans complained and began leaving the ball park after beverages ran out.

"We're just glad we don't have artificial turf; that gets really hot," said Victor Fuentes, who was 3-for-6 with two doubles. Fuentes spoke to reporters after the game with a towel draped around his neck dripping with cold water and ammonia to keep cool.

During a 1999 heat wave, a thermometer on the artificial turf at the old Cinergy Field just before the opening pitch registered 154 degrees. Today's temperature on the grass field at Great American Ball Park ticked up to 103 degrees, compared to 99 as the day's official local high.

Des Moines Register August 18, 2015

Heat Takes Toll on Animals and Farm Economy

By ERIKA ENGLEHAUPT

Tom Williams of Pottawattamie County looked across his feedlot last week to find his cattle panting with their tongues hanging out, many lying listlessly on the ground. Some were dead. All told, Williams lost nearly 200 of his 2,500 head.

"I've never seen anything like it, and I've been doing this all my life," Williams said. The biggest loss is not from the deaths, he said, but from lost production of animals that did not gain weight during the hot spell. The cost of a dead steer may be $500 to $600, but Williams estimates he could lose that much from 35 to 40 survivors having eaten too little to reach market weight. Williams said he is not insured for this kind of loss.

Farmers throughout the region are reporting the deaths of thousands of swine, poultry, and cattle. Dairy production is also down by about half, according to the Iowa Department of Agriculture.

This year's heat wave has set records for temperature and agricultural losses. Early government estimates of national agricultural losses top $75 billion, compared to $64 billion for the 1988 heat wave that ravaged the Great Plains.

Past heat waves also killed or damaged livestock production, although this year's losses are on track to surpass all records. A heat wave in 1995 cost the cattle industry more than $28 million in animal deaths and decreased performance. In 1999, a heat wave in Nebraska led to more than 3,000 cattle deaths and $20 million in economic losses.

Animals usually seek shade and rest when their temperatures rise, said Joseph McCoy, a large animal veterinarian in Omaha. But all livestock can experience heat stress when high temperatures last for several days or more, and hot nighttime temperatures are especially damaging because animals cannot recover from the daytime heat. McCoy said feedlot managerscan install water sprinklers, provide shade, and avoid transporting cattle during extreme heat.

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