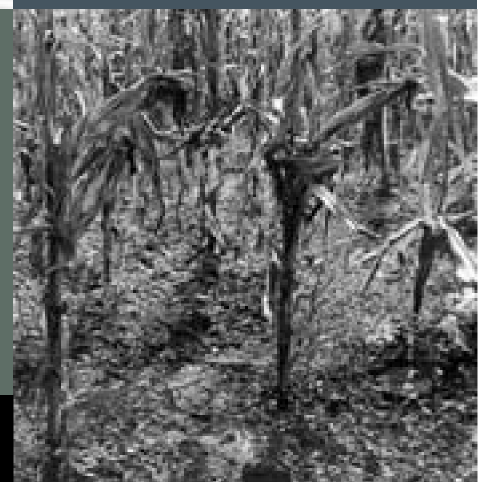
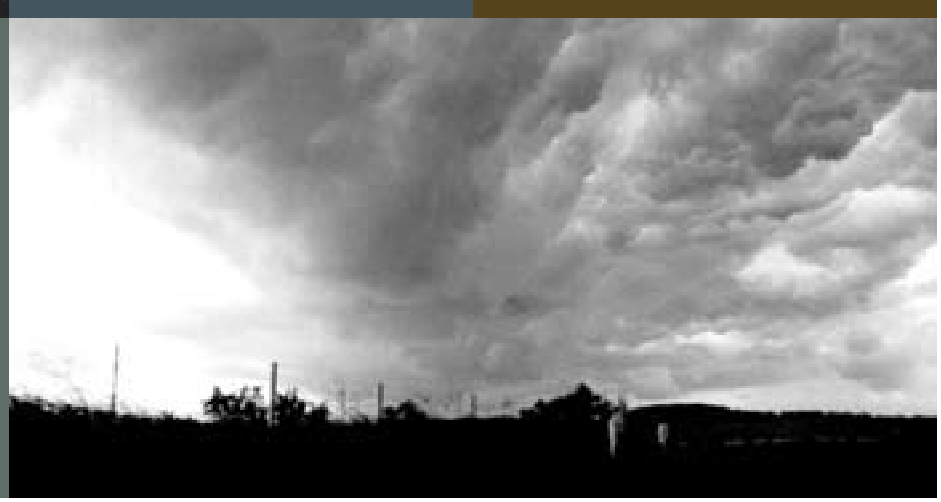


IMPACTS OF RECENT CLIMATE ANOMALIES:

LOSERS AND WINNERS

STANLEY A. CHANGNON • KENNETH E. KUNKEL • DAVID CHANGNON



Data/Case Study 2007-01

Illinois State Water Survey
A Division of the Illinois Department
of Natural Resources
and an affiliated agency
of the University of Illinois

IMPACTS OF RECENT CLIMATE ANOMALIES: LOSERS AND WINNERS

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ABSTRACT

This document focuses on the impacts from a wide variety of climate anomalies in the continental United States during 1985-2005, and for which there are good measurements of resulting societal, environmental, and economic impacts. Climate anomalies produce sizable losses, but some also benefit society and the environment in ways that often go unrecognized but persist for years. The last 20 years (1985-2005) are the first era with quality, in-depth studies of these impacts, particularly economic ones. Delineation of impacts from recent anomalies has applications in helping to assess impacts that future changes in climate could create.

Most major businesses in the nation are highly climate sensitive, including agriculture, transportation, power generation, construction, and retail. This document should be useful and benefit the many sectors affected by climate anomalies, and also those who must make decisions relating to such conditions. The ten major climate anomalies during the 1985-2005 period were:

- *1985-1986 Wet Period* (western and central United States)
- *1988 Drought* (West, Rockies, Great Plains, Midwest, and East)
- *1990 Record Wet and Warm Year* (southern and central United States)
- *1993 Floods* (central United States)
- *1993-1994 Cold and Snowy Winter* (High Plains, Midwest, and East)
- *Summer 1995 Heat Wave* (Great Plains, Midwest, and East)
- *1997-1998 El Nino* (West, South, and Midwest)
- *1999-2000 Droughts and Heat Waves* (Midwest, High Plains, South, and Rockies)
- *2001-2002 Warm Winter* (northern United States)
- *2004 Cool, Wet, and Sunny Growing Season* (High Plains, South, and Midwest)

Assessment of various impacts associated with the ten climate anomalies revealed several nonclimatic factors, as well as climate conditions, were responsible for the sizable economic losses from these recent climate extremes. One influential nonclimatic factor was related to the insurance industry and its poor handling of weather/climate losses in recent years. Several societal factors also played a significant role in recent sizable climate-caused losses. Population growth and often growing wealth have increased society's vulnerability to climate anomalies. Demographic changes have shifted the nation's population density to more weather-vulnerable locations. Flood and storm assessments further have revealed growing problems of an aging infrastructure across the nation.

The economic impacts of the ten climate anomalies assessed herein totaled $258.7 billion in losses and $125.0 billion in gains (2006 dollars). Total gains represented 33 percent of the total economic impacts. Gain values exceeded loss values in four of the ten anomalies (1990, 1997-1998, 2001-2002, and 2004). The 1988 drought had the largest loss, $86.5 billion, and the 2004 growing season had the greatest gain, $26.6 billion. The anomalies caused 7,955 deaths, and most resulted from heat waves in 1988, 1995, 1999, and 2000. Assuming the economic measures presented are reasonably correct, the economic impacts of the anomalies, plus findings from other climate impact studies, are useful inputs for estimating the impacts that a future climate change due to global warming may produce.

ACKNOWLEDGMENTS

Studies of these ten anomalies were supported by a variety of agencies. The 1985-1986 wet period and its impacts were assessed as part of a project funded by the National Science Foundation. Assessment of the 1988 drought was supported by funds from the Natural Hazards Center, Midwestern Regional Climate Center (MRCC), and the National Climate Data Center (NCDC). Investigation of the 1993 flood was done under a grant from the Climate Analysis Center (National Oceanic and Atmospheric Administration or NOAA). Four anomalies (record warm-wet 1990, 1995 floods and heat wave, 1999-2000 heat wave and droughts, and the 2004 growing season) were all investigated as part of the research and services program of the MRCC and the Illinois State Water Survey. Studies of El Niño 1997-1998 were done under a grant from the Climate Prediction Center of NOAA, and assessment of the 2001-2002 warm winter was done under a grant from the NCDC. We are deeply indebted to hundreds of individuals who contributed data and information used in these studies. We appreciate the reviews of James Angel and Mike Palecki. Chief Derek Winstanley provided a very thoughtful review. Eva Kingston provided a detailed editing, and Sara Nunnery helped with the illustrations and did the layout of the report, and we thank them.

CHAPTER 1: IMPORTANCE OF CLIMATE ANOMALIES

Climate extremes, defined as periods of high or low temperatures and dry or wet conditions lasting a season or longer, can create a myriad of societal and environmental impacts over large areas of the United States. Recent extremes, such as the drought of 1988, with losses of $86.5 billion (2006 dollars) and the 1993 floods with losses of $34 billion (2006 dollars), reveal the magnitude of impacts from climate extremes.

The United States has a wide variety of climates: tropical climates in Florida and southern California, desert climates in the Southwest, a moist maritime climate in the Northwest, humid coastal climates along the West and East Coasts, a mountain climate in much of the West, and a continental climate in central and eastern sections of the nation. Continental climates have many extremes, being in areas far from any oceans. All parts of the nation experience wide temperature and precipitation extremes that persist for months and sometimes years.

The characterization of such events requires systematic collection of climate data. Observations of temperature, precipitation, and other climate elements have been collected across the United States since the 1800s in a variety of networks. The National Weather Service's Cooperative Observer Network (COOP) is a particularly valuable source because it has been in existence since the late 1800s. Stations in the COOP use standard, high-quality instruments and uniform observing practices. The attention paid to high data quality throughout the life of the network, the large number (several thousand) of stations, and the very long records make these data invaluable for characterizing contemporary climate events. A number of stations have taken measurements continuously for over 100 years. Observations are taken daily and typically include precipitation, maximum temperature, minimum temperature, snowfall, and snow depth.

When weather extremes persist for several months, the events discussed in this report, we refer to them as climate "anomalies", indicating that climate conditions are unusual. Typically, in climatic analyses, events are characterized in terms of their differences from average conditions, or in terms of a ranking relative to all other similar periods. The usual convention is to define "normal" conditions as the average of the most recent 3 complete decades, for example, 1971-2000. Because this report spans events occurring over a 20+ year time period and summarizes studies done at the time, the specific 30-year period defining normal conditions varies from study to study.

As used herein, a climate "anomaly" is an event in which the magnitude of the deviation from normal conditions is unusually large, occurring infrequently in the historical record. The unusual conditions are regional in extent, involving multi-month periods of extremely high or low temperatures and/or wet or dry conditions. However, there is no standard convention among climatologists about the exact thresholds that would warrant the label of "anomaly" or "extreme". Usually, an event must be below the 10^{th} percentile or above the 90^{th} percentile. But the events that just barely meet these thresholds may not cause large impacts. More significant ranks are the 5^{th} and 95^{th} percentiles. It is our experience that events that rank less than the 5^{th} or greater than the 95^{th}

Fig. 1-1. Climate regions of the United States.

percentiles create impacts of substantial societal significance. The events discussed in this report meet these criteria in at least one climatic characteristic over a substantial area.

Climate anomalies occur in all seasons and all areas of the nation. Some last 3-4 months and others 24 months or longer over one or more multi-state areas. Figure 1-1 shows the nine U.S. climate regions as defined by the National Climate Data Center (NCDC). Two or three separate anomalies occur in different regions in the nation in some years.

The Climate Extremes Index (CEI) is a single seasonal measurement that reflects climate extremes across the entire nation (Karl et al., 1996). This NCDC index is based on major seasonal and annual departures of temperatures, precipitation, droughts, and tropical storm frequencies, expressed as percent of the United States affected by extremes. The CEI values do not measure economic or societal impacts, however. A National Climate Impact Indicator (CII), based on a crop moisture index and a residential energy demand-temperature index, also is computed by NCDC. The CII measures the effect of key seasonal climate conditions on two vital sectors of the nation's economy (agriculture and energy use). These values are not equated to financial magnitudes of losses or gains across the nation, however.

This document focuses on a wide variety of climate anomalies that occurred in the continental United States during 1985-2005, and for which there are good measurements of societal, environmental, and economic impacts.

Why report on climate anomalies and their impacts?

- Climate anomalies cause sizable losses and also generate benefits for society and the environment that often go unrecognized but persist for years.
- Delineation of impacts from recent anomalies has applications in helping to estimate those that future changes in climate could create.
- The 1985-2005 period is the first era with quality, in-depth studies of impacts, particularly economic ones.

Most major business activities in the nation are highly climate sensitive. It is relatively easy to identify weather-sensitive sectors of the U.S. economy, but the important question is, How sensitive? The Chicago Mercantile Exchange (2000) estimated that 20 percent of the nation's $9 trillion economy is weather sensitive. Dutton (2002) estimated that the weather-sensitive components of the nation's Gross Domestic Product (GDP) total $3.8 trillion, more than twice the estimate of the Chicago Mercantile Exchange.

Agriculture responds to climate conditions that determine whether crop yields are good, average, or poor. The United States has a complex system of air and surface transportation, and climate extremes influence each form of transportation—commercial airlines, river barges, trains, and trucks. Major seasonal climate-related shipment delays are a major problem for manufacturers, and large or small profits for many retail businesses often result from extremes. Climate extremes lasting one or more seasons also have major impacts on energy use and costs, and property losses caused by major floods from prolonged wet periods are sizable (Changnon, 2006a).

Anomalous climate conditions, such as heat waves and prolonged cold periods, affect human health and safety, and cause deaths. Assessment of deaths caused by U.S. weather and climate conditions reveals that the three major killers (and their annual average number of deaths) are heat waves (1,800 deaths), excessive precipitation-major floods (107 deaths), and extreme cold periods (68 deaths). Deaths due to storms are lower: lightning (66 deaths), tornadoes (64 deaths), and hurricanes (15 deaths). Thus, climate extremes are the nation's most life-threatening atmospheric condition.

Climate aberrations also shape environmental conditions. Prolonged extremes can kill many plant varieties and cause substantial soil erosion. Record flooding in 1993 breached many levees and renewed the growth of natural plants in floodplains. It also caused massive erosion of farm soils. Thus, climate anomalies are critically important because they affect a region's environmental conditions, as well as its economy and the health of its residents.

This report should be useful for many sectors affected by climate anomalies and those who must make decisions relating to such conditions. It was designed to serve diverse audiences, and all measures use English units. Types and magnitudes of recent climate anomalies also provide insight about what may happen if the climate changes in future years to wetter or drier and warmer or cooler conditions.

Ten major climate anomalies during the 1985-2005 period were selected for presentation, based on previous studies and for which high-quality impact data were available. These were not all the anomalies during the 1985-2005 period, but only those with in-depth information available on impacts created. For each anomaly, this report describes the atmospheric conditions that caused the anomaly, including their time and space distributions, and provides information about impacts. The following chapters describe these anomalies. Table 1-1 lists the anomalies, their locations, and

Table 1-1. Major Climate Anomalies and Selected Major Impacts during 1985-2005.

- *1985-1986 Wet Period* in western and central United States = record high levels of Great Lakes and Great Salt Lake created major shoreline damages, and major river flooding occurred. October 1985-September 1986 was the 3rd wettest such period in the Midwest.
- *1988 Drought* in the West, Rocky Mountains, Great Plains, Midwest, and East = urban water shortages in California, Chicago, Atlanta, and New York, and major agricultural losses. Summer 1988 was the 4th driest and 5th warmest in the Midwest.
- *1990 Record Wet and Warm Year* in the south and central United States = major shifts in energy usage and reduced high crop production. This was the 2nd wettest year in the Midwest.
- *1993 Floods* in central United States = major property damages and excessive crop losses. Summer 1993 was the wettest on record in the Upper Mississippi River basin.
- *1993-1994 Cold and Snowy Winter* in High Plains, Midwest, and East = major property damages and transportation problems.
- *Summer 1995 Heat Wave* in Great Plains, Midwest, and East Coast = near record loss of lives and major energy usage costs. The July 12-15 heat wave in Chicago was the 3rd hottest on record.
- *1997-1998 El Niño* produced various seasonal extremes over the entire United States = a wide variety of losses and benefits to the economy and environment. The winter of 1997-1998 was the warmest on record in the Midwest.
- *Droughts and Heat Waves in 1999-2000* over large parts of the nation = many deaths, large crop losses, and record large wildfires.
- *2001-2002 Warm Winter* over the entire northern United States = major increase in retail sales, travel, and house sales, plus near record low heating costs. The winter of 2001-2002 was the 3rd warmest in the Midwest.
- *2004 Cool, Wet, and Sunny Growing Season Conditions* in the High Plains, South, and Midwest = record high crop yields with record agricultural profits. Summer 2004 was the 3rd coldest in the Midwest.

some of their major impacts. Selected rankings, based on data back to 1895, for the central United States are given for some of the events.

This study of climate anomalies during the past 20 years presents climate and impact values from previous studies. Dollar values of losses or gains for a given anomaly are those measured and reported at the time of the event. Furthermore, time-oriented discussions and illustrations of prior-to-anomaly conditions presented in those studies are used herein. Climate conditions at the time of the anomaly were compared to averages (normals) for 30-year periods prior to the event. For example, temperature conditions during a 1980s anomaly were compared with the 1951-1980 normals. Discussions about records and ranks of the climate conditions associated with each anomaly are based on comparisons with conditions prior to the year/season being assessed. That is, if the year 1994 was listed as the nation's third warmest on record, it was ranked based on the 1895-1994 data, not data from years after 1995. It was deemed appropriate to present the anomalous conditions and their impacts in the year(s) they occurred for proper perspective of magnitude. The summary chapter presents losses and gains for all ten anomalies with the economic values adjusted to 2006 dollar levels, allowing comparisons of anomalies.

Assessing Weather and Climate Impacts

All weather-sensitive elements on earth experience daily weather impacts. Average and near average conditions affect environmental conditions and human activities, and most sectors are well adjusted to them. Adjustment problems develop when either hourly/daily weather or monthly/seasonal climate anomalies occur. Weather extremes, such as hurricanes, tornadoes, and hailstorms, cause serious sudden damages. Climate anomalies involving prolonged periods of cold/hot and wet/dry conditions also have major impacts for humans, the environment, and the economy. Magnitude of losses from climate anomalies is typically much greater than losses from weather (storm) extremes.

Climate anomalies selected for assessment were those studied previously and for which quality data and information on the impacts were available. There never has been a systematic collection of quality data on economic and environmental impacts of climate conditions (NAS, 1999). Meaningful impact assessments have been done by only a few scientists and economists, who collected and evaluated data and information from a variety of sources. Most of those studies included only data from insurance companies, government agencies, and the news media. Economic modeling does not yet measure well impacts of infrequent yet severe aberrations. Successful impact measurements entail special data collection efforts during and after extreme periods (Changnon, 2006a).

Comprehensive assessments of the impacts resulting from climate conditions are complex and difficult to perform. Climate conditions, and extremes in particular, produce a wide variety of damages, losses, and benefits to the environment, human health and well being, and the economy. It is important to recognize that some impacts can be losses to some sector and benefits to another sector. For example, badly damaged property is a loss to owners, but the rebuilding provides economic benefits to the construction industry. Cold winters increase heating costs for consumers but provide added income for utility firms.

Assessments of impacts require knowledge of 1) climate conditions, 2) climate relationships to other physical conditions such as hydrologic cycle, and 3) how climate and climate-induced physical changes relate to human health/safety, society, and the economy. Hence, very few scientists have seriously attempted to assess the complexities associated with quantifying the impacts of climate conditions, and in particular those related to climate anomalies.

How are the data and information used to define impacts gathered? First, from some institutions there are direct measurements of losses or gain. Second, impact measures come from use of defined relationships between climate conditions and other physical conditions. These include plants, insects, animals, trees, soils, and crops. Third, impact information comes from use of established relationships between physical conditions and societal, economic, and health conditions. Sources of data/information needed for these complex assessments include a wide variety of experts in government agencies, industry, and business communities. A large number of experts have been identified over the past 40 years by the authors of this report. Some of the impacts were calculated, or estimated, by the authors using existing relationships.

Some of the impacts could not be defined quantitatively because of a lack of essential data or the lack of relationship for a climate condition and an outcome. One such example is a lack of data on the economic value of water added to reservoirs in certain U.S. regions. The economic impacts of lives lost and injuries could not be determined with any certainty.

For these reasons, assessments of the total losses and gains of a climate anomaly are underestimates of the actual values. Based on the studies herein of ten anomalies, the total losses and gains are considered to represent between 85 and 95 percent of the total economic outcomes.

Collection of the extensive data and information needed to measure impacts of the ten climate anomalies was a major endeavor. As a result of decades of consulting with private sector firms and services-oriented work for Illinois, assessors of the anomalies presented herein had developed numerous contacts to obtain impact data/information. A level of trust about how information being provided from the private sector was carefully developed, and most sources indicated they did not want their names or companies identified. Development of this information network has been a unique, long-term endeavor. Several sources of impact data and information were used to define and quantify the impacts listed herein. These included economists, financial institutions, stock market experts, weather advisory firms, utility firms, agribusinesses, railroads, airlines, universities, retail associations, insurance industry (crop and property), and government agencies (local, state, and federal).

Quality of impact data available varies widely. Limitations of what is available are important to understand, and these are discussed in the following text.

Human Impacts

Information about physical and psychological impacts of climate anomalies on humans is quite variable. There is no source of information on psychological effects of climate or weather extremes. It has been found, as shown herein for several anomalies, that storm losses and prolonged climate anomalies, such as multi-year droughts and floods, resulted in stress and anxiety among many people in affected areas. No specific quantitative information exists, however. Partially biased data on human fatalities from weather and climate extremes exists. For example, cause of death may be identified as a heart attack but may not also record that the person had just finished massive snowfall shoveling or was found dead in an overheated apartment in July. Hence, weather-related death totals tend to be underestimates.

Environmental Impacts

Information on many environmental impacts has serious limitations. Extensive data are collected about water quantity and quality, however, and allow useful quantitative measures of the impacts of extremes on the hydrologic cycle. There is no systematic data collection about the extent of various species of plants, trees, or wildlife damaged or killed by climate extremes. In a few cases, such as the 1993 flood, environmental measurements were made of wild plants and trees in floodplains of major rivers. Certain extremes are known to influence the population and activities of certain insect pests, but quantified information does not exist.

Economic Impacts

The complex issue of identifying economic impacts due to weather and climate extremes has not been addressed extensively until recently. The National Academy of Sciences (1999) assessed economic impacts of natural hazards, noting paucity of systematic efforts to collect national loss and gain data. Increasing attention on the economic impacts of climate during recent years by a few scientists and economists has led to collection of quality data on several events and to studies defining most climate impacts (Changnon, 2003a). Even with these extensive efforts to collect data from many sources, most measures of the losses/costs and financial gains associated with extreme events are best estimates of the actual values.

Losses and costs (2006 dollars) of major recent events extensively studied include the 1988 drought that produced losses of $86 billion (Riebsame et al., 1991); the prolonged 1993 floods in the Midwest that produced losses of $34 billion (Changnon, 1996); odd weather conditions associated with the strong 1997-1998 El Niño, which produced $24 billion in gains and $13 billion in losses (Changnon, 1999b); and an unusually warm and snow-free winter in 2001-2002 that produced nationwide benefits of $23 billion (Changnon and Changnon, 2005a). Interestingly, that unusual winter created large and generally positive impacts on the nation's economy at a critical time. Economists believed the mild weather and its impacts were a factor in moving the nation's economy out of an ongoing recession (Greenspan, 2002a). Six other anomalies also had been studied extensively.

In addition to the four definitive event-oriented studies, some scientists worked to quality control and adjust questionable storm loss data available from the National Weather Service (Pielke, 1999). Others assessed property and crop insurance records to create useful databases on annual losses over past years from various types of extreme events (Changnon and Changnon, 2003). One such economic assessment included defining how seasonal extremes increased heating and cooling costs, how good and bad growing seasons affected yields of major crops, plus assessment of annual losses due to hurricanes, tornadoes, hail, wind storms, and winter storms (Changnon et al., 2001). Collectively, these economic data, coupled with data from studies of recent extreme climate anomalies, provided an opportunity to establish, for the first time, meaningful estimates of the annual nationwide weather and climate losses since 1950 (Changnon and Hewings, 2001). Resulting annual average national losses totaled $43.12 billion (2006 dollars) from extreme (abnormal) climate conditions. In contrast, Canadian studies (Bruce et al., 1999) found the annual average weather-climate losses in Canada totaled $19.4 billion (2006 dollars).

Weather-sensitive U.S. activities experience both economic gains and losses, depending on the climate conditions. For example, good growing-season conditions bring high crop yields and increased incomes, whereas cold winters bring high heating costs. Most major extremes produce damages that translate into economic losses, but some individuals and institutions also experience financial gains in the aftermath of a major damaging climate event (Changnon, 1996).

Sizable gains were identified in several studies of major climate extremes. For example, the studies of the 1988 drought and the 1993 floods, which collectively produced losses totaling $120 billion (2006 dollars), revealed economic gains of $18 billion, 15 percent of the total losses from the two events. Assessments of economic outcomes from the 1997-1998 El Niño-caused climate extremes and those from the record warm winter of 2001-2002, revealed each produced national gains of about $23 billion. Crop-related gains in years when good climate conditions occurred during 1950-2000 averaged $2.3 billion (2006 dollars) annually (Changnon et al., 2001). Assessment of energy usage in the same 51 years found 22 years with major gains, averaging $4.7 billion per year (2006 dollars), or 84 percent of the total losses. These various values resulted in annual average gains of $31.61 billion.

Climate Variability

Examination of the climate of the past 125 years reveals multi-decadal periods with many climate anomalies and other periods with few (Changnon and Changnon, 1998a; Kunkel et al., 1999; Changnon, 2003b). These temporal differences have a great influence in how nature and humans response to extremes.

Recent climate conditions have provided a range of variability in U.S. extremes. The nation experienced a "climatologically quiet" period lasting from the late 1950s through the mid-1970s. That period was largely devoid of climatic anomalies like severe droughts or wet periods that had occurred frequently during the 1920s, 1930s, 1940s, and 1950s. This quiet regime lasted sufficiently long that many weather-sensitive operations, including the insurance industry, designed, financed, and operated based on conditions in this period largely free of climate extremes (Roth, 1996). Many weather-sensitive operations and their managers became attuned to functioning in this period of few major extremes.

Conditions began to change during the late 1970s, as U.S. climate anomalies again became more common, much as they were in the 1920-1950 period. Suddenly, many managers of weather-sensitive activities faced problems they did not understand (Changnon and Changnon, 1998a). A run of cold, snowy winters that began in 1977 heralded the beginning of a parade of climate aberrations. The list below describes several of major extremes from the late 1970s to 2000.

- The late 1970s-early 1980s had a series of four abnormally severe winters.
- The early 1980s had the five wettest consecutive years on record in the nation, producing record high lake levels on the Great Lakes and Great Salt Lake, with attendant major shoreline damages around the lakes and extensive riverine flooding.
- Droughts developed in the Southeast in 1986 and covered half the nation in 1988-1989. California had its six consecutive driest years on record before the drought broke in 1992.
- The summers of 1992 and 1993 became the two worst years of hail loss for crops and property in the High Plains. Prolonged storminess lasted throughout both growing seasons creating billions of dollars in crop losses, and major hail damages in several cities, including Denver, Wichita, Dallas-Ft. Worth, and St. Louis.
- Record Midwestern flooding, in duration and areal extent, occurred in 1993, at the same time the Southeast had an extreme warm season drought.
- Severe flooding occurred again in 1995, followed by a severe heat wave.
- A cold season with extremes of wet and stormy conditions in the West and South, and warm, dry conditions in the nation's north occurred as a result of a strong El Niño event in 1997-1998.

By 1980, the U.S. climate, after being benign for about 20 years, again became more variable, with conditions more typical of the nation's long-term climate. This greater variability with more extreme events has continued to present. The sample of ten climate anomalies is from this period of numerous extremes since 1985.

CHAPTER 2: WET PERIOD 1985-1986

Climate Conditions

Precipitation across the northern half of the nation began exceeding average levels in 1982 and this wet tendency continued through 1986. Precipitation during 1985-1986 was exceptionally heavy in the Great Lakes region and the intermontane area of the West.

Seasonal precipitation amounts around the Great Lakes, September 1985-November 1986, were 152 percent of the long-term average (fall 1985), 103 percent (winter 1985-1986), 94 percent (spring 1986), 112 percent (summer 1986), and 141 percent (fall 1986). Figure 2-1 shows 5-year moving average precipitation values in the Great Lakes basin for 1855-1987, revealing that the amount for 1983-1987 was the second highest on record. The sequence of wet years in the 1980s

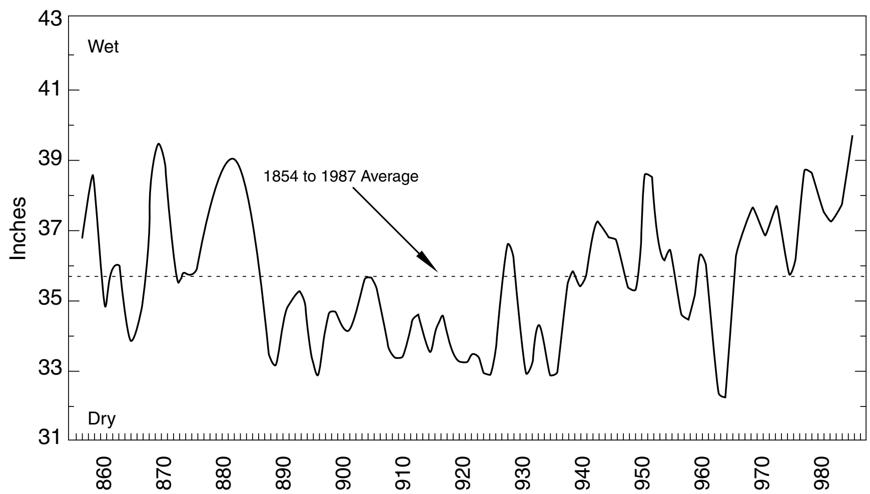


Fig. 2-1. Precipitation (inches) over the Great Lakes, expressed as a 5-year moving average, for 1854-1987.

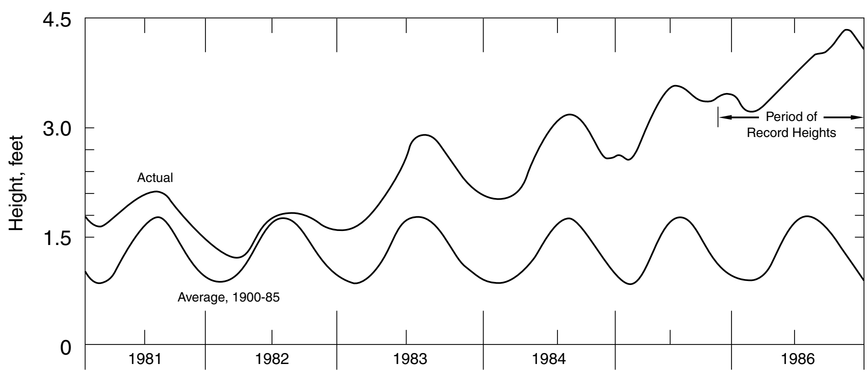


Fig. 2-2. Level of Lake Michigan, 1981-1986, and the average based on 1900-1985 (Changnon, 1987). The zero value is actually 577 feet above mean sea level.

brought the levels of several Great Lakes to record heights by 1986. Figure 2-2 illustrates the rapid increase in the level of Lake Michigan.

Precipitation in the intermontane region of the West during 1981-1984 was the heaviest in 120 years (Karl and Young, 1986), and the 1981-1986 precipitation values for the region were 134 percent of normal for 1951-1980 (Morrisette, 1988). Figure 2-3 shows the increase of precipitation over time across the basin of the Great Salt Lake. By 1985, the Great Salt Lake had risen 10 feet (Fig. 2-4).

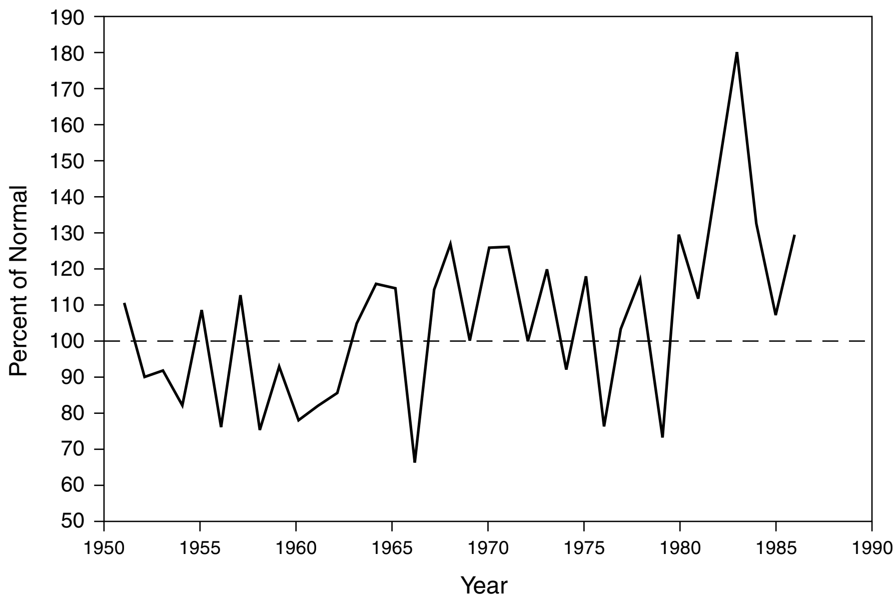


Fig. 2-3. Percent of normal precipitation in the Great Salt Lake basin, 1951-1986 (Morrisette, 1988).

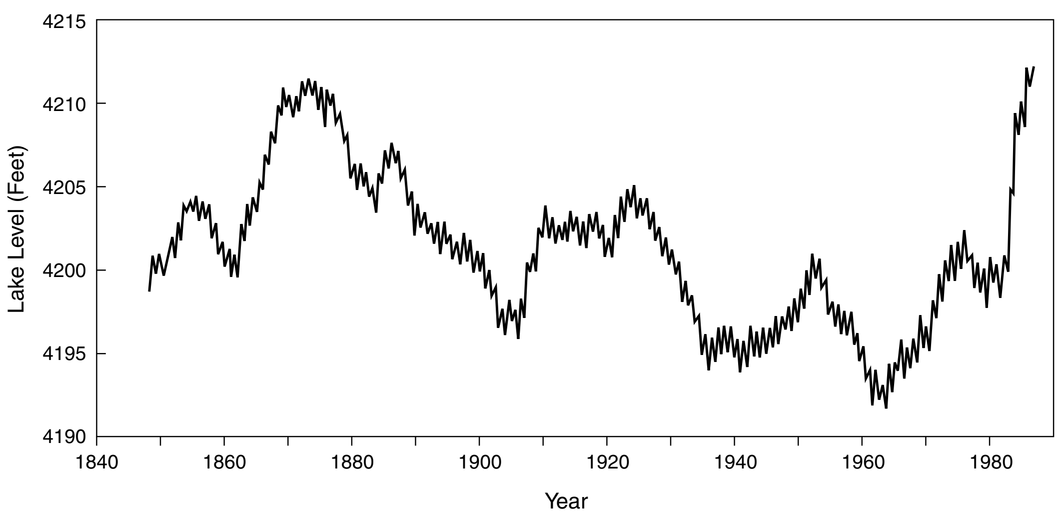


Fig. 2-4. Level of the Great Salt Lake, 1847-1987 (Morrisette, 1988).

Temperatures in both wet regions were near normal (1951-1980) through the 1985-1987 period, and cloud cover was above normal. These conditions limited evaporation from the lakes and added to the increased lake levels.

A severe, short-term drought developed in the Southeast during December 1985-July 1986. This climate anomaly was labeled a “record” drought *(Weatherwise*, 1986). States affected included Virginia, Kentucky, Tennessee, Alabama, Georgia, and the Carolinas.

Impacts

Excessive precipitation in both regions led to some riverine flooding and major increases in lake levels. The Great Salt Lake rose 12 feet by 1986, the highest level on record (Fig. 2-4). All the Great Lakes rose to record or near record high levels by 1986. These levels, coupled with high winds, caused immense damages to shorelines and shoreline structures (Fig. 2-5) from erosion and flooded facilities (Quinn, 1987). Eroded shoreline sands were produced with major losses of existing beaches and facilities adjacent to the lakes. Mineral works and industries alongside the Great Salt Lake were damaged badly at a cost of $78 million (1986 dollars), and they spent $85 million

Fig. 2-5. The major increase in the level of Lake Michigan brought high waters and damages to shoreline properties like this building in Chicago, once 1,000 feet from the shoreline.

trying to protect their facilities. The State of Utah responded to the problem by building a massive pumping facility and a 30-mile-long canal to divert water from the lake into the desert west of the lake by 1985. Winter flooding was bad in California and Nevada, and a record snowmelt in the northern Rocky Mountains produced damaging floods in Montana, Wyoming, and Utah when the Great Salt Lake reached its highest level in 120 years. Total losses and costs to lake-adjacent flooded properties and damaged railroads and highways alongside the Great Salt Lake amounted to $373 million (Morrisette, 1988).

There were numerous impacts and adjustments to the record high levels of several of the Great Lakes during 1985-1987 (Quinn, 1987). These include (in 1987 dollars):

Impacts to shores and shoreline facilities ($9.8 billion)

- Bluff and beach erosion
- Pier and building destruction
- Breakwater burials
- Dock submersion
- Sewer and drainage line submersions
- Buildings and home flooding
- Inaccessible harbors at several sites

Community and business adjustments ($1.187 billion)

- Breakwater construction ($80 million)
- Beach restoration ($360 million)
- Building and dock repairs ($747 million)

State and Federal Governments ($1.3 billion)

- New rules for beaches and related shoreline facilities
- Funds to restore beach protection facilities
- Debate about an increased diversion at Chicago to lower lake levels
- Construct flood prevention structures (U.S. Army Corps of Engineers)
- Re-evaluate water-level regulations (Congress)

International entities (International Joint Commission)

- Existing regulations for modifying high and low lake levels declared unrealistic
- Flow from Lake Superior restricted by 30 percent for several weeks
- Canada reduced water diverted into Lake Superior
- Outflow from Lake Ontario increased above prior plans

Ironically, there also were some benefits from the high lake levels (Fig. 2-6). Those who profited included lake shippers, ship owners, and the hydropower generating plants along the Niagara and St. Lawrence Rivers, which handle the outflow from the lakes. Damages to shorelines around the lakes were estimated at $9.8 billion (Changnon, 1987). Costs of adjustments experienced by lakeshore communities and many businesses amounted to $1.187 billion.

Flooding occurred elsewhere during 1985-1986. The Northeast and central regions experienced severe riverine flooding during January-April 1985. Hurricane Juan caused widespread flooding in West Virginia, Virginia, and Pennsylvania, with 62 deaths and losses of $1.4 billion in September 1985. Fall 1985 floods occurred across Minnesota, Wisconsin, Michigan, and Illinois, helping to raise the Great Lakes, and the Mississippi River rose above flood stage from central Wisconsin to southern Arkansas (Fig. 2-7). As shown in Table 2-1, the major losses related to the many riverine floods across the nation during 1985-1986 totaled $8.10 billion (Changnon et al., 2001).

A topic that created considerable controversy was a proposal by the U.S. Army Corps of Engineers to increase the diversion of lakewaters at Chicago to lower the high lake levels. Illinois

Fig. 2-6. Levels of Lakes Erie, Michigan, and Superior, based on 15-year moving averages, 1875-2001 (Changnon and Burroughs, 2003).

Fig. 2-7. Prolonged wet conditions created riverine flooding in several states, as illustrated by the flooding along the Illinois River in 1986.

feared flooding along the Illinois River, but subsequent calculations revealed a high level of diversion at Chicago would not significantly lower lake levels (Changnon, 1987).

Heavy rains and near normal temperatures during the 1986 growing season favored agriculture in the Midwest. Corn yields were 20 percent above the 1960-1985 average, and soybean yields were up 11 percent. This resulted in added farm incomes of $910 million. In contrast, crops in the Southeast, badly damaged by the severe drought, had yields reduced 40-65 percent (Fig. 2-8). Farm income was down $385 million below average, based on those of recent years (Table 2-1).

The economic outcome of heavy precipitation and record high levels of the Great Lakes showed losses and adjustment costs of $12.287 billion. Gains, largely due to added hydropower generation in the Northeast, were $185 million.

Various losses from the 1985-1986 climate anomaly totaled $21.145 billion (Table 2-1). Gains totaled $1.095 billion. There were 79 deaths related to the high lake levels and the riverine flooding. The other anomaly, a drought and heat wave in the Southeast, led to $1.1 billion in crop losses and caused 104 deaths.

Table 2-1. Losses and Gains (1986 dollars) from the Climate Anomaly, 1985-1986.

Sector	*Losses/costs (billions)*	*Sector*	*Gains (billions)*
Business	1.187	Shippers	0.060
Property	0.373	Hydropower	0.125
Flooding	8.100	Farmers	0.910
Shorelines	9.800	Total	1.095
Government	1.300		
Agriculture	0.385		
Total	21.145		

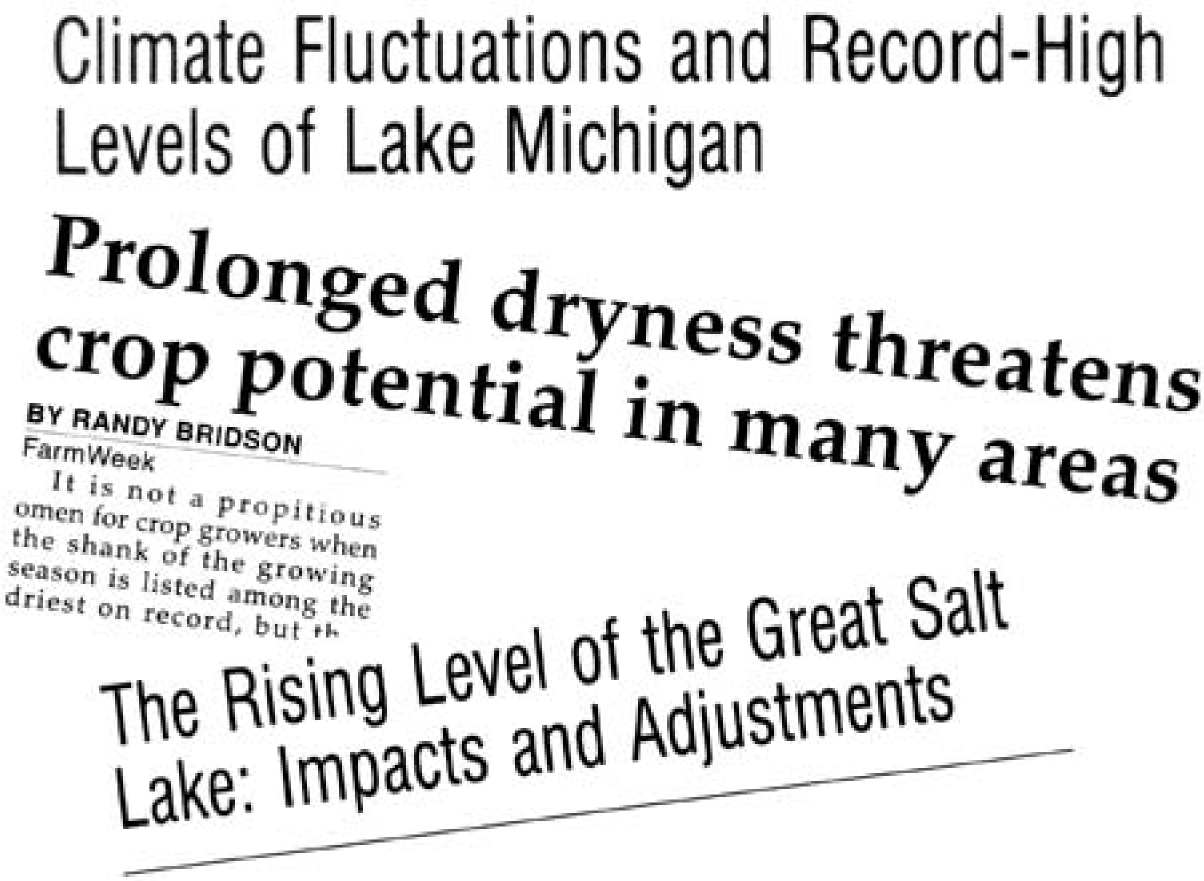


Fig. 2-8. Headlines illustrate some varied impacts of climate extremes, 1985-1986.

CHAPTER 3: THE 1988 DROUGHT

Climate Conditions

In late 1987, a drought began developing in the Northwest and East regions of the nation as precipitation fell below normal levels. The Southeast already had experienced a drought that began in 1985 (Chapter 2), and drought conditions developed in the Midwest, Pacific Northwest, and northern Rockies in early 1988 (Fig. 3-1). The drought expanded and covered 40 percent of the nation by June 1988 (Fig. 3-2).

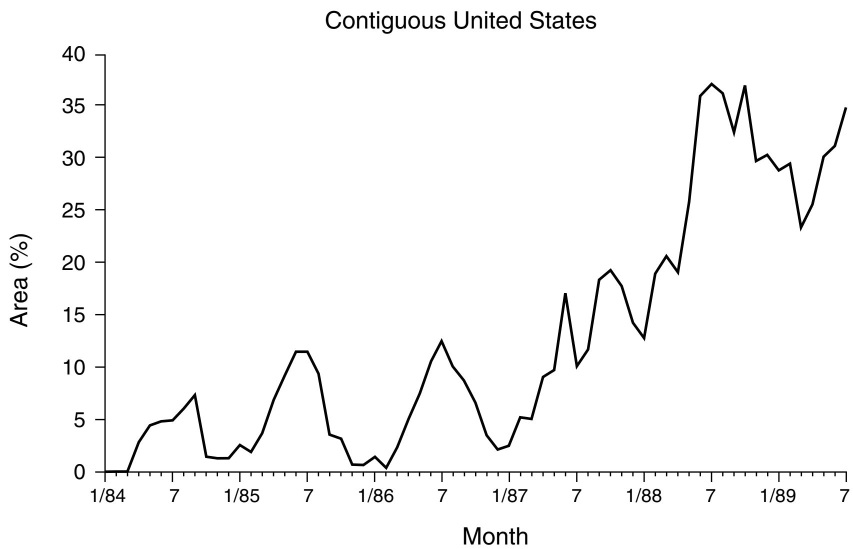


Fig. 3-1. The drought's areal extent, June 1988 (Riebsame et al., 1991).

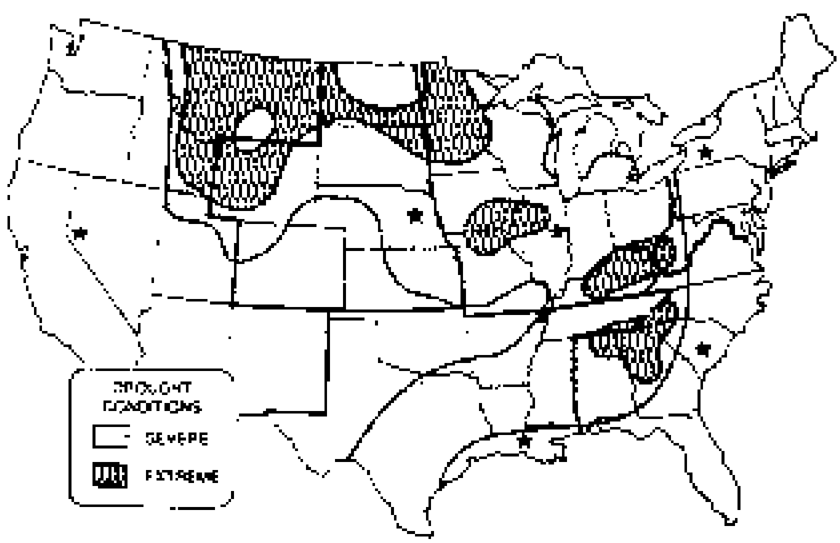


Fig. 3-2. The percent of the contiguous United States experiencing severe or extreme drought conditions, January 1984-July 1988 (Riebsame et al., 1991). The stars are locations of regional climate centers and the heavy lines are their boundaries.

The 1988 drought appeared especially severe as the preceding 25 years had been consistently wet. The drought developed from late 1987 to July 1988; conditions slowly improved from August 1988 to March 1989, and then the drought partially redeveloped during April-July 1989 when it ended. Winter 1988-1989 had wide extremes: either very wet (South and Great Plains) or very dry (Great Lakes, West Coast, intermountain regions, and East Coast).

The drought from January 1988 to June 1989 was among the ten most severe droughts of the 20th Century. National precipitation in 1988 ranked as remarkably dry with only three past years (1910, 1917, and 1956) rated as drier (Riebsame et al., 1991). In some regions, such as the Midwest and northern High Plains, the magnitude of the drought was a rare event, matching the conditions of the 1930s Dust Bowl (Fig. 3-3). While the 1988 drought was not unprecedented, it stood in sharp contrast to the unusually wet conditions over much of the nation in the previous two decades, a situation that made the drought impacts appear extreme. Temperatures during the drought were much above normal (Fig. 3-4). The summer of 1988 had extremely high temperatures in the High Plains, Midwest, and the Northeast, and several major heat waves occurred in these areas.

Fig. 3-3. Newspaper headlines illustrate the severity of the 1988 drought.

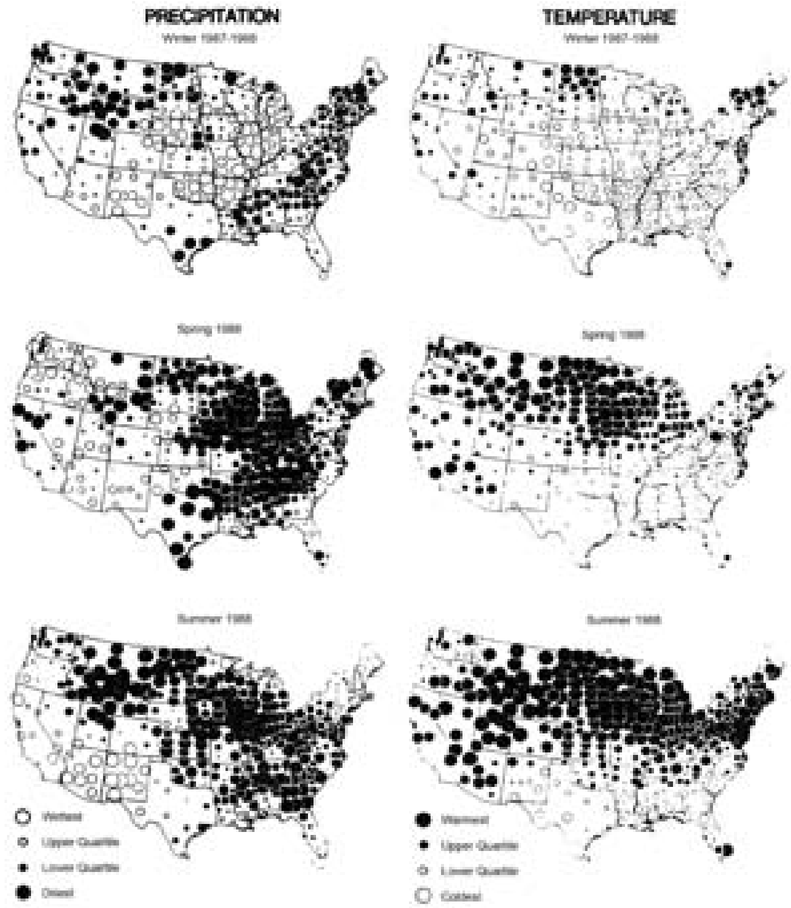


Fig. 3-4. Severity of seasonal precipitation values (left panels)
and temperatures (right panels) across the United States,
winter 1987-1988, spring 1988, and summer 1988 (Riebsame et al., 1991).

Impacts

Several major agricultural regions and watersheds experienced the drought's severity. In the central United States, the primary area for growing corn and soybeans, April-June 1988 rainfall was the lowest of the 20th Century (Fig. 3-4). More than 70 percent of the nation's corn and soybean regions had severe to extreme drought conditions during the 1988 growing season (Fig. 3-5), and the nation's spring wheat belt had the lowest growing season (April-July) rainfall since 1936.

The amount of precipitation that fell over the Upper Mississippi watershed was near record low levels. Only 1934 and 1936 had lower values over this huge watershed. The result, unprecedented low river levels, created major problems with navigation and community water supplies. Figure 3-6 shows that river levels in the western Great Lakes area, which normally rise significantly in March, decreased and remained far below median levels. Rivers in the northern Great Plains (Fig. 3-6) also had very low flows beginning in May 1988, and remained well below median monthly levels through September 1988.

Fig. 3-5. Corn had severe damage from hot and dry conditions in Iowa.

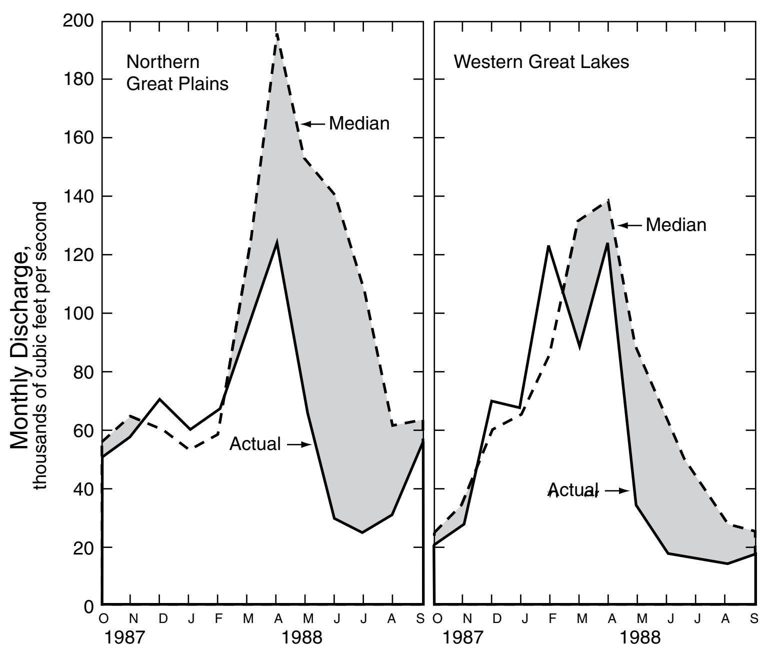


Fig. 3-6. Monthly mean streamflows for October 1987-September 1988 and median flows, based on 1951-1980, for two major regions (Riebsame et al., 1991).

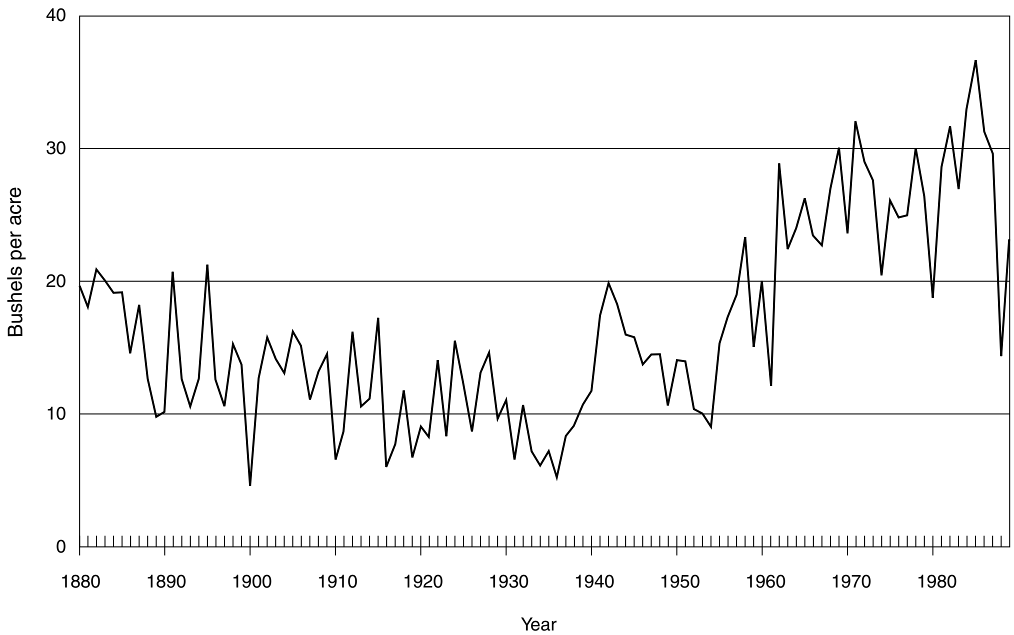


Fig. 3-7. Annual wheat yields for the Dakotas, 1880-1989 (Riebsame et al., 1991).

The pervasive drought created many economic, social, and environmental impacts. In general, most impacts were damaging, causing losses and increasing costs to respond (Riebsame et al., 1991). The 1988 corn production was 45 percent below average; soybean production was down 26 percent; and other grain crops had reductions of 50 percent or more. The history of wheat yields for the Dakotas (Fig. 3-7) shows a major decrease to 14 bushels per acre in 1988, the area's lowest yields since the 1961 drought. The types of impacts were:

Environment

- Wildlife (reduced populations and food lost for bird migrations)
- Forest (major losses due to fires, stunted growth, and seedlings killed)
- Fish (major losses in low-flow streams and effects of poor water quality)
- Soils (increased wind erosion)
- Water (reduced quality, low and warm flows, and unable to handle normal pollutants)

Water Resources

- Lowered streamflows and groundwater levels
- Lowered Great Lakes and reservoir levels
- Increased water costs
- New sources developed (new wells and piping for water transfers)
- Increased problems and costs for water treatment and sewage treatment
- Interstate conflicts over water supplies developed

Human Health

- Many heat deaths (>5,000)
- Increased illnesses (asthma, mental stress, and anxiety)
- Emotional problems (anxiety over heat stress, loss of income, and higher cooling costs)

Agriculture

- National crop surpluses reduced
- Farmers in drought areas hurt by low yields
- Increased prices for corn, soybeans, and wheat
- Commercial forestry industry hurt
- Agribusiness incomes reduced

Transportation

- Rivers (barge movement slowed or halted on major rivers)
- Railroads (increased shipments and greater incomes)
- Airlines (few traffic delays)

Power Generation

- Record consumption of power (increased income for power companies)
- Hydropower generation reduced and costly fossil fuel substituted
- Many brownouts from damaged equipment

Commerce and Industry

- Weather insurance industry (high losses)
- Tourist industry (business losses)
- Construction (fewer delays and more income)
- Shippers (higher costs)

Urban Areas

- Reduced water supplies and higher water costs
- Elderly populations (increased sickness and deaths from heat)
- Increased water consumption

Table 3-1 lists financial losses and costs (1988 dollars) associated with the 1988 drought. The results show the agricultural sector was the major loser, with crop losses valued at $15 billion. National surpluses of stored grains were used to sustain the export industry. Crop losses raised prices, a benefit to farmers in nondrought areas. Livestock industry impacts were many animal deaths, more diseases, and inadequate, high-priced feed. The 1988 pasture conditions were classed as the worst on record. Agribusinesses suffered as low farm income led to few sales, and reduced yields decreased revenues for grain elevators and merchandisers. The agribusiness industry lost $800 million. Continuation of the drought conditions into mid-1989 led to more crop losses in 1989, totaling $2.4 billion nationally.

Record low flows on the lower Mississippi River restricted and then halted barge traffic. Shipments dropped 50 percent, a loss of $300 million. This coupled with higher shipping costs, caused the transportation losses and costs to reach $1 billion (Table 3-1).

Table 3-1. Losses and Costs (1988 dollars) Associated with the 1988 Drought.

Losses/costs	*Dollars (billions)*
Federal disaster assistance	4.3
Federal crop insurance and firefighting	3.4
Transportation	1.0
Farm production (uninsured)	15.0
Energy use	11.2
Food costs	10.5
Forest losses	5.2
Agricultural services/sales	0.8
Tourism	0.4
Total	51.8

The record high summer 1988 temperatures led to major increases in use of air conditioning, increasing income to power utilities and increasing costs for consumers totaling $1.1 billion. Inability to sustain hydropower generation led to more coal-fired generation that increased utility costs by $45 million. Other problems included low river flows that limited cooling water availability and higher surface water temperatures decreased efficiency of cooling, at a cost of $55 million.

Hot, dry weather reduced incomes for the tourism industry, a loss of an estimated $400 million. Lower levels of rivers and lakes limited fishing. Danger of wildfires led western states to restrict camping and hunting. The construction industry profited due to fewer rain days, which increased income by $130 million. Figure 3-8 illustrates the variety of impacts.

The lumber industry suffered major losses due to forest and wildlife fires. In the West, 68,000 wildfires burned 6.1 million acres of forest, the greatest loss since 1900 (Fig. 3-9). More than 30,000 firefighters served during July-August 1988. Heat and fires also killed thousands of seedlings. Losses and damages to the nation's forests totaled $5.2 billion.

Food costs increased greatly as a result of the drought and poor yields. Much higher prices for crops produced led to an increase in food costs, amounting to $10.5 billion nationally. The drought hurt retail sales as a result of reduced farm incomes, higher food prices, and higher power costs. It also depressed real income growth by 2.9 percent in 1988.

Drought-associated costs for government agencies were diverse and extensive. Many communities had to pay more for water supplies, such as for new wells, and several cities provided cooling centers so their residents could escape the heat. Some areas such as Atlanta had major water-supply problems (Changnon, 2000b). Maintaining supplies for Atlanta and other southeastern communities required costly reductions of hydropower generation and barge transportation on rivers supplying Atlanta and other regional communities. States fought fires and suffered losses of taxable income, and many provided funds for agricultural relief. For example, Illinois provided $65 million in farm aid. Federal funding was required to fight many western forest fires at a

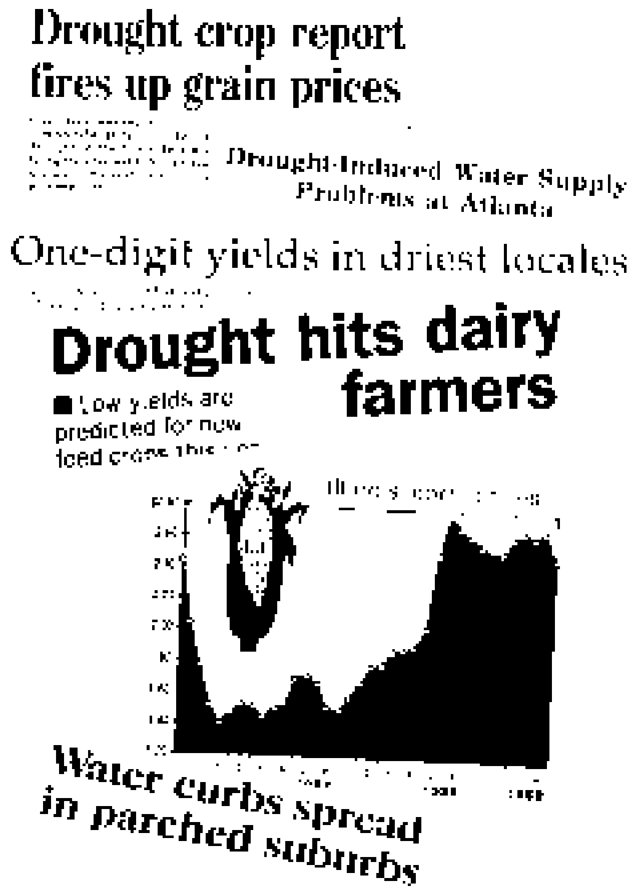


Fig. 3-8. Headlines reveal numerous and different impacts of the 1988 drought.

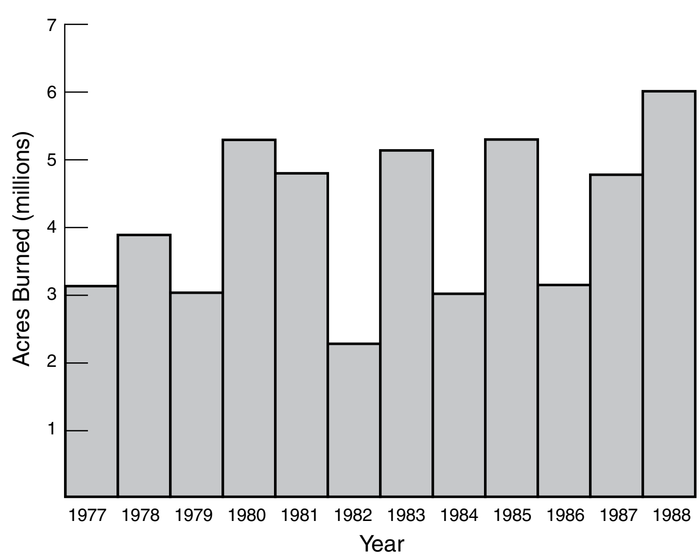


Fig. 3-9. Total U.S. acreage burned by forest fires, 1977-1988 (Riebsame et al., 1991).

cost of $300 million. The federal government provided $4.3 billion in disaster assistance to 26 states. The federal crop insurance program paid out $3.1 billion for crop losses. Economically, the agricultural sector was hardest hit by the 1988 drought—the nation lost 31 percent of its normal grain production.

The 1988 drought, with $51.8 billion in losses and costs, was likely one of the most costly climate anomalies of the 20th Century. Yet, it was not a major factor in the nation's economy (Riebsame et al., 1991). The GNP had a 0.6 percent downturn attributed to the drought, and the CPI rose 5 percent in 1988, but economists assigned only 0.6 percent to the drought effects.

There were some economic gains from the 1988 drought. These were related to utilities that had increased power sales resulting from the high summer temperatures; added work for water development firms; and increased shipments on railroads, which gained $300 million because barge shipments were limited due to low flows on major rivers. Major beneficiaries were agricultural producers in nondrought areas, which realized gains from normal yields because of the high prices caused by the drought. They gained $3.6 billion. Various economic gains from the 1988 drought reveal total gains of $5.383 billion, about 10 percent of the total losses/costs (Table 3-2).

The drought and the high summer temperatures had detrimental effects on human health and well being. Considerable mental stress occurred in farm areas, and anxiety clinics were set up in the Midwest. Mental stress came from difficult economic situations, including higher costs for food and power for air conditioning. The biggest impact was heat-related deaths. Excessive heat in 1988 led to an estimated 5,000 fatalities (Riebsame et al., 1991). Most heat deaths occurred in metropolitan areas of the East Coast and Midwest. Many deaths occurred among elderly persons in low-income situations and without air conditioning.

Table 3-2. Economic Gains (1988 dollars) from the 1988 Drought.

Gains		*Dollars*
Agricultural producers in nondrought areas had higher prices for their crops		$3.6 billion
Railroads carried shipments diverted from barges		$300 million
Water-producing technologies–well drillers, cloud seeding firms		$160 million
Electric utilities		$1.1 billion
Coal companies from increased coal use for power production		$63 million
Construction industry had more income due to less rain		$130 million
Commercial aviation–few weather delays		$28 million
	Total	$5.383 billion

CHAPTER 4: THE RECORD WARM AND WET 1990

Climate Conditions

Annual temperature and precipitation values for 1990 were highly unusual across a large part of the United States. It was the warmest year on earth up to that point in the 20th Century (Lecomte, 1991), and it was the nation's seventh warmest and tenth wettest year during 1895-1990. Normally, warm years in the prior 96 years were dry, reflecting on the oddity of 1990 wet conditions.

The climatic uniqueness of 1990 was more marked in the High Plains, Midwest, and eastern United States. A 17-state region was extremely wet and had a high annual mean temperature, ranking 1990 as a singular combination. It was the "warmest and wettest" year ever in these regions (Changnon and Kunkel, 1992). No other year in the prior 96 years approximated the mix of the near-record high annual temperatures and record high precipitation in 1990. These conditions were found from Kansas north to Canada and east through the Midwest to the Pennsylvania-New York area (Fig. 4-1).

Annual state precipitation amounts ranked in the top ten during 1895-1990 in 15 states (Kansas, Nebraska, South Dakota, Missouri, Illinois, Iowa, Wisconsin, Michigan, Indiana, Ohio, Kentucky, West Virginia, New York, Maryland, and Pennsylvania). Annual 1990 mean temperatures ranked in the top ten of the 96-year period in 13 states (Nebraska, South and North Dakota, Minnesota, Iowa, Missouri, Wisconsin, Kentucky, Ohio, Pennsylvania, West Virginia, Maryland, and New York). The regional precipitation departure was 7.6 inches above average, the wettest on

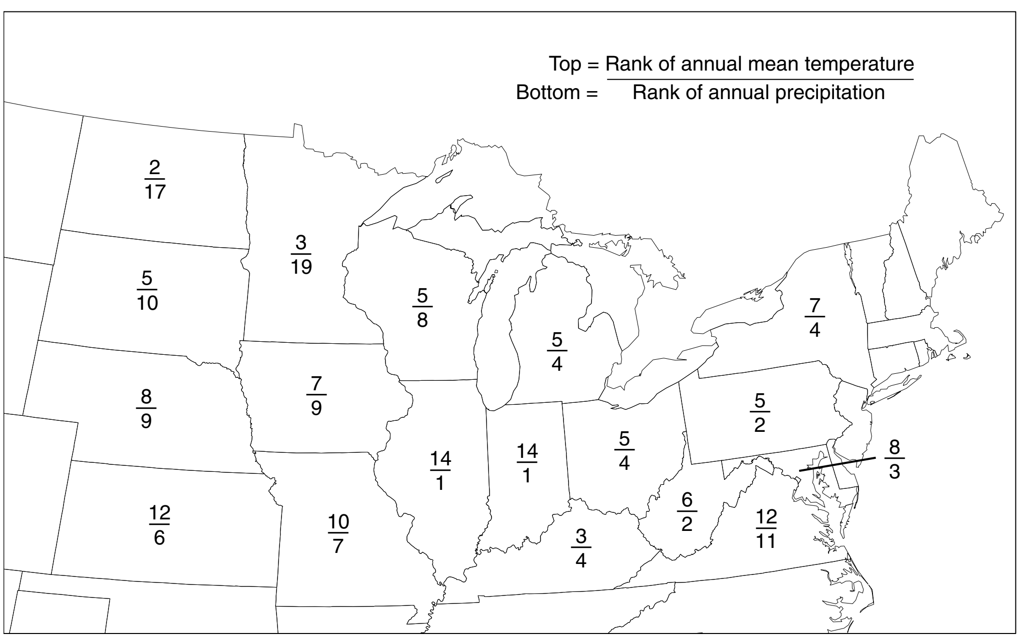


Fig. 4-1. Ranks of state annual temperatures (top value) with 1 = warmest value since 1895, and precipitation (bottom value) with 4 = fourth wettest value since 1895 (Changnon and Kunkel, 1992).

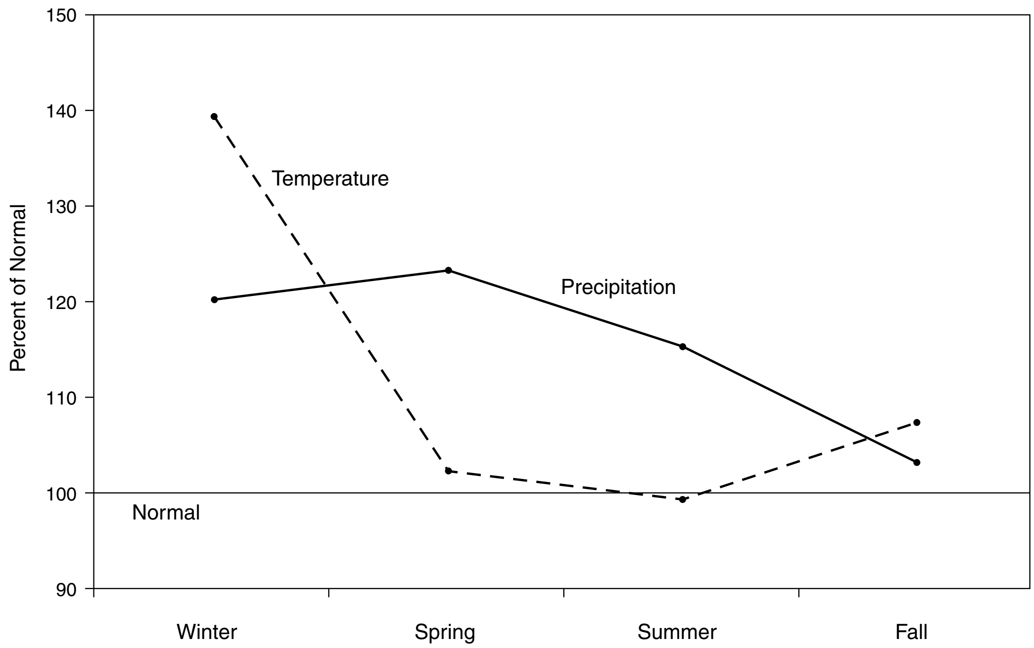


Fig. 4-2. Seasonal temperature and precipitation values for 1995 and for the central United States, expressed as a percent of normal values for 1961-1990 period (Changnon and Kunkel, 1992).

record. The annual mean temperature was 2.4°F above average, the fifth warmest year on record for this region. Annual temperature and precipitation values for 1990 approximate some of those suggested for the region by certain global climate models as a result of human-induced global warming.

High annual temperatures in the 15-state region were a result of extremely high temperatures in the fall and winter seasons, with near-normal values (based on 1961-1990 values) in spring and summer 1990 (Fig. 4-2). The region's extreme wetness in 1990 resulted from excessive precipitation in all but fall months when near-normal amounts prevailed in the north-central region (Fig. 4-2). All four seasons experienced abnormally large numbers of severe convective storms, an outcome expected in a wet year. Several states experienced record high monthly numbers of tornadoes including Iowa (21 in March), Indiana (13 in June), Kentucky (11 in June), Michigan (6 in September), and Illinois (7 in November).

Impacts

Environmental, human, and economic impacts in the north-central region from the unusual 1990 climate conditions have been assessed (Changnon and Kunkel, 1992). The wet winter and spring of 1990 ended the soil moisture shortage lingering in the High Plains and Midwest from the 1988 drought (Chapter 3). By June 1990, soil moisture was rated as adequate to excessive throughout the 17-state region.

Excessive rains from late January through March 1990 produced flooding along many regional rivers during March and April (Fig. 4-3). Major riverine, urban, and rural flooding followed in May and June. Flooding occurred again in October-December in parts of the region. Flooding was a problem in most of the 17 states throughout 1990 (Fig. 4-4). Numerous urban floods hampered operations of water and sewage treatment plants. For example, polluted floodwaters at Chicago had to be diverted back into Lake Michigan twice, and flood losses were high.

Effects of the 1990 conditions on agriculture were surprising. The wet winter-spring of 1990 (Fig. 4-2) delayed planting of grain crops by several weeks, leading to increased soybean planting and less corn over several million acres of the Midwest. Figure 4-5 shows flooded farm fields in Ohio during May 1990. The cool, wet April-May period also increased insect pests, and higher-than-average wind speeds of spring and summer limited opportunities to spray for pests. Planting delays also brought two potential dangers: greater vulnerability to heat-induced stress at critical crop growth stages in July-August, and potential damages from frosts/freezes before the late harvest times, a result of the late planting. High daily summer temperatures and no early frosts/freezes occurred, however. The growing season had numerous severe storms, flooding fields (Fig. 4-5), and producing extensive hail and wind damage (Fig. 4-6). July and August had very little rain, and 1990 crop yields were below average. State corn yields were 6-9 bushels/acre below average, and soybean yields were 1-2 bushels/acre below average. Income benefits to farmers in the region were higher than average, primarily due to high market prices, and were assessed at $1.6 billion (Table 4-1). Agribusinesses also benefitted from the good farm incomes: the total increase in income in 1990-1991 was $1.15 billion.

Impacts in the energy sector varied depending on users and producers. The warm winter reduced heating demands and expenditures for gas, and the near-average summer temperatures did not create high use of air conditioning. The warm January 1990 led to savings for users, amounting to $320 million across the region. Consumers of gas and electricity in the central and eastern regions of the nation were winners in 1990, with reduced costs amounting to $2.9 billion. In turn,

Fig. 4-3. A river in Iowa has sent floodwaters over a small town.

Heavy rains pushing rivers out of banks

Rainfall threatens to worsen flooding

Midwestern flood victims wet, jittery

Sandbags hold back Illinois River

Cleanup under way

■ Storm damaged area warehouses, school building

"It was really amazing with those warehouses. The storm just picked those up and threw them on the railroad tracks.

Dry skies easing Midwest flooding

Planting for beans, corn latest in 20 years

Fig. 4-4. Headlines describe the spring 1990 floods.

Fig. 4-5. Ohio farm fields flooded in May 1990.

Fig. 4-6. Rural farm buildings in Illinois were damaged by high winds from a June 1990 storm.

Table 4-1. Economic Impacts (1990 dollars) in 17-State Area from 1990 Climate Conditions.

Losses/costs (billions)		*Gains (billions)*	
Property damages	0.63	Farm income	1.62
Utility industry	3.40	Agribusiness profits	1.15
Government costs	0.62	Energy use	2.90
Insurance costs	0.51	Construction profits	1.40
Tourism	0.19	Retail sales	2.13
Transportation	0.38	Total	9.20
Total	5.73		

power companies were losers due to the large decrease in sales. Frequent storms caused numerous power outages, adding to costs for power utilities. Costly power outages occurred in large urban centers, including Detroit, Chicago, Cleveland, Des Moines, and Minneapolis, totaling $0.5 billion. Chicago had four power outages, and each affected more than 250,000 residents for periods from 6 hours to 4 days.

Much-above-average storminess in 1990 created excessive losses and costs for property insurance companies, amounting to $510 million. In 1990, there were 12 catastrophic storm events (each causing >$1 million in damages) in the 17-state region, 33 percent more than normal (9 storms). Flooding produced considerable damage, and the total loss to property was $630 million (Table 4-1), compared to the region's annual average of $413 million.

Frequent storms had several impacts on movement of people and goods. Regional airports had many closures due to adverse weather, and O'Hare Airport in Chicago, the nation's hub for air travel, had at least one closure every month in 1990. Most detrimental to surface transportation was excessive fog in 1990, which reduced or halted surface and air travel over several 1- to 3-day periods. This created many serious accidents, and major travel and shipping delays. Flooding also hampered travel, and losses and recovery costs for the transportation sector totaled $380 million.

Retail businesses benefitted from the mild winter and fall conditions (Fig. 4-2). Sales were well above average in these seasons, leading to an income increase of $2.13 billion for regional businesses. Low snowfall in 1990 reduced winter sports in the region's northern sectors, however, and numerous storms in the warm season led to many event cancellations. Many campgrounds experienced prolonged flooding, and the net effect of 1990 conditions on the region's tourist industry was a loss of $190 million.

State and federal government responses to impacts led to considerable spending. Several states received Presidential disaster declarations due to winter, spring, and fall flooding in 1990, and from major tornado damages in June and August. State agencies also provided relief funds, and many cities and towns had to expend funds on their flood-damaged water treatment and sewage treatment plants. Additional government expenditures in the 17-state area in 1990 totaled $620 million.

What costs and financial gains did the extremely warm, wet year of 1990 produce? The net effect of the various economic impacts (Table 4-1) reveals total gains of $9.2 billion, which exceeded the $5.7 billion in losses and costs. The 1990 winners and losers were a different combination than found in the other nine climate anomalies described herein.

The unusual climate conditions in 1990 also had impacts on human health and life. Severe tornado outbreaks in the 17-state region included 254 tornadoes, a record number for one year, and led to 59 deaths. Abnormally stormy and foggy conditions caused boat accidents, airplane crashes, and many auto accidents, leading to 75 deaths. Other fatalities were due to lightning (18 deaths), hypothermia (5 deaths), and drowning in the flash floods (56 deaths) including 29 persons who drowned in a flood at Shadyside, Ohio. The regional total was 213 climate/weather-induced deaths, well above the regional average of 134 deaths per year.

CHAPTER 5: RECORD 1993 MIDWESTERN FLOODS

Climate Conditions

The great floods of 1993 embraced the entire Upper Mississippi River basin and had a unique long-term evolution. Like major droughts, the flood's potential severity, longevity, and great areal extent were not well recognized during its developing stages. In July 1992, above normal rainfall began in the basin and continued through March 1993, producing minor winter flooding. Snowmelt waters, coupled with very heavy spring rains across the central United States, created a typical springtime flood in the basin that lasted three weeks. By April, Midwestern soil moisture was fully recharged. Very heavy May rains exceeded 6 inches in the Kansas and Missouri area, and more than 9 inches fell in mid-May in Minnesota and South Dakota. Heavy rains then fell in June through the Dakotas, Minnesota, Wisconsin, Iowa, and Illinois, and major flooding began along all the region's rivers. Figure 5-1 depicts the area with above average summer rainfall. Normally this area receives 10-13 inches of summer rain, but 16-36 inches that fell in summer 1993.

Assessment of the monthly precipitation amounts in the Midwest during spring and summer 1993 (Fig. 5-2) reveals different rainfall regimes: 1) a buildup phase in April-May, 2) a transition phase to very heavy rains in June, 3) sustained heavy rains in July-September, and 4) lesser rains in October. Rain in the basin exhibited ten episodes of heavy rains (>1 inch), between May 8 and August 20. During June and July, there were eight consecutive weeks of extreme rainfall, a spectacular climate event (Kunkel, et al., 1994).

Illinois, Iowa, North Dakota, and South Dakota recorded their wettest summers on record, as did Montana and Idaho, and above normal annual precipitation occurred in 29 states. The year 1993 ranked as one of the ten wettest years since 1895.

A climatological assessment of the highly unusual conditions that shaped the record flood of 1993 reveal five key conditions:

- Heavy rains throughout the summer covered vast areas of the Mississippi River basin, and summer rains in and around Iowa were record highs (Fig. 5-1).
- Flood-producing conditions had developed many months prior to the main flood such that wet soils and high river flows existed when the heavy summer rains began.
- Massive daily rains during June 29-July 10 brought immense flooding across the basin.
- The area of heavy rains was centered on the Upper Mississippi River basin, and all sub-basins contributed to flooding on major rivers.
- Low evapotranspiration in summer 1993 kept soil moisture high, a result of numerous cloudy days.

In contrast, drought and heat wave conditions occurred in the Southeast during May-August 1993. Temperatures above 95°F occurred on 45 days during June and July in Georgia and South Carolina. Another area of the nation with conditions quite different than those in the Midwestern flood area was the Northwest. That area experienced a very cool summer with temperatures more than 6°F below normal across Montana, Idaho, and Oregon, forming another unusual climate anomaly in 1993.

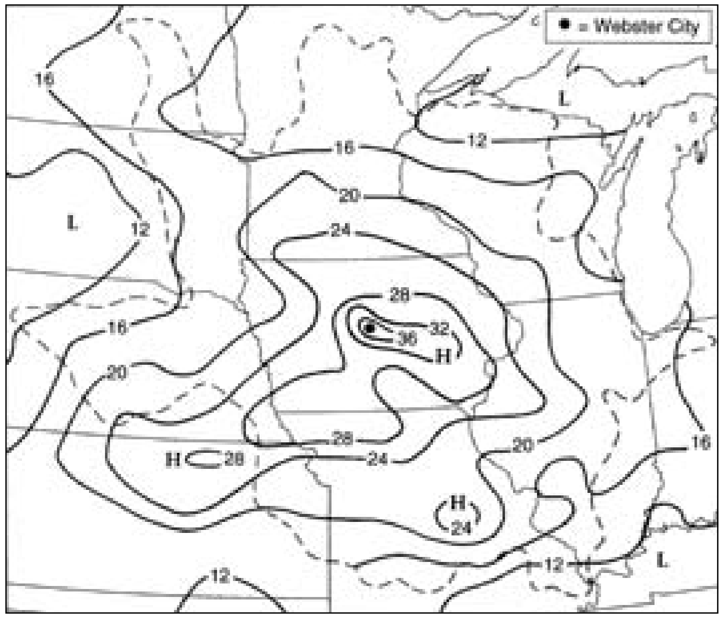


Fig. 5-1. Total rainfall (inches) for summer 1993. Isohyetal lines are solid and the dashed line is the boundary of the Upper Mississippi River basin (Kunkel, 1996).

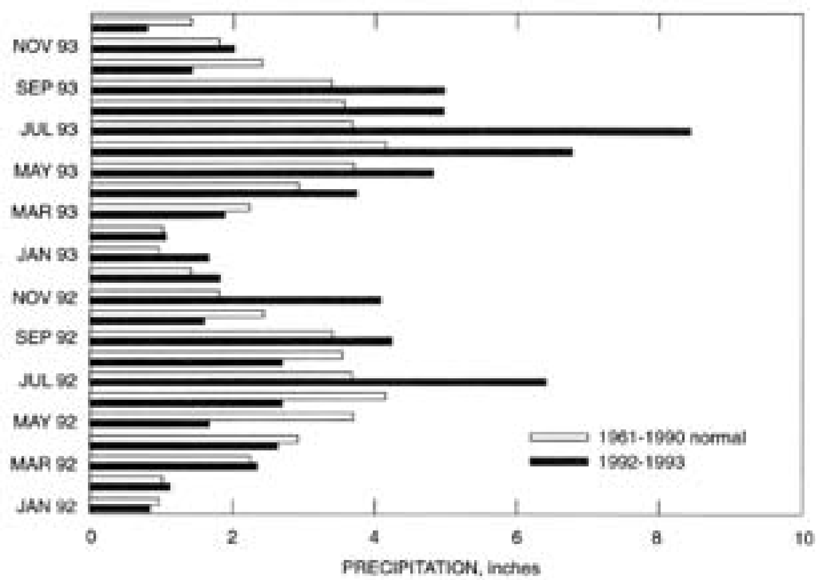


Fig. 5-2. Monthly precipitation values (inches) January 1992-December 1993, and their normals for the Upper Mississippi River basin (Kunkel, 1996).

Impacts

The 1993 flood anomaly was unique with respect to its heavy rainfall throughout the summer, its long duration, and the large areal extent. The flood inundated 10,300 square miles in nine states (Fig. 5-1). As shown in Figure 5-3, there were a multitude of environmental effects and sizable economic impacts (Changnon, 1996). By mid-summer, Koellner (1996) showed that the Mississippi River had reached record-high levels near St. Louis (Fig. 5-4). As the 1993 flood developed, considerable uncertainty among experts over whether it qualified as a 50-year, 100-year, or 500-year event revealed that floods, like droughts, are not always defined by their geophysical dimensions, but by the damages they inflict. That the 1993 floods qualified as record flooding by the damages created is not open to question: it was the nation's record-setting, damaging floods of all time. However, the floods also benefitted the agriculture, business, and transportation sectors.

Fig. 5-3. Headlines from various sources during the peak of the flood in mid-July (Changnon, 1996).

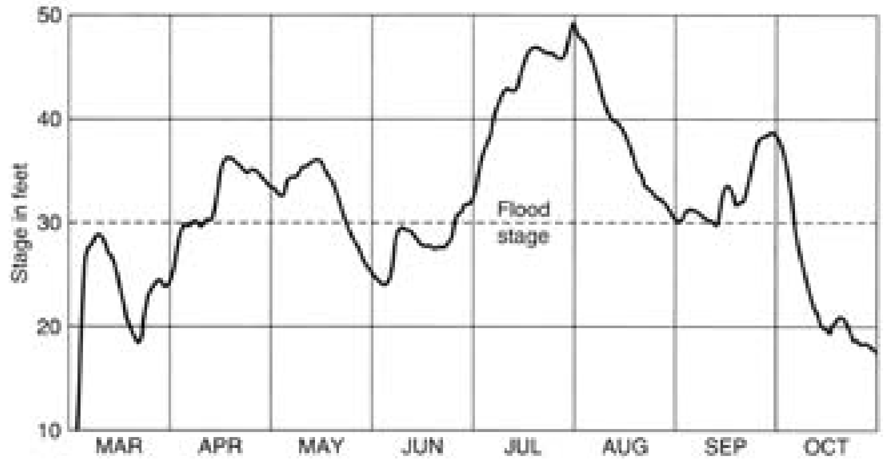


Fig. 5-4. A hydrograph depicts the level of the Mississippi River at St. Louis with extremely high levels during June-August 1993, and the river's flood stage (Koellner, 1996).

There were major effects in four areas: 1) the environment, 2) the economy, 3) government activities at local, state, and federal levels, and 4) society. Major impacts centered around the uniqueness of the prolonged extreme rainfall and resulting high waters. More than 1,000 levees were destroyed, and 4 percent of the Corn Belt farmland was inundated. This included 5.1 million acres of corn and 3.1 million acres of soybeans. Corn yields decreased 50 percent in Iowa, Minnesota, and Missouri, and 20-30 percent in Illinois, Indiana, and Wisconsin (Fig. 5-5). Major east-west railroads had extensive damages. As shown in Figure 5-6, flood-caused track outages closed numerous major rail lines, halting train operations for many weeks between the nation's three rail hubs, Chicago, St. Louis, and Kansas City (Changnon, 2006b). Major environmental effects related to erosion and siltation, including waterborne chemicals. Much of the region's landscape was changed forever. While there were some benefits in river floodplain ecosystems, the flood caused a rapid spread of destructive zebra mussels into the region's rivers, an environmental catastrophe (Changnon, 1996). The mussels were an invasive species brought into the Great Lakes in the ballast water of foreign ships. There were also damages to the Gulf of Mexico's ecosystem from eroded soils and riverborne chemicals carried there by floodwaters in the Mississippi River.

Economic impacts were the greatest on record for any U.S. flood in the 20th Century. These impacts involved property losses to individuals in and near flooded communities, to floodplain farmers, and to Midwest businesses and industries. Businesses with losses included retail sales, agricultural production, utilities, manufacturing, transportation, tourism, and recreation. The Mississippi River was closed to barge traffic for four months beginning in June, leading to a massive shift of grain and coal shipments to north-south-oriented regional railroads. Flood-produced damages, delays, and costs to most railroads in the Midwest totaled $480 million, the greatest loss ever experienced by American railroads (Changnon, 2006b). Property losses from the flooding totaled $1.95 billion.

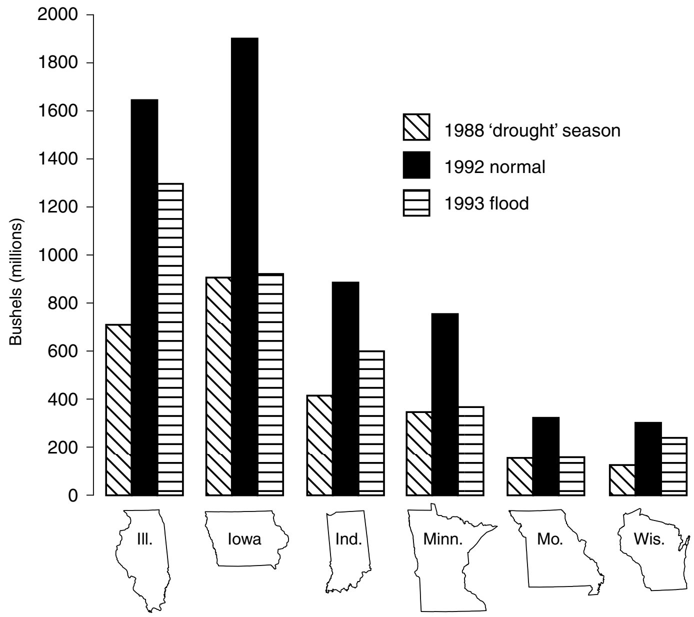


Fig. 5-5. Corn production in Corn Belt states, 1993, 1992 (normal values), and 1988 (Changnon, 1996).

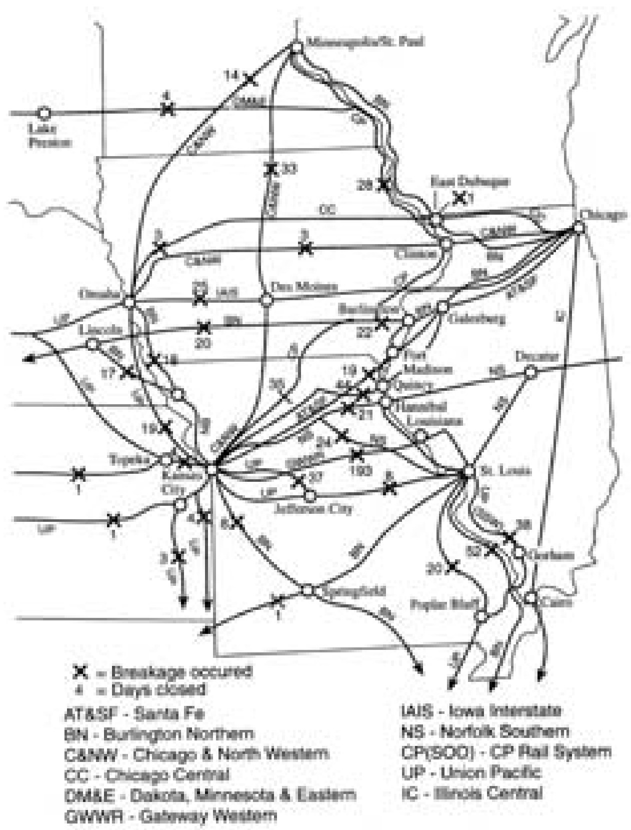


Fig. 5-6. Flooding closed railroad lines for a week to 6 months (Changnon, 2006).

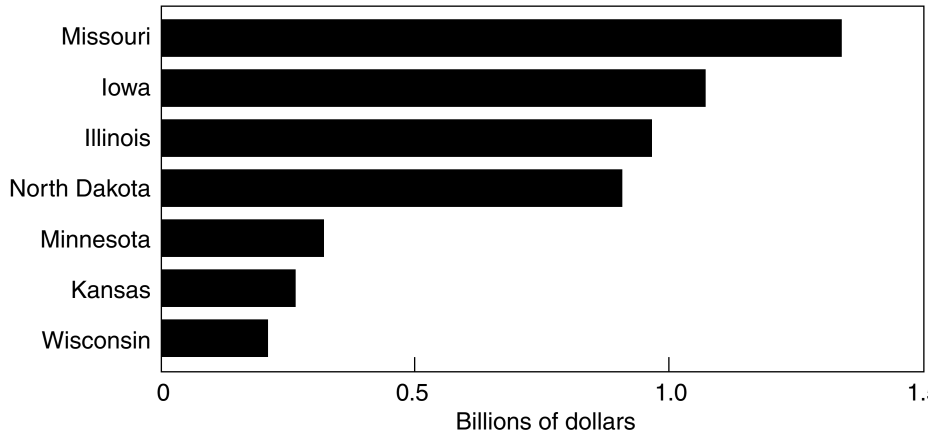


Fig. 5-7. Property damages from the 1993 flood covered seven states (Hewings and Mahidhara, 1996).

Figure 5-7 shows estimates of the property losses for the seven states with the greatest losses, and losses exceeded $1 billion in Illinois, Iowa, and Missouri. Many Midwestern governors declared their states disaster areas and sought federal funds, primarily for farmers with flood-damaged crops and homeowners with damage. As shown in Table 5-1, flood losses for all sectors totaled $24.7 billion. Delayed losses of $2.1 billion a year or more after the flood included those resulting from pollutants released by floodwaters, soil losses, groundwater damages, and environmental changes.

In contrast, grain farmers in unflooded areas of the nation were winners, as the flood caused crop prices to soar 15-35 percent, an income benefit totaling $6.2 billion (Table 5-1). Certain railroads also benefitted $38 million from hauling grains and other commodities unshippable by barges.

Although losses over the nine-state flooded area were excessive and created the nation's most costly flood ever, the flood had little impact on the nation's economy as a whole. Economic impact analyses for 1994, with and without the 1993 flood, revealed several interesting outcomes. The flood did not change the nation's GDP in 1993, but it was predicted to increase the GDP in 1994 by 0.02 percent due to expenditures for flood repairs (Hewings and Mahidhara, 1996). The 3.3 percent rate of inflation in 1993 was unchanged by the flood, but that rate increased from 3.5-3.6 percent in 1994 as corn and soybean losses in 1993 caused wholesale farm prices to rise 6 percent. Corporate profits in 1993 dropped 0.01 percent due to the flood losses and insurance costs, but profits increased 0.8 percent in 1994 due to rebuilding and cleanup efforts. A year after the flood nearly $3 billion had been spent on reconstruction, a boon to the construction industry (Hewings and Mahidhara, 1996).

Table 5-1. Losses and Gains (1993 dollars) Due to the 1993 Flood.

Sector	*Losses (billions)*	*Sector*	*Gains (billions)*
Agriculture	8.900	Agriculture	6.200
Transportation	1.900	Transportation	0.038
Business/industry	2.955	Construction	3.000
Property	1.950	Total	9.238
Government	6.930		
Business & environment (delayed losses)	2.100		
Total	24.735		

Impacts to government entities were extensive, including huge costs for flood monitoring-prediction, fighting the floods, and subsequent aid to individuals. Federal payouts resulting from the flood totaled $6.2 billion. Considerable federal and state funding ($0.73 billion) also went into re-building area infrastructures. For example, many bridges over the region's rivers were damaged, and some had to be rebuilt.

The flood also raised major policy issues about floodplain management and adequacy of crop and flood insurance. Identification and awareness of these problem areas were actually positive outcomes. Major questions raised (Changnon, 2005) included: How adequate are the nation's flood control structures? How can crop and flood insurance be altered and improved? How should programs for buyouts of floodplain property be handled? How to shift to more appropriate environmental uses of flood-prone lands?

Impacts to society were pervasive, but only 52 persons were killed by the flooding and no widespread diseases occurred. Extensive losses of homes and jobs (30,000 lost jobs) created great stress, anxiety, and insecurity, conditions that lasted several months after the flood. More than 94,000 persons were evacuated during the flood, 45,000 of them were still homeless by the end of November 1993, and 60,000 homes were a total loss.

CHAPTER 6: COLD, SNOWY WINTER 1993-1994

Climate Conditions

The 1993-1994 cold season began early in fall 1993 and lasted into April 1994. The fall of 1993 was the nation's third coldest one on record, and winter (December-February) 1993-1994 ranked as the tenth coldest one on record for the Northeast (Fig. 6-1). The cold and heavy snow conditions that defined this climate anomaly occurred in the High Plains, Midwest, East, and Northeast (Fig. 6-2).

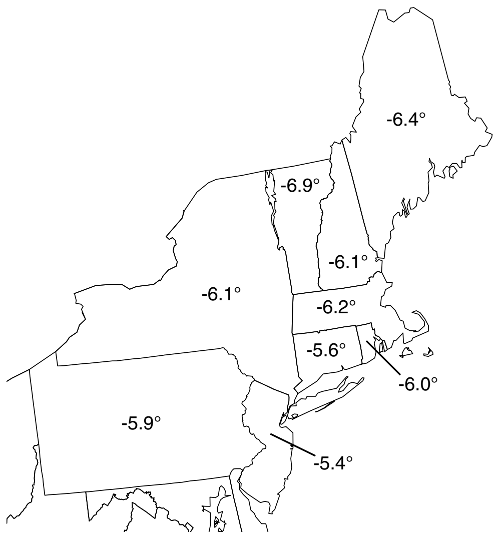


Fig. 6-1. Departure of winter (December-February) 1993-1994 temperatures below normal (1961-1990), degrees Fahrenheit, in the Northeast.

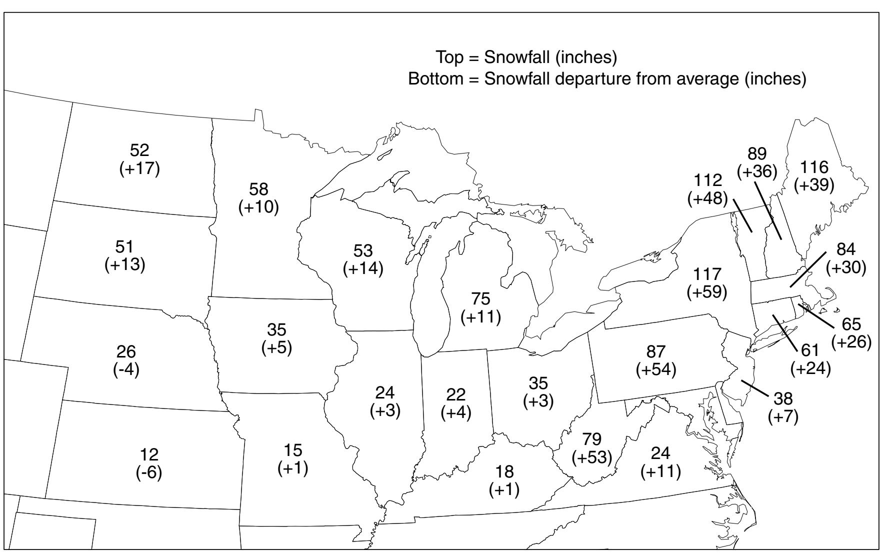


Fig. 6-2. Total cold season (November 1993-March 1994) snowfall amounts and departures from average values (inches) for 1901-1990 and for each state in the anomaly region.

Winter 1993-1994 was a mixture of very low temperatures, quite stormy conditions, high winds, and record snowfalls. Snow totals in the East and Northeast ranged between 40 and 220 inches, and amounts in Boston and several other eastern cities were record highs. As shown in Figure 6-2, snowfall amounts in most states were above average, with very large departures in New York, Vermont, Pennsylvania, and West Virginia. Stormy conditions began in late October and ended in early April, a 5.5-month period of climate extremes. Each of the 12 major winter storms produced snowfalls in excess of 12 inches, and nine also produced extensive areas of glaze. Interestingly, the western third of the nation experienced almost totally different climate conditions with temperatures much above normal and low precipitation during the cold season.

Freezing temperatures in early fall, produced damaged crops, and a very early major winter storm in late October brought record cold daily temperatures and heavy snow to the central and eastern United States. November and December were marked by numerous flash floods resulting from heavy precipitation and snowmelt in the Midwest and East. Coastal flooding also was common during these months due to frequent high winds along the East Coast. Cold air outbreaks in both months brought record low daily temperatures across the region. These lows were associated with major winter storms that occurred in the Upper Midwest, High Plains, and East in late November and December. December snowfall totals were record highs in Virginia, West Virginia, and Maryland.

January 1994 had low mean temperatures across the anomaly region, with record-low daily temperatures from Chicago east to New England. The mean monthly temperatures for New England ranked as the third lowest on record, and Figure 6-3 shows temperature departures and ranks for the climate anomaly region. Heavy precipitation continued in 1994, largely through occurrence of numerous major winter storms, including five in January, two in February, one in March, and one in early April. January-March temperatures in the region continued to be below normal, and February values were 4°-8°F below normal. The mean temperature for January-February in New England ranked as the lowest on record.

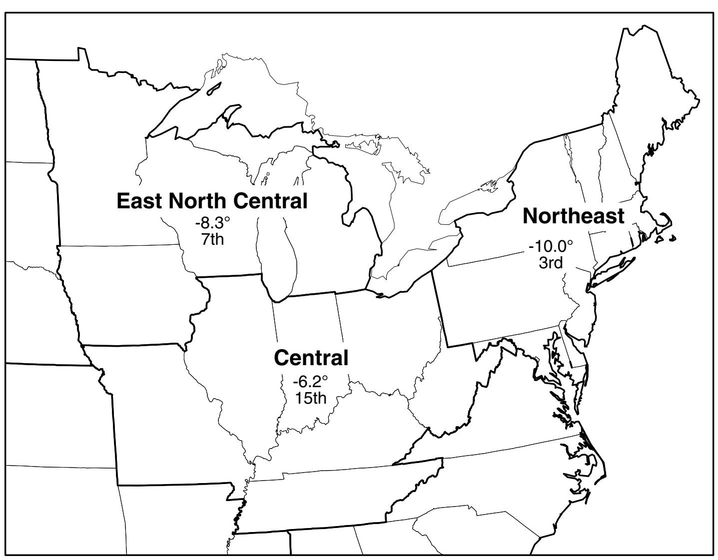


Fig. 6-3. Departure from average (1895-1990) of January 1994 mean temperatures for climate regions in the anomaly area (3rd means the third coldest January on record).

Impacts

The 1993-1994 cold season brought an array of impacts, primarily losses and related costs (Changnon et al., 1996). Heavy snowfall and thick ice from the 12 major storms resulted in losses and costs (to respond and repair) that totaled $10.8 billion. The property insurance industry, which assessed storms causing damages exceeding $5 million, identified six events during the 1993-1994 cold season. Resulting property losses totaled $1.765 billion. Many roofs collapsed and poles and power lines broke after heavy snows and ice storms (Fig. 6-4).

Flooding was a major factor in many property losses. Coastal flooding along the East Coast eroded beaches and damaged shoreline properties. Numerous flash floods from snowmelt and heavy precipitation caused extensive property losses, and 18 persons drowned. Flood-related property losses, largely uninsured, totaled $3.2 billion.

Extremely low temperatures were another factor. Damages to uninsured property from frozen pipes and water mains totaled $135 million, and early cold temperatures caused crop losses of $180 million. Use of gas and electricity for additional heating demands was excessive, and added consumer costs totaled $6.5 billion (Changnon and Hewings, 2000). These added purchases provided a major gain for the utility industry. However, repairing the many power lines (and telephone lines) downed by snow and ice cost $2.34 billion.

Winter conditions raised costs and payments by local, state, and federal agencies. New England states spent $430 million to address their excessive winter problems. Snow removal costs for the anomaly region were $815 million above normal costs. Federal and state aid to those damaged by heavy snows and flooding, and to provide support to those unable to pay high utility costs, cost $1.14 billion. Total government expenditures were $1.953 billion.

Fig. 6-4. Heavy snows and ice storms in Ohio downed power lines and blocked a rural road.

Retail sales across the region were diminished, as were construction activities. Collectively, losses to these business sectors were estimated as $2.4 billion. Storm-induced travel limitations hurt the tourist industry, and business decreased by $300 million from average.

The region's transportation systems also had severe impacts. Highway travel frequently was halted and greatly delayed, and regional railroads experienced costly delays (Changnon, 2006b). Business losses and costs related to the numerous road closures were $4.0 billion. Losses and costs for repairs related to surface travel systems were $180 million. Airlines experienced major problems with closed airports and stormy conditions aloft, causing thousands of flight cancellations. Loss of business and related costs for the commercial airline industry totaled $1.3 billion. Total losses and costs from the 1993-1994 anomaly were $24.375 billion (Table 6-1). Gains experienced by the utility industry were $6.5 billion, and post-winter repairs were $600 million in income for the construction industry, leading to total gains of $7.1 billion (Table 6-1).

The environment also experienced many losses, primarily trees and underbrush damaged by heavy snows and glaze (Fig. 6-5). Damages to forests in the Northeast led to losses of $260 million (Table 6-1).

Society experienced losses and numerous problems that created widespread anxiety in the region. There were major travel delays, difficulties in reaching jobs, and prolonged power outages, all conditions producing stress. Thousands reported experiencing frostbite and hypothermia from record cold temperatures. Winter conditions led to 101 deaths. This included 61 deaths from the severe cold, 18 deaths from floods, and 22 deaths from vehicle accidents. More than 1,200 weather-related injuries also were reported.

Table 6-1. Losses and Gains (1994 dollars) Resulting from the Climate Conditions during the 1993-1994 Cold Season.

Sector	*Losses (billions)*	*Sector*	*Gains (billions)*
Uninsured property damages	3.20	Utilities	6.50
Insured property losses	1.765	Construction	0.60
Transportation	1.480	Total	7.10
Utility line repair costs	2.34		
Forests	0.26		
Agriculture	0.18		
Government	1.95		
Business	4.00		
Retail/construction	2.40		
Energy	6.50		
Tourism	0.30		
Total	24.375		

Fig. 6-5. Heavy snow and ice in New England damaged trees.

CHAPTER 7: THE 1995 FLOODS AND HEAT WAVE

Climate Conditions

An interesting climate anomaly developed in April 1995 and lasted through August 1995. The area affected included the Great Plains, Midwest, and East Coast. This 31-state area began experiencing heavy precipitation in early April, and heavy rains persisted into late June. Rainfall totals for this 3-month period were 110-210 percent above average in this area. Parts of Oklahoma, Kansas, Missouri, Illinois, and Indiana had amounts more than double their 3-month normals for 1961-1990 (Fig. 7-1). Many areas had 18-30 inches of rain, resulting in major floods. May rainfall was the heaviest on record in Kansas, Illinois, Missouri, and Indiana. Heavy rains of 10-25 inches fell during May in Texas, Oklahoma, Louisiana, and Mississippi. California also experienced heavy precipitation, with totals of 20-70 inches during January-April 1995.

High temperatures began developing across the High Plains, Midwest, and East during early July. High dew point temperatures, a result of evaporation from the wet soils, developed across the Midwest in July (Fig. 7-2). A 5-day period of exceptionally high air and dew point temperatures occurred during July 11-15. Temperature values in Iowa, Wisconsin, Illinois, and Michigan ranked as the most intense July heat wave of the 20th Century (Kunkel et al., 1996). Figure 7-3 shows the record high rankings of daily air and apparent temperatures during July 11-15. Apparent temperatures exceeded 100°F, and resulted largely from the record high dew point

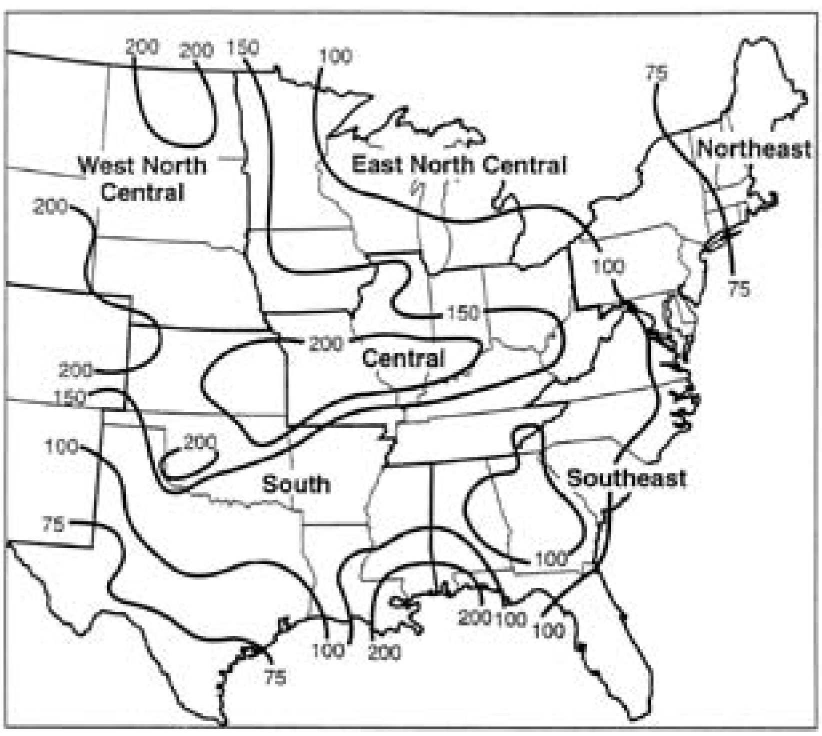


Fig. 7-1. Percent of normal precipitation, based on values for 1961-1990, for April-June 1995.

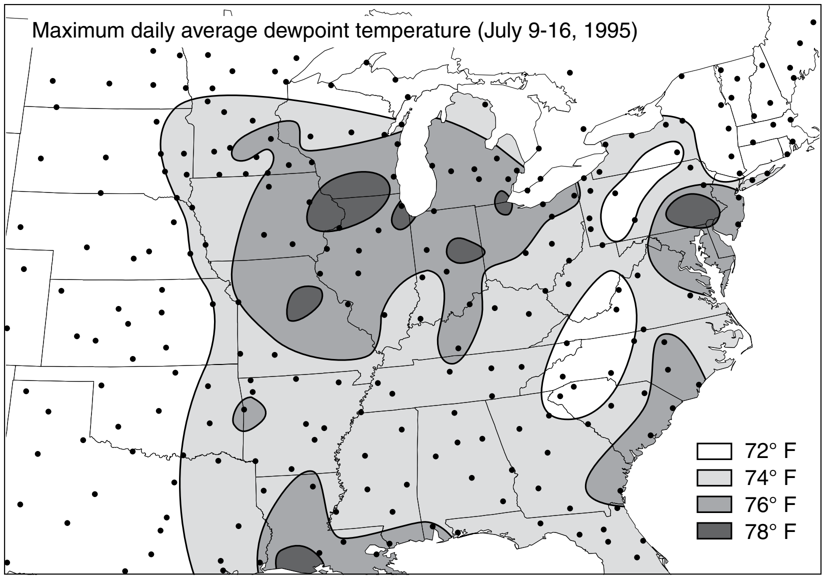


Fig. 7-2. Maximum daily average dew point temperatures (degrees Fahrenheit) observed during July 9-16, 1995 (Kunkel, et al., 1996).

values. Apparent temperature is a value that integrates measures of air temperature, moisture, and wind, and reflects the ability of the human body to dissipate heat. These regionally excessive moist conditions were from excessive evaporation from wet soils of the region, resulting from prolonged heavy rains in April-June (Fig. 7-1). Much above normal (1961-1990 base period) temperatures (4-7°F) persisted into August across most of the nation. Record high August temperatures occurred in several eastern and Midwestern locales. Many states in the Ohio River valley and New England had one of their driest Augusts on record.

Impacts

Above normal April-June rainfall resulted in saturated soils and major flooding. The Palmer Drought Index for early June indicated saturated soils over much of the Great Plains and western Midwest, but soil moisture values farther east were near average.

Surplus moisture led to widespread flooding (Fig. 7-4). All Illinois and Missouri rivers were above flood stage by May 1, and by mid-June, the Missouri River from Kansas City to St. Louis was 8-10 feet above flood stage; the Mississippi River from Iowa to Arkansas was 6 feet above flood stage; and the lower Ohio River was 4 feet above flood stage. Barge traffic on major rivers had to stop for six weeks. Governors of Missouri and Illinois called out their National Guard units to help fight the flooding. Losses to property and transportation firms resulting from the flooding totaled $4.9 billion (Changnon et al., 2001), and 23 persons were killed by the floods in the Midwest. In addition, heavy May rains resulted in floods over parts of Texas, Mississippi, and Louisiana, creating losses of $5 billion and 21 fatalities. California floods during January-April caused losses of $3 billion and 27 deaths. Owners of less than 10 percent of all properties damaged had flood insurance.

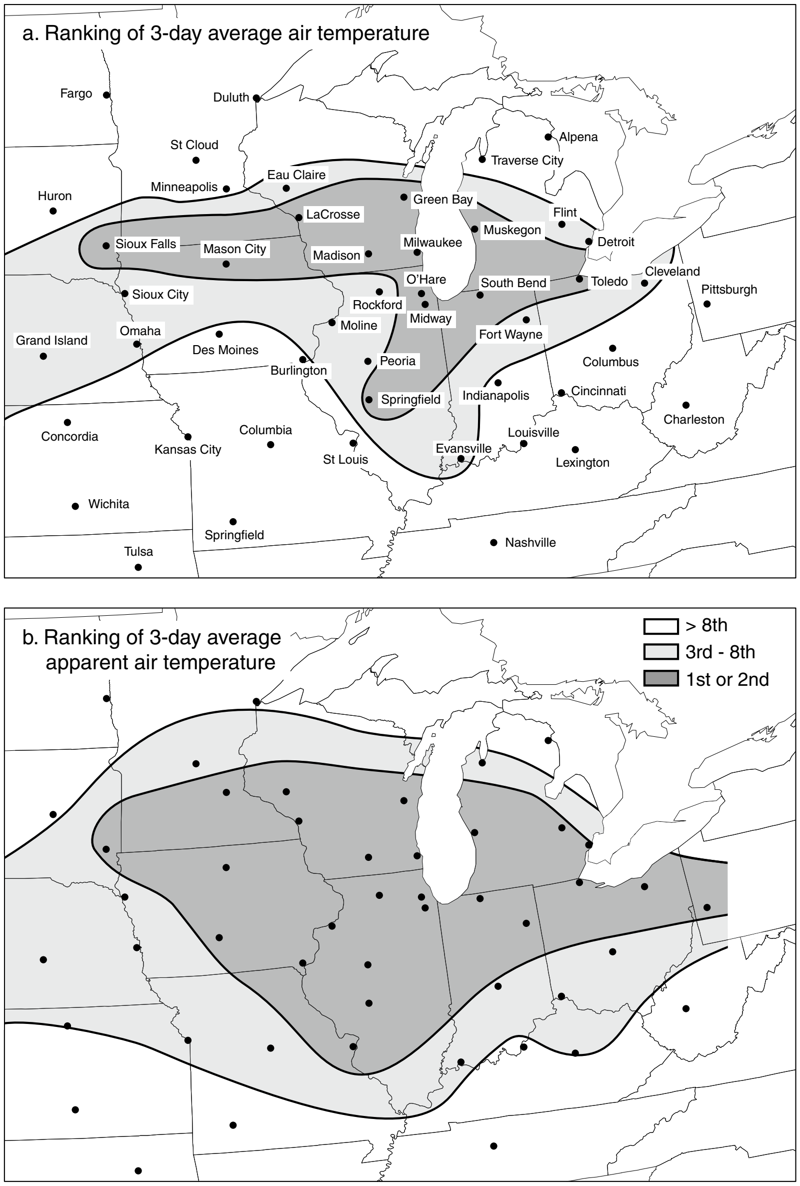


Fig. 7-3. Ranking of maximum 3-day average air temperature (top map) and of the maximum 3-day average apparent temperature (lower map), July 11-15, 1995 (Kunkel et al., 1996).

Late planting due to spring wetness, field flooding, and then near-record high temperatures in July and August hampered agricultural production in the central Great Plains and Midwest. Wheat yields in the High Plains and Midwest were down 5-10 bushels per acre (bu/acre). The nation's highest corn and soybean yields in 1995 occurred in the Midwest, but these yields were well below average. The corn yields of various states were 4-11 bu/acre below average, and soybean yields were down 1-5 bu/acre. As shown in Table 7-1, losses from economic impacts in agriculture totaled $6.15 billion (Changnon, et al., 2001), and various agricultural impacts occurred (Fig. 7-5).

National Guardsmen relay sandbags for use in reinforcing the Big Swan Levee near Winchester. The Illinois River levee, along with the neighboring Scott County Levee, were under watch last week, even as floodwaters started to fall. See more on flooding problems inside. (Photo by Ken Kashian)

Flood spotlights levee weaknesses

Fig. 7-4. National Guard troops in Missouri reinforced a levee with sandbags to halt the flooding (*Farm Week*, 1995).

Table 7-1. Losses and Gains (1995 dollars) Produced by the 1995 Floods and Heat Waves.

Sector	*Losses (billions)*
Property	4.900
Agriculture	6.150
Energy	0.510
Railroads	0.120
Retail business	0.092
Government	1.820
Total	13.592

Sector	*Gains (billions)*
Energy	0.510
Tourism	0.098
Business	0.108
Total	0.716

The July heat wave created several impacts, but the most critical was to human health (Changnon et al., 1996). The short but intense July heat wave caused 830 deaths nationally. The heat wave killed 718 persons in the Midwest, 87 percent of the national total, and the heat wave deaths were concentrated in Illinois and Wisconsin. This event joined the ranks of other recent heat waves (1966 and 1988) in number of deaths in the Midwest. Most who died in 1995 were urban residents, with 525 deaths in Chicago and 60 deaths in Milwaukee (Fig. 7-6). Most deaths occurred during a 4-day period, July 13-16 (Fig. 7-2). As in previous heat waves, deaths began two days after the heat wave began. Urban heat islands greatly exacerbated the heat problems. Urban heat islands exhibit much less nocturnal cooling than occurs in rural areas, and this nocturnal difference was a critical factor in the level of heat stress inside the cities.

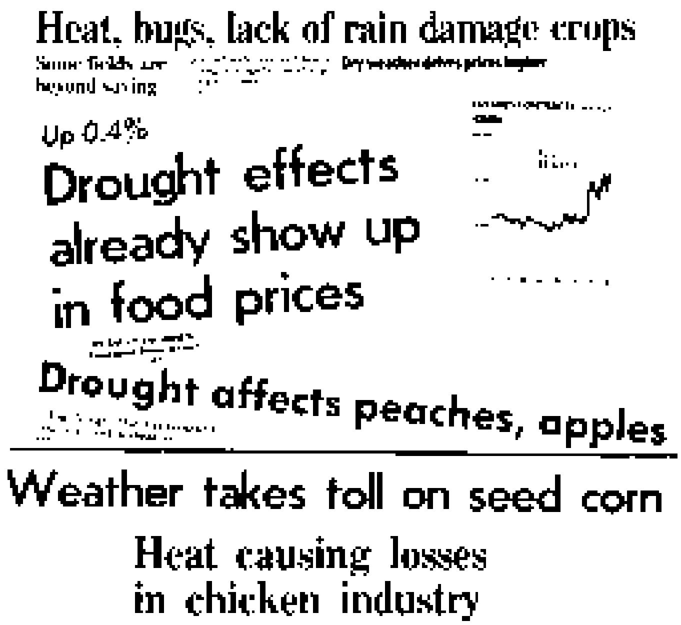


Fig. 7-5. Headlines reflect the impacts of high temperatures and dryness on agriculture.

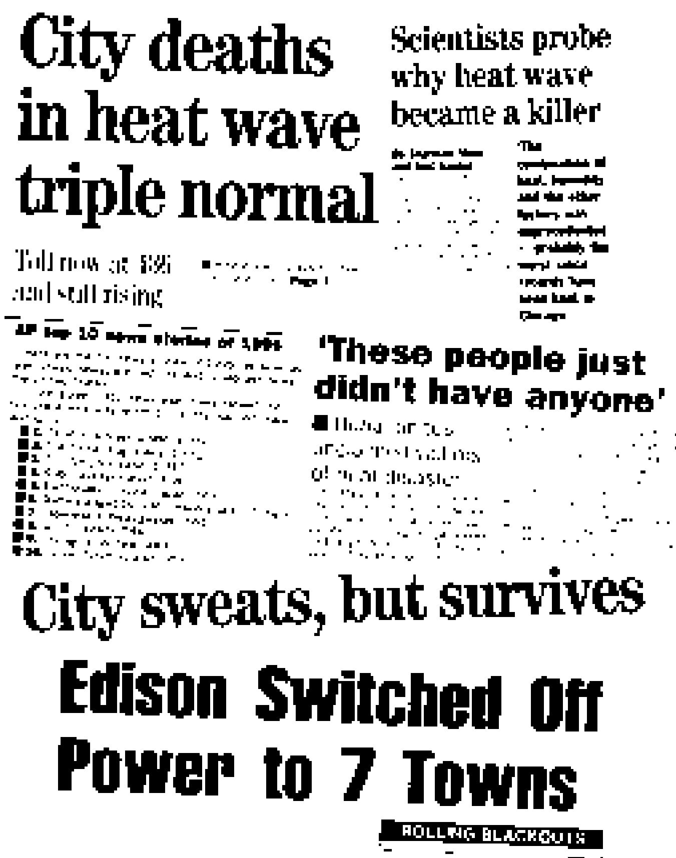


Fig. 7-6. Headlines reflect the impacts of the 1995 heat wave in Chicago.

Fig. 7-7. Chicago responded to the 1995 heat wave by seeking solutions to future heat waves.

Urban deaths occurred when apparent daytime temperatures exceeded 105°F, and nocturnal values were 85°F or higher. The Chicago 1995 deaths were compared to those in July 1936, when the century's most severe heat wave occurred. The 11-day heat wave in 1936 caused 297 deaths, many fewer than in 1995. Two reasons for more deaths in 1995 were identified (Changnon et al., 1996). One concerned a societal shift. In 1936, people were not afraid to go outside at night to sleep, and/or leave windows and doors open. But with a more dangerous society in 1995, city residents were afraid to do so, and many died in enclosed residences. Second, heat waves are most deadly with elderly persons (73 percent of all deaths are people 65 years or older); since 1936, that population has grown rapidly, resulting in greater vulnerability in 1995. The extensive death total in Chicago brought on sizable inquiries about factors causing so many deaths, leading to plans for dealing with future heat waves (Fig. 7-7).

The 1995 heat wave also had many other impacts. Energy use for air conditioning vastly increased, reaching all-time record highs by mid-July in Chicago and Milwaukee. A densely populated section of Chicago experienced a major power outage on July 13-14, and 40,000 people lost power through the hot night of July 14, a factor related to numerous deaths (Fig. 7-6). Regional power companies had increased their revenues for July to $510 million, whereas consumers paid that much in higher bills.

Highways and railroads were damaged due to heat-induced heaving of pavements and buckling of tracks. A freight train crashed in Ohio due to buckled rails. Added railroad costs, including repairs, were $120 million. Reduced retail sales during high-temperature periods lowered regional business income $92 million. The heat also affected livestock and killed 850 dairy cows in Wisconsin and poultry flocks in the region. Milk production declined 35 percent and agricultural losses were $38 million. Federal disaster relief for flood damages, crop losses, and excess heat totaled $1.56 billion, and state relief payments and costs were $260 million.

Climate extremes produce winners and losers, and 1995 extremes were no exception. Winners (Table 7-1) included power companies, and tourism in Wisconsin and Minnesota, where people went to escape the heat, had a 20 percent increase in visitors and a gain of $98 million. Manufacture and sale of air conditioners went up 52 percent over 1994 totals, and the nation's prime manufacturing firm of air conditioners was operating three shifts a day to keep up with the demand, a total gain of $108 million.

Government responses to the heat wave included requests by Illinois and Wisconsin governors for federal aid, after declaring Chicago and Milwaukee disaster areas. President Clinton provided $100 million in emergency funds for low-income home energy assistance to help people in 19 states. The 10 Midwestern states received 73 percent of the federal aid.

Net economic effects of the heat wave led to $936 million in losses and costs. Gains for utilities (Table 7-1) were $510 million, and total benefits were $716 million. Floods and the heat wave caused 853 deaths, and total losses and costs resulting from the 1995 climate anomaly were $13.592 billion (Table 7-1).

CHAPTER 8: EL NIÑO 1997-1998

Climate Conditions

The term El Niño refers to a coupled ocean-atmosphere phenomenon leading to warm sea surface temperatures along the Equator in the eastern Pacific Ocean, resulting in large-scale atmospheric circulation changes in the tropics and portions of the extratropics in both hemispheres. When an El Niño event occurs, it can be a major factor affecting cold-season weather patterns and storm tracks in the mid-latitudes of North America (Kousky and Bell, 2000).

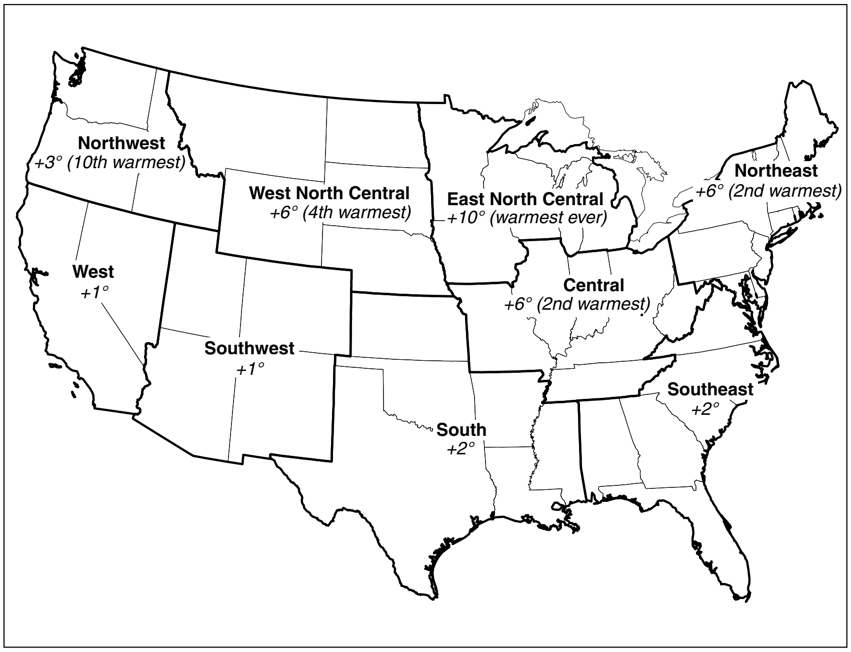
The 1997-1998 El Niño was extremely strong and provided one of the nation's important climate anomalies of the 20th Century. It developed rapidly in the tropical Pacific during May 1997 and became the largest and warmest El Niño over the past 100 years. Its strong influence on the atmosphere led to climate anomalies in all parts of the nation. Atmospheric scientists began predicting in May-June 1997 its effects on the nation's climate for the upcoming fall, winter, and spring, calling for wet and stormy conditions on the West Coast and southern states, but warm, dry conditions for the northern two-thirds of the nation. Ensuing weather and climate conditions of 1997-1998 showed these predictions to be quite accurate.

The lack of hurricane activity in the Atlantic during 1997 was a result of El Niño (Friday, 1998). Storms struck California and Texas in December, and more severe storms attributed to El Niño occurred along the West and East Coasts during the winter. Wetter-than-normal conditions occurred along the southern tier of the United States during November-December 1997 and continued into April 1998. Rainfall in many areas along the Gulf Coast and in California was 200-300 percent above normal, but precipitation was below normal in the nation's northern areas (Fig. 8-1).

A very severe ice storm in New England during January, producing $5.4 billion in losses (1998 dollars), was considered El Niño related (Kousky and Bell, 2000), but very few winter storms occurred in the northern United States and very little snow fell. Mild Pacific air masses moved east across the northern United States, which had an abnormally warm, dry winter (Fig. 8-1). It was labeled a "year without a winter" (Changnon, 2000a).

Climate conditions in January-February 1998 were identified as the warmest and driest on record in the northern two-thirds of the nation. The magnitude of the nation's average winter temperature in 1997-1998 was the second highest on record (Fig. 8-2). Numerous severe storm outbreaks occurred in the Southeast during January-March, with a series of flood-producing storms in the Deep South during those months. Several tornadoes occurred in the South, and one in Florida killed 42 people. A severe winter storm swept across the central United States in March, signaling the end of the warm, dry El Niño climate conditions.

The El Niño-related climate extremes led some scientists to identify global climate change as the cause of the record El Niño conditions, an issue that underwent extended scientific debate for many months. Warm temperatures continued through March and April. Heavy spring rainfall in the Midwest led to flooding, blamed on El Niño (Kousky and Bell, 2000), and the resulting wetness delayed 1998 crop planting. Conditions in Texas and other parts of the South went from wet to dry during March-April followed by severe summer droughts. Although El Niño's atmospheric effects ended in May 1998, dryness in Mexico and Florida led to continuing droughts and widespread forest and vegetative fires.



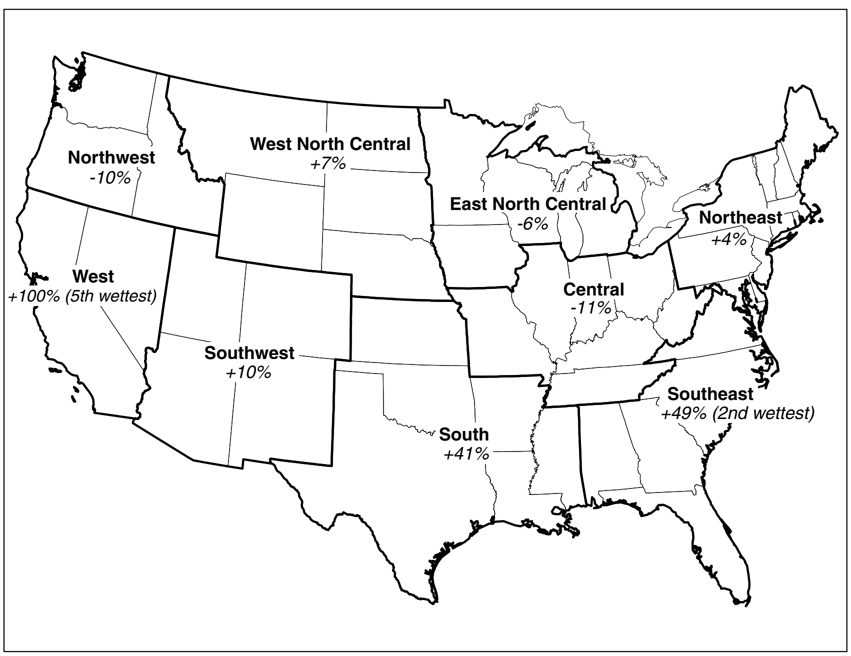


Fig. 8-1. Departures of the winter (December 1997-February 1998) temperatures in degrees Fahrenheit (top map) for the nation's nine climate regions, and the precipitation departures (lower map) expressed as percent of normal for each region (1961-1990) (Changnon, 1999b).

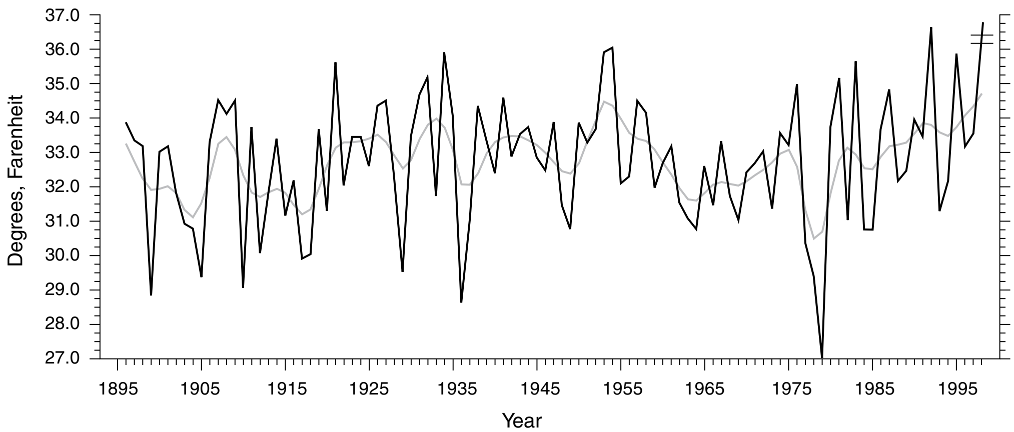


Fig. 8-2. The nation's winter mean temperatures, 1895-1998 (Changnon, 2000b).

Impacts

When the El Niño event developed in 1997, most weather experts predicted resulting conditions would have serious if not disastrous impacts on the U.S. economy. The news media issued dire tales about El Niño during fall 1997 as climate disruptions led to storms that battered the West Coast and southern United States. Many people changed vacation plans, insurance leaders pondered their losses and raised rates, and victims of every type of weather event blamed El Niño (Fig. 8-3). A comprehensive assessment of the impacts of the unusual cold-season climate conditions of 1997-1998 related to the strong El Niño event, however, revealed an amazing mix of outcomes across the nation (Changnon, 1999b).

El Niño's influence created considerable damaging weather in the South. In March 1998, a leading National Oceanic and Atmospheric Administration scientist stated that El Niño 1997-1998 was "the most damaging ever" (Friday, 1998). Scientists attributed a series of weather disasters from October 1997 through May 1998 to the record intensity of El Niño, and these weather disasters were noteworthy for their variety and wide distribution across the nation. In assessing losses, events and climate conditions included as being El Niño-related were those that had been so identified by government atmospheric scientists acting in an official capacity.

As predicted when the El Niño oceanic conditions grew to record proportions in the tropical Pacific during June-August 1997, the West Coast was assaulted by a series of coastal storms and heavy rains causing floods, numerous landslides, and damages to agriculture, with California losses totaling $1.1 billion. A record early snowstorm swept across the High Plains and upper Midwest in October, and then an extremely severe ice storm struck the Northeast in January, creating losses in excess of $0.5 billion. Both were attributed to El Niño's influence on the atmosphere. Winter storms produced heavy precipitation in the Southeast and West, resulting in widespread flooding and damages to regional crops. Government relief aid for California totaled $370 million and $250 million for Florida.

The property insurance industry identified 15 catastrophes, events each exceeding $25 million in losses during the 9-month period ending in May 1998 when El Nino's influence on the

Fig. 8-3. Headlines illustrate some issues raised by the El Niño-related anomaly, January-April 1998 (Changnon, 2000a).

weather had largely ended. Total losses by these events were $1.7 billion. States with losses from three or more catastrophes included Alabama, California, Florida, Georgia, Louisiana, Mississippi, and North Carolina (Fig. 8-4). Florida experienced losses in 5 of the 15 catastrophic storms, and 3 of these storms caused more than $100 million in losses nationally. The single greatest loss was $305 million, the result of heavy rains and flooding, hail, and tornadoes in a storm system on April 15-17 that swept across Arkansas, Missouri, Kentucky, Illinois, and Tennessee, and also killed 11 people. Major winter storms account for the storm counts (Fig. 8-4) in the upper Midwest and New England.

Flooding devastated several fruit and vegetable crops, and national prices for fresh produce rose 7.9 percent in January and another 5 percent in March. Floods and storm damages in California were cited as the main reason for the increase in the national price of food 0.4 percent in February. The nation's tourism industry had a 30 percent drop in income. The drought that developed in April-July 1998 in the Deep South caused $0.5 billion in crop losses, and costs in Florida (widespread fires) and damages to crops and cattle in the South were $5.11 billion. High summer

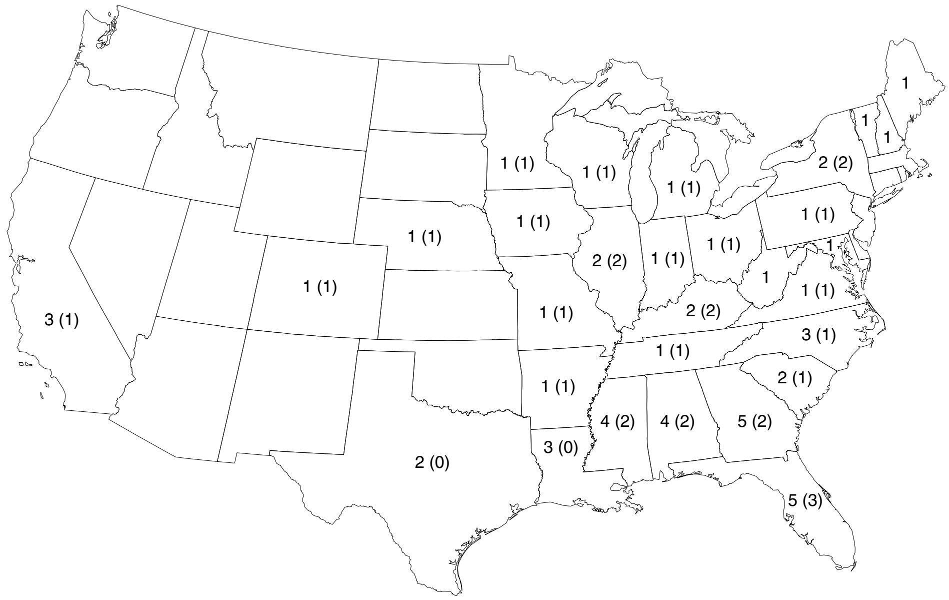


Fig. 8-4. The number of catastrophes, events causing national insured property losses greater than $25 million, September 1997-May 1998. Values in parentheses are the number of times the losses exceeded $100 million (Changnon, 2000b).

Table 8-1. Losses and Costs (1998 dollars) from Climate and Weather Conditions Attributed to El Niño 1997-1998 (1998 dollars).

Activity/sector	*Losses/costs (billions)*
Property	2.800
Federal relief	0.610
States	0.125
Agriculture	5.760
Environmental damage	1.180
Sales lost (snow equipment)	0.060
Tourism	0.200
Total	10.735

temperatures caused 211 fatalities. As shown in Table 8-1, the national losses resulting from El Niño weather conditions totaled $10.735 billion.

The mild, almost snow-free winter in the northern United States produced by El Niño brought benefits and resulted in major economic gains in the northern sections of the nation (Changnon, 1999b). El Niño's influence on the atmosphere also effectively eliminated any major Atlantic hurricanes during 1997 (Friday, 1998), and annual U.S. hurricane damages had been averaging $5 billion per year in the 1990s. This lack of hurricane damages meant major savings for home owners and businesses in hurricane-prone areas, the government, and insurers. The lack of

Fig. 8-5. The mild, dry, and largely snow-free winter of 1997-1998 in the Midwest brought numerous benefits, as illustrated by various news headlines (Changnon, 2000b).

hurricanes and winter storms effectively saved an estimated 800 lives during 1997-1998, but 389 deaths occurred as a result of El Niño storms and flooding in the West and South.

Abnormal warmth in the nation's five northernmost climate regions, as shown on Figure 8-1, were attributed to El Niño (Kousky and Bell, 2000). This led to major reductions in heating costs with less use of natural gas and heating oil, saving consumers \$6.7 billion. Generally mild conditions with little precipitation and temperatures averaging 6°F above normal also had a major positive influence on construction, retail shopping, and home sales in the northern two-thirds of the nation (Fig. 8-5). Record seasonal sales of goods and homes brought sizable added incomes for retailers, realtors, and homeowners. Summation of the various reported gains produced a national total of \$5.6 billion above normal expenditures. The lack of hurricane losses, as well as no losses due to the lack of spring snowmelt floods, benefitted the federal government, which normally faces large relief costs related to hurricane and flood damages. Table 8-2 lists the national gains.

The net effect on the nation's economy from these varied benefits was detectable. For example, the Federal Reserve Board announced in February that the warm January caused a 4 percent drop in production at the nation's electric and gas utilities, ending a run of months with production increases that economists had expected to be +0.3 percent in January. El Niño's net influence on the weather, and an Asian financial crisis, combined in February to eliminate inflation in the prices paid by wholesalers, as food processors and manufacturers charged wholesalers 0.1 percent less than in January for finished goods. Inflation was held to zero during January-March, the first time in 10 years, and the CPI went unchanged due to falling energy prices. The GNP rose at a rate of 4.2

percent during the first quarter of 1998, as compared to the 3.4 percent expected (U.S. Department of Commerce, 1998)

Utilities that used the accurate forecasts for a mild winter and waited to purchase their natural gas supplies on the spot market, as prices fell rapidly, also reaped sizable benefits for their customers. One Iowa-based utility saved $39 million by using the predictions, and two Michigan utilities reported forecast-based savings of $48 million and $147 million, respectively.

Assessment of the national impacts, both losses and benefits (Tables 8-1 and 8-2), reveals that economic benefits outweighed losses, a major surprise to many who had predicted huge losses. Benefits were nearly $20 billion, whereas losses/costs were $10.7 billion. This mixture of regionally different weather extremes and highly different impacts over a six-month period reveals how a mix of economic gains, as well as losses, can occur from widely differing climate conditions in the United States. The 389 deaths related to this nationwide anomaly were a result of storms and floods.

Table 8-2. Economic Gains (1998 dollars) Attributed to Climate Conditions Caused by El Niño 1997-1998.

Activity/sector	*Gains (billions)*
Heating costs down	6.7
Increased sales (homes and retail)	5.6
Reduced costs (snow removal)	0.4
Reduced costs (few floods and no hurricanes)	6.3
Construction	0.650
Reduced costs for transportation	0.175
Total	19.825

CHAPTER 9: DROUGHTS AND HEAT WAVES 1999-2000

Climate Conditions

A major heat wave developed over the Midwest during July-August 1999. In certain areas, the average apparent temperature in July ranked in the top three since 1948 (Fig. 9-1). Areas of severe drought also developed during the summer in the central Midwest, Texas, Louisiana, Georgia, and Florida. July 1999-May 2000 conditions in the Missouri-Illinois-Indiana area were extreme, with precipitation ranking as the tenth lowest on record and temperatures as third warmest. The Midwestern drought ended in June 2000. Very high temperatures and drought developed elsewhere during spring 2000, covering a much larger area than in 1999. By August 2000, the drought encompassed the Rockies, Southern Plains, and the Southeast (Fig. 9-2). This drought began developing in late 1999 (Fig. 9-3) and quickly expanded to cover 36 percent of the nation by August 2000. These various conditions in different areas were related to the strong La Niña event that developed rapidly after El Niño 1997-1998. The La Niña lasted from mid-1998 into mid-2000 creating U.S. climate anomalies (Kousky and Bell, 2000).

A six-state area from Texas-Kansas east to Mississippi had its fourth warmest July-August on record in 2000. June-August temperatures in the Montana-Idaho-Wyoming area were the tenth warmest on record (NCDC, 2000). Locations in the Southern Plains had 15-27 days with summer temperatures 100°F or higher.

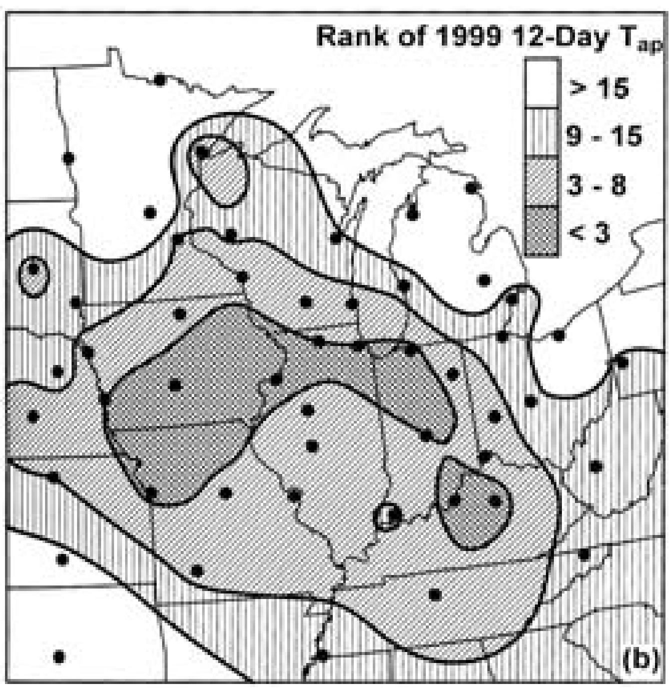


Fig. 9-1. Apparent temperatures during a 12-day period in July 1999, ranked in relation to all past heat waves since 1948. Small numbers indicate a high rank (Palecki et al., 2001).

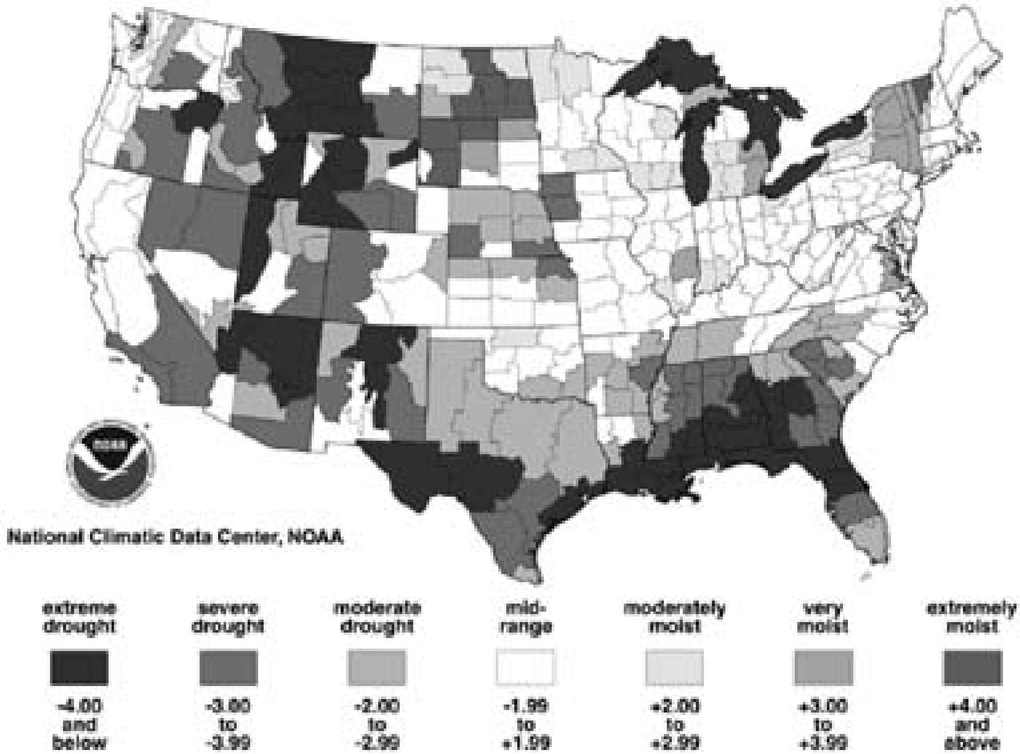


Fig. 9-2. The national pattern of drought conditions in August 2000 (NCDC).

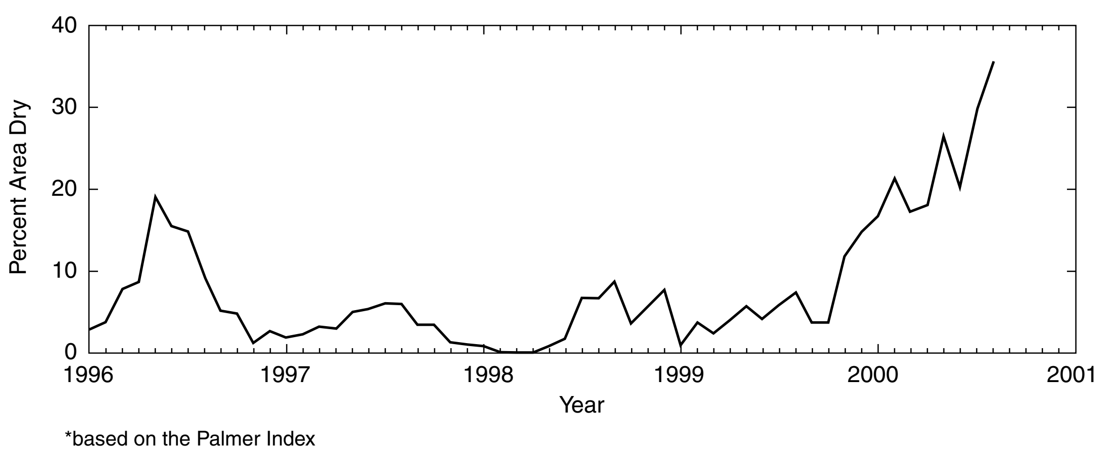


Fig. 9-3. Percent of the United States experiencing severe to extreme drought, January 1996-August 2000 (NCDC).

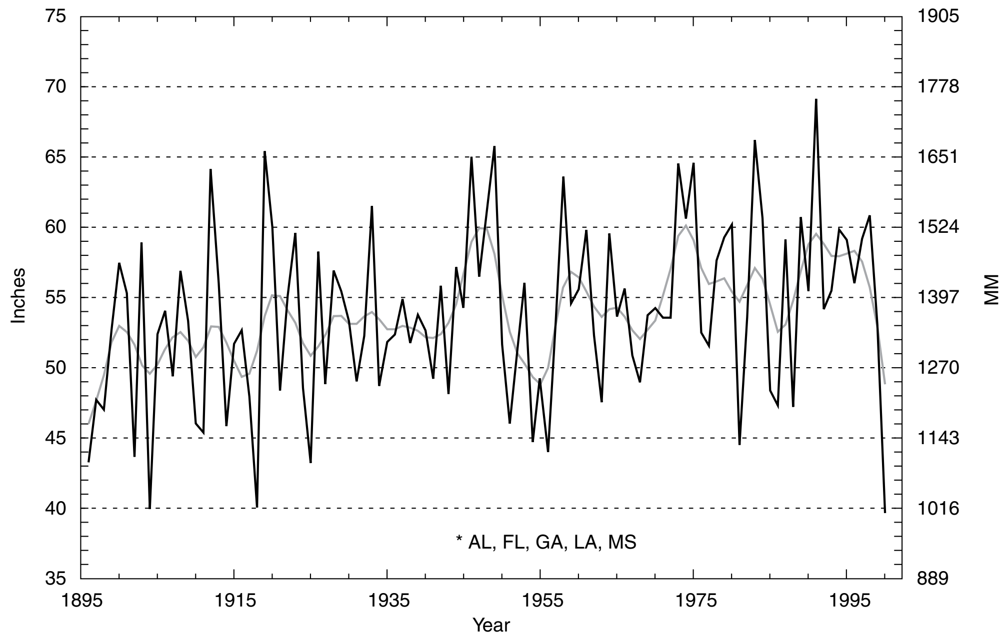


Fig. 9-4. Precipitation in the Deep South for 12-month periods from 1895-1896 to 1999-2000 (NCDC).

Dry conditions prevailed over the areas with high temperatures. September 1999-August 2000 was the driest such period on record in the Gulf Coast states (Fig. 9-4). This period also was dry in the far West and northern Rockies. By mid-summer 2000, the nation's severe drought areas included the Gulf Coast, High Plains, Rocky Mountains, and parts of the West Coast. The Deep South states had been experiencing drought conditions since mid-1998, and the September 1999-August 2000 period was that region's driest on record. June-August 2000 rainfall in Montana, Idaho, and Wyoming was the sixth lowest on record since 1895, and Texas had its driest summer on record. The southern Plains also had low precipitation, and the September 1999-August 2000 precipitation there ranked as the tenth lowest on record.

Nationally, the average temperature for the year 1999 ranked as the third highest on record and that for 2000 ranked as the 11th highest since 1895 (Fig. 9-5). Annual temperatures were above normal in all the states west of the Mississippi River except Arkansas and Washington.

Impacts

Hot and dry conditions in 2000 resulted in numerous wildfires in the Rockies and southern plains, which had a severe drought (Fig. 9-6). In the mountains of the West, 6.6 million acres were burned, the worst fire season on record. A fire in May 2000 in New Mexico caused $140 million (2000 dollars) in property losses and rated as one of the insurance industry's catastrophes. Property losses due to fires in 2000 totaled $1.95 billion, and losses of western timber totaled $6.8 billion. Drought conditions also killed trees over 4 million acres of Florida and Georgia, a loss of $1.15 billion, bringing the national total of timber losses to $7.95 billion (Table 9-1).

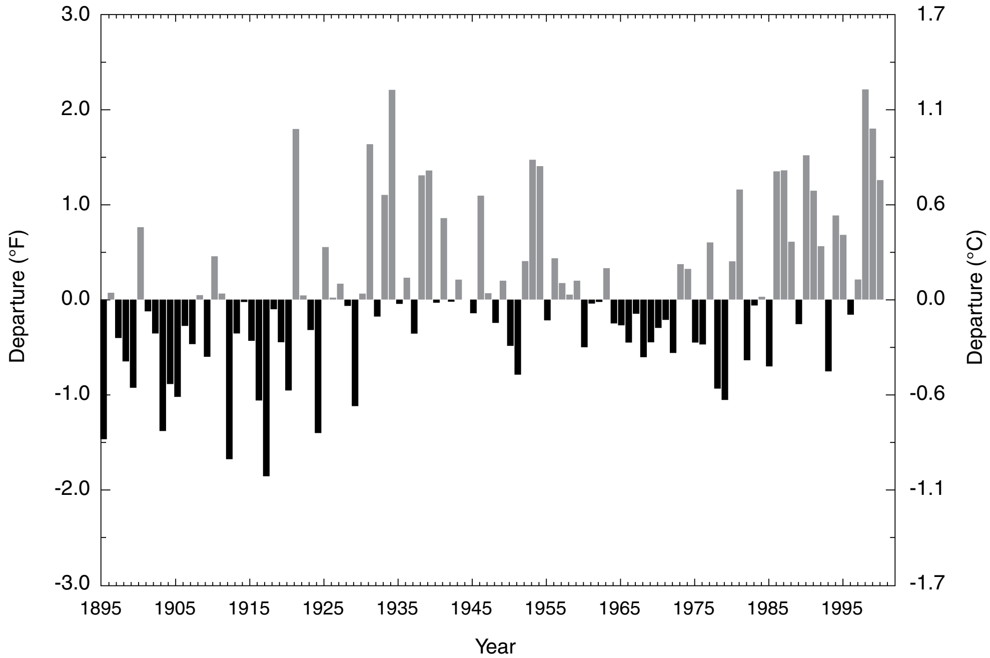


Fig. 9-5. National annual temperature values, 1895-2000, expressed as departure from the average for 1895-2000 (NCDC).

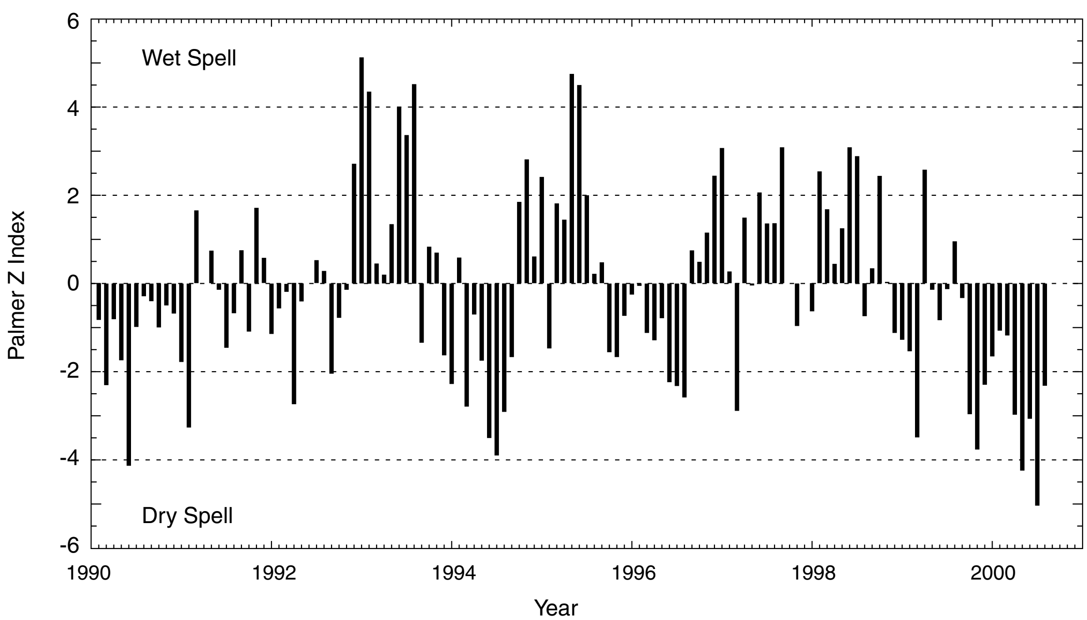


Fig. 9-6. Drought index for the nation's western region, January 1990-August 2000 (NCDC).

Hot, dry conditions during the 2000 growing season had disastrous effects on crops in the southern Plains and Deep South. Georgia's agricultural losses totaled $690 million, and Texas crop-livestock losses were $600 million. The year's total losses for agricultural production and livestock were $6.41 billion. These losses led to an increase in the nation's food prices estimated as $600 million, and farm income losses decreased agribusiness sales $300 million below expectations (Table 9-1).

Several southern communities suffered water-supply shortages. Conservation efforts were widespread, and many communities required additional water facilities (new wells and pipelines to other water sources). These endeavors cost cities and states $850 million.

Drought conditions led to other government expenditures, including costs for firefighting and for farm relief in eight states. High summer temperatures in 1999 and 2000 caused considerable buckling of highways and streets, requiring closures and costly repairs. Federal and state expenditures related to hot, dry conditions in 1999-2000 were $1.65 billion.

Extremely high summer temperatures also increased use of electricity for air conditioning. Added power usage in 1999 and 2000 cost consumers $2.13 billion. This was added income for utilities, but they faced $38 million in added costs for repairs due to numerous power outages, particularly in the large cities like Chicago and St. Louis (Fig. 9-7).

The hot, dry conditions in 1999-2000 were costly, leading to a total of $21.840 billion in losses and related costs (Table 9-1). Utilities had gains of $2.092 billion. Sales of air conditioners produced added retail income of $75 million. Thus, this anomaly produced gains totaling $2.167 billion.

Hot, dry conditions also had major impacts on humans, including numerous heat wave deaths (Fig. 9-7). Many thousands experienced stress and anxiety. This included farmers and residents in the fire-prone areas of the West and High Plains. Major heat waves both summers caused several major power outages so many people had no protection against the severe heat. Deaths due to heat stress in the late July 1999 heat wave occurred across many states (Fig. 9-8). A peak of 127 deaths occurred in Illinois, a result of 114 deaths in Chicago (Palecki et al., 2001). The nationwide total for 1999 was 309 deaths. In 2000, there were 417 deaths due to excessive heat nationwide, leading to a 13-month total of 726 deaths.

Table 9-1. Losses and Costs (2000 dollars) Associated with Hot, Dry Conditions, 1999-2000.

Activity/sector		*Losses/costs (billions)*
Forests		7.950
Agriculture		6.415
Water supply additions		0.850
Government		1.650
Energy		2.135
Property losses (fires)		1.950
Food		0.600
Agribusiness		0.300
	Total	21.840

Fig. 9-7. The 1996 conditions had varied impacts on humans, power provision, and crops.

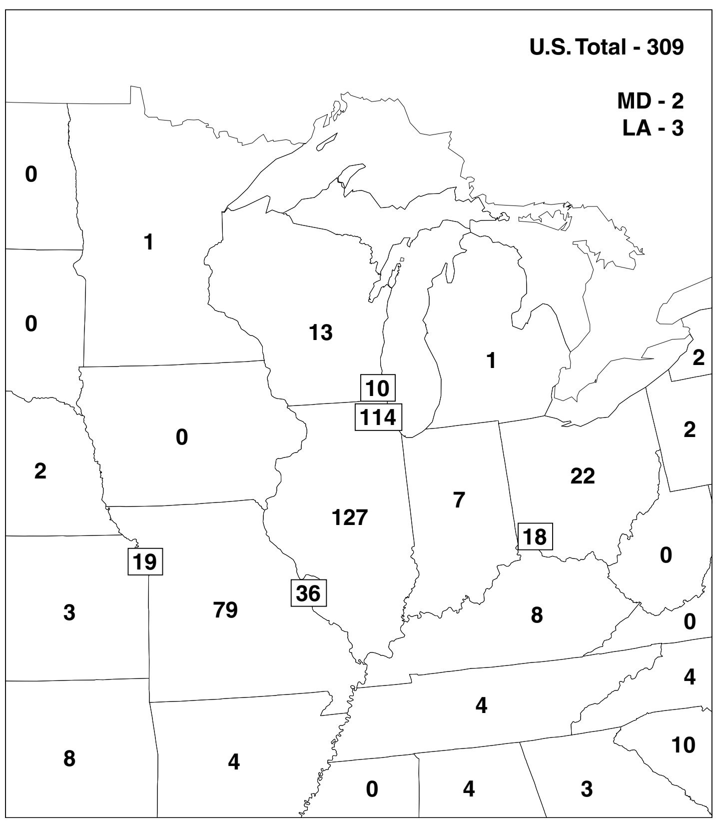


Fig. 9-8. Numerous deaths resulted from the July 1999 heat wave (Palecki et al., 2001). The boxed numbers are subtotals for major cities.

CHAPTER 10: WARM WINTER 2001-2002

Climate Conditions

The November 2001-January 2002 period was the nation's warmest on record since 1895. November 2001-February 2002 was unusually warm, snow free, sunny, and dry over most of the contiguous United States. Winter temperatures were near to above average in all 48 contiguous states (Fig. 10-1), with greatest departures in the Great Plains, Midwest, and East. Winter temperatures in Iowa, Michigan, New York, New Jersey, Connecticut, Massachusetts, New Hampshire, and Vermont were record highs. These conditions led to major effects on the nation's economy, both gains and losses.

The federal government (NOAA, 2002) reported that November 2001-January 2002 was the warmest such period on record since 1895, being 3.8° F above the national long-term average. More than 55 percent of the contiguous United States had below average precipitation, and snowfall was only 55-70 percent of normal throughout the North. Midwestern cities, including Chicago and Detroit, reported record-high numbers of hours of sunshine. February continued this trend throughout most of the nation, resulting in a uniquely warm, dry, snow-free, and sunny four-month period (Fig. 10-2). Climatological winter, December-February, was rated the nation's fifth warmest in the past 100 years, and many states in the Midwest and Northeast had their record warmest winters. As shown in Figure 10-2, national temperature departures above the 1895-2002 averages were 5.2°F in November, 3.1°F in December, 4.0°F in January, and 2.3°F for February 2002. These temperature conditions led to reduced energy demands and kept natural gas prices much below normal (Changnon and Changnon, 2002).

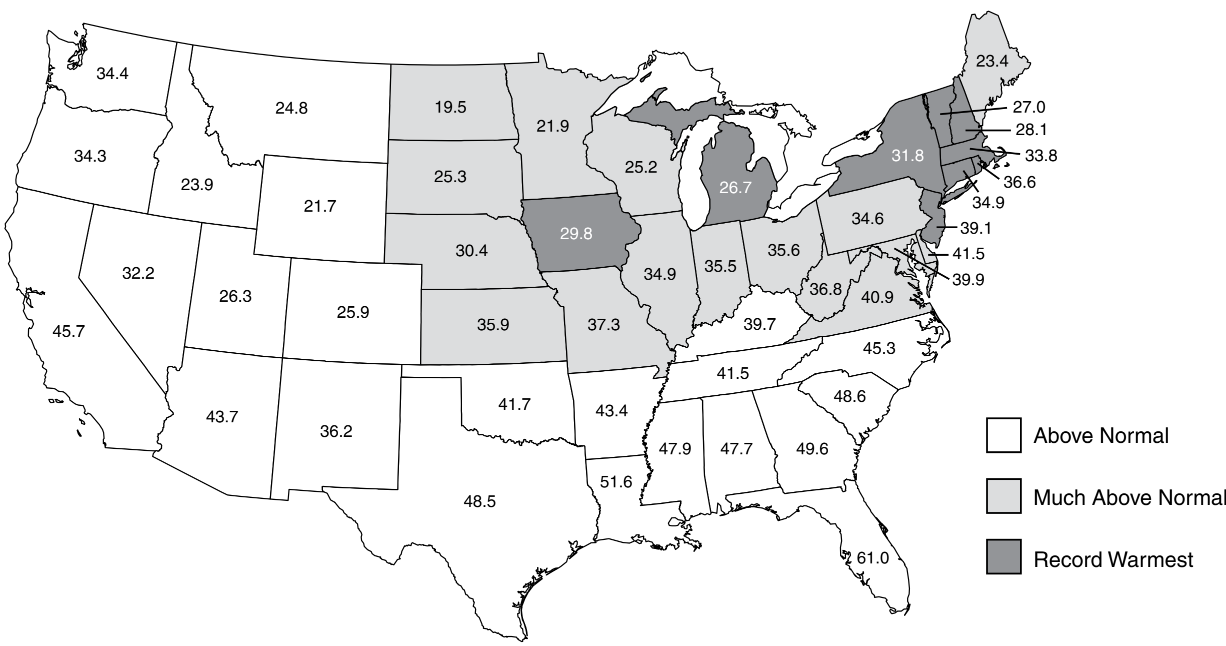


Fig. 10-1. State average winter temperatures (December 2001-February 2002). Shading denotes departures above the normal for 1971-2000 (NOAA).

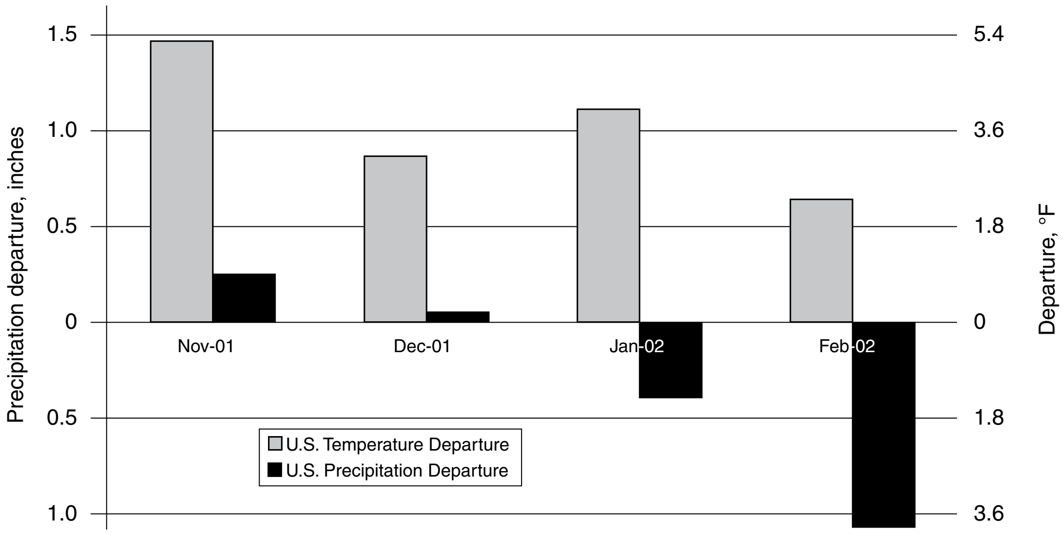


Fig. 10-2. National monthly temperature and precipitation departures from the 1895-2002 average for November 2001-February 2002 period (Changnon and Changnon, 2002).

Much of the nation had below average precipitation, and snowfall was well below average throughout most of the North. National precipitation in November was 0.25 inch above average (Fig. 10-2). Values were average in December, 0.4 inch below average in January, and 1.05 inch below average in February. More winter weather occurred in March.

Impacts

During the last quarter of 2001 (October-December), several national economic measures (Greenspan, 2002a) reflected the impact of the mild November-December weather (Fig. 10-3). The stock market responded favorably: the Dow Jones gained 13 percent, and the NASDAQ composite went up 30 percent over the prior quarter. People went to shop more often than in normal cold winters. One result was that retail and food service sales jumped 0.3 percent in November (gain over prior month), 0.6 percent in December, and 1.2 percent in January. A useful indicator of the nation's economic status is the Gross Domestic Product (GDP). Fourth-quarter 2001 GDP was 1.7 percent above that for the third quarter, the highest rate in two years. Personal spending was 6 percent higher in the fourth quarter than in the third quarter. Very little severe winter weather occurred, which caused insured property losses to fall to less than $400 million, the lowest fourth-quarter values in 22 years.

Economic impacts continued during the first quarter of 2002 as mild conditions persisted through January and February. Alan Greenspan (2002b), Chairman of the Federal Reserve Board, reported that the lower heating costs had added billions of dollars to consumers' disposable income. This quarter also saw a record number of house sales, an outcome attributed to the mild weather, and vehicle sales also set first quarter records. Record-high winter temperatures reduced energy demands and kept natural gas prices well below normal. Mild weather in January and February

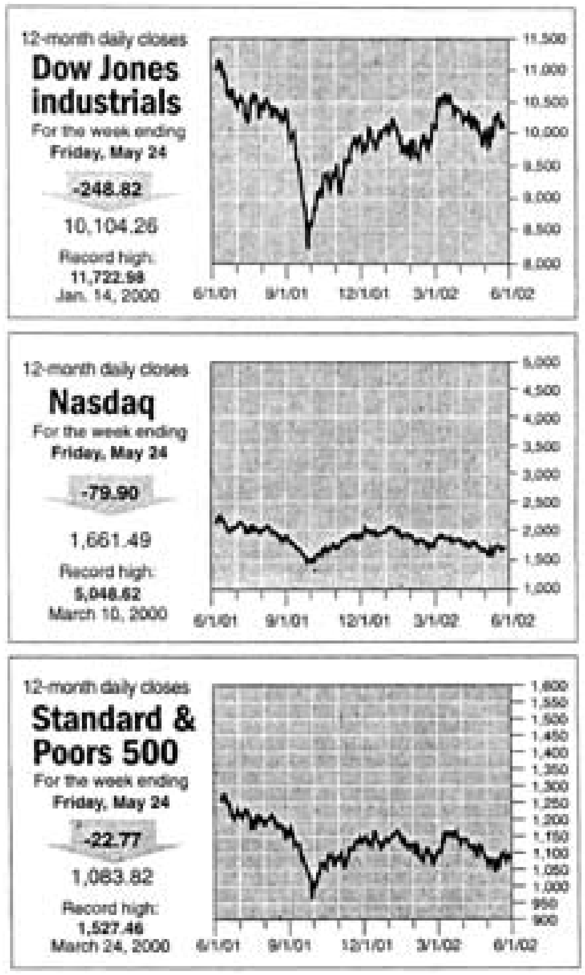


Fig. 10-3. Trends in three indices reflecting the stock market during 2001-2002.

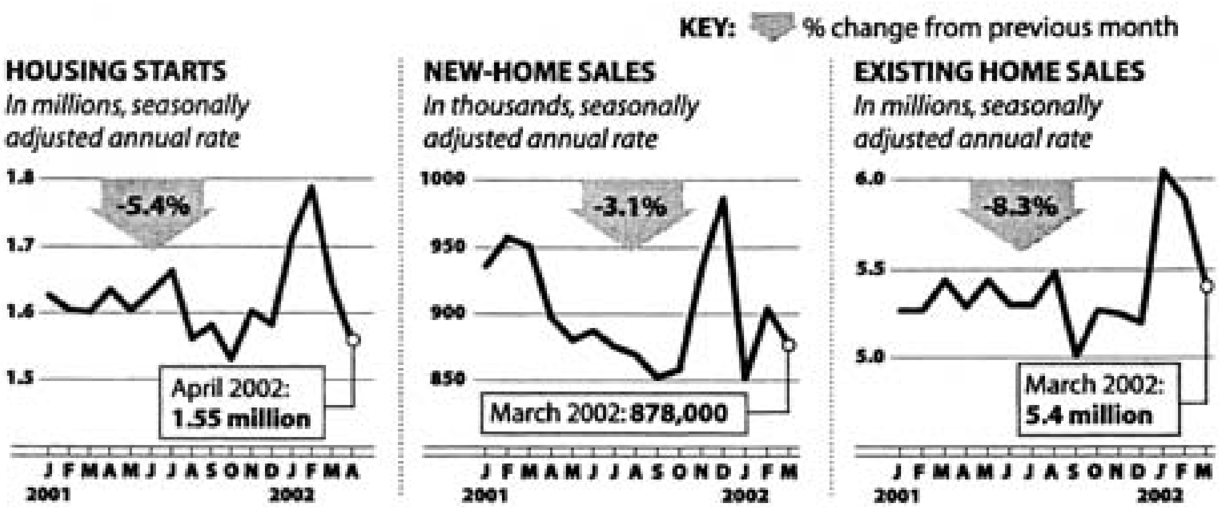


Fig. 10-4. Monthly values of various measures of the housing market during the January 2001-March 2002 period. Shaded arrows represent decreases in March 2002 (Changnon and Changnon, 2002).

also had a major effect on construction of new homes, with an increase of 6.3 percent in January and a rise to 7.4 percent in February, the highest level since the mild El Niño winter of 1997-1998 (Fig. 10-4). Sales of new homes in February rose 5.3 percent, and sales of existing homes totaled 11.63 million units in the first two months of 2002, a record high for the season.

Retail sales were up 1.2 percent in January, the largest monthly increase since March 2000. Consumer spending, which accounts for two-thirds of the U.S. economy, increased by 0.5 percent in January and went up 0.6 percent in February. Incomes were up by the same percentages, the largest expansion since 1999. Spending on nondurable goods, such as food and clothing, went up 1.1 percent in January and another 1.3 percent in February. Spending on tourism rose 0.4 percent in January and 0.6 percent in February. Many tourist sites in the Midwest and East suffered financially from lack of snow, whereas ski resorts out West, where snowfall was normal, made above average profits. The good winter weather helped boost construction employment 8 percent and led to re-openings during January-February of 13 car manufacturing plants that had closed in the fall due to the recession. The nation's GDP during January-March 2002 was 5.8 percent, the highest rate in three years (Fig. 10-5). The federal government reported faster-than-expected economic growth, increasing by a 1.7 percent rate in the final three months of 2001.

The outcomes reveal the winter had two classes of economic impacts: Direct impacts, those due almost totally to the climate conditions, and less direct, or mixed impacts, resulting from climate extremes and other economic factors. Direct impacts during 2001-2002 were lower heating costs, reduced transportation delays, lower road/highway maintenance costs, added construction activities, and reduced insurance losses. Indirect impacts included retail and home sales (Fig. 10-4), and tourism (Changnon and Changnon, 2005a).

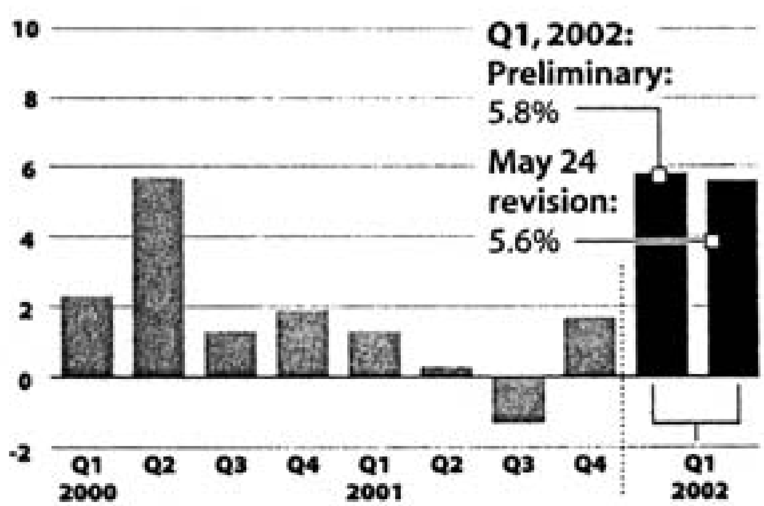


Fig. 10-5. Values of the nation's Gross Domestic Product for 2000 through first quarter of 2002. The values are percent change from the preceding quarterly period, seasonally adjusted to the annual rate (Changnon and Changnon, 2002).

November-February expenditures for homes and retail products were up to $5 billion above expected, normal levels. At the end of winter, federal, state, and local highway/street departments reported huge reductions of 50-80 percent in the cost of snow removal and use of salt. Nationally, resulting financial gains were $750 million, but private snow-removal services had $40 million losses. The construction industry reaped sizable profits from housing starts up by 6.3 percent in January to a seasonally adjusted rate of 1.68 million units, the highest level in two years, and February housing starts reached their highest level since 1948 (Fig. 10-4). Winter construction spending rose by one percent each month. These winter increases represented an additional $2 billion income for the construction industry.

A major area of impacts largely attributable to the weather was heating costs. Natural gas prices fell significantly during the winter. Extremely high prices for natural gas and electricity had developed during the prior (2000-2001) winter, which led many major users to set early-season gas contracts at prices that were too high, given the mild winter and low prices that ensued. The winter's low heating bills were a bonanza for consumers, but major utilities lost large sums. One East Coast utility reported a revenue loss of $92 million, an 8.3 percent decrease below average. Consumers in the Chicago metropolitan area saved a billion dollars, and nationwide savings were $7.5 billion in lower energy costs (Changnon, 2002).

Lack of bad weather and only one winter storm catastrophe also had positive impacts for the insurance industry: winter property losses were 78 percent below average. Total first-quarter (2002) severe weather losses were $580 million, the lowest in more than a decade. Benefits from few winter storms during 2001-2002 were $3.8 billion (Table 10-1).

The nation's transportation sector benefitted greatly from the mild, largely storm-free winter. Airlines suffered few delays, and reduced fuel and operating costs were $145 million for the four months. Surface shipment systems (railroads and trucks) had lower operating costs, totaling $110 million.

Figure 10-6 illustrates the mix of winners and losers from this climate anomaly. Table 10-1 lists the national gains and losses from the mild, almost snow-free winter. Total benefits were $20.6 billion, and winter losses totaled $400 million, an outcome similar to that with the warm, dry El Niño winter of 1997-1998. Both anomalies had gains approximating $20 billion derived from two exceptionally warm winters. This suggests that a future climate with warmer U.S. winters, as postulated under certain global warming scenarios, would be a positive economic outcome. No deaths were attributed to the unusual, mild winter conditions, another benefit.

The unusual weather of 2001-2002 across the nation and the huge and generally positive impacts to the nation's economy came at a critical time. Figure 10-5 shows how the nation's GDP grew in the first quarter of 2002. Some economists claimed the mild weather and its impacts were a factor in getting the nation's economy out of an ongoing the recession (Greenspan, 2002). Figure 10-6 illustrates the diverse impacts of this climate anomaly.

Table 10-1. The National Gains and Losses (2002 dollars) from Climate Conditions, November 2001-February 2002.

Activity/sector	*Gains (billions)*
Heating costs	7.500
Sales (retail and homes)	5.000
Snow removal (government)	0.750
Construction	2.000
Transportation	0.255
Insurance	3.800
Lack of flood losses	1.300
Total	20.605

Activity/sector	*Losses (billions)*
Tourism	0.270
Snow equipment	0.090
Snow removal (private)	0.040
Total	0.400

Fig. 10-6. Headlines during the El Niño event reflect the wide variety of impacts.

CHAPTER 11: THE 2004 GROWING SEASON

Climate Conditions

Climate conditions during the 2004 growing season in the Midwest produced exceptionally high yields of all crops, with resulting record values 10-25 percent above prior yield records. Interestingly, crop experts and crop-weather models used during the 2004 growing season to estimate yield outcomes failed to predict the enormous magnitude of final yields, an outcome of considerable economic importance. This also revealed a lack of understanding of the climate-yield relationships with current crop hybrids and farming practices. Breeding of corn and soybeans over time had developed varieties increasingly less sensitive to weather stresses. Table 11-1 shows the official corn and soybean yields predicted by the U.S. Department of Agriculture for the nation in early August and then actual harvested yields from September-October 2004. Predictions were substantially less than actual yields, an outcome unexpected by crop experts, and one also indicating a lack of understanding of the impact of climate conditions in the 2004 growing season.

Weather and climate conditions that affect crops and their yields have undergone intensive study for more than 80 years. These studies have included field tests (Hollinger and Changnon, 1993), and statistical analysis of how various Midwestern weather conditions affect yields (Offutt et al., 1987). Most attention has been given to the effects of temperature and rainfall conditions, and most findings agreed that soil moisture (from rainfall) and temperature levels in mid- to late summer were most critical for determining corn and soybean yields. Extremely hot and dry summers during the 1930s drove corn yields to record lows. Early planting was devised so that temperature- and moisture-sensitive periods of corn development occurred in late June-early July before typical crop-stress conditions that often develop from mid-July through August.

Solar radiation is another key condition affecting crop growth and development by promoting photosynthesis in corn and soybean plants. Solar radiation data were not incorporated over the past several decades in crop-yield models because collection of radiation data was limited to instruments at only a few locales. Fortunately, a recently developed numerical crop model includes solar radiation as estimated from sky cover data (Grant et al., 2004). Sky cover (clear, partly cloudy, or cloudy) data have been collected widely since about 1900, but this new crop model uses these data as a surrogate for solar radiation (Mahmood and Hubbard, 2002). Use of this model with input of temperature, rainfall, and sky conditions during 2004 resulted in yield values closely matching actual yields. This outcome revealed that the large number of clear days during summer 2004 were a key factor in the record high yields.

Table 11-1. The Nation's 2004 Corn and Soybean Yields (bushels/acre) as Predicted in August and as Harvested in September-October.

	Yields		
Crop	*Predicted*	*Harvested*	*Difference*
Corn	149	160	+11
Soybeans	38	43	+5

The inability of crop experts during the growing season to predict the magnitude of the 2004 crop yields correctly (Table 11-1) resulted from a lack of information about the presence and effect of numerous sunny days in 2004. Number of clear days was 50-85 percent above average across the 11-state area (Fig. 11-1). A climate oddity is that these numerous sunny days came with below average summer temperatures and above average rainfall (Fig. 11-2) across the Great Plains and Midwest. Examination of Midwestern climate conditions over the past 120 years reveals that when many clear days occurred in the past, summers were quite hot and dry. The summer 2004, however, was the coolest on record at many locations in Iowa, Illinois, and Indiana, and the frequency of hot days, those exceeding 90°F, was 3 days or less across the Midwest.

Summer 2004 climate conditions were unusual in other respects too, including the great areal extent of favorable temperatures, rainfall, and sky conditions across the Corn Belt (Changnon

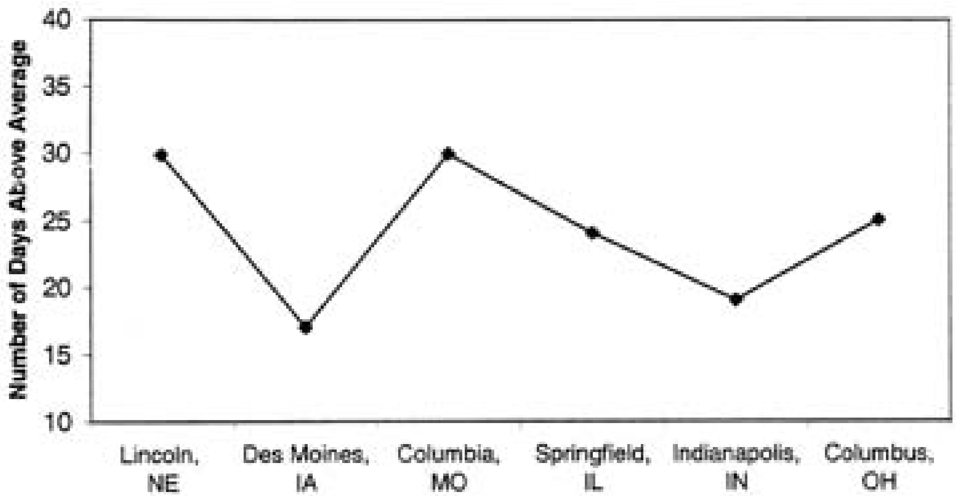


Fig. 11-1. The number of summer days with clear skies, expressed as the number of days above average (based on 1941-2000) for stations located west to east across the Corn Belt, June-August 2004.

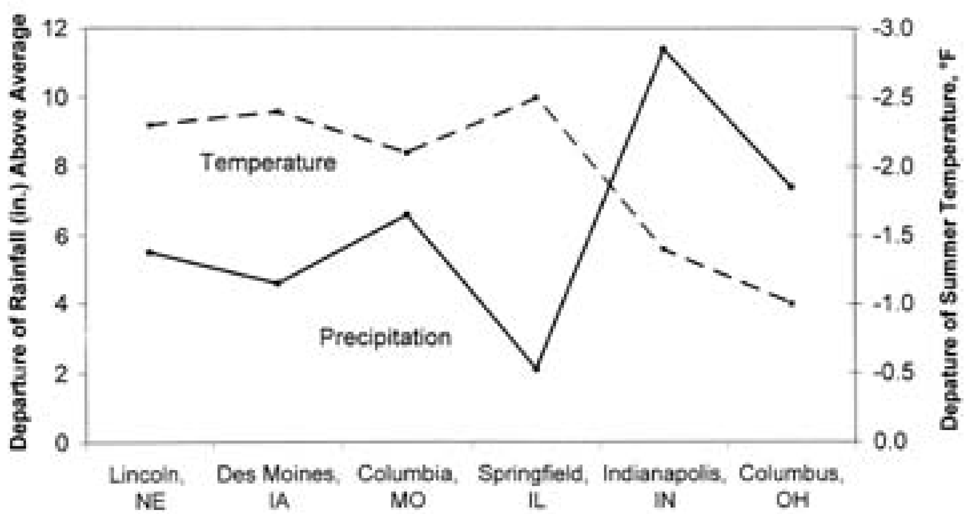


Fig. 11-2. Departures from average (1941-2000 base) summer 2004 temperatures (degrees Fahrenheit) and rainfall (inches) at stations from west to east across the Corn Belt.

and Changnon, 2005c). Canadian high pressure resulting from the intrusion of 20 strong cold fronts dominated the atmospheric circulation in the central United States during the summer, limiting movement of warm, moist air into the region, keeping temperatures below average, and creating the high frequency of clear days across the entire Midwest plus Nebraska, Kansas, and South Dakota.

Impacts

Unique weather conditions in 2004 produced record-high yields for all major crops (corn, soybeans, and spring wheat), the first time in history that such a wide region had high yields of all crops (Changnon and Changnon, 2005c). Record yields had profound effects on crop prices, given large foreign demand and decreasing dollar value, resulting in a huge income increase for Midwestern farmers. Seldom does the entire Midwest experience near uniform summer climate conditions, reflecting another unique aspect of 2004 (Fig. 11-3).

The fall 2004 corn and soybean harvest revealed what crop experts had been predicting—high yields, but predictions were not as high as final yields (Table 11-1). The changes in predicted yields over time for three prime crop states and the nation are shown (Fig. 11-4), revealing predicted values increased over time but never reached final yield values in November. The Illinois average corn yield was 180 bushels/acre (bu/acre), 16 bu/acre above the record. For the first time in many years, corn yields were high across all parts of the state (Changnon and Changnon, 2005b). The average soybean yield for Illinois was 50 bu/acre, 4.5 bu/acre above the previous record.

Other lesser crops, including grain sorghum and alfalfa hay, also set yield records for the Midwest. Such exceptionally high yields in all major and minor crops are highly unusual and are

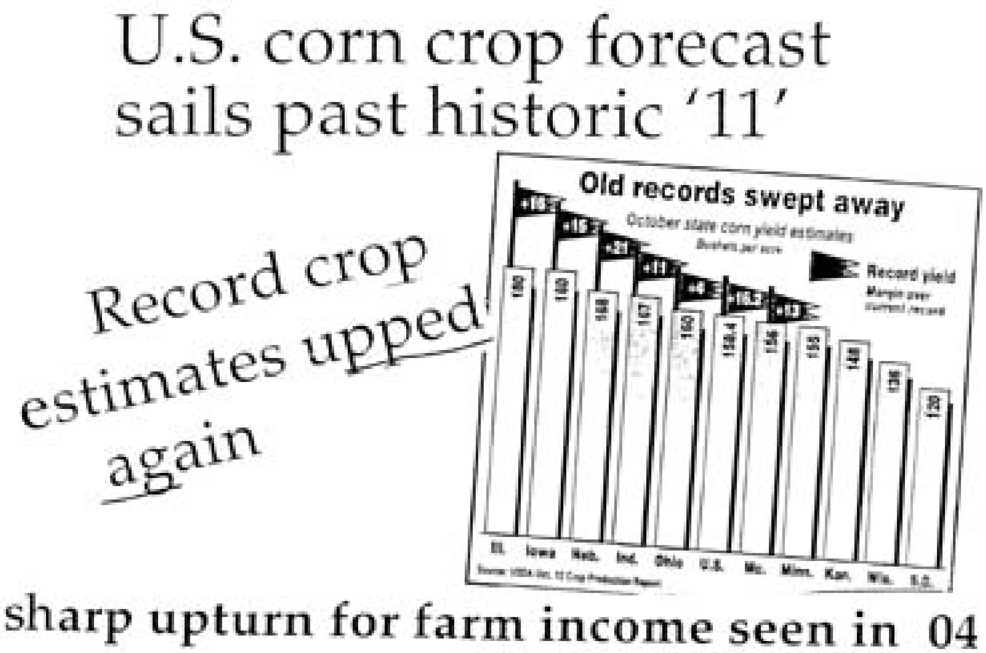


Fig. 11-3. High 2004 crop yields made the headlines.

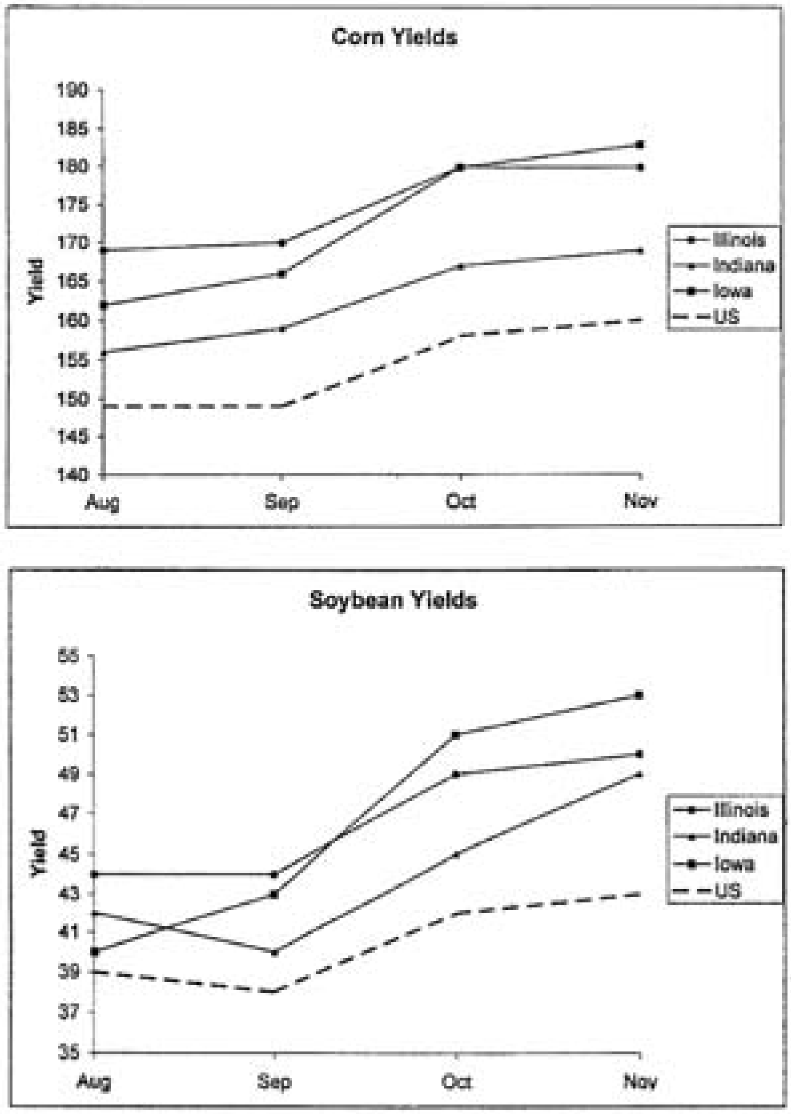


Fig. 11-4. Predicted and final corn and soybean yields (bu/acre) in 2004 for three states and the nation (Changnon and Changnon, 2005b).

indicative of a growing season with near perfect crop-weather conditions. For example, high U.S. corn yields occurred in 2003, whereas soybean yields were below average, revealing differences in growing-season weather conditions affecting each crop.

Record-high corn yields in 2004 in Illinois, Iowa, Indiana, Ohio, Nebraska, and Missouri (Fig. 11-3) led to the new national yield record (160 bu/acre, 18 bu/acre above the record). Regional soybean yields averaged 46 bu/acre, 7 bu/acre above average, and national soybean yields averaged 43 bu/acre, a new record high.

The net effect of this near perfect 2004 crop climate was a national corn harvest of 11.74 billion bushels and a soybean harvest of 3.15 billion bushels, more than 10 percent above past record totals and 30 percent above the nation's average grain production for 1994-2003. The increased production, taken at standard prices, was $14 billion above average farm incomes during 1994-2003. The U.S. Department of Agriculture reported that the huge harvest, coupled with strong crop prices, resulted in a U.S. farm income totaling $73.7 billion in 2004, 25 percent above amounts in any prior year (Miller, 2004). The Secretary of Agriculture stated, "This record income total related to near perfect growing conditions and increased foreign demand for grains" (Miller, 2004). The average 2004 income for individual Midwestern grain farmers was $91,000, nearly double the 1999-2003 average (Fig. 11-3).

This huge income boost to Midwestern farmers had several impacts. Farmland prices rose to $5,000 per acre in Iowa, Illinois, and Indiana. Grain elevators across the Midwest had to store surplus grain in nearby fields (Fig. 11-5) because storage bins were full and elevators could not handle the enormous grain production. Furthermore, shipping facilities, including river barges and railroads, could not keep up with loads requiring shipment to grain processing firms and to ports for export. Railroads experienced gains from added shipments valued at $100 million (Table 11-2).

Manufacturers of farm equipment experienced large sales, increasing John Deere's third-quarter earnings by 32 percent. Agribusinesses in the Midwest profited $8.6 billion from increased sales and grain processing. Government-supported crop insurance costs were reduced $2.4 billion below average. Thus, total economic gains and reduced costs from this 2004 anomaly were $25.1 billion. Those seeking to purchase farmland faced higher costs, and the estimated added costs paid in land sales in 2004-2005 were $100 million.

Table 11-2. Gains and Losses (2004 dollars) Resulting from the Conditions during the 2004 Growing Season

Sector	*Gains (billions)*	*Sector*	*Losses (billions)*
Agribusiness	8.600	Farm Prices	0.100
Government	2.400	Total	0.100
Railroads	0.100		
Agriculture	14.000		
Total	25.100		

Fig. 11-5. Surplus corn was stored outside a large grain elevator during November 2004.

CHAPTER 12: FACTORS AFFECTING MAGNITUDE OF CLIMATE LOSSES AND GAINS

Assessment of the various impacts associated with the ten climate anomalies revealed several nonclimatic factors, as well as climate conditions, responsible for the sizable economic losses from these recent climate extremes. Shifts in climate conditions can affect the frequency and intensity of extremes. One nonclimatic factor influencing recent climate impacts is related to the insurance industry and its handling of recent weather/climate losses (Roth, 1996). Several societal factors also have played a significant role in recent sizable climate-caused losses (Changnon et al., 2000). Population growth is one factor that has increased society's vulnerability to climate extremes. Demographic changes have shifted the nation's population density to more weather-vulnerable locations, another factor. Growing wealth with more value of personal property is another factor (Pielke, 1999). Another factor noted in several flood studies relates to the nation's infrastructure of aging facilities and inadequately constructed buildings and homes (Hooke, 2000).

Review of the climate anomalies and their impacts, as presented herein, revealed the influence of various nonclimatic factors. The following text explores these factors and attempts to identify the role of past climate fluctuations and all other factors influencing the magnitude of climate-produced impacts.

Insurance Industry Problems

Record-high insured property losses during the 1990s, including those from the 1993 flood and El Niño 1997-1998, created immense concern among crop insurance, property insurance, and reinsurance industries. Studies of storm frequencies (Changnon and Changnon, 1998b; Kunkel et al., 1999) did not reveal major temporal increases in storm frequencies or intensities. Extensive analysis of when and where insured storm losses increased pointed to shifts in insured risks for which the insurance industry had not adjusted its rates (Roth, 1996). Once historical loss data were adjusted to reflect shifting coverage, inflation, and evolving construction practices, it was found that the insured losses of the 1990s were matched by equally high losses in the 1950s (Changnon, 1999a). Thus, recent peaks in insured losses were not unique, and the corporate losses resulted from the industry's lack of adjustment for climate variations, and for population growth, and for shifting risks (Kunreuther, 1998). Some insurance leaders believed, however, that peaking losses represented the start of climate change due to global warming (Swiss Re, 1996; LeComte, 1993), whereas others believed the shift was due to natural fluctuations in climate (Changnon et al., 1996).

Changes in Business and Infrastructure Sensitivities to Climate

The enormous losses and benefits caused by the ten climate anomalies over the past 20 years illustrates the nation's changing vulnerability to climate (van der Link et al., 1998). Over time, the nation's businesses and infrastructure have become more susceptible to climate extremes. The ever-growing population with its concomitant demands for food, water, energy, and other weather-affected resources have made the nation more vulnerable to extremes that reduce these resources.

There are other reasons why this vulnerability to extremes has increased. For example, production systems have become increasingly disaggregated. Hence, reliance on timely transportation of goods, parts, and supplies has grown. Most such forms of distributed production can handle short weather delays but not multi-week or monthly stoppages such as those caused in the floods of 1993 or the cold, snowy conditions of 1993-1994. In such events, raw supplies were not available and production stopped, crippling business.

An aging infrastructure is also more susceptible to prolonged extremes. For example, the nation's large urban water-supply systems are replete with major leakages, and safety concerns arose about old dams and storage during prolonged wet periods. Aged water transportation arteries were often unable to cope with damages from prolonged flooding, or with sizable water demands during major urban droughts (Changnon, 2000b).

Agriculture also became financially more sensitive. Ever larger farm units with greater debt, resulting from land acquisition and the need for new facilities and more farm machinery, increased vulnerability during multiple years of low yields. Dispersed farm holdings were found to be a good way to insure against small-scale severe weather threats such as hailstorms, but were of no value during droughts or floods.

The nation's utilities have exhibited a decreasing capacity to provide necessary power supplies, a result of many economic problems and deregulation. The net effect has been less capability to handle demands from prolonged periods of extremely high temperatures over large areas, or prolonged low temperatures in winter. Increased brownouts with lengthy power outages occurred, and industrial/commercial losses resulted.

Impacts of climate extremes on the government and, in turn, on taxpayers, have become sizable. Relief programs have been used to help people get through the trauma of losses, but the multi-billion-dollar relief bills to pay for climate-induced losses since 1985 are an enormous contribution to the ever-growing national debt. Federal relief payments for weather and climate disasters grew from $670 million during 1956-1970 to $4 billion in 1991-1995 (Sylves, 1998). Furthermore, many federal policies relevant to handling these climate anomalies with more sensible fiscal approaches were found to be flawed (Hooke, 2000). The nation's floodplain management program was recognized as inadequate in the floods of 1993, 1995, and 1997-1998 (Changnon, 2005). In each flood, less than 10 percent of properties damaged had flood insurance. The crop-weather insurance program has been modified, but more effective legislation and a sounder crop insurance program (Changnon and Easterling, 2000) resulted only after multiple agricultural disasters in 1988 and 1993.

Societal Issues

Economic impacts from weather and climate extremes, and temporal fluctuations of those impacts, are a function of society's vulnerability to climate. Insured property losses due to weather-climate extremes have grown steadily from $25 million annually (2000 dollars) in the early 1950s to more than $5 billion annually in the 1990s (Fig. 12-1). Losses from catastrophes, events that exceeded $5 million in property damages, have grown steadily from about $100 million annually in the 1950s to $6 billion annually in the 1990s (2006 dollars). The annual number of catastrophes grew from 10 events in the 1950s to 35 in the 1990s (Changnon, 1999a). The 1990-1997 total insured losses (2006 dollars) were $49 billion, and federal relief payments were $12 billion.

Regional trends in insured property losses display sharp spatial differences. On the West Coast, the Arizona-New Mexico-Colorado-Texas area, and in southeastern coastal area states, the number of catastrophes exceeding $100 million (2006 dollars) in property losses during 1990-1997 was double those in the prior 40 years (Changnon, 1999a). Elsewhere in the nation, these costly events in 1990-1997 increased by only 15-20 percent over those in 40 prior years.

When the nation's annual insured property losses were divided by the U.S. population, a flat trend resulted (Fig. 12-2), with isolated peaks in six years from major hurricanes losses. This curve is quite different than the loss values in Figure 12-1. For example, catastrophes causing losses exceeding $100 million, after adjustment for inflation, averaged $551 million per event in the 1990s, just $12 million more than the average of the 140 catastrophes over the prior 40 years. This reveals that storm intensity had not materially increased over time.

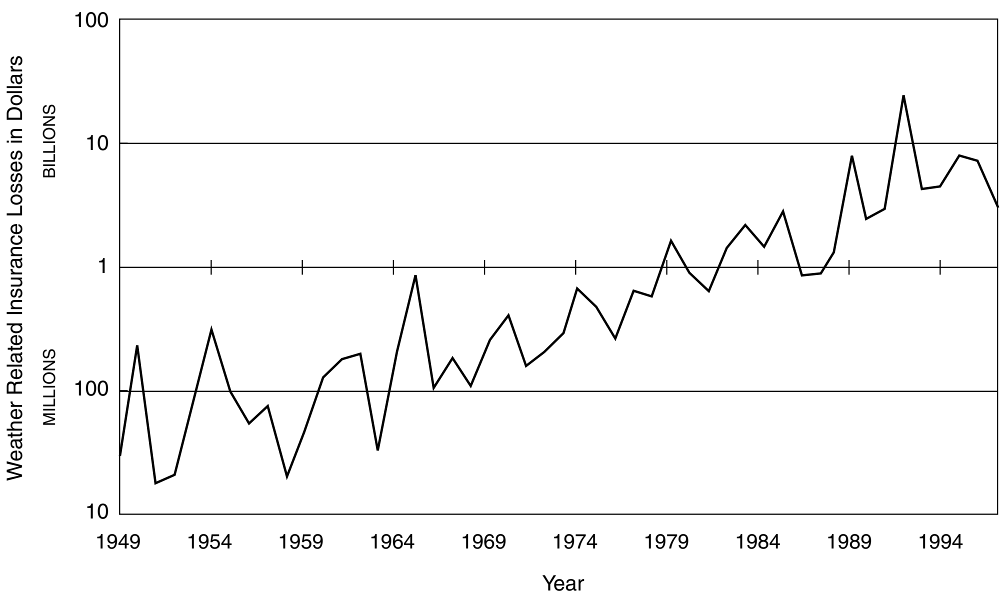


Fig. 12-1. Annual losses (1997 dollars) to insured U.S. property from weather/climate catastrophes, 1949-1997 (Changnon and Hewings, 2001).

After careful adjustment for societal and insurance factors, most storm and climate extreme loss data do not display upward trends over time. Comparison of this information with the upward trends in actual dollar losses, and consideration of where losses have grown most (Southeast, Deep South, and West) indicates that major causes of upward trends in losses related to climate extremes are societal factors (Changnon et al., 2000). These factors include:

- Growth of wealth, with more valuable property at risk.
- Increasing density of property.
- Demographic shifts to coastal areas and to storm-prone warm climate areas experiencing increasing urbanization.
- Aging infrastructure, structures built below standards, and inadequate building codes.
- Interdependency of business and distributed product development.

Thus, results from recent assessment studies show an overall increase in the nation's vulnerability to weather and climate extremes (Kunreuther, 1998). Recent comparative studies of trends of losses and of weather extremes revealed no long-term increases of most extremes to correspond with recent losses (Kunkel et al., 1999).

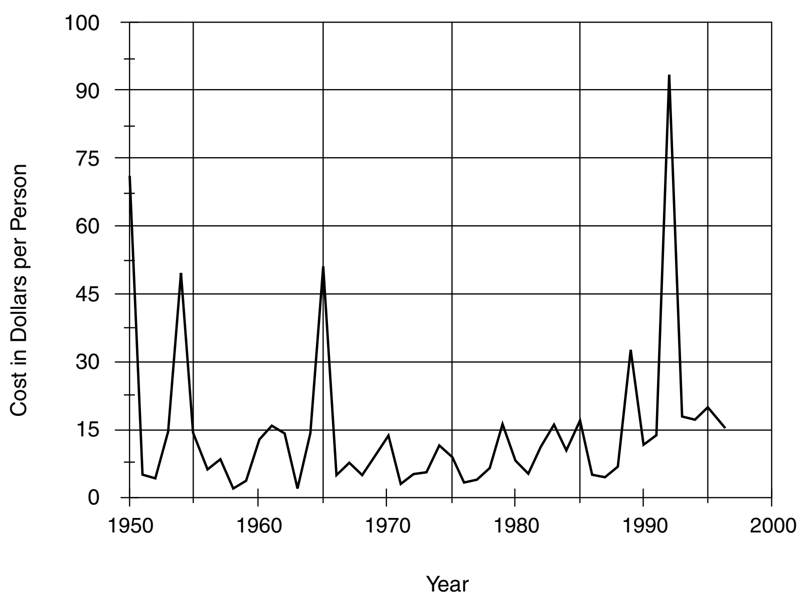


Fig. 12-2. Annual insured U.S. property losses (1997 dollars) from catastrophes divided by the annual U.S. population, 1950-1996 (Changnon et al., 2001).

CHAPTER 13: SUMMARY AND PERSPECTIVES ON PAST AND FUTURE CLIMATE IMPACTS

The total economic losses and gains from the ten climate anomalies assessed in this document were adjusted, using standard financial factors, to 2006 dollar values (Table 13-1). Total losses exceed total gains. Gains represented 32 percent of the total gains and losses of $383.739 billion. Gains exceeded losses in four of the ten anomalies. The 1988 drought had the highest losses, and the 2004 growing season had the greatest gains. Of the 7,955 deaths caused by the anomalies, most resulted from heat waves in 1988, 1995, 1999, and 2000.

The atmosphere affects the United States in three ways. One is from near average, non-extreme climate conditions that routinely occur in each season. Second, are the impacts of severe storms such as hurricanes and tornadoes. Third, are the effects of climate anomalies, the topic of this document.

Economic impacts of the ten climate anomalies were most significant at regional and state scales where many losses were concentrated. For example, the $6 billion in flood-related losses in Illinois in 1993 rated as 12 percent of the Gross State Product for 1993. Costs for handling the severe winter conditions of 1993-1994 in New England, $430 million, were 11 percent of the total annual expenditures of that six-state region. The largest state losses from natural hazards typically rate as 5 percent or less of the 48 states' domestic products (SNDR, 2000). Interesting national impacts also occur. The Chairman of the Federal Reserve Board claimed that economic impacts of the mild 2001-2002 winter got the nation's economy out of an ongoing recession. Damages from El Niño-generated storms and floods caused national food prices to rise 0.4 percent in 1998, and the GNP rose 4.2 percent in 1998, as compared to the 3.3 percent expected.

Table 13-1. Total Economic Losses and Gains (2006 dollars) and Deaths from the Ten Climate Anomalies

Anomaly	*Losses (billions)*	*Gains (billions)*	*Deaths*
1985-1986 wet period	39.541	2.048	621
1988 drought	86.506	8.990	5,000
Warm, wet 1990	8.445	14.168	213
1993 floods	34.382	12.933	52
1993-1994 cold winter	32.906	9.585	101
1995 flood/heat wave	17.669	0.945	853
1997-1998 El Niño	13.097	24.126	389
1999-2000 heat/drought	25.559	2.545	726
2001-2002 warm winter	0.450	23.078	0
2004 growing season	0.106	26.606	0
Total	258.715	125.024	7,955

Table 13-2. Losses and Gains (2006 dollars, billions) from 10 Climate Anomalies for Selected Sectors, 1985-2005.

	Agriculture	*Power*	*Government*	*Property*	*Business*	*Transportation*	*Construction*
Losses	62.878 (8)	39.169 (6)	33.955 (8)	42.877 (6)	18.805 (8)	7.076 (5)	1.870 (2)
Gains	42.135 (5)	33.447 (7)	2.510 (1)	0	15.507 (5)	4.169 (5)	10.405 (6)

Note: Numbers in parentheses represent the number of anomalies with impacts for each sector.

Losses and gains of the ten climate anomalies were sorted according to major sectors of effects (Table 13-2). The primary sector, agriculture, experienced $62.878 billion in losses and $42.435 billion in gains from anomalous conditions. Property losses ranked as second highest loss amount, but lower energy costs for consumers were the second-ranked gains. Power costs for utilities were third-ranked losses. Government losses and costs were also excessive, totaling $33.955 billion.

Losses and costs were most frequent for the agriculture, government, and business sectors, each with losses during eight anomalies. Gains were most frequent in the power and construction sectors with seven and six anomalies, respectively. The agriculture, business, and transportation sectors had gains from five anomalies. Total agricultural losses came from eight anomalies averaged $7.86 billion per event. Agricultural losses were highest in 1988 ($26.4 billion) and second highest in 1993 ($12.4 billion). In contrast, agricultural gains in 5 of the 10 anomalies averaged $8.53 billion per event. Property losses averaged $7.11 billion per anomaly. Power-related losses averaged $7.82 billion, whereas power-related gains averaged $4.78 billion per event.

Assessed Losses and Gains from Recent Climate Conditions

Losses

Annual loss values from most weather and climate extremes that have produced major U.S. losses have been assessed in recent studies. Using good data collected since 1950, important measured variables include losses due to floods, hurricanes, and tornadoes, plus climate-induced crop losses and the temperature-driven costs of energy usage. These five variables plus four others (thunderstorms, hailstorms, winter storms, and windstorms) defined most of the national climate extreme-caused losses during 1950-2000 (Changnon, 2006a).

Total losses from the nine climate and storm variables created an annual average national loss value of $43.12 billion (Table 13-3). Property losses ranked highest, followed by government costs and then energy use costs. Each of the nine condition's average loss value also was expressed as a percent of the total, and three conditions—energy costs, hurricanes, and flooding—accounted for 69 percent of total losses (Winstanley and Changnon, 2004).

Table 13-3. Average Annual National Losses/Costs and Gains (2006 dollars) Resulting from Extreme Climate Conditions, 1950-2000 (Changnon et al., 2001; Changnon, 2006a).

Activity/sector	*Losses/costs (billions)*	*Gains (billions)*
Transportation	1.92	0.36
Retail sales	1.50	4.56
Agribusiness	2.28	1.98
Farmers, crops and livestock	3.98	2.28
Energy use	5.58	4.71
Property damages	12.55	0
Government	8.40	7.92
Tourism	0.24	0.18
Insurance	5.23	7.80
Construction	1.44	1.82
Total	43.12	31.61

Losses not measured by the nine variables for which quality data existed also were estimated. Losses from these nine conditions incorporated many of the direct losses created, but they did not include secondary and tertiary losses and costs that develop over time (from six months to five years after an anomaly). Following are estimates derived for conditions not measured by the nine variables.

Use of insurance catastrophe data as a measure of property losses from floods and severe storms excluded direct losses from events with property losses under the $5 million loss threshold for catastrophes, as well as uninsured property losses. Insurance experts (Roth, 1996; LeComte, 1993) estimated that weather catastrophe losses account for about 90 percent of all insured U.S. property losses caused by weather extremes. Catastrophes account for $2.498 billion (2006 dollars) in average losses per year. Uninsured property losses had an average annual loss of $414 million (Changnon et al., 1996).

Major crop losses due to precipitation and temperature extremes ($3.124 billion annually) did not include losses to livestock or speciality crops, which averaged $600 million annually (Changnon et al., 2001). Livestock losses in the extremely severe 1988 drought and the record 1993 Midwestern floods were 4 and 3 percent, respectively, of the total agricultural losses. Speciality crop losses in the Deep South and California from the record damaging El Niño weather of 1997-1998 were $193 million (Changnon, 1999b). Annual average weather losses to the nation's vegetable processing industry are $54 million. As a result, the average annual losses for all aspects of agriculture are $3.98 billion (Table 13-3), and those for agribusiness are $2.28 billion (based on anomaly results showing that agribusiness losses averaged 57 percent of all crop and livestock losses).

Major climate extremes also substantially can reduce retail sales, as they did in California during the stormy, wet winter caused by El Niño 1997-1998 (Changnon, 1999b). Weather extremes produce major losses for the nation's transportation systems, including commercial aviation, the trucking industry, riverine shippers, and railroads. For example, the flood of 1993 caused record losses of $576 million for the nation's railroads and $732 million for river-based barge industry (Changnon, 1996). Warm winters of 1997-1998 and 2001-2002 provided gains averaging $360 million per year for the transportation sector.

Losses and gains defined from conditions during 1950-2000, coupled with the above additions to the insured values, and measures of losses and gains from the ten recent climate anomalies, were used to develop the list (Table 13-3) of average annual losses and gains for the nation (Winstanley and Changnon, 2004).

The measure of losses and gains from major extremes puts a good perspective on the national level of sensitivity to climate. Maunder (1986), in a first extensive assessment of U.S. weather and climate impacts, analyzed the nation's economic losses due to adverse weather and climate conditions, and these further were assessed as part of the gross revenue (Table 13-4). These percentages are a meaningful measure of sensitivity in various sectors, revealing agriculture as relatively high (15.5 percent), but in all other sectors, climate losses are a small portion, 2 percent or less, of the gross revenue. Maunder's (1986) assessment of the climate impacts for British business and industry sectors showed that most sectors lost 1-5 percent in a major severe winter and between 2-4 percent in a severe hot, dry summer.

How does the annual average loss value herein ($43.1 billion) relate to other estimates of losses from weather hazards and extremes? Maunder's (1986) assessment produced a total of $39 billion (2006 dollars). This is only $4 billion less than the recent total (Table 13-3), and this increase over time reflects increased societal vulnerability. Pielke (1997) estimated that national losses from weather extremes (and not including temperature extremes) averaged $375 million per week (2006 dollars), or $19.5 billion per year. A recent major hazards assessment (Mileti, 1999) stated, "Dollar losses to crops and property from natural hazards (1975-1994) were between $230 billion and $1 trillion. A conservative estimate is $500 billion." If this value is used, the annual average loss would be $33.8 billion (in 2006 dollars). Because the report states that about 80 percent of all losses are due to "climatological disasters," the resulting total would equal $27 billion in annual losses due to climate extremes. In summary, the recent annual average loss value (Table 13-3) exceeds earlier estimates of climate losses.

Analysis of the climate conditions causing the maximum loss in each year during the 1950-2000 period revealed six conditions that ranked highest in one or more years. High energy costs ranked highest in 16 of the 51 years. Hurricane losses were highest in 12 other years. Flood losses ranked highest in 12 years; and crop losses ranked first in 11 years.

Table 13-4. Average Annual Losses (2006 dollars) due to Adverse Climate Conditions and Their Portion of the Annual Gross Revenue (Maunder, 1986).

Sector	*Losses (billions)*	*Annual gross revenue (percent)*
Agriculture	25.100	15.5
Construction	2.994	1.0
Manufacturing	1.791	0.2
Retail sales	6.007	2.0
Transportation (surface/water)	0.288	0.3
Aviation	2.276	1.1
Communications	0.231	0.3
Electric power	0.135	0.2
Energy	0.159	0.4
Government	0.024	0.01
Total	39.005	

Gains

Assessments of economic gains from past weather extremes have been minimal, particularly those that relate to damaging forms of climate extremes. However, gains have been assessed for each of the ten climate anomalies herein. For example, studies of the 1988 drought and the 1993 floods revealed economic gains that equaled 14-26 percent of the losses. Assessments of the economic outcomes from the El Niño 1997-1998 cold season and from the record warm winter of 2001-2002, revealed national gains of almost $25 billion in each event with lower loss values (Table 13-1).

Assessment of 1950-2000 crop gains from good climate conditions showed an annual average gain of $2.28 billion (2006 dollars), or a total of $116.3 billion for the 51-year period. Assessment of energy usage showed 22 years with gains, averaging $4.71 billion per year, 84 percent of the total losses for 1950-2000. Beneficial extremes (good growing seasons, warm winters, storm-free conditions, etc.) produced national economic gains averaging $31.61 billion (2006 dollars) annually (Table 13-3).

Potential Future Economic Outcomes Resulting from Climate Change

Several studies have suggested that a future change in climate resulting from global warming will bring more weather and climate extremes (IPCC, 1996; Karl et al., 1999). Some have speculated about huge damaging financial outcomes in the future from these extremes (Reiss, 2001; Pearce et al., 1996). If the economic measures presented herein are reasonably correct, they can serve as the basis for developing a list of issues to consider related to future economic impacts.

Average and extreme past annual losses during 1950-2000 were assessed (Changnon et al., 2001) as indicators of possible economic outcomes from future climate changes commonly predicted to include more weather and climate extremes. As a first approximation of higher losses, one can consider the values of the five major loss years in the 1950-2000 period (2006 dollars):

- 1988 ($104.2 billion)
- 1972 ($65.3 billion)
- 1992 ($52.3 billion)
- 1954 ($47.8 billion)
- 1955 ($47.2 billion)

Major loss factors in each of these years varied. For example, 1988 losses were all related to the huge drought. In 1972, there were high flood losses ($19.2 billion), sizable energy costs ($31.7 billion), and large hurricanes losses ($14.3 billion). Hurricanes in 1992 caused $44.3 billion in losses, 87 percent of the annual total. Losses in 1955 were high because of hurricanes ($17.7 billion), energy costs ($16.7 billion), and floods ($6.2 billion).

Highest and lowest annual loss values during 1950-2000 had a large difference. The lowest three values were $2.845 billion (1963), $3.793 billion (1966), and $4.037 billion (1968). The lowest one-year value is only 2.7 percent of the highest value, $104.2 billion.

One of the scenarios for climate change under global warming is a warmer, drier United States with more extremes (NAST, 2001). If one assumes that the measures of maximum energy use, maximum crop losses, and losses from storm conditions reflect this type of climate, then these measures can be used to assess potential economic impacts of a climate change. Annual loss values for 1950-2000 were used to create a scenario of large annual loss. The annual losses from each climate condition during 1950-2000 were ranked, and the highest five were averaged. These "bad-year" averages were summed, yielding an annual loss total of $84.877 billion (Changnon and Hewings, 2001). This approach for assessing high potential future losses does not include economic gains that will occur, especially if the future brings conditions such as warmer winters (less use of energy). Gains in years of major national losses were 10-25 percent of the total losses, which would reduce the net national impact of the bad year value of $84.877 billion to between $63.7 billion and 76.4 billion. These various measures of climate impacts on the nation's economy are not sizable. However, they do not reflect impacts that could occur from sea level rise or those in other nations that would impact the United States.

Economic modeling also has been used to derive estimates of future economic impacts. A recent economic assessment using three climate scenarios and their estimated impacts on the U.S. economy in 2060 revealed a range of outcomes (Mendelsohn and Smith, 2002). The net national annual economic impact was $45 billion (2006 dollars) in benefits with a climate having a 2.8°F increase and a 15 percent precipitation increase. A scenario with a 9°F increase and no precipitation change was estimated to create (by 2060) a national loss of $24.9 billion (2006 dollars), with a range of estimates from $61 billion to $2.1 billion in losses. The authors note that these various predicted economic impacts would be about 0.1 percent of the GDP expected by 2060, and they further note their values are about an order of magnitude less than those of the IPCC (Pearce et al., 1996).

Burroughs (1997) assessed economic models and their use in assessing climate change impacts, pointing to modeling weaknesses and the complexities of integrating the outputs of global climate models with those of macroeconomic models. He further pointed to many other unpredictable factors such as technology developments over the next 50-100 years and their impossible-to-predict influence on economic impacts of future weather.

There are additional considerations and sources of uncertainty in assessing the potential for climate change impacts. First, the use of past extremes as a guide to the future may be of limited value if the climate changes are larger in magnitude than the historical anomalies and if the sensitivities of economic losses to climate anomalies are highly nonlinear. Second, it is likely that the absolute value of impacts will rise if population and wealth continue to increase; however, losses expressed as a proportion of GDP may be approximately equal to present-day values for extremes of similar magnitude to future climate changes. Finally, even if overall impacts are not large in a national context, there may be local areas or specific sectors experiencing very significant or even catastrophic losses (e.g., a Hurricane Katrina type outcome).

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