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Drought and Climate Change

Miscellaneous papers on the 1988 Drought and the issue of future climate change

by

Staff members of the Midwestern Climate Center

MIDWESTERN CLIMATE CENTER

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Midwestern Climate Center
Climate & Meteorology Section
Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820-7495
(217)244-8226

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PERSPECTIVES AND PROSPECTS FOR USING CLIMATE INFORMATION[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Perspectives on Use of Climate Information

Climate information served as the first major application of the weather sciences in the U.S. In fact, climate information was essential to this nation's settlement and then our advance as a world economic power. Climate information is essential if we are to maintain and enhance our economic prosperity and wisely use our natural resources.

The systematic collection of weather data was first mandated in the War of 1812 and assigned to the doctors in the army posts. They were to generate climate information for better understanding of health-related problems, as well as for defining frontier climate conditions for the military.

The growing needs for climate information as the nation moved into the industrial era with its production agriculture later in the 19th Century fueled the establishment of a national network of cooperative weather observers; the U.S. Weather Bureau was established in the Department of Agriculture where it resided until the pressures to serve aviation's needs for weather forecasts led to the Weather Bureau's shift to the Department of Commerce in 1940.

Thirty years later, several global weather disasters occurred in the 1970's and these helped direct attention again to climate. This national concern led to the enactment of the National Climate Program which served as national recognition that the nation's climate was a resource just like our waters, soils, and forests. If our climate is to be wisely cared for and used, we must have adequate, accurate, and timely information about climate.

The history of climate information has led, by the test of time, to certain "truths." First, the collection of weather data, and then its quality control and archival at the National Climatic Data Center so as to produce climate data and certain information, typically in published and computer formats, are roles of the federal government. Second, state roles in the climate information arena have largely been to help provide local access to climate data and in some instances to generate and deliver climate information through state climatologists. Third, the private sector has typically provided value-added climate products to serve the special needs of their customers.

Answers to the following series of questions further define climate information.

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[1]Paper presented at "Conference on Uses and Benefits of Climate Information," Washington, DC, April 20, 1988.

A. What Are the Major Applications of Climate Information?

There are three general applications. These include:

1) Design of structures and the planning of activities sensitive to weather forces (i.e., bridges).

2) Operation and management of activities/structures.

3) Assessment of importance (i.e., floods and droughts).

B. What Are the Basic Types of Climate Information?

There are many ways to classify climate information. However, from a user viewpoint, usage is often separated into two types.

1) Historical Data and Anytime Usage.

This pertains to the aforementioned design applications (i.e., wind values for building loading), or past data to assess events (i.e., this has been the wettest decade on the Great Lakes since 1854-63). This is often labeled "historical data" usage.

2) Now-only climate information updated routinely and rapidly and accessible in timely formats.

This type includes year-to-date climate summaries and/or climate predictions. It is used for operations (such as accumulated heating degree days for fuel decisions), or in timely assessments (i.e., yesterday's rainstorm was a 100-year rainfall).

C. What Is the Spatial Nature of Climate Conditions?

It is important to realize that most climate abnormalities are regional in nature covering all or parts of many states, yet seldom national in scale — think of the droughts of the 1930's and 1950's, or the recent wet conditions that have led to the record high levels of the Great Lakes and the Great Salt Lake. This physical truth about climate has made it difficult for local agencies or states to deal with climate events or aberrations.

D. What Are the Major Values of Climate Information?

1) To enhance our productivity, to make our commerce more efficient, and to IMPROVE THE NATION'S ECONOMY.

2) To effectively manage and protect our nation's NATURAL RESOURCES.

E. Who Are the Users of Climate Information?

The answer is everyone. In broad terms there are two main groups.

1) The private sector. This group includes agribusiness, the energy industry, transportation, tourism, and all other commerce that is weather-sensitive.

2) The public sector. Here we find farmers, the general public (i.e., was a record high temperature broken yesterday). Importantly, this includes our local, state, and federal agencies who must use climate information to advise, monitor, manage, or regulate activities relating to crops, soils, water, air quality, and other natural resources.

2. Prospects for Improved Use of Climate Information

Let us focus on the future and the good prospects for enhanced usage of climate information. Three major factors have developed since the National Climate Program Act 10 years ago, and these collectively allow for enhanced usage of climate information.

A. Understanding Usage.

The first factor relates to the usage and users of climate information. Major assessments of the uses and needs of climate information have been done by the NCPO, by panels of the NA, and regional climate centers, a new institution which I will describe later. These assessments collectively revealed that the nation was far from attaining optimum benefits from use of climate information either in economic terms or for protecting our natural resources.

Reasons for this less than adequate usage have been identified and they include:

1) The climate information desired were not available. The information were not at spatial density desired or were not at the accuracy considered certain, or the information on type of desired conditions was not available.

2) The climate information desired was available but not accessible in the time frame of need, or in the formats needed by user.

3) Users (many actual and potential) were not knowledgeable about a) what climate information exists, b) the value of climate information in their activities, or c) how to use the climate information in a decision process.

4) Lack of applied research addressing climate impacts on natural conditions or on socio-economic activities done in a definitive, user-oriented manner.

The point is, we have learned what the obstacles are and we have begun to move forward to address these intelligently. The next two factors show how this is being implemented.

B. Advances in Relevant Technologies.

The second factor enhancing usage relates to advances in technology such as:

1) Development of relatively inexpensive means to automatically measure, record, and transmit data on a large variety of weather conditions. This has helped get more of the data desired available and in much faster response times.

2) Computer developments leading to relatively low costs for considerable analytical power have been critically important at central climate data storage and analysis centers, and at the individual level where climate information can be assessed through PC's.

3) Relatively inexpensive and diverse means to communicate and transmit climate information between climate data centers and users have evolved.

C. Conclusion.

The sum of these developments is the capability now to develop computer-based climate information systems that process and produce vast quantities of climate information quickly with climate updates. We have the CAC system based on considerable but limited natural data, and then systems in the Midwest and High Plains based on automated data and spatially very dense data.

The information about past, present, and future climate conditions are becoming much more easily accessible to farmers, government decision makers, city engineers, state agency staffs, agribusinesses, and hosts of other users.

3. Institutional Developments

The third factor enhancing usage of climate information in the last five years have been the development of new institutions and changes that have occurred in others. At the time the National Climate Program Act was enacted in 1978, the governmental infrastructure relating to climate data and information was complex and at time chaotic. There were many players, varying responsibilities and often confusion.

Since then there have been a series of special weather-related networks established in many states, across regions, and even nationally. Several states operate in-state networks of automated weather stations; Nebraska operates one that spans six states as part of the High Plains Regional Climate Center, and new national scale networks for lightning and rainwater chemistry exist. These networks have either developed within existing state or federal institutions, or in new institutions, such as the Regional Climate Centers.

In the last few years we have seen the development of a new institution, the Regional Climate Center. It functions between the federal and state players in climate services. Regional centers were founded to provide special regional data sets and climatic expertise.

There are now five centers with one in the Northeast, Midwest, Southeast, High Plains, and Far West. One is being planned in the South.

The centers are under the NCP Office which helped develop the regional concept. Congress has been very supportive, viewing these as means for carrying out the mandates of the National Climate Program.

The regional centers act as an interface with federal agencies, state agencies, and the private sector. Although they are in their development stage, their primary functions are:

a. to enhance the nation's basic climatic network of cooperative weather observers,

b. to coordinate regional and state data gathering networks,

c. to develop specialized regional climate data bases,

d. to serve as clearinghouses for information,

e. to operate near real-time regional climate information systems,

f. to plan, organize and conduct applied climatic research focused on topical issues, and

g. to perform educational, extension type programs to help users.

4. Summary

In summary, there is wide use of climate information in the public and private sectors, collectively helping the nation's economic position and management of our natural resources.

The prospects for enhancing usage of climate information appear excellent if our state and national networks of data collection can be maintained and enhanced, and if a national system of regional climate centers can be established and developed adequately such that a new infrastructure for climate information is developed. As these systems stabilize, I also foresee the growth of the private sector in the business of climate information delivery, and further enhancement of our nation's economy through wiser and greater use of climate information.

CLIMATE CHANGE AND WATER USE IN AGRICULTURE[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

The subject of climate change has become a central scientific and policy topic. In considering the impacts of climate change on water needed by agriculture, I find a broader overview of the issues of climate change and the Greenhouse Effect important as a basis for an assessment.

Assessment of the effects of climate change on agriculture is faced with two major dilemmas. First, the expected changes in atmospheric conditions due to trace gases a) are presumably going to occur at a faster rate of change than ever before experienced, and b) are going to reach levels, particularly of temperature, not experienced in the last 200 years (some say experienced in the past 100,000 years). Such extremes greatly affect the utility of various impact models and their assumptions.

The second dilemma posed by the $C0_2$-driven Global Climate Models (GCM's) used to ascertain future states of climate occurring 30, 50, or 100 years from now, is the lack of specificity about how, where, and when the changes will occur. They do not specify well the seasonal conditions over regions critical to agriculture, nor do they specify yet another key ingredient for measuring effects, the degree of weather variability around the envisioned mean. The various GCM's further disagree widely in their predicted outcomes of the future climate. These two dilemmas are significant in how one pursues research of climate change and its effects on agriculture.

It also seems important now to list some "truths" about the effects of climate change on agriculture that recent studies have indicated.

First, agricultural scientists have long been cognizant of weather effects on crops and have attempted to measure effects of climate fluctuations. Recent studies of climate change indicate that farm level production would be changed enough to cause geographic shifts in crop zones. Other studies of increased $C0_2$ levels in the atmosphere indicate positive direct impacts on crop growth. In essence, most work to date has been to derive first approximations, with a sense of confidence in measuring the agricultural effects of change with existing models.

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[1]Paper presented July 6, 1988 at Universities Council on Water Resources Annual Conference, (in Proceedings) entitled, "Climate Change and Water Research: Research Needs and Opportunities."

A second "truth" often espoused is that agriculture could adapt to expected climate change by new crop strains, better management, shifting of crop zones, etc., Parry et al. (1988). Unfortunately, these views have largely ignored the socio-economic aspects of adjustment.

Thus, a third "truth" is that social adjustment to climatic change in the agricultural system is complex, poorly understood, and is largely unaddressed. Parry's (1988) studies of effects of climate on agriculture in marginal environments (the hot, dry, wet, cold regions) have shown that small changes in climate will result in altered yields, farm incomes, and regional food production. Certain technical adjustments (such as altering planting dates) and policy responses (such as changing support policies) are alluded to as outcomes in his analyses. Sinha (et al., 1988) point to the potential differing agriculture impacts from climate change on big versus small nations, and they raise the broader question about adaption versus prevention (of CO_2 and other trace gases). Crosson (1988) speculates that the global costs of warming due to CO_2 doubling do not appear high enough to crate global consensus that the warming would be too much. The important point is, the assessment of agricultural effects reaches global markets and international politics.

A fourth "truth" is that a few agricultural scientists have now become concerned about how to meaningfully address the more complex aspects of climate change including the change of conditions over time, the magnitude and timing (seasonal) of change, the related weather variability, and also the related social, economic and policy factors. In essence, this group realizes that new approaches are needed, and these go far beyond what has been done to date in impact analysis.

The fifth "truth" is related to the realization that new knowledge is needed in several areas to address the questions of assessing the effects of climate change. One realization is that current models are less than adequate. Another is that the role of crops and forests as sources and sinks of CO_2 needs to be more effectively addressed. Although I chose not to address forest agriculture in this paper, there seems to be little doubt that the buildup of atmospheric carbon over much of the past 200 years is the result of forest clearing, first from the temperate forests and more recently from the tropical forests (Sedjo and Solomon, 1988). Fossil fuels have only dominated as the CO_2 source in recent years.

Knowledge is also desperately needed to consider the interactions of future climate with future human factors including population growth, economic growth, patterns of economic development, and technological change. For agriculture to address climate changes and be meaningful, the "changing climate" must be considered within the context of future world changes in agriculture demand, in agricultural capacity, and in regional comparative advantages. In a recent assessment of global scale agricultural issues and future climate changes, it was concluded that changes expected over the next 50 to 75 years will not limit the expansion of world food and future capacity in step with the world demands (Parry et al.. 1988). However, they predicted that climate changes will result in significant shifts in regional competitive advantages. Jag (1988) in a recent assessment of climate change and its possible effects on forestry indicates that the two most confounding problems are the uncertainties over the human responses apt to occur, and the regional responses and varietal displacements. The point is that regional effects are the key to correctly assessing overall impacts of a changing climate on agriculture.

A sixth "truth" relates to the current utility of global climate models (GCM's). They are as yet unable to make regional scale estimates useful for refined studies of agricultural impacts. This includes their inability to describe the sequence of shifts of weather changes over each year, pentad, to decade of the next 50 to 75 years; their inability to describe future climate conditions in desired area detail; their inability to describe the variability around the mean; and their lack of information on the shifts in weather extremes (will there be more or less?). The model products are essentially inadequate regionally and temporally for doing definitive impact assessment.

2. Assessing Effects of Future Changes

Let me now focus on the approaches for assessing the impacts of climate change on water for crop agriculture. In this instance, I have included precipitation and all other relevant climatic conditions affecting available water. I am going to comment largely on crop production agriculture and not on forest agriculture.

Because of the direct and visible relationship between climate conditions and food and fibre production, the agricultural impacts of suspected climatic changes have been the subject of considerable analysis. Approaches used in assessing effects of climate change on agriculture have usually followed three lines of endeavor. The most typical approach utilized has followed a 2-stage analysis (Sonka and Lamb, 1987).

a. First, an altered climate state for a specific geographic region was hypothesized, including those from GCM's. This altered state tended to be defined for a period well in the future (that is, 50 or more years). The change was specified in general terms such as a change in seasonal or annual rainfall or temperature.

b. Then, the translation of the altered climate state into changes in agricultural production has been generally accomplished with a quantitative agroclimatic model. These models tended to be simplistic, and often statistical in nature.

One includes in this group of models the classic crop yield-weather (or climate) regression models. We also have the physiological crop models that include weather variables. These sets of models have been useful in gaining understanding of agroclimatic relations, but they have limitations for climate change assessment.

Years of research dealing with weather effects on agriculture have also yielded useful information that can be fed into climate change effect modeling. Among many, one can readily cite studies of the weather conditions that affect various crop diseases and pests, studies of how rainfall rates affect erosion, and how modified weather, including rain and hail affect crop production.

A second approach used in climate change studies that has been newly examined, in a limited way, is based on expert systems and artificial intelligence. These might be best labeled as "sensitivity analysis" for determining climate effects. Recent work, for example, has used expert systems approach in Corn Belt agriculture to define the magnitude of effects related to varying levels of rainfall and temperatures during the growing season (Richman and Easterling, 1987).

A third approach has involved actual simulation testing. For example, agricultural test plots in Illinois are being subjected to various climate scenarios (Changnon, 1988). Controlled growth chambers to simulate the effects of climate changes on crops are another means to asses the physical relations.

Without belaboring all the pros and cons of the modeling, sensitivity, or simulation approaches to assess climate change, it is important to focus on some of their major weaknesses and strengths for assessing climate change and its effects on agriculture.

For example, regression modeling has a difficult time with separating ever changing technology from weather influences. Further, all forms of modeling based on past conditions are questionable because their effect estimates are likely not reliable when climate conditions from future Greenhouse warming are used in them. This is because these climate conditions differ from those sampled in the past and hence invalidate the assumptions used to construct the models. Physiological-based models are superior but we lack the necessary input data for many areas. Sensitivity approaches based on expert systems type analyses and simulation studies have desirable features for climate change assessment and need further research. All this points to one major fact, however: there is a great need to develop methods to better assess climate change and its impacts on agriculture.

It is important at this stage to consider other factors involved in how climate change is assessed and what results climate change may have on crops. A principal reason for analyzing the effects of climate change on agriculture has been to discover and test possible actions that could be taken to mitigate adverse consequences and to exploit favorable effects. Figure 1 (from Sonka and Lamb, 1987) depicts the adaptations that can occur in the individual farm level and/or those at the market or societal level. At the farm level, adaptation to change can occur but only if the decision maker is able to alter the production process. If he does not, the effect will be altered asset values. However, a more likely reaction will be to change the production process. These can include shifts in crop choice, crop varieties, tillage practices, fertilization rates, or use of supplemental irrigation. Figure 1 also depicts responses apt to occur through market and institutional mechanisms. The market would lead to adjustments in demands and supplies. Institutional responses may be the most pronounced effects of climate change, and these need research as part of the agricultural effects impacts.

Thus, it is important to consider agriculture as a series of interlocked systems (Figure 2 from Sonka and Lamb, 1987). The lowest level consists of the physical and chemical microprocesses which become integrated with the physical framework of specific plant and animal commodities.

The farm unit level allows for incorporation of behavioral and economic factors within the production system. In turn, individual farm unit decisions are aggregated at regional and national market levels, and world wide effects extend through international trade for agricultural commodities.

Importantly, climatic and socio-economic forces each produce major impacts throughout this system - they both affect production and simultaneously operate at varying geographic scales. I believe future comprehensive climate change modeling should address all levels and integrate these models at each level.

That is why most recent modeling efforts of climate change that typically address only one level to make judgments about effects of climate change on agriculture have often met with skepticism. Questioning had several causes, some of which are tied to the modeling process employed. Of particular importance among these causes are the following:

a. A fundamental dichotomy in assumptions. Although sufficient time had been assumed to pass so that a significant change in climate occurred, other factors (food needs, technological change, governmental policies, etc.) were essentially held at current levels.

b. The methodology explicitly addressed the "wrong" question. More sophisticated approaches would have considered issues such as: How will or can agriculture and society adapt to a changing climate? If actions are taken to reduce the man-induced causes of climatic change, how will the evolution of the agricultural system be affected?

Such questions have a number or key characteristics that should determine the analytical approach used to address them:

a. Time is not reflected by instantaneous changes, but is continuous. Therefore, evolutionary processes, with respect to climate, agricultural practices, and exogenous forces, must be incorporated into the analysis.

b. The changing climate should have explicitly-identified attributes of variability, including how variability is affected by the process of climate change.

c. The capacity should exist to assess societal reactions to the changing climate. Potential responses include actions relating to technological change, governmental policies, and management practices.

d. The role of the market as a means to convey information should be an integrating factor. Use of the market mechanisms will allow the analytical system to consider the effect on prices and production of the changing climate, as well as effects of population levels, commodity supplies in competing non-affected areas, and consumer tastes and preferences.

An innovative integrated modeling approach is needed to evaluate the issues associated with effects of a changing climate. This approach would integrate models of differing processes and levels of aggregation. Three types of models would be incorporated into the research effort, as shown in Figure 2.

a. Physiological plant growth models that utilize detailed climatological data as input.

b. Firm-level decision models that explicitly allow for incorporation of uncertainty of manager expectations.

c. Regional supply/demand models to estimate price effects due to production changes in the study area as well as indicating the effects of factors exogenous to the study area.

This model framework is general in orientation. Although potentially useful for the analysis of a number of climate topics, the following discussion will illustrate application of this framework to analysis of the impact of climate change for a specific geographic location.

An interesting potential study area of agricultural importance is the corn and soybean producing regions of the central United States. This area is sufficiently large to currently be affected by a range of diverse climatic conditions. Significant changes in production in the region could alter world market conditions for these commodities. The component of the analysis focusing on the physical processes and firm-level decision models would need to be replicated in a number of representative locations within the region. In addition to corn and soybeans, the potential for shifting to an alternative crop such as wheat, oats, or sorghum would need to be part of the analysis.

Because a changing climate is a central component for the effort, incorporation of time into the analysis will be necessary. Figure 3 presents the time-based sequence of the three levels of models. Possibly 5-year rather than annual time frames would be appropriate, given the long term nature of climatic change. The impact of changing climate in the first period (T=l) would affect production through the plant growth models. Also in the second period (T=2), the market would reflect the altered production amounts of period one. Decision model expectations in period 2 would reflect the altered climate in period one as well as the price of that period. This iterative process, with market feedback, would be continued throughout the several periods under consideration for a 30-, 50-, or 100-year period of changing climate.

Development of such a modeling capacity would provide the powerful and flexible research needed to do meaningful research of climate change. Initial analysis could focus on alternative patterns (scenarios) of climatic change. Based on prior climatic research, a limited number of alternatives bracketing the range of possibilities for future climate conditions could be evaluated. The interaction of the postulated changing climate and exogenous forces may prove to be of particular importance. Therefore sensitivity analyses, incorporating differing levels for key factors such as world population growth and changes in food production in competing regions, could assess the interrelationships of these factors with a changing climate.

3. Recommendations

This assessment of approaches to assess the climate change issue and water for agriculture leads to certain recommendations for research. I hope that I have made it clear that climate change impact research, to be more meaningful, must embrace the following concepts:

a. Climate change as transient states, occurring continuously over time and hence crossing agricultural response thresholds.

b. Agriculture as an integrated production system of producers, business, and consumers impacted by direct linkages and feedback mechanisms.

c. Agriculture and climate in the broader context of environment, society and economy, all of which will undergo changes in addition to changes in climate.

Regression models have limited ability for addressing climate change and their use, if any, should be coupled to other models. Physiographic models need further development but are needed for most impact applications.

Since unusual climate changes (rate of change and levels of change) are expected, they make models based on historical data of questionable value. Hence, research to develop reactions to extreme climatic conditions are needed. Here, sensitivity analysis through artificial intelligence techniques need study. I further recommend research in climate simulation through agricultural test plots and growth chambers. In these and other laboratory type simulations, the new physical relations for climate extremes can be better defined.

A major recommendation relates to the fact that past analyses have tended to implicitly assume an instantaneous change in climate; to focus largely on the physical processes; and to ignore adaptations that society is likely to implement as the climate changes. For agricultural impacts, we must link physiological crop-growth models, farm-level decision models, and regional models of supply and demand. An integrated modeling framework will require model development but it is a key direction to pursue.

In summary, methods of performing impact analysis need development. As Sinha et al. (1988) state, current methodologies are not applicable in the context of determining global food security and climate change.

A final recommendation relates to the inability of GCM's to provide adequate inputs needed for sophisticated modeling of effects. In an assessment of the Greenhouse issue, Crosson (1988) identified the top research tasks to be a) reducing the uncertainty over the rate of climate change (will it be smooth or discontinuous?), and b) reducing the modeling uncertainties over regional climates. To this end, climate scenarios need to be developed to embrace the various potential future climate states and to incorporate expressions of shifting variability of weather over space and time.

4. Acknowledgements

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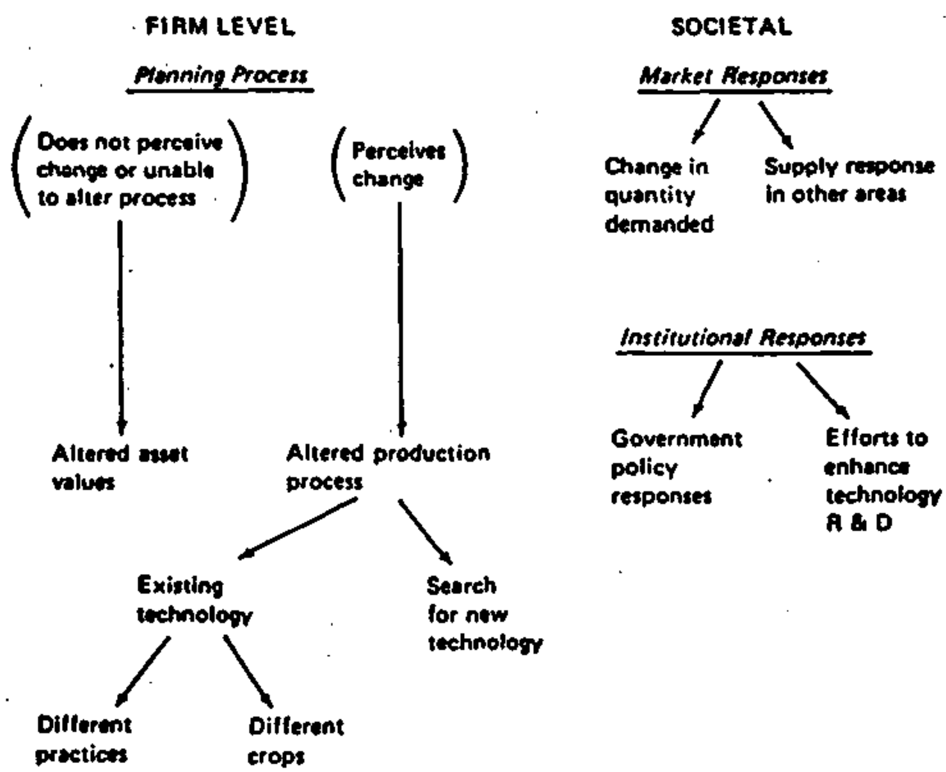


Fig. 1 Types of direct economic adaptations to a changing climate.

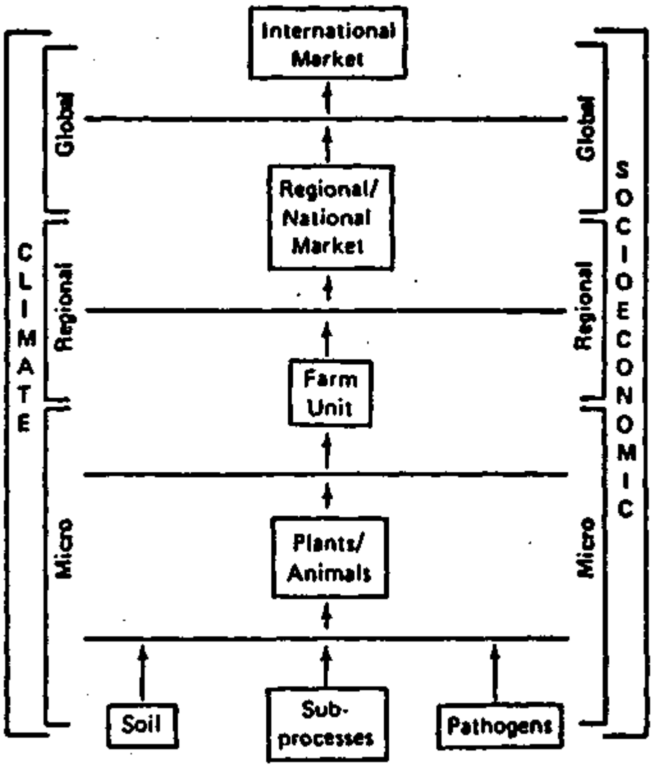


Fig. 2 A view of agriculture as a system of linked systems.

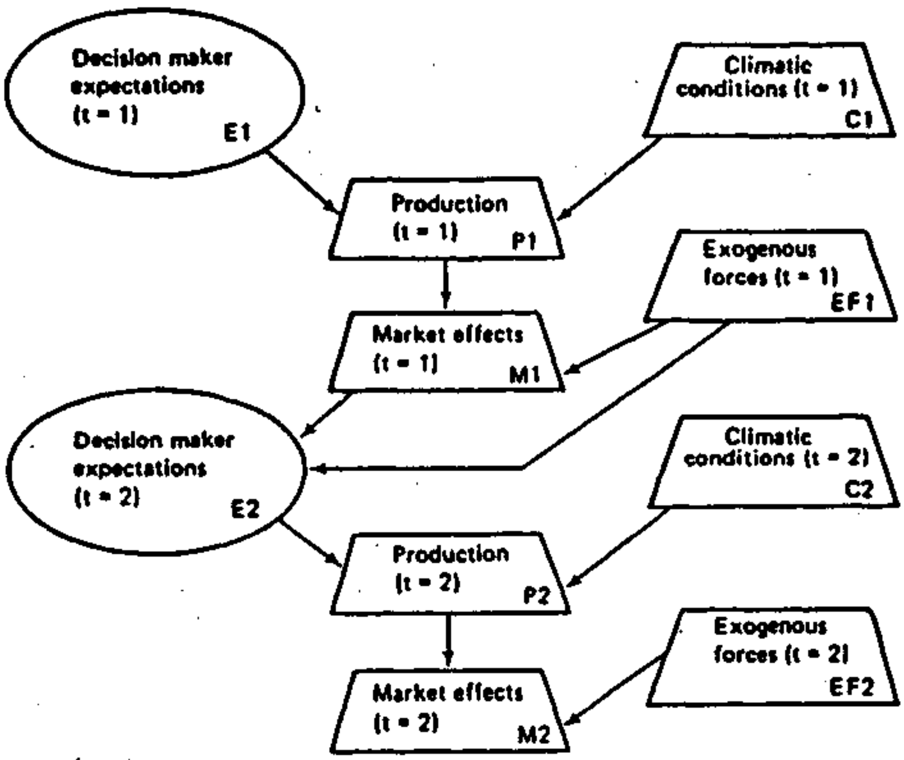


Fig. 3 General schematic of linkages over time for a two-period example.

MIDWESTERN DROUGHT CONDITIONS - 1988[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. What is Drought?

Drought in any region has a rather specific definition, uniquely special to the region. Its definition is a mixture of the soils, the climate, and human activity within the region; conditions that produce drought in the Great Plains are not those that produce drought in the Midwestern Corn Belt.

To understand the current drought in the Midwest is to first consider how a drought is defined. Understanding drought definition and the characteristics of drought helps us understand what is, and has been, occurring in the Midwest. It may seem obvious to say that extreme weather conditions interface with most aspects of Midwestern life, but the intertwined web of drought into particularly every human activity is obvious in our recent newspaper accounts. However, what is a drought to the Mayor of Indianapolis is not necessarily a drought to an Indiana farmer living 20 miles away from the center of the city. Understanding the differences in drought based on needs and use of water is an essential feature in effectively dealing with drought, particularly in the Midwest.

Figure 1 shows how changes in precipitation manifest themselves through the physical system beginning with reduced runoff, lowered moisture in the soil, and decreased ground water for wells. Tracing these impacts throughout the hydrologic cycle, and then into the fabric of our economy helps understand the complexity of drought.

Last year in analyzing past Illinois droughts we drew a simplified graph (Fig. 2) showing how precipitation departures from normal over a 12-month period related to the severity of drought. This shows that when precipitation becomes 80% of normal for 12 months in a Midwestern area, certain endeavors are impacted and certain people experience drought problems. However, once the precipitation over a 12-month period has fallen to 60% of normal, then everyone, the farmers, the urban water supplies, transportation systems, and the recreational activities are all experiencing drought.

It is important to appreciate that drought, for different arenas, appears at different times. Figure 3 portrays the delay in how a drought promulgates itself through the hydrologic system. It is felt first, and most obviously, as precipitation deficiencies, and is then recognized quickly in decreased surface runoff. Slightly later the departures become more evident in the soil moisture, and as time progresses, the drought's impact is recognized in streamflow and then 1 or 2 months later in ground water. In a few minutes, I'll be discussing some of the

[1]Prepared for Weather Channel Talk on 7/14/88.

impacts of the Midwestern drought and show this time sequence in 1988, beginning first as a precipitation drought, then becoming an agricultural drought, and then a water supply and recreational drought.

In the concern and sometimes hysteria of dealing with a severe drought, we tend to forget that droughts are an integral part of the climate of the United States. What we have been experiencing in the Midwest may be the worst spring drought in recent record, but as the Figure 4 shows, precipitation over the last 145 years in Illinois has tended to be a constant "seesaw" of ups and downs. Over the last 20 years Illinois, and all the Midwest has been in an extremely wet regime; actually, the wettest since quality weather records began before the Civil War.

Similarly, the Figure 5 shows the history of temperatures in Illinois since 1840. One sees low values up to 1880, followed by warming from the late 19th Century until the middle 1930's and a gradual cooling from 1940 to present. Thus, the Midwest has experienced, in the last 20 years, an abnormally cool and wet period. It has been favorable to high crop production and adequate water supplies.

Figure 6, based on the occurrence of 12-month droughts in Illinois since 1900, further illustrates the climatic situation. Most severe droughts, since the turn of the century, have occurred 30 to 50 years ago, and we have had few droughts, and none of great severity, since the mid-1950's. Our current drought, although very severe for a short-term period, is yet to be established as the start of a long-term drought such as experienced in the 1930's or early 1950's in the Midwest.

The final point I wish to make, to analyze the characteristics of Midwestern droughts is revealed in the Figure 7. Here we see a series of graphs that help put dimension on various characteristics of our climate and the fluctuations in weather and climate that can occur.

Yes, we can find cycles, often weak, in the precipitation. Such cyclical behavior gives some skill at predicting wet and dry periods but with not high accuracy. Another thing that we note (2nd graph) is that the climate of the Midwest, and for that matter much of the United States, moves in and out of periods of either high or low variability of weather. For example, the last 15 to 20 years in the Midwest, in general, have been cooler and relatively wet, as I have already mentioned. However, this has also been a period of greater weather extremes, as shown. We have had the wettest 5 years on record in the early 1980's and these led to record high levels in the Great Lakes. We've had the worst winters on record in the late 1970's and early 1980's, and now we are experiencing an extremely abnormal springtime drought.

Thus, a drought of severity might well be expected as one proceeds through a climatic period that is featuring many extremes in both temperature and in precipitation. This is one of the reasons why it's difficult, if not impossible, to make any rational claims that this drought is an indicator of an man-induced climatic change or a precursor of the Greenhouse Effect.

2. How Bad is the Current Drought from a Climatic Standpoint?

Most of us enjoy numerical statistical analysis of extreme weather conditions, so let's begin with answering the question, "How bad was June 1988 in the Midwest?"

Precipitation was terribly deficient with most areas having between 0.25 inch and 2 inches when 4 inches is the average. It was the driest June of this century in approximately half of the Midwest. Some areas went 30 days without measurable precipitation, a new record for this part of the year. It is important to recognize that in much of the Midwest May and June are normally the wettest months of the year so that the 1988 departures of 50% of normal rainfall or less are highly unusual.

June and now July temperatures in the Midwest have been quite unusual. Maximum daily temperatures, which cause the high evaporation of moisture from our plants, soils, and lakes have been quite high, ranging from 5° to 8°F above normal. However, minimum temperatures have ranged from near normal to slightly below normal, giving us a great range in temperatures. These lower than normal morning temperatures are a reflection of the low relative humidity.

Plant available moisture in the upper 20 inches of the soils of the Midwest by early July had disappeared. On a regional scale, we have had some recent rains in parts of the Midwest in the past 2 weeks. However, they have tended to be scattered, with localized areas receiving 0.5 to 1 inch in late June and now in mid-July. However, many areas of the Midwest have received very little rain since the first of June, and what is easily the worst early- year drought on record continues.

To illustrate the magnitude of the drought over the last few months, I would like to show you how the Midwest rainfall has ranked by states. Figure 8 shows the rank of the April-June precipitation in the 9 states under the purview of the Midwestern Regional Climate Center and 9 State Climatologists. Here one sees the absolute severity with the April-June rainfall achieving rank 1, or lowest, in most states. The rain in the first six months of 1988 (Fig. 9) ranks as slightly less severe. In Iowa, Wisconsin, and Ohio, the 1988 rainfall values through June rank as the lowest ever, but as slightly lesser ranks in the other states. Regardless, in many areas, the lack of rain during these months is unprecedented in this century.

Comparison of the average state-wide precipitation with the climate records extending back to 1895 produces a ranking for the 1988 values as presented in Table 1. One sees that in Wisconsin, in each of these various time segments, the 1988 drought has ranked as the driest over the last 90 years. The drought has been most severe in the April-June period. If one uses the Palmer Drought Index as a measure of current conditions, we find that portions of Minnesota, Iowa, Wisconsin, Ohio, and Kentucky can be classified as experiencing "extreme drought," whereas most of the Midwest is classified as in "severe drought."

The extent and severity of the 1988 spring drought and early summer drought exceeds even the Dust Bowl years of the 1930's. A major difference between past bad years concerns the amount of precipitation before the drought developed, a condition we are now going to explore. In many respects, the drought pattern of 1988 looks somewhat like that of 1934. Figure 10 shows the monthly precipitation that preceded the other three bad spring droughts in the Midwest. These include 1933-1934, 1935-1936, and 1952-1953. The heavy line for 1987-1988 rain values shows we shifted from above normal rainfall in late 1987 into a continuing decline. The major difference of 1987-1988 monthly values from those of other bad years relates to the fact that the early ones were preceded by many more months of precipitation that oscillated between near normal and below normal values.

The "anatomy of the 1988 drought" is further illustrated in Figure 11. Here, the monthly precipitation amounts in the region beginning with November 1987, 8 months ago, and through early July, are shown. One sees two very important features. First, November and December were extremely wet months with amounts that were more than 3 inches, or double, their averages. Thereafter we see a continuing decline in monthly rainfall. Inspection of the temperature departures shows a long running sequence of abnormally warm months, except for February 1988, as manifested in the maximum daily temperatures. High daily temperatures and the low precipitation collectively produce high evaportranspiration.

An important fact revealed in this graph, and one that has helped ameliorate the agricultural effects of the 1988 drought in the Midwest, is the extremely rainy November and December 1987. In the severe spring droughts of the 1930's, such extremely wet winter months did not occur before them. The heavy precipitation in November and December of 1987 totally recharged the soils of the Midwest, and in the deeper prairie soils of the Corn Belt, this has provided sufficient moisture in deeper soil levels to sustain the growth of the corn and soybean crops, at least until very recently. Now that the tasseling period has begun for corn, the moisture demand is high and the lack of moisture becomes very critical in deciding how many ears occur on each stalk and how many kernels will be on each ear.

Undoubtedly the single most significant aspect of the Midwestern drought of 1988 is the time of its occurrence. Careful historic studies of Midwestern droughts of durations of 3 to 6 months show they typically develop in the late summer and fall and extend into winter; they seldom develop in the spring as has this drought.

Typically, only 3% of all precipitation droughts that last 3 months occur in spring, revealing the rarity of a springtime drought. Table 2 is a frequency analysis showing the amount of low precipitation for different spring periods expected to occur once every 2 years, every 5 years, every 10 years, and up to once every 100 years. In the far right hand column are the values experienced in central Illinois during the spring of 1988. Comparison of these values against those in the rest of the table reveals that they are lower; that is rain we have experienced since January 1 was less than expected only once every 100 years! Thus, the absolutely most abnormal aspect of the drought has been the time of its occurrence, which, as noted before, is normally the wettest time of the year in the Midwest.

3. What are the Impacts?

We have a convincing case that the spring and early summer drought of 1988 in the Midwest is an extremely unusual and severe event. Clearly, the impacts have been severe and wide ranging.

You'll recall in my earlier comments about defining drought that I mentioned two points: first that droughts take time to develop through various parts of the hydrologic cycle and related areas of human activity. Second, that droughts eventually become pervasive; that is, if sufficiently long lasting and severe, they affect all weather-sensitive parts of the environment.

From that viewpoint one now sees evidence of diverse effects, as illustrated in Figure 12, a montage of headlines from Midwestern newspapers. Actually, the precipitation drought in its earliest phases was beneficial to Midwestern agriculture. That is, corn and soybean planting could be done early, which is considered advantageous in order to miss the drier and warmer conditions typical of late July and August. However, since planting time, the high temperatures producing great evaportranspiration of moisture from plant leaves and soils, coupled with the abnormally low rainfall have been a growing problem. For certain crops like corn which can deep root, a dry spring can be beneficial. The dryness forces the crop to deep root and to reach and rely more on deeper soil moisture levels. As I noted before, these soil moisture levels in the Midwest were high in 1988 due to the abnormally heavy rains in November and December.

This moisture has sustained the corn crop moderately well, but now most estimates indicate that we have an extreme agricultural drought. Figure 13 shows how the quality of the crop declined during June, being rated as "good" over less than 20% of the areas of all states by June 26. Corn yields are predicted at this time to be reduced between 30 to 60%, depending on the area of the Midwest and the amount of rainfall in the future.

Continuance of high temperatures and below normal rainfall during the July tasseling period, which is now occurring in large parts of the Corn Belt, will greatly reduce the number of ears and kernels on the ears, and further reduce yields.

It is less certain at this stage how badly the current conditions will affect the soybean crops. Soybeans have begun blooming over much of the Midwest and the ultimate outcome of bean yields will be greatly affected by the weather conditions in the next 4 to 6 weeks. A return to near normal temperatures and precipitation may well result in a moderately good soybean crop. Of course there is much speculation on the ensuing effects on livestock and future prices of food commodities.

The drought has begun to permeate beyond the lawn and agricultural crop stage. The lowered streamflow has caused the nationally recognized problems in river transportation (Figure 14). The low flows in the Illinois, Ohio, and Mississippi Rivers have held barge traffic up, and have required lesser loads and fewer barges to get through the shallow waters.

The drought has begun to affect urban water supplies, particularly in communities that have less than adequate reservoirs or ground water sources. Water conservation is being used in many communities throughout the Midwest. Another impact that is notable, and because the drought began during the early portion of growing season, is the impact on the environment. Many ornamental plants have been damaged or killed, and many will have, at best, zero growth. Damage to wildlife such as pheasant, ducks, and fish has become very evident and there will be major reductions in their populations.

An important aspect of the water resources of the Midwest are the Great Lakes, the largest natural water body in the world. Figure 15 shows the history of the levels of Lakes Superior, Michigan-Huron, and Erie from January 1986 to present. (The rhythmic curve is the average level.) Of great interest is the rapid fall of levels from record high values shown in 1986 (note the bars) and early 1987 to below average levels today. This precipitous fall in lake levels of 2 to 3 feet in 12 to 15 months is the most rapid decline in lake levels during this century. During the record high lake levels of 1985 and 1986, and when enormous shoreline damage was occurring, lake experts indicated it would take 3 to 6 years for the lakes to return to their long-term average levels shown in these figures. However, the severity of the drought, and the high temperatures causing great evaporation from the lakes, have caused this precipitous decline in lake levels.

The impacts of the drought of 1988 in the Midwest are significant and now widespread. However, as with any weather abnormality, there are "winners" as well as "losers." Decreased shipping of grain on barges in our major rivers has lead to increased rail shipments and benefits to railroads. Decreased water supplies have led to an increase in the drilling of wells and profits to well drillers. Those farmers who had the foresight to insure their crops against weather perils will have their financial losses ameliorated. Clearly, some farmers will win big by the 1988 drought whereas others will lose big. Others will make enormous profits in the grain market, and I suspect others will lose badly.

4. What Solutions Exist to Address Drought from an Atmospheric Standpoint?

In the midst of trying to address drought and to develop additional water supplies, the atmospheric scientists around the nation are often asked, "what can be done?" It seems to me that there are at least 4 basic answers that come to mind. First, we describe the event to put it into perspective for those attempting to make drought-related decisions.

A second area of advice, which isn't totally dependent on the atmosphere, relates to relocations or diversions of water. In recent weeks we have heard proposals by the U.S. Corps of Engineers to divert water from Lake Michigan through the Illinois River to increase the flows of the Mississippi. This would alleviate the problems of barge transportation by increasing the level of the rivers. Figure 16 shows a cross section of Chicago and how Lake Michigan waters are diverted through Chicago for several purposes. These include providing the city's water supplies and industrial water needs, and also to help in the dilution of the treated sewage effluent, and to maintain our river levels for barge transportation down the Illinois River system below Lockport, shown on the map.

The amount of diversion proposed, which is triple the current regulated level, would produce a slight lowering of the lakes, estimated as between .5 and 1 inch during a year. Since the lakes are used for many other purposes including shipping, water supplies, and hydroelectric power generation, other states and Canada are concerned about any lowering of the lake levels. Consideration of rapid decline in the lake levels from the record highs to the below average conditions, one can see why this "solution" is a critical policy issue.

Another potential solution to help alleviate some drought stress that has been considered is weather modification. Cloud seeding to increase rainfall in convective clouds of the east, or to increase snowfall in the western mountains, is clearly an emerging technology. Good evidence exists that winter snow conditions, if properly seeded by silver iodide, can increase snowfall from 10 to 30%.

However, in the Great Plains, Midwest, and Southeast the question arises, "can cloud seeding do any good?" Current cloud seeding techniques utilize aircraft that penetrate clouds and leave seeding materials aloft to increase the efficiency of rainfall production. The artificial seed acts to grow more ice crystals just like natural clay particles from soil act. These added ice crystals capture more water droplets in the cloud and this process releases more heat to make the cloud grow and produce more rain. Our best estimates are that rainfall from certain Midwestern clouds could be increased from 10 to 20% by judicious cloud seeding.

Two points arise in drought: first, are there sufficient clouds of the right type to treat to produce any usable amount of water, and second, will it really work? Evidence from research in the Midwest involving our Illinois meteorologists and the agricultural scientists in Illinois, Indiana, Michigan, and Ohio suggest hope if proper equipment, well trained scientists, and precautions are used. Currently there are interests in Ohio who are launching a cloud seeding project. My thoughts about use of weather modification in drought is to consider a mobile seeding system of aircraft able to move rapidly over an entire state, or several states, to wherever the clouds exist Suitable clouds do exist at times in droughts, but not in great numbers.

A second point to consider is that weather modification may be a useful tool in drought, but not so much to try to save the 1988 crop but to enhance the soil moisture over the winter and spring of 1988-1989. Examination of the 10 driest spring seasons in the past 100 years in the Midwest reveals they all ended up in years with below normal annual rainfall. Thus, it would appear highly likely that 1988 will be a dry year, and that we will be entering the 1989 crop season with less than adequate soil moisture. Thus, even if the current temperatures and the very low rainfall ends, the "after affects" for Corn Belt agriculture will be felt well into 1989. This may help justify attempts to use weather modification during the cloudier periods of the fall, winter, and spring to help increase precipitation.

The final and important issue that atmospheric scientists can potentially help with are predictions or prognostications of the termination of drought. Climatologically-based statistical techniques have been used to try to estimate precipitation tendencies for months and seasons ahead. The best in techniques, show only slight skills, particularly in drought periods of estimating the termination of a drought. However these may be useful. Drought ending detection is made more difficult in the Midwest because a typical 12-month or 24-month drought usually contains a few months of normal to above normal rainfall.

However, our studies in the Midwest reveal that the months that typically mark the ending of a severe drought have much above normal precipitation, ranging from 30 to 70% above normal. These in turn are followed by 2 months of near normal precipitation. Thus, if we enter such a sequence, this may be a strong signal that the 1988 drought has ended.

In summary, it is difficult to find a past drought that is similar to this year's drought and no good analogy exists to predict the ending of this 1988 drought It is already clear that the 1988 drought will rank as the worst short-term drought of this century in the Midwest. Since long-range forecasts for heavy rainfall are not very encouraging, this drought has the potential for becoming even worse in the Midwest

Table 1. 1988 Rankinsg - Midwest

	January-June	April-June	May-June
Illinois	4th driest	driest	driest
Indiana	3rd driest	driest	driest
Iowa	driest	driest	driest
Kentucky	2nd driest	2nd driest	2nd driest
Michigan	4th driest	driest	driest
Minnesota	1th driest	3rd driest	driest
Missouri	6th driest	driest	5th driest
Ohio	driest	driest	driest
Wisconsin	driest	driest	driest

Table 2. Frequency Distribution of Precipitation Droughts Based on 1888-1987 Records

Precipitation (inches) for Given Frequency (of years).

Period	2	5	10	25	50	100	Actual (1988)
Jan-June	18.9	14.8	. 13.0	11.4	10.5	9.7	9.3
March-June	14.9	11.0	9.7	8.1	7.4	6.7	5.9
April-June	11.8	8.4	6.9	5.7	4.9	4.4	3.4

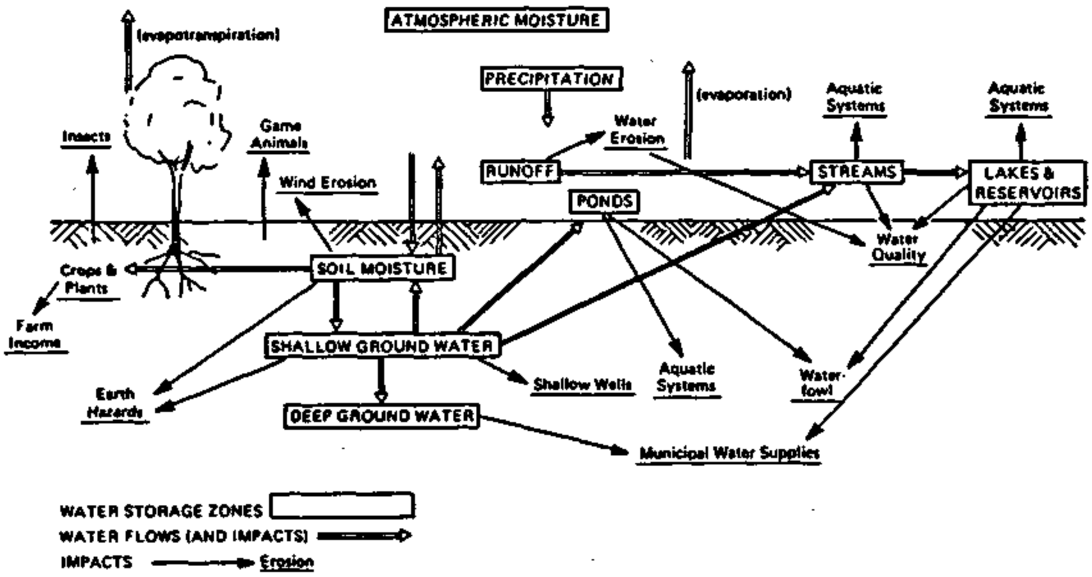
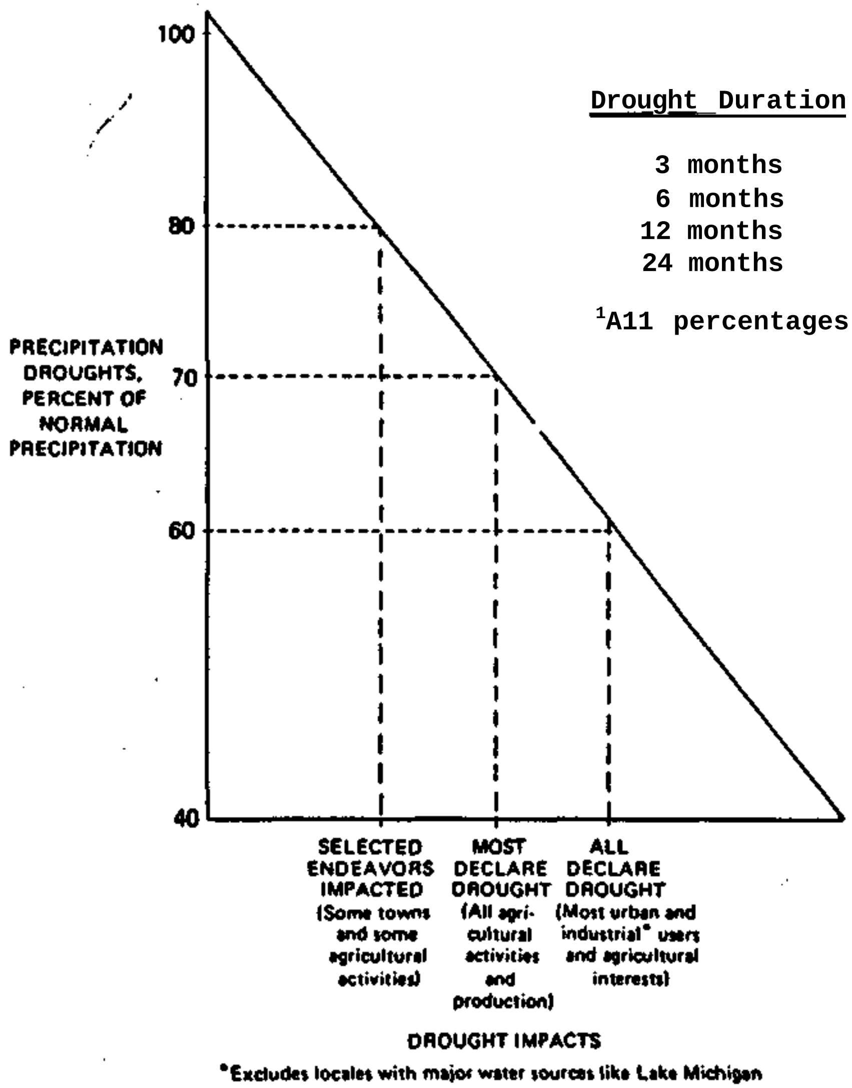


Figure 1. Hydrologic conditions affected by droughts, and related impacts.



Severity of Precipitation Droughts

Drought Duration	Moderate Drought[1]	Severe Drought[1]
3 months	45 to 60%	≦44% of mean
6 months	56 to 70%	≦55% of mean
12 months	70 to 80%	≦69% of mean
24 months	78 to 90%	≦77% of mean

[1]All percentages in relation to mean values

Figure 2. Relationships between 12-month precipitation droughts in Illinois (expressed as a percent of average precipitation) and drought impacts.

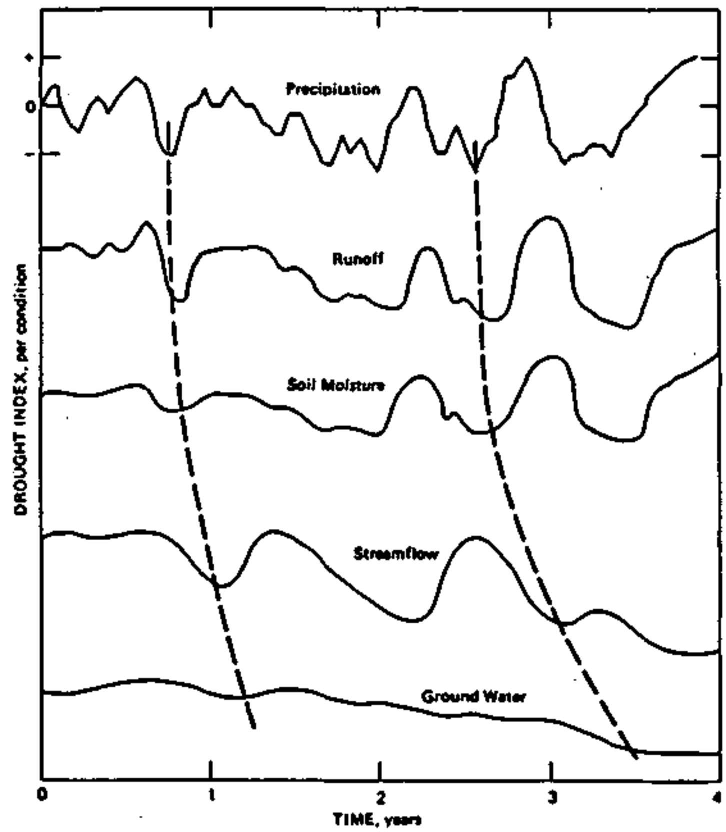


Figure 3. A schematic showing how precipitation deficiencies during a hypothetical 4-year period are translated in delayed fashion, over time, through other components of the hydrologic cycle.

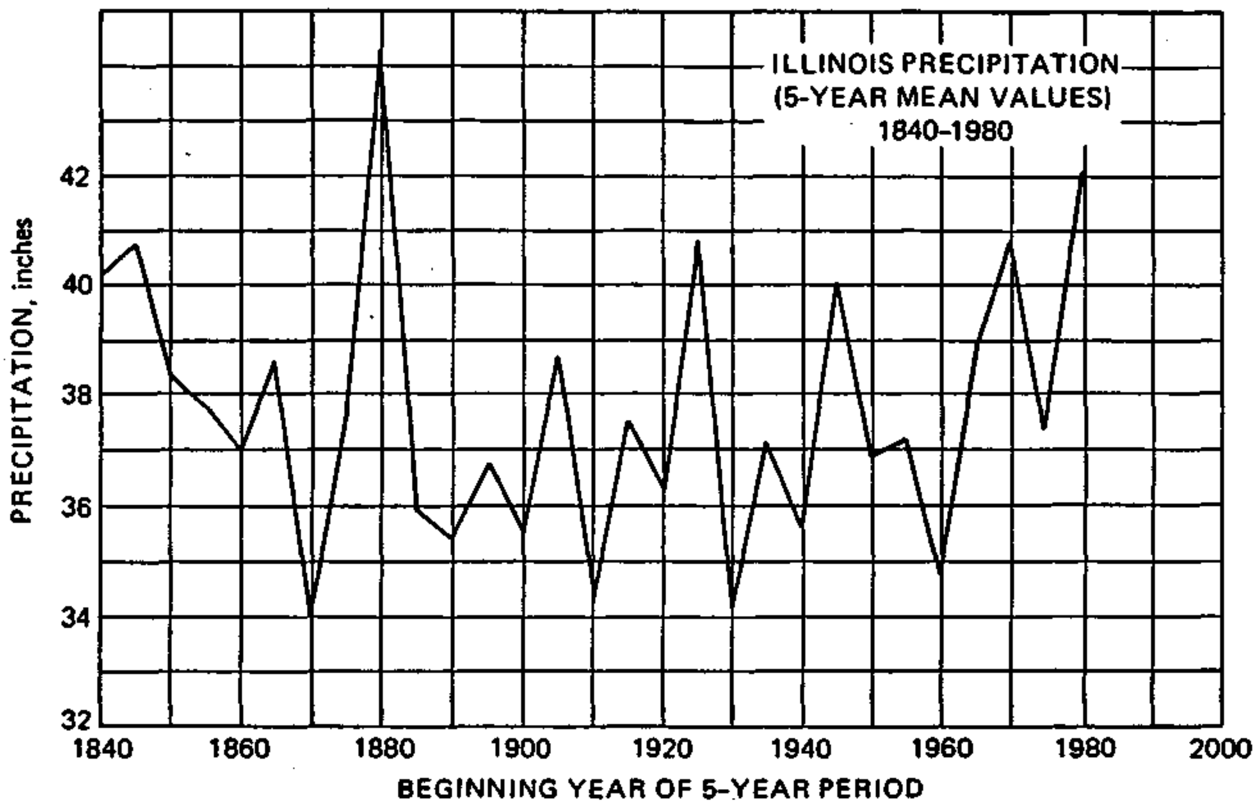


Figure 4. Illinois state-wide average precipitation (5-year mean values).

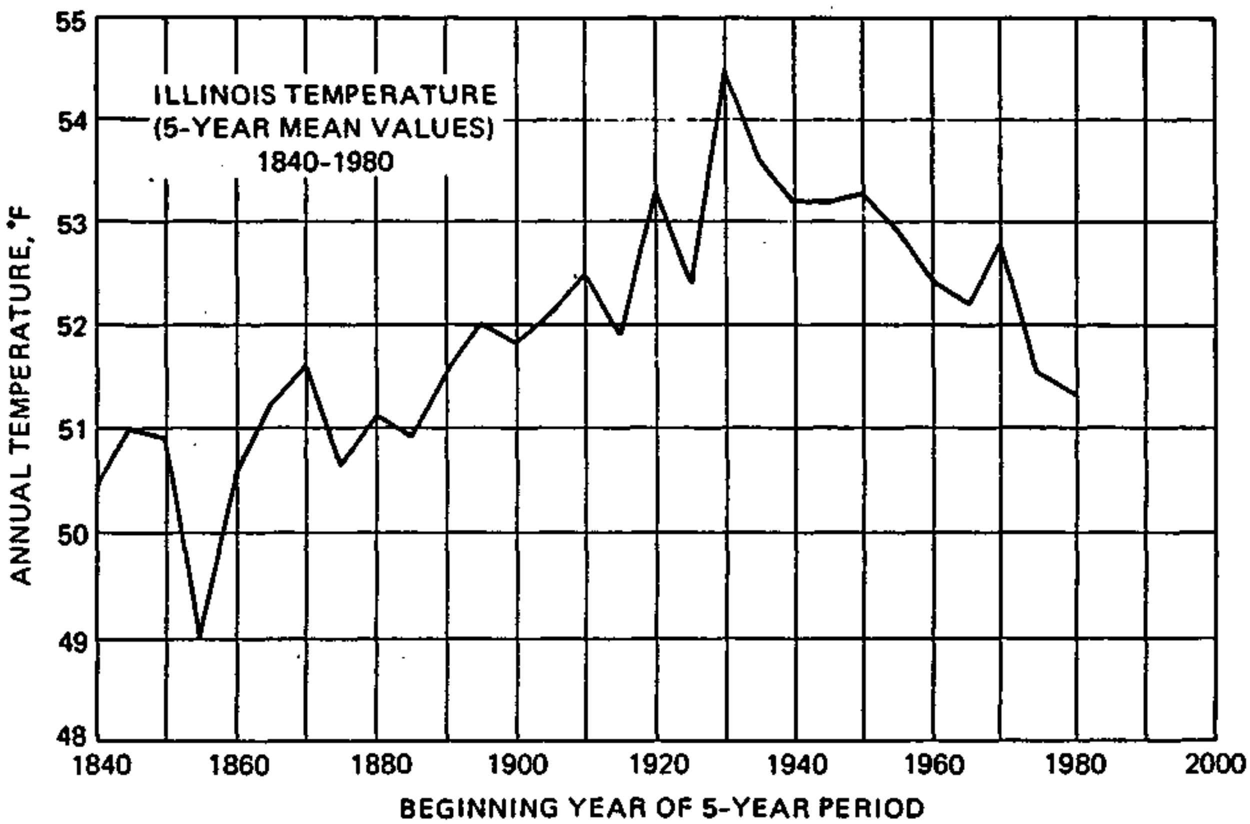


Figure 5. Illinois state-wide average temperature (5-year mean values).

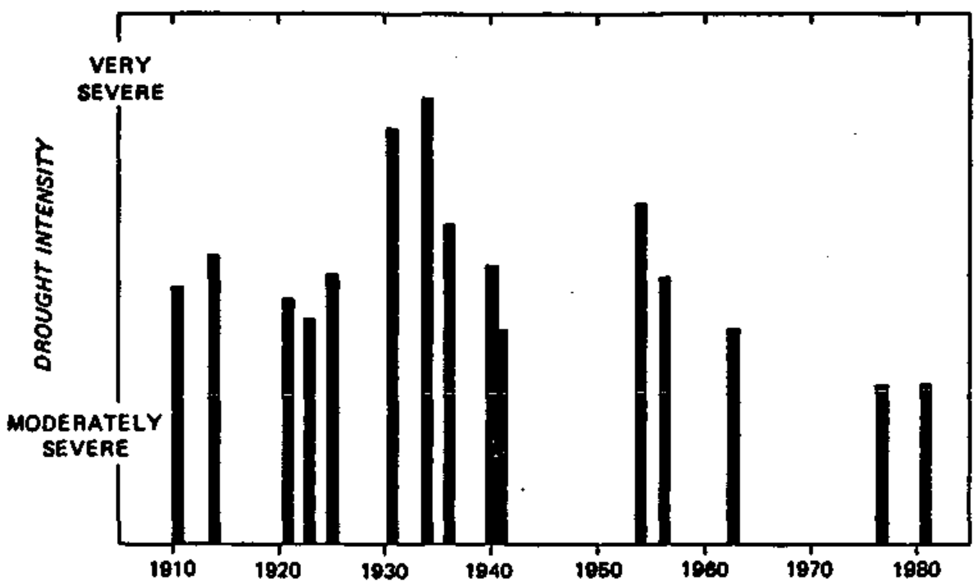


Figure 6. This bar graph shows the relative severity of 12-month droughts between 1905 and 1983. Droughts have been infrequent and only moderately severe since the early 1950's.

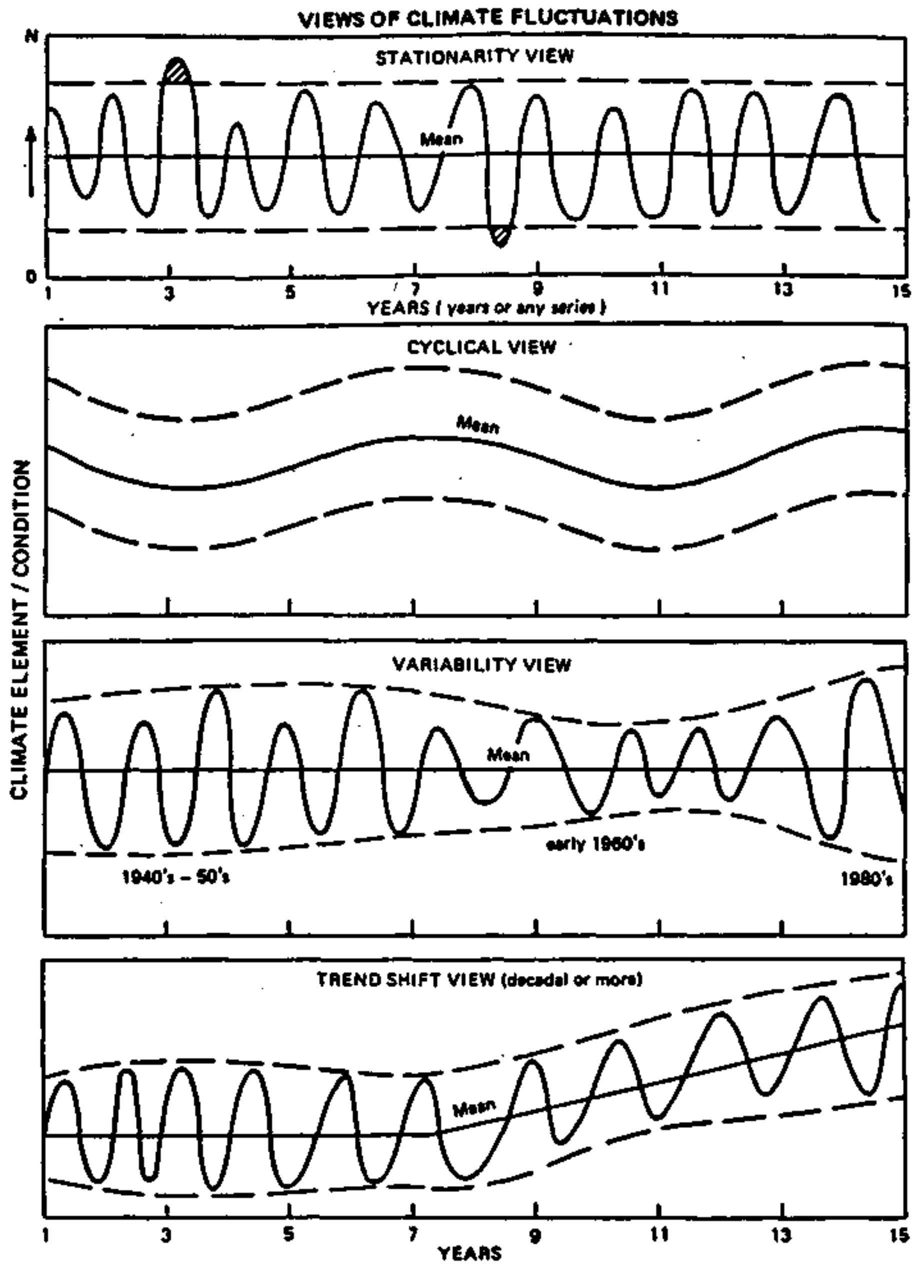


Figure 7. Various ways climate can change.

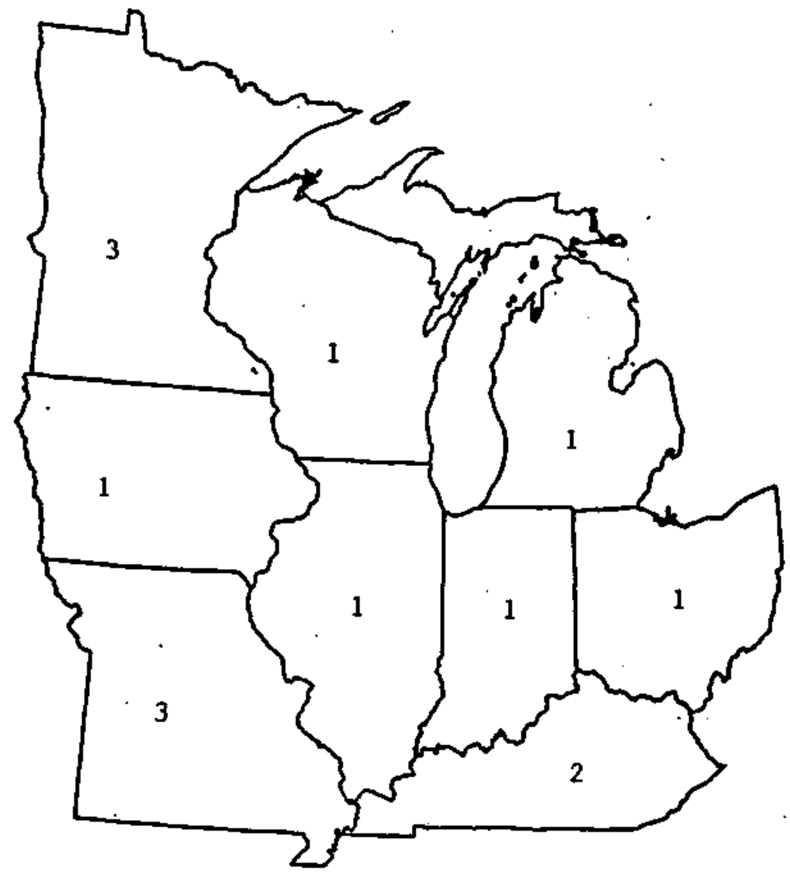


Figure 8. Ranking of April-June 1988 precipitation (1 = driest). This is based on 94 years of historical data for period 1895-1988.

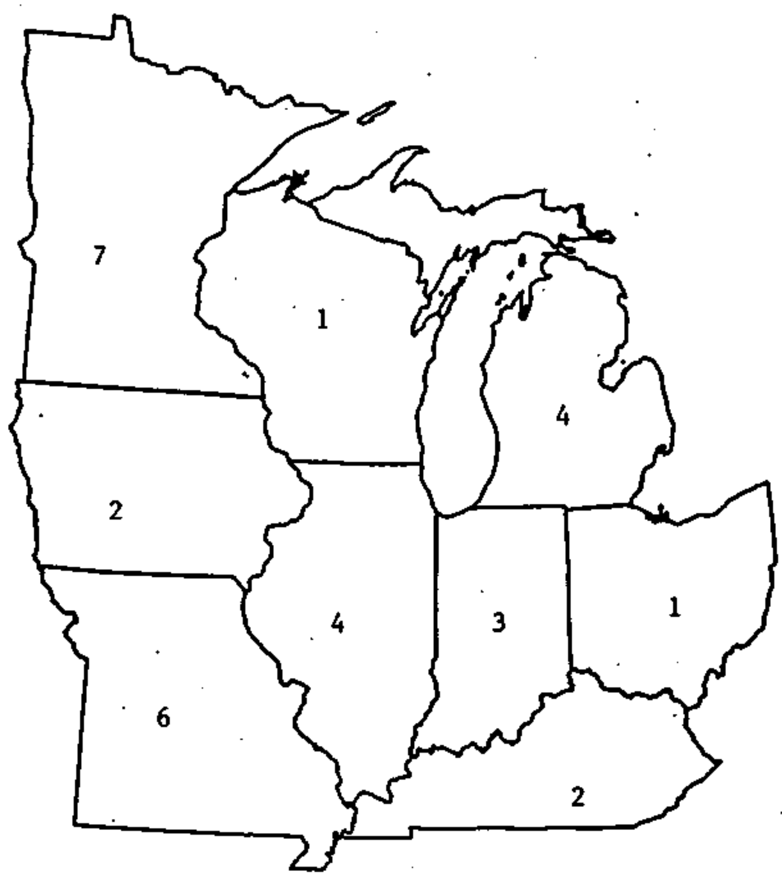


Figure 9. Ranking of January-June 1988 precipitation (1 = driest). This is based on 94 years of historical data for period 1895-1988.

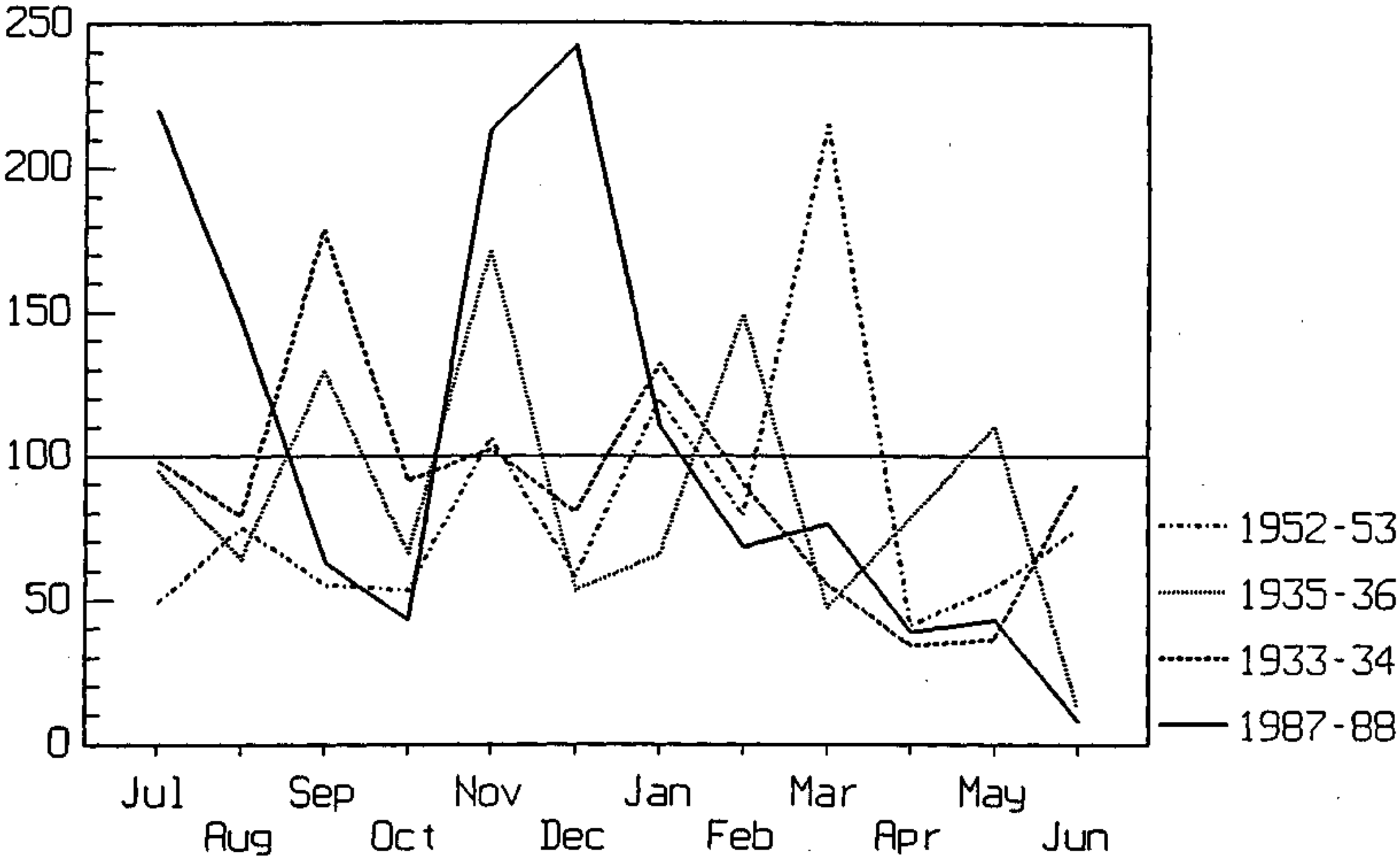


Figure 10. Monthly precipitation (expressed as % of normal) for the Midwest for several drought episodes.

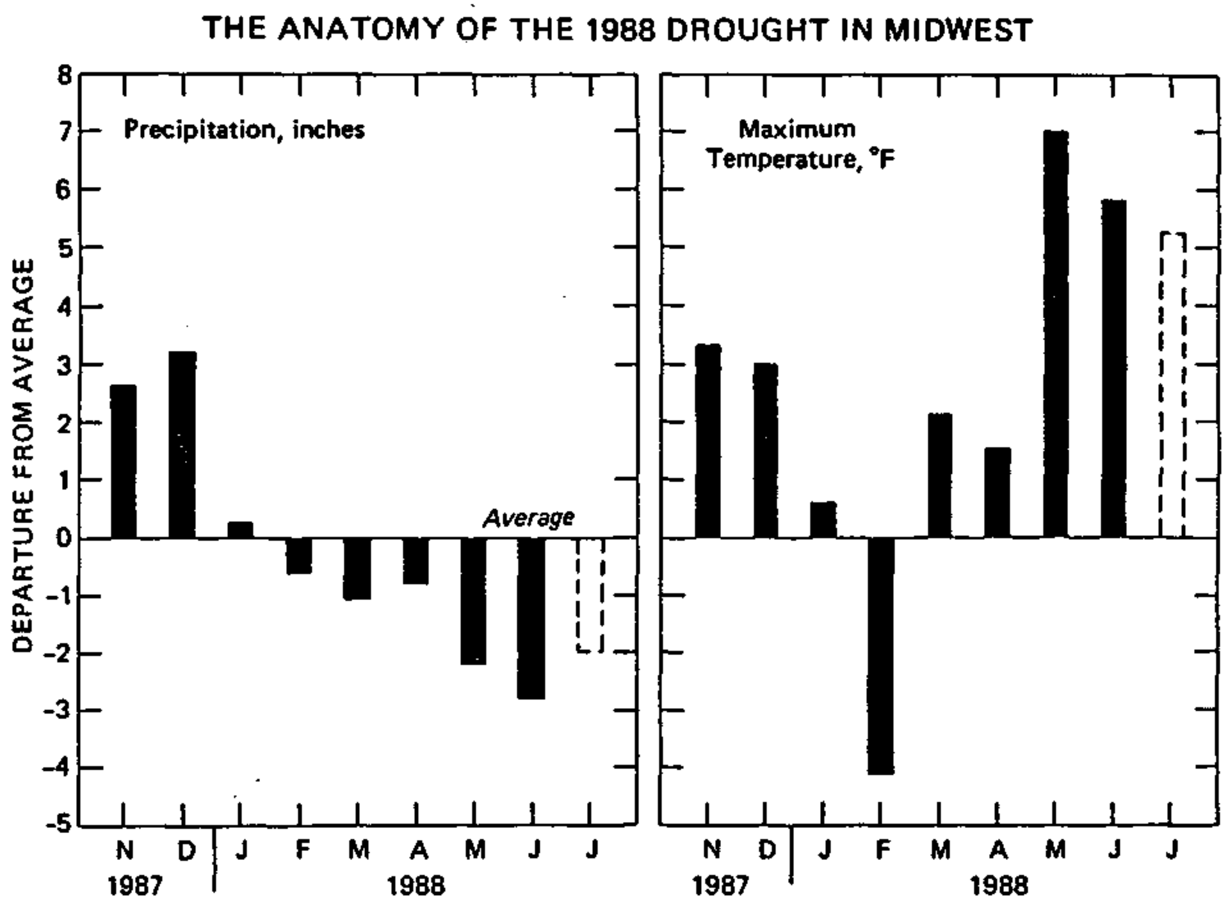


Figure 11. Monthly precipitation and temperature for the Midwest for the 1987-1988 drought.

Illinois State Water Survey
Department of Energy and Natural Resources

DROUGHT

by Steven D. Hilberg and
Stanley A. Changnon, Jr.

Figure 12. Montage of headlines from Midwestern newspapers.

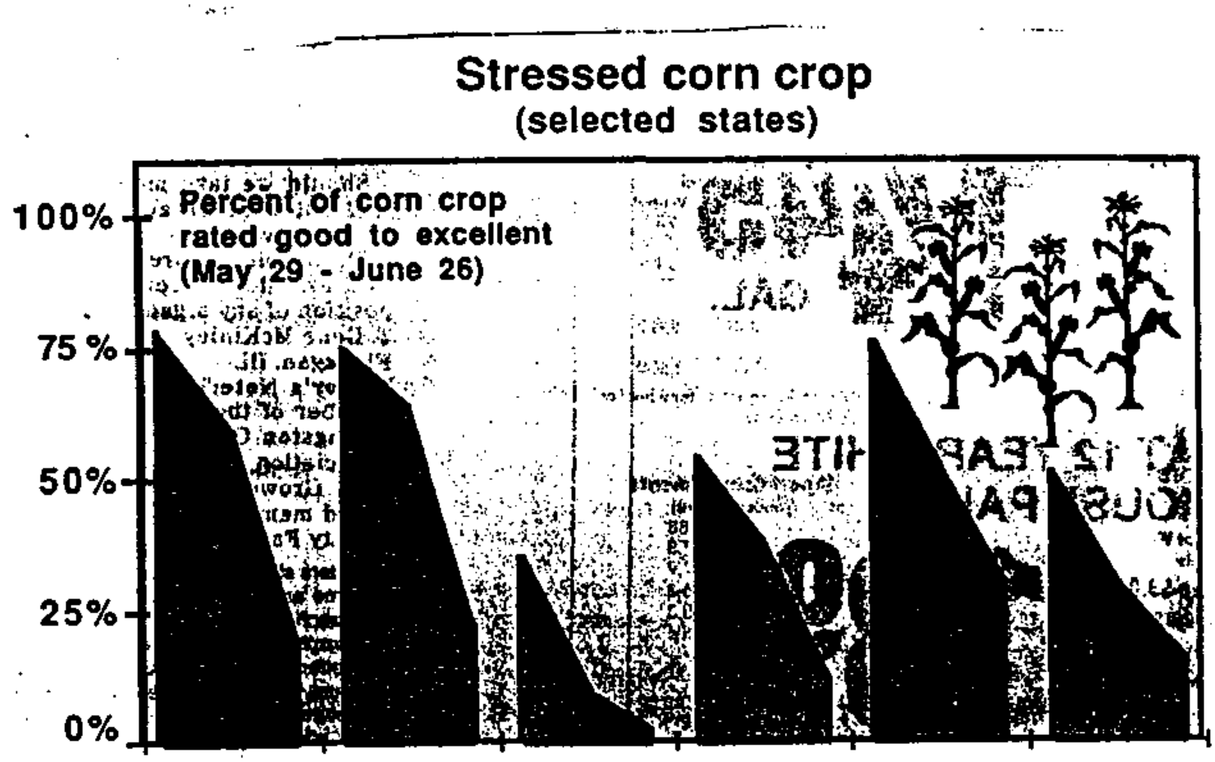


Figure 13. Change in percent of corn crop rated good to excellent during the period May 29-June 26, 1988.

Figure 14. Barge traffic on the Mississippi River.

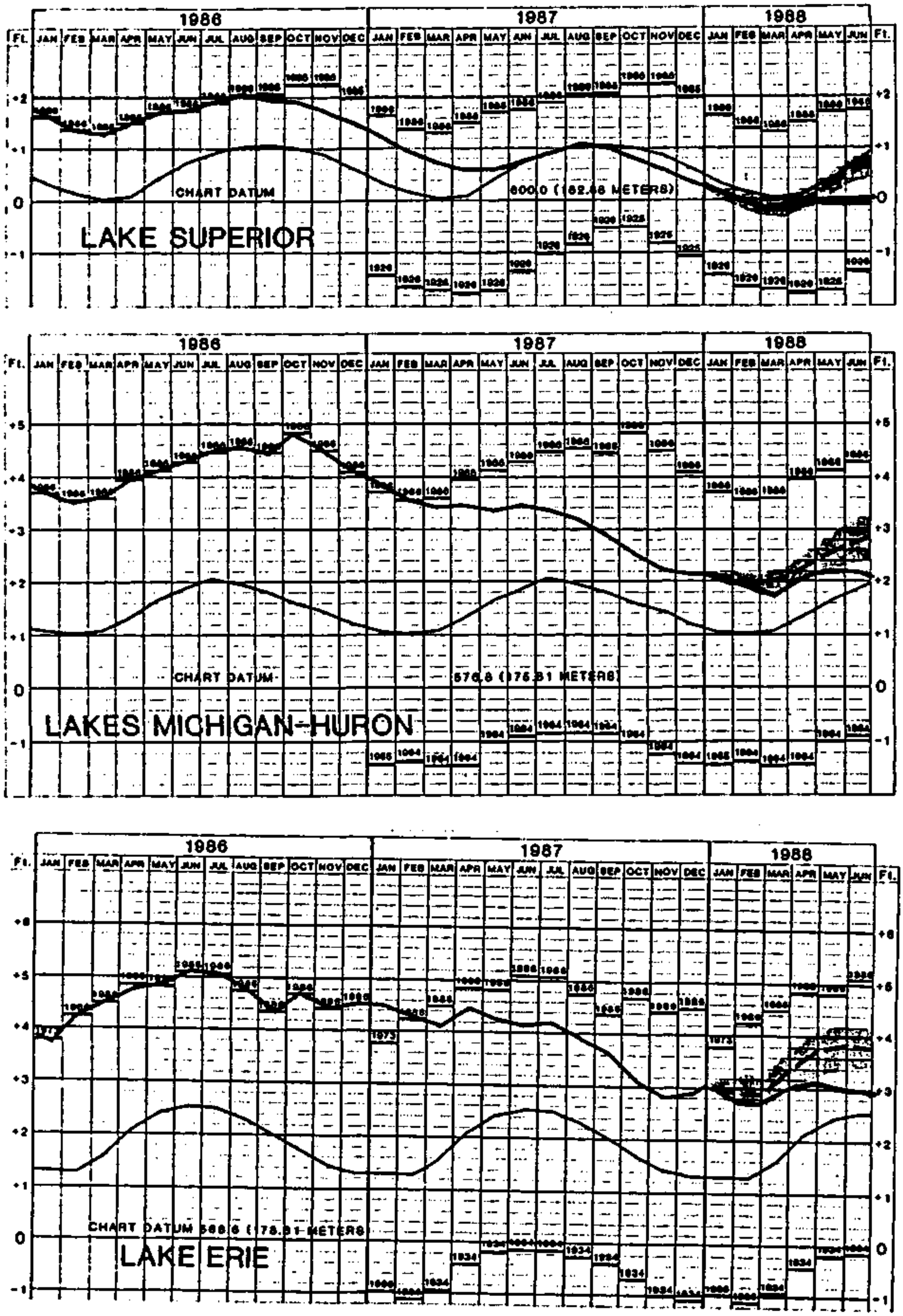


Figure 15. Lake levels during the period 1986-1988 on Lakes Superior, Michigan-Huron, and Erie compared to average.

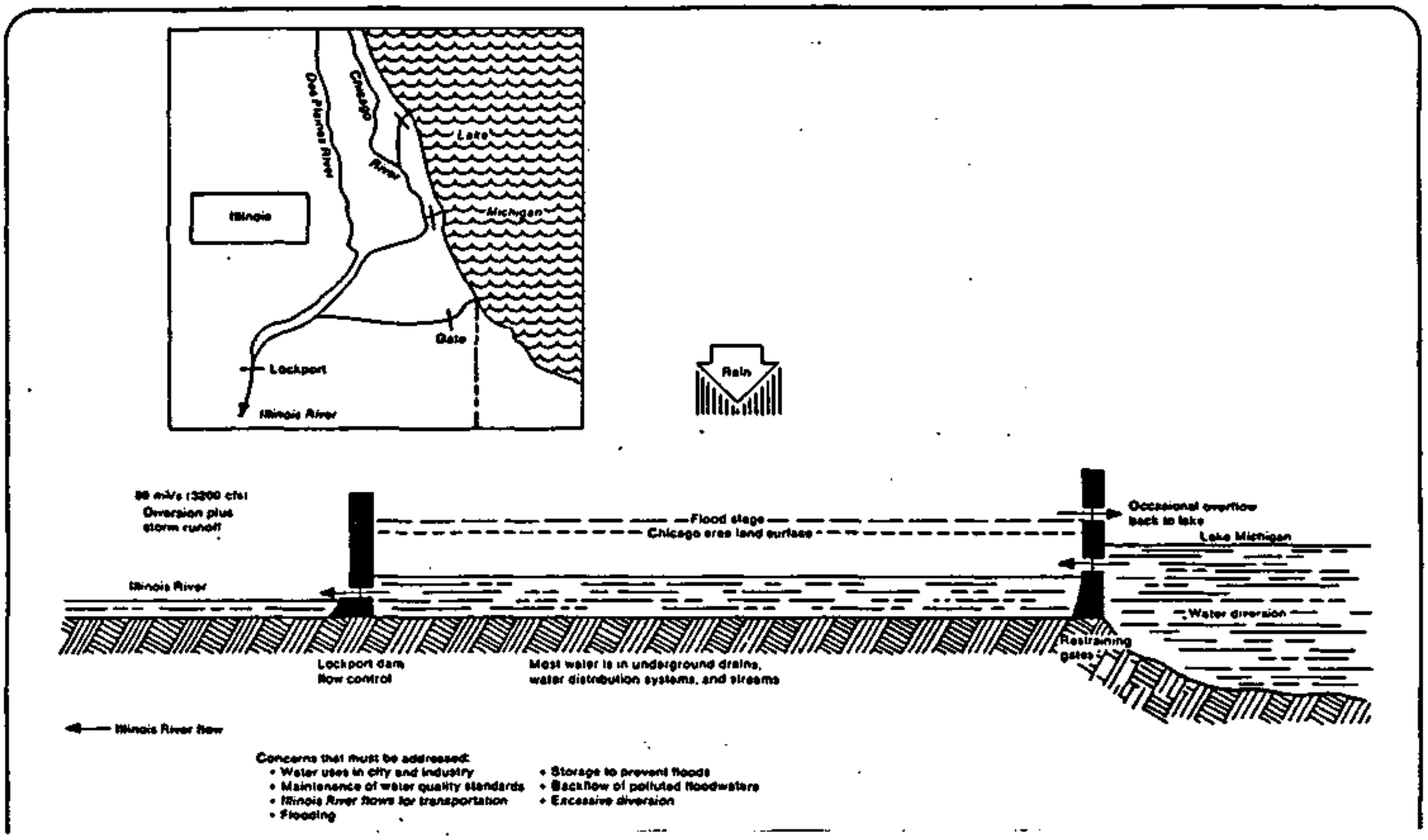


Figure 16. A schematic cross section of the water management system for the Chicago area.

DROUGHT, GLOBAL CLIMATE CHANGE, AND IMPLICATIONS FOR WATER RESOURCES AND AGRICULTURE[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

I appreciate the opportunity to discuss with you the effects of the current drought on the climate change issue, and in turn, the long-term implications for U.S. water resources and agriculture. I understand that the Congressional Climate Study Group, several members of Congress, and the EES Institute have been aggressively addressing the global climate change issue for more than a year. As a scientist who has focused on climate change and its effects for more than 35 years, and as a director of scientific research in water and weather, I applaud this effort

I remind us all that most of us have been living in a human-altered climate for many years. Our cities have climates vastly altered from their rural conditions including more rainfall and storms. In rural areas of the country we have more clouds due to jet contrails, our visibility has been reduced, and the quality of the rain has been changed. Thus, global climate change is not a totally new concept. Please note also that we have adjusted to the aforementioned climate changes.

2. The Drought

There are four important aspects of the current drought that relate to climate change. First, it is the first major prolonged, severe drought in the United States since the early 1950's. This means that most decision makers in the public and private sectors are dealing with a phenomena that they have not faced in their careers. I believe the drought will rank as one of the major natural disasters in the United States of this Century. It has been ubiquitous and hence unique.

Second, the extent of drought conditions have been almost national. The effects were truly pervasive, and even in areas where the drought was not severe, some gained advantages.

The physical characteristics of the drought are very important: in the Southeast this is the sixth year of a prolonged drought; in the West we are going into the third year with deficient precipitation; and in the Midwest and High Plains this is the second year with much

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[1]Presented at Meeting of Environment and Energy Study Institute, U.S. Capitol, 14 September 1988.

above normal temperatures and below average precipitation. Values reached record proportions in certain months such as May, June, and August 1988. The agricultural drought in the Corn Belt initiated this spring, a very uncommon time for drought development and intensification, also helping to make the drought appear unique.

The unusual nature of the drought, more than 30 years since a severe one, and its great areal extent, led to the third important factor related to the drought, the wide perception that it was due to the Greenhouse Effect. Atmospheric scientists largely disagree with this concept, but the news media and the public have concluded there was a connection. A public poll by CNN done in July showed that 78% of the respondents felt that the drought in the Midwest was due to the Greenhouse Effect Although there is no causal connection, the important point here is that the drought conditions of 1987-1988 are believed by the global climate modelers to represent potentially the average weather conditions that will occur in 40 to 50 years. Thus the impacts of this current drought give insight into what may become the common problems in the future.

What messages has the drought given us that can be translated to planning and policy development? Certainly a key one is that our society has become ever more sensitive to fluctuations and extremes in weather and climate. In the last 15 years we have seen four record cold severe winters, a run of extremely wet years in the central U.S. and West, leading to record high levels of the Great Salt Lake and the Great Lakes, and now a severe drought. We recognize that the drought has affected every sector of our economy including agriculture, transportation, tourism, commerce and business, energy production and use, water resources, and personal finances. Effects on government agencies have been sizable and costly. Possibly the most severely impacted single area has been our environment where damages will persist for decades even if the drought ends soon.

In a general sense we understand that we have become much more sensitive to climate fluctuations and that we have moved into the period of greater fluctuations and greater extremes. However, an important point is that our understanding of how climate impacts us and particularly in complex ways is more poorly developed than one might believe. This lack of understanding can be devastating for policy setting.

For example, the warm-dry conditions of 1987 and early 1988 led to near record low flows in the Ohio and Mississippi Rivers by June 1988, and this led to major reductions in barge shipping in these rivers. The loss to the barge industry is reported at $200 million and no one has any idea of the additional costs to farmers, elevators and other shippers who have turned to the railroads in the Great Lakes areas, but they, in turn, have profited from the problem. The potential for tripling the diversion of Lake Michigan water at Chicago to aid the river problems was met by concern in the Great Lakes Basin in Canada. The proposal was interestingly untimely because it came at a period of precipitous declines in the levels of all the Great Lakes.

Let me further illustrate how our lack of understanding of climate relationships and other physical processes cripples us in the planning and policy sense.

a. In 1986 and early 1987 the Great Lakes were at record high levels and causing great problems. Hydrologic models estimated that it would require between four to seven years for the lakes to return to average levels. However, 18 months later, the lakes have fallen two to three feet, and most are below their averages and falling rapidly.

b. Research concerning how weather affects corn yields has been on-going for 50 years, ever since Henry Wallace initiated studies in the 1930's. Yet we have been plagued all summer by the inability of anyone to come up with reasonable estimates of the effects of the weather on the corn yield, whether it's in Champaign County, Illinois, the State of Iowa, or the Corn Belt Clearly the current relationships are ill-defined.

c. Another area of major impact relates to human health. Various sources estimate the Heat Wave of 1988 caused between a few hundred deaths and 10,000 deaths, but there is no great certainty as to the number of heat deaths.

These episodes reveal that to make good decisions one has to have a good understanding of climate, relatively updated information, and knowledge of climate impacts. Secondly, most persons in critical positions in government lack the experience and information to react effectively to climate-induced problems.

Consideration of the drought and climate change issue relates to an important message -- the drought still persists. Although we are going into a drier part of the year with less evaporation, we have serious deficiencies in the agricultural heartland in soil moisture and shallow groundwaters, with near record low streamflows in parts of the Midwest and West. We are moving into the classically-defined water resources drought. Climatology gives us several important signals. In the drought areas we will end 1988 as a dry year. Climate statistics, coupled with the water shortages, reveal that there is less than 4% chance that we could have enough precipitation in the next six months to escape the drought in any of our drought areas of the Southeast, Midwest, northern High Plains or Far West Most farmers will be doing spring planting in soils that have deficient soil moisture, one of the first times in the last 20 years at least in the Midwest. Our attempts to look farther ahead have led to scanning the records of the last 100 years in the Midwest for comparable analogies: we found three pairs of years like those of 1987-88. They were 1910-11, 1932-33, and 1952-53. Each of these analogies were followed by three years with persistently above normal temperatures, below normal precipitation, and very dry summers. If we are indeed in the same general climatic regime of the past 70 years, then continued drought appears likely.

3. Implications to Water Resources and Agriculture

What do the drought and global climate change imply for U.S. agriculture and water resources? Most hydrologic structures in the United States have been designed with a view of stationarity in climate. Thus, our water systems will find it difficult to deal with significant climate fluctuations, either of trends and/or changes in extremes. We also know that the global climate change will be altering the interannual variability, average values, and extremes of climate.

The implications for water resources are very severe. The amount of water that will be available will be reduced and potentially well below many current design levels. We envision problems with public and industrial water supplies, transportation on the major rivers and the Great Lakes, irrigation supplies, hydropower generation, and recreation, all coupled with simultaneous increases in water usage. Coupled with decreased available fresh waters in most of the U.S. will be increased sea level, producing fresh and salt water interfacing problems on our sea coasts. Finally, the quality of our waters expected to carry an ever larger waste load will be reduced.

The gravity of these impacts lead to some very predictable outcomes that relate to programs and policies. For example, ground water use will be increased and mining will become more serious in heavily irrigated and urban areas dependent on ground water. We will face serious challenges at the local and state levels over water rights. We will have severe internal political problems relating to water with a warmer and drier climate. Conflicts with Mexico and Canada over shared waters will be frequent In becoming more sensitive to climate and water, our society will also have to deal with many water management policies and practices which will become outmoded.

The implications of climate change for agriculture will be equally serious. We have learned in the drought that we had major yield losses with all varieties and the quality of the crop has been hurt We will be experiencing carryover problems relating to fertilizers and herbicides that have interannual problems not previously considered in the humid climatic zones of the eastern U.S. The drought greatly affected the agricultural research experiments in the Midwest and seriously affected the seed production industry revealing the fragileness of our current system. Some believe we will adapt to future change through breeding and, if necessary, relocation to climate change, but this at a minimum is enormously costly.

Forested agriculture is in serious trouble. Trees have lifetimes of 50 to 70 years, and varieties being planted now will have to grow in a stressful climate. Irrigated agriculture and especially crop agriculture, both dependent on water and/or special climatic zones, such as those in the lee of the Great Lakes, will undergo major changes due to water shortages and altered climates.

Agriculture has another unique problem with climate change. On one hand we must attempt to adjust to a warmer-drier climate in the agricultural heartland of the United States, but we must also worry about the effects of the climate changes in the other major food producing regions of the world. Global interdependency on food supplies is an enormously serious problem. One has to predict that a current complex set of federal policies related to agricultural support, loss payments, and exports will obviously will be totally outmoded.

4. Summary

The on-going drought has revealed the enormous complexity of the impacts and extreme sensitivity of our society and environment to a warmer-drier climate. The impacts in the water and agricultural areas, as well as to other aspects of the environment, have been severe and will be long lasting. The drought and its impacts should serve as an alarm for the agricultural and water resource interests to the almost unimaginable problems that climate change will bring.

From my perspective I see certain action items. I would recommend that the federal government assemble a group that can develop strategies to manage the continuation of the current drought We need to move away from crises management.

Secondly, I am concerned about the nation's capability to adequately monitor the change. We have serious problems in the instrumentation and data collection needed to monitor the slow change.

Third, although we know the impacts of change will be sizable, we lack the sophisticated understandings of the relationship between climate and our physical and socio-economic systems. Thus we need interdisciplinary research.

Fourth, I think we need to rejuvenate research attention to ways to modify the hydrologic cycle to conserve water, to reduce evaporation, and to increase precipitation.

Fifth, we need to educate the public and decision makers on the issue. This needs to be accomplished by regional efforts where climate changes will be addressed. For example, the Midwestern Regional Climate Center is joining with the Canadian and U.S. Climate Centers to host a conference of representatives of all sectors impacted by climate change in the Great Lakes to begin an awareness and action program.

Regional and basin-scale planning to adjust and deal with the evolving climate change will be quite effective, particularly in dealing with water resource problems since most water structures have lifetimes ending during the next 50 years and can be redesigned to meet new circumstances if adequate planning is pursued. To this end, the current development under Congressional leadership of the Regional Climate Centers in the United States is a positive movement in that direction. These centers provide the special data bases needed, can conduct the public education and awareness programs needed for the change issue, and have the expertise and the data to do the applied research needed in the climate impacts arena.

The current drought has helped created wide national awareness in the climate change problem. Second, it is now leading to the development of a constituency for action relating to climate change at the national and global scales. Third, the national-scale drought has demonstrated the enormity of the problems that a warmer-drier climate will have on our water resources and agriculture.

CLIMATE CHANGE AND HYDROLOGIC AND ATMOSPHERIC ISSUES: LESSONS OF THE PAST[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

What are some of the key issues relating to the atmosphere and hydrosphere that future climate change in the Great Lakes Basin will produce? I refer here to effects, possible responses, and then adjustment to likely future climate changes equalling or exceeding anything experienced in the basin during the past 200 years.

One fundamental way to prepare for such issues is to consider past experiences. What has happened during major past climate fluctuations that gives insight as to what might happen again? or, What in the past provides guidance as to what should happen? There are at least four major lessons to be learned from past impacts and responses to air and water issues in the Great Lakes Basin. Awareness of these will help us plan for such issues in the future.

2. Lessons from the Past

A. Lesson One.

We lack understanding of climate's interactions with society. Recent assessments about how the climate interacts with the environment and affects the economic fabric of our society have pointed to an enormously important lesson~we lack adequate understanding of climate impacts, particularly of the complex interactions between the physical effects and the resulting socio-economic impacts and policy responses (Institute for Environmental Sciences, 1985). If this is true, and I believe the record supports this position, we are not able to understand, with sufficient certainty, how a major change in the climate of the region would impact the physical environment, and in turn, how this would relate to the socio-economic conditions that will exist 50 years from now (Changnon, 1987a).

Some initial studies have estimated possible effects of future severe climate changes on Great Lakes Basin water supplies and water use (Cohen, 1986a, 1987); on lake fisheries (Goodier *et al*, 1985); on lake levels; and the resulting economic outcomes to shipping on the lakes (Marchand *et al*, 1988). These are useful initial studies but they are limited to single sector investigations.

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[1]Paper presented at the First U.S.-Canada Symposium on Impacts of Climate Change on the Great Lakes Basin, September 27-29, 1988, at Oak Brook, IL

A major facet of this issue, and one we know embarrassingly little about, is the absolute "interdependence" between the environment, the social fabric of the basin, and the weather conditions over time, or climate. Furthermore, there are many signals that, due to population growth, the socio-economic structure in the Great Lakes region has become ever more sensitive to climate fluctuations (Cohen, 1986b). The enormous impacts from the lake level fluctuations during the past 25 years prove to us that even relatively small climate oscillations around the "average condition" create major losses and gains, and furthermore that serious impacts can develop rapidly (Bruce, 1984).

In the past, we have operated with only limited information about how the climate affects us. As a result, we have often made incorrect economic, environmental, and policy decisions. For example, this lack of knowledge about relationships such as how the multi-year dry periods of the early 1960's affected water quality, or how the recent wet periods affected the atmospheric transport and deposition of pollutants, has plagued decision making.

Let me illustrate this lesson further by reviewing certain events during the recent shift from the basin's wettest 5 years on record, those during 1982-1986, to a region-wide drought with precipitous falls in the lake levels during the 20 months since January 1987 (the second most rapid declines in the levels of Superior and Michigan-Huron on record). Responses involving adjustments in the diversion of lake waters during the record high lake levels served as examples of what to do, whereas those proposed during the rapidly falling levels have served as dramatic illustrations of what not to do. The point is: one cannot widely plan nor make meaningful responses without understanding the current and likely future climatic conditions. This also illustrates that better long-range predictions of the climate conditions for months, seasons, and years ahead are desperately needed, as well as better near real-time climatic information.

Now, let us consider how inadequate climate information, or its misuse, could cause a major problem in the future. We continue to make in-depth assessments to find ways to sustain lake levels near the "average" (IJC Reference Study, 1986). This seemingly worthwhile goal remains illusive unless major structural changes are made in the system. Even if both nations agreed to manage the lakes differently (i.e., alter the diversions) and to make some extremely costly investments in major engineering solutions (lower connecting channels, changes in locks, etc.) to help remove some of the lake level fluctuations, some of these changes could become useless in a vastly changed climate. We will likely find in 30 to 40 years that we are dealing with a climate that is so different from today's as to make most such solutions for today's climate regime of doubtful utility in the future! Major investments now to deal with current climate extremes could be inappropriate until we better understand the complexity of climate impacts and what the future very altered climate will be like. For example, the climate models all predict serious reductions in average lake levels, and it appears unlikely that associated "wet period" extremes 50 years from now will bring high lake levels comparable to those of the past 100 years. Hence, why design or expend funds now to avert losses for such high level conditions?

This lack of information about the characteristics of this sizable future climate change and how these would affect the Great Lakes Basin is the key reason for this, the first of a series of U. S.-Canada symposia. Our nations need to begin to obtain a first approximation of the troubles and advantages that future climate conditions will produce, and in turn begin to consider what could be done about them. The outcome of this conference should be information that can help serve as a platform for designing the research on climate effects and the planning for adjustments, including policy, in the basin. There is still time to do it, but we need to begin now.

B. Lesson Two.

Climate has changed due to natural and man-made forces: we are attempting to hit a moving target A second important lesson is to realize that the climate does change, has always changed, and is changing now due to natural causes. Further, human influences on the atmosphere have already produced sizable climate changes in the past 100 years.

A major recent fluctuation in the basin's climate is an interesting example of change and its influence on basin water management. The extremely wet period of the early 1980's was "basinwide," and now the 1987-1988 drought is also "basinwide." The basinwide nature of both events is very interesting because climatologists who have studied the region's climate over the past 100 years will tell you that this represents a very different climatic regime from what commonly had prevailed before. The precipitation regime over the lakes has typically been divided geographically; that is, what happened with the precipitation over a given period in the southeastern basin was different from the conditions in the northwestern basin (Brinkmann, 1983). This allowed for water management planning involving certain strategies, but these strategies have not been realistic in the current, very different basinwide weather conditions. If what has been happening in the past few years, that is, more uniformity of precipitation extremes across the basin, is a precursor of the future climate, then it illustrates how managers can suddenly have a new "ball game" to address. Gaining understanding of climate fluctuations and future changes in climate at the management and policy levels becomes critical to more effective planning.

A second aspect of past climate and fluctuations relates to inadvertent effects due to man's activities. Detecting climate change is made difficult by "urban effects" on climate that systematically affect temperature records over time. Conversely, 75 percent of all North Americans have lived since 1920 in urban areas, locales where all climate conditions have been sizably modified by urban influences on the atmosphere (Changnon, 1976). Studies of the basin's large metropolitan areas including Chicago, Detroit, and Toronto reveal they are not only much warmer than surrounding rural locales, but they have very different winds and lower humidities. Further, they and their surrounding areas experience more clouds, more precipitation, and increased storms due to urban influences. In addition, in our heavy jet aircraft travel corridors there has been 10 to 30 percent increases in cloud cover since about 1960, and the "quality" of the climate has been altered for many years as witnessed by 30 to 50 percent decreases in visibility and altered precipitation chemistry throughout the basin. The point is that the basin's population has lived in a man-altered climate for the past 70 years, and thus has functioned and adjusted essentially unknowingly to sizable man-imposed climate changes. Thus, the postulated future global change is not a totally new condition to adjust to. This condition and the consideration of past climatic fluctuations in the basin provide three conclusions and recommendations.

1) Study of the historical adjustments to man-induced climate changes in urban and rural areas since about 1920 should provide useful lessons about what can and should be done to adjust in the future.

2) Estimations of future climate effects will be attempting to assess an uncertain climate outcome (i.e., How fast will it change? How much will it change? What will change?

etc.), and an equally uncertain societal structure. The environment and the socio-economic systems will greatly change over the next 30 to 60 years without any change in climate, and this difficult-to- estimate change must be factored into meaningful "estimates of how future climate changes will impact the basin." Indeed, we are attempting to "hit a moving target"!

3) Analysis of how weather-impacted sectors react to climate change (Changnon, 1987a) reveals that atmospheric scientists must do a better job of describing climate 'change' and 'fluctuations' to nonscientists. Confusion exists over the issue because explanations have varied and have often been too simplistic. We need more concise, yet definitive descriptions of the postulated future climate changes and scenarios, coupled with accurate definitions of the uncertainty levels so that information users can better assess the risks.

C. Lesson Three.

The issues are transboundary and will need new approaches for their resolution. Another critically important lesson found in the history of the atmospheric and hydrospheric issues of the Great Lakes Basin is the fact that these issues automatically become international issues, not just national issues. Although this may seem obvious, how the U. S. and Canada have collectively handled transboundary air and water problems in the past is a key to understanding better what to do in the future.

Great Lakes policies have traditionally developed in an ad hoc manner as specific problems appeared. These often arose as a result of unknowns in the physical sciences, and up to a point, the ad hoc approach worked well. However, the recent transboundary air and water pollution problems have caused the ad hoc approach to become inadequate. The acid rain issue is one example of where physical measurements of atmospheric effects and environmental effects were considered by some as too scanty and thus economic impacts were not on a solid foundation (Carroll, 1982). Nevertheless, real or perceived damages have led to specific policies on acid rain in Canada and in certain eastern states. The U.S. policy of "more research before we act" is seen by many as valid, yet also viewed as a delaying tactic. The lack of scientific certainty over the impacts of acid rain was a central factor in the U. S. policy.

Regardless, the two nations have yet to demonstrate a capability to carry policy actions through, especially when: a) a long period of time is involved, b) changing governments are involved, and c) major scientific uncertainties exist (Changnon, 1987b). We must seek informed regional and planning-oriented policy making. It is not difficult to speculate that problems emanating from future climate change will require new thinking, new policy approaches, and new policy-making institutions. However, we will continue to be plagued with problems of understanding how changed climatic conditions will impact our physical and socio-economic systems! Responses to problems with inadequate information generally always compound the problem. Thus, we return to the absolute need for research to better understand how climate affects the environment and society.

D. Lesson Four.

The need for credibility and specificity in predictions of future climate conditions. The fourth major lesson to be learned from the recent past, and one that greatly affects what our nations, provinces, states, municipalities, and private sector entities could and should do to adjust to the future change in climate, is the degree of **credibility and specificity** about the future climate changes (Changnon, 1987a). We need more research to better describe the future climate change.

The greenhouse effect has raised international concern because 1) clear evidence of increasing CO_2 and other trace gases exists, and 2) all global climate models (GCM's) have estimated that, as a result, the future global temperature will change rapidly and be warmer. They all predict warming but of varying magnitudes. Concern exists, as it should, but the immediate and related question is, "What will it mean in my city, state, or region of interest?" Will the effects of a given future climate scenario be small or large, and can we adjust to them? One Canadian group (Marchand *et al,* 1988) investigated how future climate changes would impact shipping on the Great Lakes, and they obtained a wide range of economic outcomes depending on the climate scenario used. The GCM's are limited by their assumptions about clouds and the radiative changes due to the gases, and also by the large space scales that are necessarily inherent in their calculations.

The net of these limitations is that what the climate models predict for the Great Lakes Basin in 20, 30, or 50 years in the future varies considerably. The future climate conditions for the Great Lakes Basin calculated from three of these models were used by GLERL scientists as input to lake basin hydrologic models. They estimated future lake levels, and for Lake Michigan, all models predicted levels well below the 1951-1980 average level, but the future levels differed greatly. One model's values led to a level down 2 feet, another was for a level down 4 feet, and the third down nearly 9 feet.

We then studied what happened along the Illinois portion of the lake during the record low levels of the early 1960's and used these results to speculate about the impacts and adjustments apt to occur with levels from these three different climate scenarios (Changnon *et al.,* 1988). Four important facts emerged in that many adjustments to address the future change could be made in a rational, cost effective manner:

1) If atmospheric scientists were highly certain about what the future climate conditions would produce as average values. (That is, "Will future mean lake levels be down 2 feet or 9 feet?")

2) If there was more certainty about the types and magnitude of the climate effects. (Again, we lack definitive studies of climate-water-social effects)

3) If the GCM's could reliably predict how the change will occur. (That is, will they consist of a few sudden jolts in climate like the drought of 1988, or will they occur very gradually)

4) If the global climate models could also predict — with greater confidence ~ the magnitudes of the spatial and temporal variability in the various conditions of the future climate.

To have a permanently lowered lake level is one thing, but from an impact and management view, it is equally important to know how we will get there and **whether** the future climate regime will produce lake level fluctuations that will be plus or minus 1 foot, 2 feet, or 5 feet around the new average level. The models' certainty levels and the specificity needed to bring basinwide planning and action on adjustments are insufficient at this time. Most lake experts we interviewed believe that given greater certainty and specificity about the future climate state, many costly adjustments required can be made over the next 50 years as part of normal replacement costs of structures like docks and lockages, water intakes, and storm outfalls.

The message from this case study of effects at Chicago is not to use a "wait-and-see" policy, but rather to call for wide awareness of the coming problem, and attention to four needs:

1) Further development of climate models to gain greater certainty and specificity

2) Development of alternative climate scenarios based on the sensitivities in the environmental and socio-economic systems

3) Intensive research on climate impacts and adjustments

4) Planning and development for new approaches for developing policy relating to the basin.

3. Summary and Recommendations

Future climate change is a certainty for the Great Lakes Basin. Consideration of the atmospheric and water issues points to two fundamental questions. Will the problems be big or small, and how can we best deal with them?

A review of the impacts and responses to past climatic fluctuations identified four lessons. These, in turn, lead to several recommendations. It appears that we must simultaneously and vigorously pursue three tracks.

First, we need to better define the climate impacts and importantly discern the *sensitivity levels* in the myriad of impacted areas to varying levels of climate change (Institute for Environmental Studies, 1985). For instance, we need to know with certainty, and for each impact sector, that a 1-degree change in the summer temperature might have little effect but that a 2-degree change would be devastating. Much greater attention to applied climate research is needed. Further, the complexity of the impacts from climate change means we need interdisciplinary research. It must involve the physical scientists, the social scientists, and the policy experts (Rind *et al.*, 1988).

I recommend we consider establishing a U.S.-Canadian joint research center (or centers) for this purpose. Past failures to accomplish long-term quality interdisciplinary research within our educational institutions supports my belief that an institution charged with such a mission is the correct solution. Such an international commitment and effort in the basin should also bring greater unanimity about the status of scientific knowledge on controversial issues, and hence will help eliminate unilateral decision making.

Second, we must have more definitive information about the dimensions of the future climate regime. As more definitive results emerge from the recommended atmospheric research, the findings must be integrated and effectively translated to those who will be impacted and those making decisions. Then, plans can be developed for responding to predicted changes that make environmental and economic sense.

Third, if the past is any kind of predictor of the future, it appears that our current response mechanisms to transboundary problems are inadequate to address effectively what will happen with sizable climate changes. New institutions and better policy-setting approaches will be needed (Changnon, 1987c), and I recommend immediate attention to this issue. However, no planning or policy-making approach will be adequate if we do not have better information on future climate conditions and in turn, how they will interact with the environment and how these physical changes translate through possible future socio-economic structures.

The bottom line to these recommendations is, "let us get prepared." We must act in these areas or we will be sentenced to an unbelievably expensive crisis management response to climate change.

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IMPROVING RESPONSES TO DROUGHT AT THE STATE, REGIONAL, AND FEDERAL LEVELS[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

My views about drought response at all levels of government are based largely on study of droughts in Illinois and the Midwest. My comments are focused largely on the 1988 drought and the lessons that it and other recent droughts illustrate about drought responses in the humid climatic regions of the eastern U.S.

2. The Illinois Case

Illinois has performed extensive research relating to many facets of droughts for the past 30 years. This included the weather conditions that cause droughts, their climatological description and interpretation, and the various physical and socio-economic impacts and adjustments that were related to droughts (Huff and Changnon, 1963; Changnon et al., 1982; Bowman and Collins, 1987).

Illinois recently conducted a 4-year water planning effort culminating in a State Water Plan (Water Plan Task Force, 1984). This water plan identified droughts as one of eleven major water issues facing the state and called for the development of a "drought contingency plan." The State Water Plan in noting the drought issue stated, "Illinois and the federal government have excellent programs which essentially span the needs of drought response. However, they need to be brought together, coordinated, and placed in the state of constant readiness." The resulting drought contingency plan (Illinois Division of Water Resources, 1983), set forth a series of important tasks including the establishment of a permanent Drought Task Force, the design and establishment of a public education effort, and the assignment of drought response responsibilities to various state agencies.

A public educational document was prepared (Hilberg and Changnon, 1984) and the Illinois State Water Survey was assigned the responsibility for drought detection and monitoring. To accomplish this end, further drought impact research was required. The ensuing 2-year research project involving the three Scientific Surveys of Illinois generated a series of drought "indices," measures which could be used to detect the onset of drought, to measure drought severity, and to detect the termination of drought This involved use of climatic data, soil moisture data, streamflow data, shallow ground water data, and agricultural

[1]Paper presented at the Strategic Planning Seminar, "The Drought of 1988 and Beyond," Washington, D.C., October 18, 1988.

data (Changnon, 1987). The point is, the Illinois efforts collectively represent an extensive effort by one state to place drought planning, monitoring, and response on a firm scientific, technical, and institutional basis.

How did Illinois utilize its plans and available information for responding to the 1988 drought? My impression is that Illinois failed to utilize available drought sensitivity criteria to monitor adequately the drought's onset and its severity. It was not until after the end of June that an Illinois report by the agency responsible for the detection and monitoring of droughts, issued a statement that the drought of 1988 had changed from an 'emerging drought to a mature drought' (Illinois State Water Survey, 1988). This statement was issued many weeks after several notable drought events occurred including a doubling of corn prices in late May, stoppages of barges along the Ohio River in southern Illinois in mid-June, and an ensuing proposal by the state government to increase the diversion of water from Lake Michigan down the Illinois-Mississippi River system. This "first mention" of a serious drought came three months after weather advisors to the Illinois Central Railroad predicted the drought would cause flows in the Ohio River (near Cairo, Illinois) so low as to affect barge traffic. The state's detection of the true severity of the drought occurred at least two months after certain physical data (and responsible analysis) indicated the drought was going to be very severe. The standing Illinois Drought Response Task Force was first convened in mid-June well after the drought had become quite severe (Drought Response Task Force, 1988). As a result, "crises management" was being used to respond to the 1988 drought in Illinois, not risk management based on the drought developing months before. The lessons based on the research of the immediate past were either forgotten or ignored. Why? I will explore the possible answers to this question later because they are relevant to considering responses to drought at all levels of government

3. The Regional Climate Center Case

During the summer of 1988, the Midwestern Climate Center (MCC) served as a major source of drought information for a 9-state area in the Midwest. It performed continuing analyses of the climatological conditions, and by the end of May 1988 was able to assess the presence and severity of the drought. The Center worked closely with the state climatologists and the Climate Analysis Center to interpret the drought and transfer information. The MCC also served as a center of expertise and information about the drought and ways to respond. Interests in the utilization of planned weather modification in Illinois, Indiana, and Ohio were responded to. Extensive interest in Ohio about launching a project led to the development of a plan for a statewide research plan. The MCC also worked with the Department of Interior to design a potential rain modification project for the Midwest

4. Response Problems at the State Level

The basis for planning and improving responses at the state level rests on an accurate delineation of the problems. Observation of drought response activities in Illinois and other states lead to the conclusion that the problems related to response are rooted in three factors: 1) the lack of drought experience among decision makers at all levels; 2) inadequate drought information, both as to content and timing; and 3) lack of knowledge about drought responses, and sources of expertise (Wilhite and Wood, 1985).

These factors create four basic response problems. The first response problem noted is the process of acting, or reacting, too late to drought-induced problems. The second response type problem is to act incorrectly; that is, to over react or choose the wrong solutions. The third response type problem relates to the failure to act at all, even when good information or precedent exists. The fourth problem is the tendency to wait until "crises management" is the only approach. This may be seen as the "safe" bureaucratic approach of dealing with a natural hazard.

The fundamental question that the questionable reactions to the 1988 drought in Illinois, and those elsewhere in humid climatic regions, raise about state drought response. "Is it feasible to plan ahead in a strategic manner with a drought risk management approach at the state level?" In answering this question, one must consider the means for responding to drought, particularly at the state and regional levels.

5. Key Functions Related to Drought Responses

At the state level, there are certain fundamental needs for information about drought that can lead to appropriate actions. Whether these informational needs are provided by the state, a regional entity, or federal entities is a question that also must be addressed. First however, let us address the needs for information and the functions. There is a need to have a fundamental understanding of drought in a given place; this becomes the basis for all other actions and responses. This understanding includes two important dimensions: the climatological characteristics of drought, and the impacts of drought including the major sensitivities, both in the physical and socio-economic sectors, related to atmospheric conditions.

The first major function, given such an understanding exists, is to monitor and communicate. Some entity, state, regional, or federal, needs to measure the climatological severity of the incipient and/or on-going drought. Second, this monitoring involves attention to local in-state problem regions and types of section problems. A related activity is the issuance of public pronouncements concerning the onset of drought, about drought severity, and drought ending. Communications specifically must include efforts to inform and educate state decision makers who typically approach drought action responses with a philosophy of "let's wait, it may rain tomorrow."

The second major functional area relates to assistance. This, usually provided at the state or regional level, includes the provision of technical advice, including publications and workshops, to deal with short-term responses and subsequently with long-term responses and solutions to drought problems such as enhanced reservoirs. Another form of assistance relates to loans to farmers and private businesses through various mechanisms including reduced interest rates by state banks. A third form of assistance is to communities and individuals. It includes activities like furnishing pipelines to connect communities to alternative water supplies, digging of new wells, hauling water, etc. A fourth form of assistance involves provision of guidelines and information to the general public. This can include warnings about danger to personal health during heat waves. Another form of assistance relates to the provision of information and advice about the use of weather modification during droughts.

A third functional area is the establishment of organizations and drought plans. One of the common activities noted in 1988 was for states to assemble a "Drought Task Force," often hurriedly assembled, to react to the drought problems. This should be a standing state group but typically is not in many states of the humid climatic zones. A state or regional climate center can develop directories for climate data and drought impact data, provide information about responses, and make available expertise. To this end, a newly developing national network of regional climate centers (Fig. 1) can provide a very useful institutional function for states in the regions. States can establish new or updated state drought plans and maintain the offices and expertise to execute these.

A fourth major functional activity relates to conservation and regulation. States can encourage local conservation of water which is generally considered cheap and unlimited in the humid east. Information about means of conservation can be provided. A state can work with communities to limit water use through local restrictions, and a state can enforce higher water rates if necessary.

6. Summary and Recommendations

Activities during the 1987-88 drought in Illinois reinforces concepts that developed from studies of prior droughts in 1952-56, 1976-77, and 1980-81. One belief is that Illinois and most other states in the humid climatic zones of the eastern United States typically lack the interest, resources and expertise to maintain the skills needed to detect and monitor the severity of droughts; to understand drought effects on their physical and socio-economic systems; and to wisely respond strategically to droughts.

My second belief is that without available skills and information, states will typically attempt to rely on expertise in adjacent states and/or in regional entities for drought information and for advice on response methods. If this expertise is not available, crises management and federal assistance become their "delayed responses" to drought.

Thus, my first recommendation for improving drought responses at the state level is: each area must have an adequate understanding of drought impacts, and access to information to detect the onset and degree of severity of droughts. Due to many acknowledged state failures, often related to a lack of resources and expertise, I recommend that these functions be accomplished at the regional level for areas where the climate and drought effects on the physical system (soils and hydrologic cycle) are similar. Applied climatological research and drought monitoring services could be appropriately conducted at regional climate centers working closely with state climatologists and hydrologists.

Better monitoring of droughts, which must be rooted in a good understanding of the physical effects of droughts (and sensitivity studies), is needed with the detection and measurement being done in a near real-time mode. I recommend an early warning drought detection and communication system be developed. To accomplish this, an improved, more focused National Climate Information System must be developed. It must involve data collection, maintenance of climate data bases, regional and national computer systems and an interactive communication system connected to several NOAA entities including the NCDC, CAC, and the regional climate centers. Such a system properly grounded on information about droughts, will serve as major new drought response mechanism not only for drought but for other climate aberrations.

A third broad concern relates primarily to the actions of the federal government in relation to drought; it too has basically used "crises management" without long-term strategic planning (Wilhite et al., 1986). The federal responses to the 1976-77 and 1987-88 droughts have typically involved an approach of "throw money at the losers." The states are not the only ones guilty of crises management in drought. As we approach the end of 1988 with continuing dry conditions over large parts of the United States, a fundamental question is, "What can and should be done in case the current drought continues into 1989 and beyond (such as occurred in the multiple-year droughts of the 1930's and 1950's)?" I recommend the assignment of a drought detection and monitoring capability within the National Climate Program and NOAA with an interagency planning and advisory group. This could be a function of a standing entity, if an appropriate group exists. It must include NCPO, NOAA, USDA, COE, and DOI. If states can afford to have "standing tasks forces for drought," then so can the federal government

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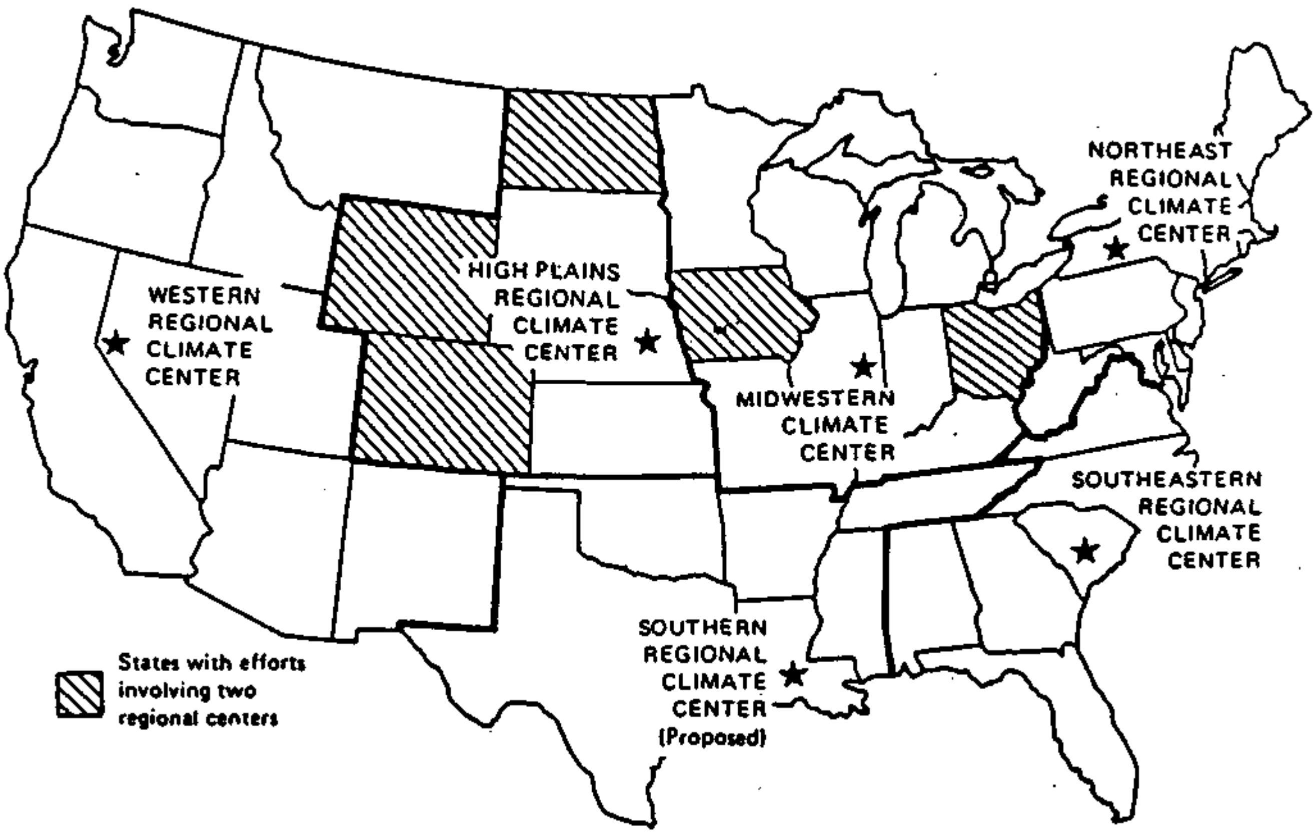

BOUNDARIES OF EXISTING AND PROPOSED REGIONAL CLIMATE CENTERS. BASED ON RESPONSIBILITIES FOR MAINTAINING REGIONAL DATA BASES

Figure 1. The:. National Network of Regional Climate Centers.

CLIMATE CHANGE AND WATER RESOURCE ISSUES[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Dlinois 61820

1. Introduction

Climate is a fundamental part of the hydrologic cycle, and sizable changes in climate will have profound effects on water quantity and quality. Recent years have shown how climate fluctuations of 15 to 30 years duration have greatly affected water resources. Persistently wet and cool weather in the Midwest and in portions of the far West led to record high levels during the 1980's in the Great Lakes and the Great Salt Lake. Simultaneously, severe prolonged drought affected the Southeast and then in 1987-88 much of the nation experienced extremely warm and dry conditions leading to unprecedented droughts and rapid declines in streamflow and lake levels throughout the west, High Plains, Midwest, and southeast.

The drought covering much of the United States helped create much greater awareness, in the public and amongst decision makers, about the seriousness of climate and the impacts that its aberrations create throughout our society and environment. Enhanced awareness of the seriousness of climate has been beneficial because it helped bring the climate change issue to wider attention; the potential for major change is a very serious issue for the United States and the world.

Awareness has also been created at the local, state, and regional levels by various recent conferences. For example, the Canadian Climate Program, the U.S. National Climate Program, and the Midwestern Climate Center collaborated to conduct a 3-day symposium in Chicago during September 1988 entitled, "Climate Change and its Impacts on the Great Lakes Basin." Representatives (120 total) came from weather sensitive sectors around the lakes including private and public sector agricultural interests, water managers, shippers, environmentalists, resource managers, etc. They were briefed by experts about climate change, and in turn they indicated the types of impacts that may occur, given the climate changes. This assessment will likely lead to the establishment of an international pilot project focusing on climate change in the basin. Such meetings create awareness among scientists, decision makers, and the public. Involvement in such conferences and review of the climate literature (Changnon, 1987) have helped identify the issues related to climate change and water resources.

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[1]Presented at the Conference on Climate Change: What's in Store for South Carolina?, at Columbia, South Carolina on October 20, 1988.

2. The New Problem

First and foremost is the fact that everywhere in the United States society is now much more sensitive to water resources than ever before. This is due to several factors including population growth, population shifts, relative loss of water quantity due to water quality problems, aging water systems, waste, and inefficient water management Regardless, this sensitivity makes our nation very vulnerable to climate change since climate controls the hydrologic cycle.

Changes in water resources are likely to be a major impact of the predicted warming caused by the Greenhouse Effect. By burning fossil fuels and clearing forests, we are adding billions of tons of carbon dioxide and other gases to the atmosphere each year. These gases trap the sun's energy and raise the earth's temperature. Most scientists now agree that if the build-up of heat-absorbing gases continues, it is likely to cause a shift in the global climate. Current estimates are that doubling of CO_2 would raise the average global temperature by 3° to 9°F in 50 to 70 years, a very rapid rate of change.

The warming would also change the climate in other ways. Precipitation would increase globally from 5 to 15%, but the effect would not be uniform. For example, some areas of the United States might be wetter than at present, whereas others would be much drier. Wide geographical variations are expected and the global climate models can not yet tell us with certainty what will happen at any specific region.

3. Some Possible Outcomes

Those who have analyzed the effects of climate change for water agree on certain likely future broad effects. These effects within the United States would likely include the following impacts (AAAS Panel, 1988).

a. Warmer winters will cause snow in North America to melt earlier in the spring. This will change the timing of floods and the filling of reservoirs and ice cover over the Great Lakes and other northern rivers.

b. Effects of climate change will probably be greatest in the arid west where a relatively small change in precipitation will make a relatively big change in water resources.

c. Extremes such as floods or droughts may change more than the average climatic conditions.

d. Warming will make it difficult to maintain irrigation in the west, though improvements in water use efficiency could help sustain it In the eastern more humid regions, areas under irrigation will likely increase substantially.

e. Rising sea levels will move salt water into coastal aquifers, and hurt the intake of fresh water from streams by extending salt water further up estuaries.

f. Most Americans who depend on municipal systems will be supplied, though water is likely to be more expensive.

g. Climate change increases the need to review rules about laws and water, especially ground water which is beginning to be a badly overdrawn resource.

h. Governments at all levels will have to reassess their legal, technical, and economic procedures for managing water resources in light of climate change.

4. Issues and Recommendations

First, because everyone's decisions and actions depend upon anticipating correctly the water resources situation in a changed climate, and since only scientists are likely to be able to produce the climate predictions, a fundamental issue relates to their research. Thus, I recommend that scientists investigating climate change must pay special attention to improving predictions on the scales of time and space most relevant to the management of water resources; that is, the scales of decades and the space scales of large basins. Furthermore, the predictions need to set bounds on the likely changes in the averages, extremes, interannual variability, and the rate of changes.

Second, some of the future climate changes are seen as highly likely, such as warming, whereas other conditions will long remain uncertain, for example, precise changes in precipitation and in other parts of the hydrologic cycle. Meanwhile, faced with uncertainty, water managers must decide upon actions now of having consequences several decades into the future and after some climatic changes have occurred. Thus, scientists should inform water managers in a continuous fashion about what is certain, about what levels of uncertainty exist, and how soon the changes are likely. Thus, water resource scientists and managers should meet regularly with scientists concerned with water and climatic change.

My third issue relates to the fact that we need to have better information on the relationships between climate factors and other hydrologic factors. We need better analysis of the relationships, for example, on streamflow variability in major basins. We need to improve existing monitoring and data collection systems to support these diagnostic studies. Such applied research and data monitoring are particular activities where new regional climate centers can play a key role.

The fourth issue concerns the fact that governments at all levels including courts and regulatory agencies who set the rules for who shall be protected, who shall own water, and how water resources shall be managed must be involved. Our public bodies build dams, canals, and pipelines to store and transmit water. Among the climatic changes the government and other public bodies are likely to encounter are rising temperatures, increasing evapotranspiration, earlier melting of snowpack, new seasonal cycles of runoff, less ice, altered frequency of extreme events, and rising sea level. Therefore, governments at all levels should reassess legal, technical and economic procedures for managing water resources in light of the highly likely climatic changes (AAAS Panel, 1988). These assessments should include techniques for the use of water, the criteria for design and operation of water systems and structures, guidelines for choosing among water structures, and regulation methods for allocating water among users. To increase the flexibility of our water systems, government guidelines should incorporate both the certainties of global climate change and the uncertainties about local-regional conditions.

Fifth, climate change increases the value of flexible institutions for allocating water. Governments initiate these institutions and set their operating rules. Government must also give attention to equity in the public good in protecting the value of water in a stream as well as the water withdrawn. Thus, governments should permit and encourage flexible institutions, including the market, that can allocate water for its most beneficial use. As the climate changes, this action should help forestall crises.

The sixth issue relates to the fact that climate change will likely create problems that make integration, management and exchanges of water over regions advantageous. Although these regions such as the Great Lakes may correspond to present boundaries of states or well known basins or regions, new water regions may be required to match the problems and opportunities for solution under a vastly changed climate. Thus, some form of governmental or quasi-governmental entities should be developed to facilitated the planning and operation of water systems over areas proper to the solution of problems caused by climate change.

Seventh, water is a cross-cutting issue, as is climate change, and the impacts of the changes will be widespread through the physical and socio-economic systems. Unfortunately, we know too little of these complex effects (Changnon, 1988). Thus, to address correctly the changes and effects of climate on water resources will require interdisciplinary research. Until institutional and personnel problems are dealt with, interdisciplinary research is hard to sustain. Government should encourage interdisciplinary research.

The eighth issue concerns the fact that climate change will open opportunities for those who adapt. Climate change could increase the return from investments that first copes first with weather variability and then deals with change. During planning, water managers should be alert for economical measures to increase flexibility and to accommodate climatic variabilities such as sea level rise and as we learn more about it, climate change. Managers can and should exploit opportunities to retain or increase flexibility of systems especially since such measures may be fairly inexpensive if put into the original design. This is an important issue for adjustments in the Great Lakes Basin, for example.

Obviously, conservation is an important means of adapting to the hydrologic impacts of climatic change. Change would increase the return from innovation that helps induce conservation. I think that industrial and agricultural innovators should be alert to water conserving technologies increased by climate change. Then through community type efforts, the public can take early advantage of new crops, cultural practices, and new industrial techniques for extracting more benefit per gallon of water.

The tenth issue relates to the fact that all regions of the United States now have major vulnerabilities to climatic changes (AAAS Panel, 1988). Most northwestern and eastern basins are vulnerable to increases in droughts and floods because of their small storage volumes. The Great Lakes Basin has very major conflicting interests over fluctuations of any type in basin water supplies and lake levels. Western basins are susceptible to decreased precipitation and runoff because of both high demand (relative to supply) and to great reliance on ground water. We must decrease existing vulnerabilities which climate change will exacerbate. In some places they can be probably decreased by arrangements for transferring water to new uses, others by building new structures, and in others by increasing the benefit of each gallon. New technologies must be developed such as weather modification to enhance precipitation and methods to suppress evaporation.

Finally, I am concerned that uncertainty about what atmospheric scientists currently agree upon adds to the confusion over climate change and its impacts. Thus, those who address climate change have a responsibility for accuracy and to convey the real complexities and uncertainties and not oversimplifications. Scientists involved in climate change predictions must make extra effort to explain clearly in conservative and understandable terms if society is to react sensibly.

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WHAT CAN THE ATMOSPHERIC SCIENCES DO TO AID IN DROUGHT MANAGEMENT?[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

How and what information atmospheric scientists provide for drought management can be quite complex and fraught with difficulties for users. Furthermore, I would claim this information is often too slowly delivered with its content too often disorganized and confusing. Confusion often results from different definitions of drought, as we saw early in the 1988 drought.

Answering my question means first considering where the impacts of drought occur. Most severe droughts in any area are pervasive and include widespread effects in the environment and socio-economic systems. The effects of drought sooner or later are realized at all levels of government.

Given the complex dimensions of drought, and the difficulty of defining drought, what can the atmospheric scientists provide? We recognize that agricultural droughts, which are often limited to the crop season, differ from water supply droughts which typically develop and last longer. Understanding the wide variety of drought definitions is certainly central in understanding what the atmospheric scientists can do for drought management. The atmospheric scientist should be integrally involved in defining droughts through interdisciplinary studies with other disciplines.

2. Three Types of Informational Services

The atmospheric scientists can provide 3 types of information in the management of drought

a. Provision of Data and Information about the Drought.

The most frequent way that the atmospheric sciences can help is through the provision of climate data and information about a drought. However, several things are important, particularly since the climate characteristics of an agricultural drought are very different than those causing a water supply drought Furthermore, the early detection of the onset of drought really rests with the atmospheric scientists through the monitoring of precipitation

[1]Paper presented at the Workshop on Drought Management at the National Science-Foundation, Washington, D.G, on November 1, 1988.

and temperature conditions. This "early detection" capability depends on how well "drought sensitivities" are understood; that is, the relation of climate conditions to shallow ground water, streamflow, and other environmental conditions.

An important part of data and information presentations concerns provision of descriptive information about the drought characteristics. Typically, we learn about X precipitation departure for Y months, etc. However, much more important than just describing the events and their departures from normal, is to "climatically interpret the event." That is, how long it has been since a comparable event occurred, and what the frequency of such an event is. Failure to provide such interpretations is to fail to provide adequate information.

Central to the issue of provision of data and information, and I emphasize drought information and interpretation, is the need for near real-time climate information. This relies on the daily accumulation of data now very possible through our communication and computer technologies, and in turn, the interpretation of the data into information about the severity of the drought. All this is now possible and is a feature of the Midwestern and High Plains Climate Center.

b. Prediction.

Of infinite importance to the decision maker attempting to deal with an on-going drought are answers to questions like: 1) will the drought worsen, and 2) when will it terminate? We are not talking about weather predictions, but rather "climate predictions." Skills in the physical prediction of conditions for months, seasons, and years ahead are still in the research stage and exhibit very limited skill. Equally useful information at this time can come from climate frequency analyses. These typically come in different packages, but two of the most common are probability analyses, and climate analogs based on historical data. Both assume that the current and future climate conditions are similar to those of the past and that assumption must be clearly stated. Regardless, both approaches have potential utility in expressing the likelihood of a drought changing or ending. However, confusion frequently develops amongst users because atmospheric scientists use different data sets, use data from different areas, or use different statistical techniques and derive climate predictions that are potentially all correct but appear different and in direct conflict to users.

c. Weather Modification.

The third area that atmospheric sciences can presumably aid in drought management relates to the use of weather modification and to precipitation enhancement specifically. Those with a sound background in weather modification, realizing it's still an emerging technology, have advocated an approach of continuous seeding to help, in non-drought years, build up the overall moisture supply. Most atmospheric scientists of repute and familiar with weather modification (a singular problem is who are the experts?) will tell you that precipitation enhancement in severe drought is difficult due to the lack of precipitation events. Cloud seeding depends on availability of suitable clouds, and in most areas droughts are marked by the lack of cloud-rain events. Nevertheless, there are clouds on some days and potentially suitable for modification.

One potential approach in the design and conduct of a project is the use of a mobile seeding system able to reach clouds over a large area such as the Corn Belt. Even during droughts, some parts of an area like the Corn Belt frequently have clouds suitable for seeding. It is well within the technology to forecast these events and move seeding systems to them.

The question still remains, at least in the East and Midwest, how well does it work? Important to this potential use of precipitation modification to drought management is the important concept that the "decision maker must decide, not the atmospheric scientist." Both in the use of the climate predictions and use of weather modification in droughts, the role of the atmospheric scientist is to provide the information with an expressed level of certainty in the prediction accuracy or the modification capability. Decision makers should utilize this information, hopefully in a qualitative risk analysis, to decide how or if to use this information or technology. All too often, the atmospheric scientist is willing to make a recommendation whether to use predictions or modification when he/she is ill-equipped to make such a recommendation.

3. Summary: User Beware

The user of the products and techniques of atmospheric scientists during droughts should understand the capabilities that exist in all three areas. This involves investigating with atmospheric scientists the quality of the information being presented.

The atmospheric scientists, on the other hand, need to provide more consistent and less confusing information. It is my contention that the myriad of sources of information in the atmospheric sciences result in a wide variety of answers in describing droughts, in the presentation of climate predictions, and in advice on weather modification. The net result is often to leave the user totally bewildered. Certainly it reduces the credibility of the information and lessens its use in important decisions relating to drought management. The atmospheric scientists need to "clean up their act" We need centralized sources of information based on expertise, and users of information need to understand where to get information and how to ask the right questions to get correct answers.

THE GREENHOUSE EFFECT, CLIMATE CHANGE, AND IMPACTS ON AGRICULTURE[1]

by
Stanley A. Changnon
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, Illinois 61820

1. Introduction

Agriculturalists understand the weather better than do most Americans. In particular, farmers and other agricultural experts understand well the extreme amount of weather variability, on all space and time scales; the day-to-day, the week-to-week, and the year-to-year fluctuations that collectively make up the Midwestern climate. The true "normal climate" of the Midwest consists of these fluctuations and the averages mean very little in describing the climate.

During the lifetime of many midwesterners, at least those 55 years or older, we have experienced the two most extreme weather periods of the past 200 years; the worst multi-year drought, that of the 1930s, and the wettest multi-year period, that from 1971 to 1985.

If one is a student of geology and soils of the Midwest, one also understands there have been periods when thick glaciers covered most of the Midwest, and other epochs when warm seas and tropical vegetation covered the Midwest. The point is, the midwestern climate conditions, due to natural causes, have varied considerably more than that we have experienced in the last few centuries.

Now we face the potential for a human-induced future climate change. Questions that arise from the agricultural sector are, "Is this future change really going to happen, and how might it be significantly different from today's widely fluctuating climate?" Indeed, one reaction is to ignore the issue because we have experienced some major wet and dry extremes in the last 50 years and agriculture has managed to survive both.

Another reaction to future climate change found in agricultural sectors is one of low concern but the view of "we can manage around it." After all, agriculture has moved forward in the last 40 years to minimize weather effects. We now plant and harvest in hours and days when it used to take weeks. Now, we also have a variety of hybrids designed for widely different weather conditions, but of course, we lack the seasonal

[1]Paper presented on July 11, 1989, Cincinnati, Ohio at the Annual Meeting of the Midwest Association of State Departments of Agricultural (MASDA).

weather predictions to make wise choices of which variety to plant.

Regardless of agricultural attitudes about future climate change, atmospheric scientists have concluded that: 1) a climate change will develop; 2) it will be a climate different than anything we have experienced in the past 200 years (and since our agricultural practices have developed); and 3) furthermore, the change will occur rapidly with rapid defined by climate standards. That is, a major shift may well occur during the next 30 to 70 years.

This paper focuses on the characteristics of the potential climate change, what are the factors that will cause the climate change, what some of the possible impacts would be to agriculture and water resources, and what actions, if any, need to be considered now to address the issue.

2. Key Questions and Answers

In presenting information, I have identified 12 questions that appear to be key ones in analyzing the Greenhouse Effect and its relation in agriculture. I have attempted to provide answers to these questions. These reflect my views as well as the distillation of the views of many other scientists.

What Do We Mean about Climate Change? Understanding the characteristics of climate change is important. Figure 1 illustrates various types of climatic change. As shown in the middle graph, one could expect there to be a change in the variability, and as shown on the graph below that, there could be also a change in the mean or average condition. As shown in the bottom graph, there could be changes in the extremes, either as to their frequency or intensity. The concept of climate stationarity (top graph) is now false.

Can Man Really Affect Weather and Climate? The answer is definitely yes. By simply looking at the sky around industrial centers one sees clouds induced from smoke and moisture, and on many "clear days," one can view a midwestern sky full of cirrus clouds being produced by contrails of jets crisscrossing the Midwest. Furthermore, we know that every facet of the climate has been changed in and around large metropolitan areas by these man-made "mountains." Man has been changing weather and climate in various ways for many decades in the Midwest.

What is the Greenhouse Effect that has made all the Headlines? For more than a decade, atmospheric scientists have been analyzing data and discussing the potential of the Greenhouse Effect to alter atmospheric temperatures and in turn change the world's climate. The drought of 1988 helped bring national attention to the issue because some surmised that the drought and the very warm years of 1986, 1987, and 1988 were indicative of the start of the climate change related to the Greenhouse Effect.

Simply, the Greenhouse Effect is created by various "trace gases" that are produced on earth and in turn reside in the upper atmosphere. They do not affect the incoming radiation from the sun, but act much like clouds and reduce the amount of outgoing radiation to the atmosphere, as reflected from the earth's surface. The net effect of the retained energy is to change the atmosphere and in turn, the earth's surface climate.

Figure 2 illustrates the growth in carbon dioxide as measured over the last 25 years. It shows a steady increase as the world continues to increase its burning of fossil fuels. However, CO_2 is not the only trace gas that helps produce the Greenhouse Effect. Figure 3 shows that it contributes roughly 50% of the total Greenhouse Gases with sizable contributions from CFC's, methanes, NO, and other sources. This makes it very difficult to control the Greenhouse Effect since so many sources of gas are involved.

<u>What Do most Scientists Believe about the Greenhouse Effect?</u> The mounting evidence for a Greenhouse Effect has led most atmospheric scientists to scrutinize the findings from the Global Climate Models and to conclude that the predicted effect is likely. They agree on the following key findings:

1. There is an ever increasing amount of CO_2 and other trace gases in the atmosphere.

2. Collectively these gases can physically cause global climate changes.

3. That the resulting effect will cause the global average temperature to increase by 3° to 5°C (all global climate models closely agree) with major global redistributions of temperature and precipitation values during the 30 to 70 years from 1990.

4. That major uncertainties exist about the exact dimensions of future regional climates, and how the change in a climate will occur over time.

<u>What Should Society Do Now about the Issue?</u> Certainly, one important action is to continue and enhance the research in two areas. We need to resolve the scientific uncertainties involved in the global climate models, and to understand how future climate changes will impact agriculture, water resources, and other areas.

A key question affecting how and when society acts is illustrated in figure 4. Here two curves illustrate how the climate could change over the next 60 years and are portrayed in schematic form to illustrate the great differences. The reactions to a climate change under a slowly, continuously evolving condition would be very different than those likely to occur with a sequence of extremely warm-dry (drought) years as illustrated in the bottom graph. Also, the type of change over time, which we now do not yet understand, will be helpful in detecting when the change has begun. A gradual change over many years is hard to detect in the Midwest where the climate has much year-to-year and decade-to-decade variability.

<u>Will the Impacts of a Changed Climate be Difficult to Adjust to?</u> Figure 5 illustrates how other factors will greatly influence how we adjust to climate change. They all impact the demand for a most basic ingredient to agriculture, that being water. One notes in the top graph that increasing population alone will put ever more demand on water. The second box illustrates that our ever increasing pollution leads to a lessening of the water resource and in turn, more demand for what good water is available.

The third graph illustrates another problem, aging water supply systems, which in turn create a loss of water resources. Finally, a warmer and potentially drier climate will produce greater stress because it too leads to higher demands for water. Thus, many factors will interact to put increased demands for water in the future, not just climate change. In essence, we have and will become every more sensitive to climate change.

What will some of the Impacts of an Altered Climate be in the Midwest? Table 1 presents a list of "speculations" based on limited research already accomplished addressing the effects of climate change. This is based on the fact that the global climate models now indicate a much warmer and drier climate is most likely for the central United States. One quick image of what it might be like is to consider the current average temperature of central Texas would be the average of Illinois. Given those types of climate, Table 1 lists the kinds of impacts have been identified relating to agriculture and other Midwestern endeavors.

The actual degree of climate change will vastly affect the severity of the impacts. For example, our studies of future effects of altered climate and a lowering of Lake Michigan on the Chicago lake front indicates a two-foot fall in the lake (due to climate change) would have relatively minor effects on Chicago, whereas the 9-foot fall predicted from the output of another climate model for the Midwest would provide disastrous impacts at Chicago for water supplies and shipping.

What will the Future Climate do to the Nation's Water Resources? Table 2 presents a list of some of the more major impacts in the U.S. from a warmer and drier climate. A major Midwestern impact would relate to the influence on water supplies and levels of the Great Lakes. Application of three global climate model outputs to the Great Lakes Basin indicates lake levels, for example, would fall between 2 and 9 feet, depending upon which model output is used.

Water, one of the great natural resources of the Midwest, and found both in ground water and surface water, would clearly become stressed to serve the needs of agriculture, commerce, and transportation. For example, the flows of the major rivers would be sufficiently decreased to make river transportation questionable for agricultural products.

Will Anyone Benefit? One of the major lessons of studying weather and climate influences on man in his natural systems reveals that major changes in weather hurt certain endeavors and benefit others. One can expect, for example, certain segments of the economy to "win" as a result of a major climate change. Certainly those capable of providing transportation (railroads) and additional water, such as irrigators, will be beneficiaries. Depending upon shifts in agriculture, one can image that those who adapt quickly to the changes in crops and other agricultural activities will reap early benefits.

What Can or Should We Do; Can We Prevent or Can We Adjust to the Future Climate Change? Adjust or prevent is the central question now and into the future, about the potential climate change from the Greenhouse Effect. Figure 6 presents the distribution of sources of the trace gases causing the Greenhouse Effects by nations of the world. This means that Greenhouse-induced climate change is an international issue of great complexity. Total prevention would be very difficult, if not impossible, to accomplish, and even partial prevention will take many, many years to plan and resolve nationally and internationally. Very serious economic effects are implicit in prevention strategies. Adjustments will also require major changes in policy and economics.

What Actions Can Be Considered and Taken Now? Table 3 lists a series of actions that appear reasonable. I believe we must act now in certain ways. It makes sense to plan to become more flexible in our climate-sensitive systems. Climate change due to natural factors may develop regardless of human effects. Secondly, certain activities being planned and conducted now have 50- to 100-year time horizons and thus must plan for the potential climate change. For example, I refer to design of water resource structures having 50- to 100-year lifetimes, and to commercial forests which must be planted now with 50-year lifetimes and the potential for growing in an altered climate.

Where Can Regional Climate Information about the Issue be Obtained? The states and the National Climate Program Office, with the support of Congress, have established a new national system of Regional Climate Centers. These and their areas are shown on figure 7. These have been instigated to address regional climate problems and to provide the data and expertise to the states and the regions for solving problems. They exist as a unique source of up-to-date information on climate change.

3. Summary

The principal findings of the analysis of the current knowledge about climate change, the Greenhouse Effect, and impacts and adjustments are summarized in Table 4. I have attempted to bring forth here the key "knowns and unknowns" about the issue. They do reveal the general uncertainties and they also reveal there is a need to act and move ahead.

Whether we like it or not, mankind has accidentally embarked on a global experiment in climate change. Although many uncertainties exist about the future characteristics of the climate in the Midwest, the agricultural consequences appear to be large and basically negative. The future climate that our children and grandchildren will live and function in will clearly be very different than that of today.

TABLE 1. SPECULATIONS ABOUT POSSIBLE FUTURE IMPACTS IN THE MIDWEST

The average climate is expected to warm by 3° to 4°C, and the precipitation would be between 10% less and up to 15% more, and there are more extremes (one possible outcome, a climate similar to the current average of central Texas).

1. Agricultural practices would vastly change (crops, irrigation, pests, chemicals, etc.).
2. Competition for water would be severe.
3. Re-distribution of U.S. population - back to the Great Lakes.
4. "External changes" would re-define export-import relationships.
5. Lifestyles would be different — traveling, energy consumption, incomes.
6. Shipping on Mississippi-Ohio River system would likely end.
7. Etc., etc.

TABLE 2. POSSIBLE OUTCOMES IN WATER RESOURCES

1. Snows will melt earlier - alter floods; less ice cover on Great Lakes.
2. Effects greatest in arid west where a little change will produce large impacts.
3. Extremes (flood and droughts) may be changed more than average.
4. Warming will make it hard to maintain irrigation in west; expansion in east.
5. Rising sea levels lead to salt water in coastal aquifers and intrusion in waterways.
6. Water will become more expensive.
7. Rules and laws about water will change.
8. Legal, technical, and economic procedures for managing water resources will need to be assessed and ultimately changed.

TABLE 3. ACTIONS NEEDED TO ADDRESS GREENHOUSE EFFECT - CLIMATE CHANGE ISSUE

1. Insist on better climate monitoring (poor shape).

2. Support intensified research in three areas:

   a. climate change models to get specific regionally.
   b. climate impact understanding to predict effects of different climates.
   c. agricultural adjustments (hardier strains, irrigation, new technologies, etc.).

3. Seek development and maintenance of low energy use systems of minimum weather sensitivity.

4. Support legislation to seek international awareness of issue.

5. Consider actions on water, soils and other resource management, regulations and laws that address fewer supplies and increased competition.

6. Utilize climate information at regional centers.

TABLE 4. TEN KNOWNS AND UNKNOWNS ABOUT CLIMATE CHANGE

1. CO_2 and other trace gases are increasing.

2. Greenhouse gases will change the global climate.

3. Global climate models are imperfect, but they agree on **global warming** in 20 to 70 years.

4. Effects on precipitation (globally), and on regional climate conditions are uncertain, but re-distribution likely.

5. Impacts could be severe, but are very uncertain (where and how much?).

6. The issue is **global,** not just U.S., and correction will take years to get international action to prevent.

7. Media has difficult time correctly presenting scientists' findings, and scientists disagree, causing public confusion.

8. Issue is interwoven with growing concern over human insult to our earth from wastes, erosion, poor conservation, natural resource destruction.

9. Great attention to CO_2 issue at policy levels.

10. Uncertainty over "prevent of adjust" strategies.

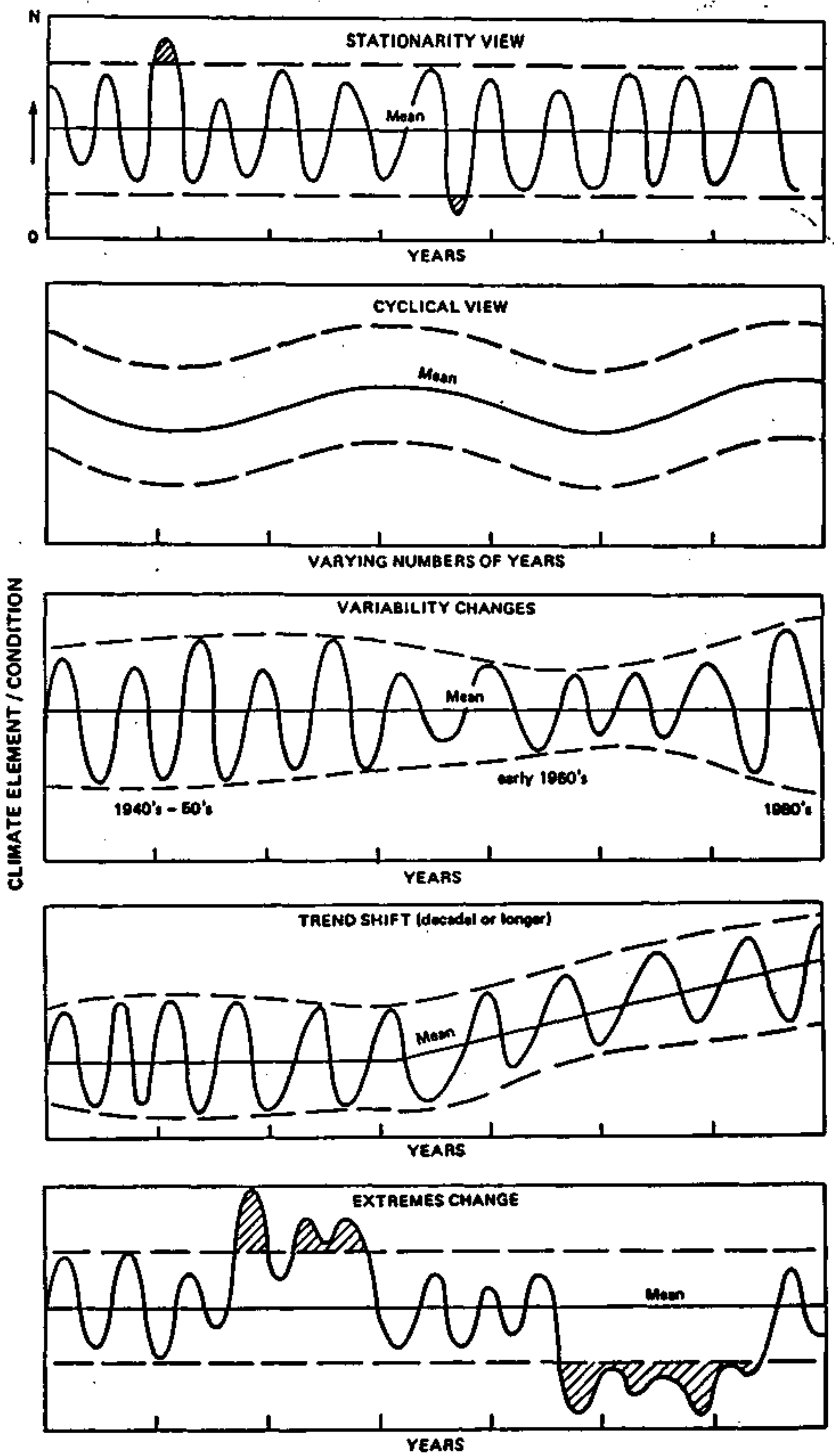


Figure 1. Various views of climate change and types of possible changes.

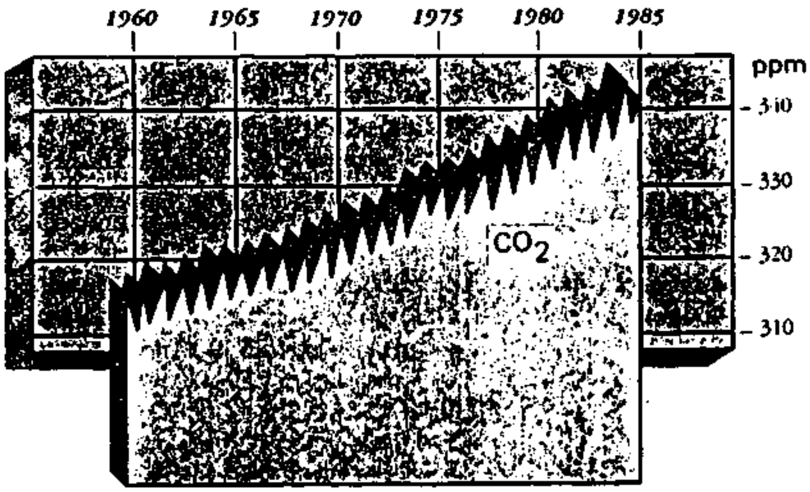


Figure 2. **The growth in carbon dioxide levels since 1958 (CO_2 concentration in parts per million, from <u>Breathing Easier.</u> World Resources Institute).**

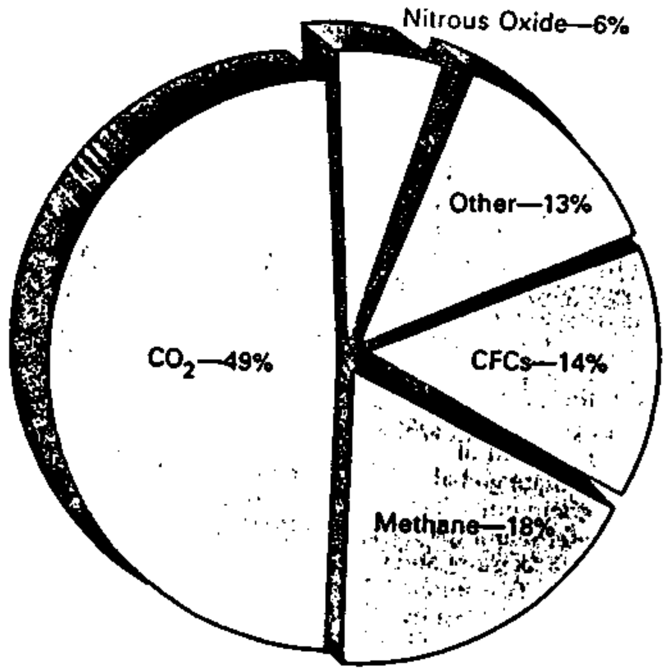


Figure 3. Manmade contributions to the Greenhouse Effect (from <u>EPA Journal.</u> Vol. 15).

A Key Question in
Dealing (Adjusting or Mitigating) with Climate Change is:

"How will it develop over time?"

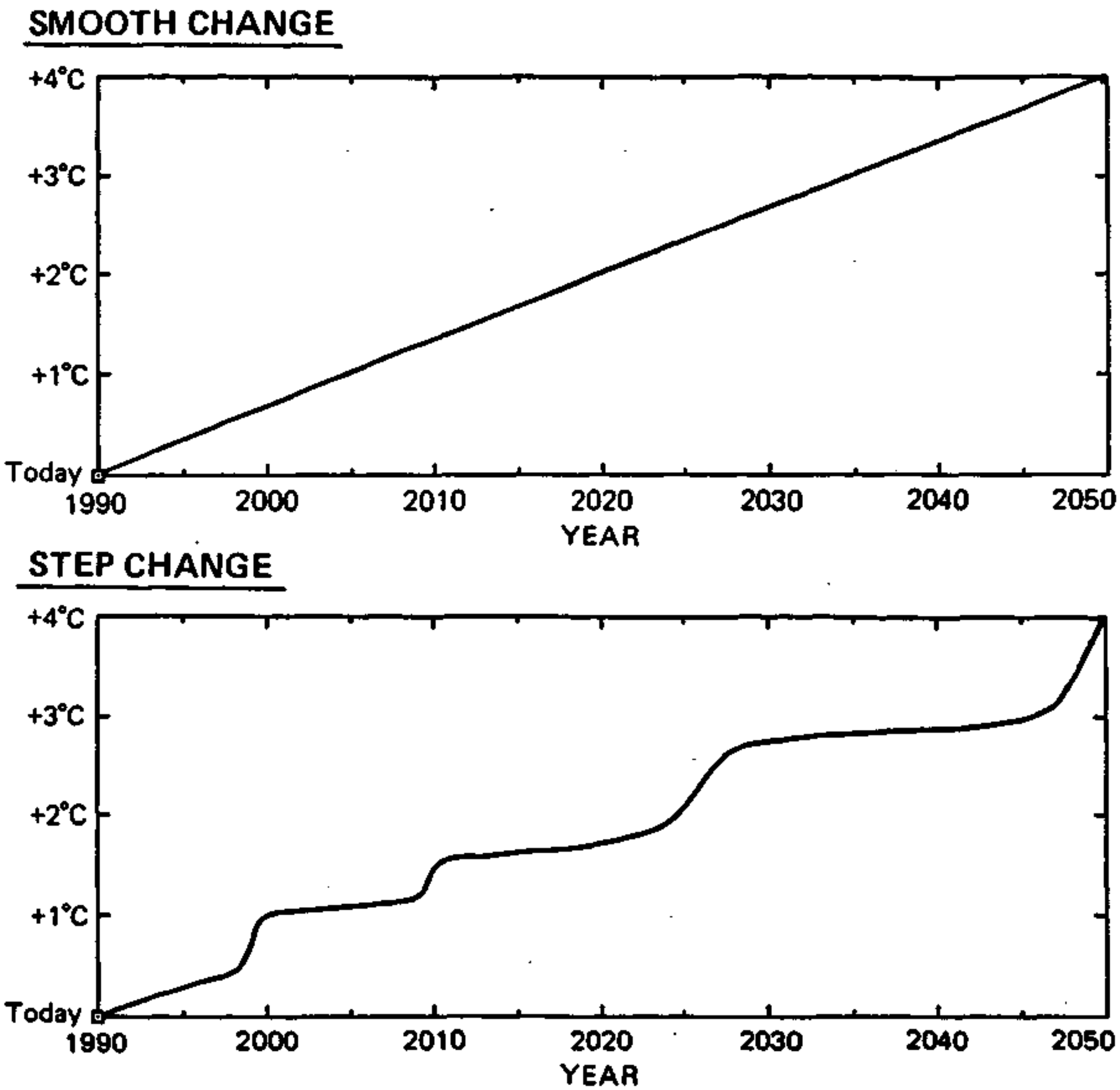


Figure 4. Possible ways that climate will change over the next 60 years.

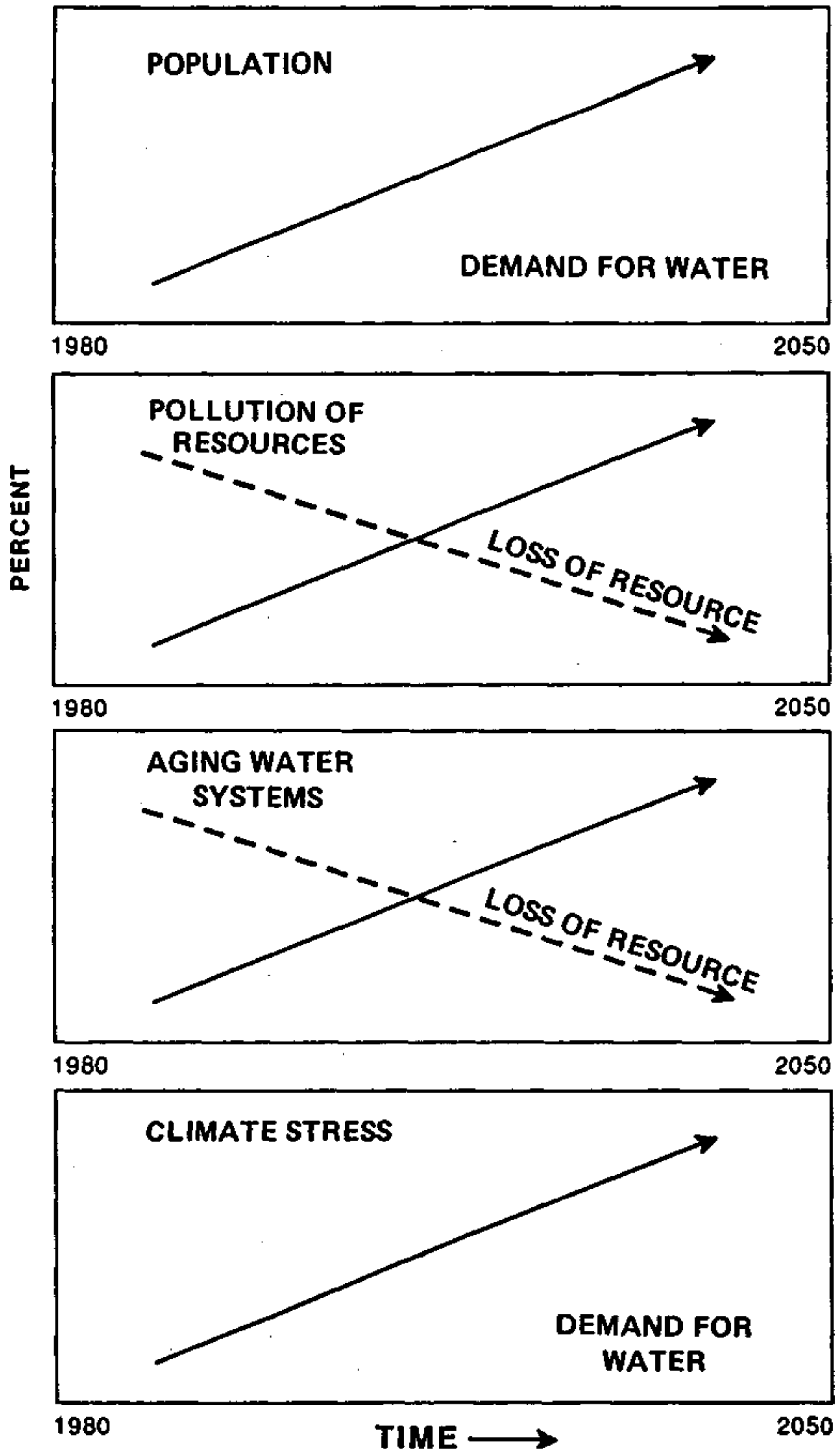


Figure 5. **Factors affecting available water supplies and demands for water.**

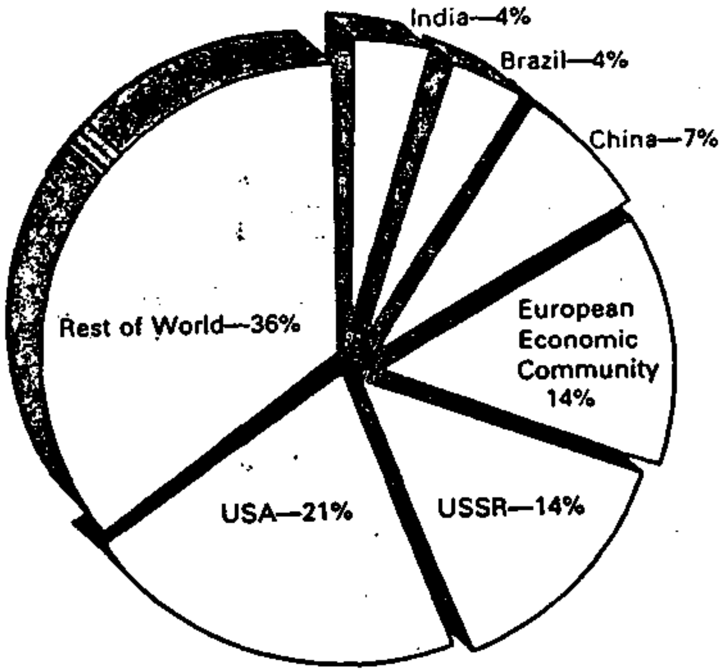
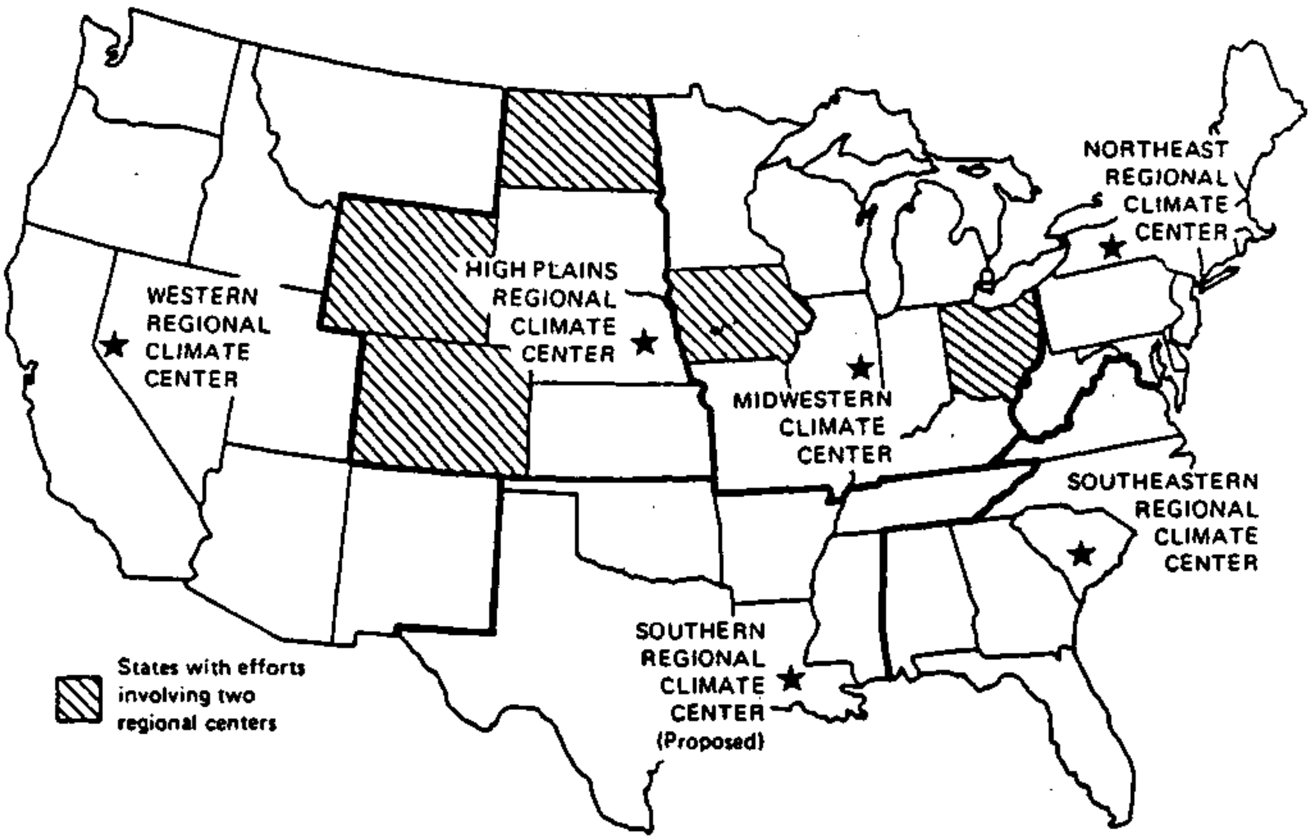


Figure 6. Regional contributions to the Greenhouse Effect (from EPA Journal. Vol. 15).



BOUNDARIES OF EXISTING AND PROPOSED REGIONAL CLIMATE CENTERS. BASED ON RESPONSIBILITIES FOR MAINTAINING REGIONAL DATA BASES

Figure 7. The National Network of Regional Climate Centers.

A SURFACE ENERGY BUDGET VIEW OF THE 1988 MIDWESTERN UNITED STATES DROUGHT[1]

by
Kenneth E. Kunkel
Midwestern Climate Center
Climate and Meteorology Section
Dlinois State Water Survey
University of Illinois
Champaign, IL 61820

Abstract

Measurements of the surface energy budget over an Illinois corn field during the summer drought of 1988 yielded Bowen ratio values around 1 compared to potential values of 0.2-0.3 if soil moisture had not been limiting. An analysis of the atmospheric water vapor budget for the upper midwestern United States suggests that the measured decrease in evapotranspiration was significant and may have played a role in the persistence and severity of the drought by reducing the atmospheric water vapor supply and increasing the atmospheric heating rate.

1. Introduction

The fundamental causes of the initiation and maintenance of drought are not entirely understood, as evidenced by our inability to predict its onset and termination. However, droughts usually are accompanied by hemispheric anomalies in general circulation patterns. These, in turn, may be driven partly by surface characteristics such as anomalies in sea surface temperature or snow and ice cover (Namias, 1983). However, after a period of time, a drought will necessarily effect changes in the surface energy budget through depletion of soil moisture reserves. These changes may, in turn, affect circulation patterns and may reinforce the drought patterns (Namias, 1960). A number of numerical modeling experiments have demonstrated the effect that soil moisture anomalies have on climatic patterns (e.g., Walker and Rowntree, 1977; Shukla and Mintz, 1982; Rind, 1982; Rowntree and Bolton, 1983; Yeh et al., 1984; Delworth and Manabe, 1988). In the case of the central United States, these experiments generally show that a reduction in surface evapotranspiration (ET) significantly reduces mid-summer precipitation and raises surface temperatures in this highly productive agricultural region. Thus, the development of soil moisture anomalies may result in a positive feedback or self-reinforcing process that aids in the maintenance of drought

The midwestern drought of 1988 provided an opportunity to monitor the effects of a severe drought on the surface energy budget. To this end, an experiment was set up in a corn field in east-central Illinois. The purpose of this experiment was to quantify the changes in sensible and latent fluxes which occur in a major drought and estimate the possible impact on mid-summer precipitation. A preliminary analysis of these measurements is presented here.

[1]Submitted for publication to Boundary Layer Meteorology. February 1989.

2. Experimental Method

The field site was located near Champaign, Illinois at 40°6'N, 88°14'W with an elevation of 228 m. A National Weather Service cooperative observer climatological station (Urbana) is located about 600 m from the field site. The dimensions of the field are 400 m (east-west) by 320 m (north-south). The experimental equipment was located 190 m from the east edge and 190 m from the south edge. This position in the middle of this mainly level field provided good fetch conditions for all wind directions.

Measurements of sensible and latent heat fluxes were obtained using the eddy correlation technique. Vertical wind, temperature, and water vapor fluctuations were measured using a sonic anemometer, fine-wire thermocouple, and Krypton hygrometer, respectively, manufactured by Campbell Scientific, Inc. A number of other meteorological variables were measured including incoming solar radiation, temperature, relative humidity, precipitation, wind speed and direction, and soil heat flux. The eddy correlation sensors were sampled at a frequency of 5 Hz and measurements were averaged over ten minute intervals. In addition, neutron probe measurements of soil moisture were made once a week at the location of the eddy correlation equipment.

The eddy correlation sensors were placed at a height of 2.4 m above ground level. The height of the corn canopy varied from 1.0 m at the beginning of the experiment (June 30) to 1.4 m at the end (August 18). The leaf area index in the vicinity of the equipment varied from 1.0 at the beginning of the observational period to 1.7 at the end. The unusually slow corn growth reflected the effects of the drought. Data were obtained on a total of 17 days and were usually restricted to daytime hours.

3. Results

a. Surface energy budget

Table I shows the Urbana monthly precipitation and temperature data for the period January-August 1988 compared with the climatological averages. During a critical part of the growing season (April-August), the total precipitation of 211 mm was only 43% of the normal for that period. Temperatures were 1.1°C above normal. Daily maximum temperatures exhibited larger departures, averaging 2.8°C above normal.

The measurements of sensible (H) and latent (LE) heat fluxes were used to calculate the Bowen ratio (B = H/LE). In addition, a potential Bowen ratio (B_p) i.e., that which would occur if evapotranspiration occurred at the potential rate, was calculated following Thorn (1976):

$$B_p = \frac{r_{st} + r_a - r_i}{(\Delta/\beta)\, r_a + r_i} \qquad (1)$$

where

$$r_i = \frac{c_p}{\beta} \, \frac{e_s(T) - e}{(R_n - G)} \qquad (2)$$

$$r_a = \frac{[\ln (z-d)/z_o]^2}{k^2 U}$$

r_{st} = stomatal resistance (a constant value of 50 s m^{-1} was assumed)
c_p = heat capacity of air at constant pressure
Δ — slope of the saturation water vapor pressure vs. temperature curve
β = psychrometric constant
e_s (T) = saturation vapor pressure at air temperature T
e = water vapor pressure
R_u = net radiation
G = soil heat flux
z = height
d = displacement height = 1.1 m
z_o = roughness height = 0.07 m
U = wind speed
k = von Karman constant

R_n was estimated from the solar radiation measurements following the approach of Weiss (1983), which treats the individual components of the radiation budget separately and then combines them. The albedo was set equal to 0.23.

Table I. 1988 monthly total precipitation (mm) and mean temperature (°C) compared with the climatological averages for Urbana climatological station.

Month	1988 Precipitation (mm)	1951-1980 Average Precipitation (mm)	1988 Precipitation (°C)	1951-1980 Average Temperature (°C)
January	55	50	-4.6	-4.1
February	33	48	-4.4	-1.5
March	64	84	4.2	3.9
April	38	98	10.8	11.3
May	39	91	18.6	17.1
June	8	100	23.0	22.2
July	93	111	25.6	24.0
August	33	93	25.0	22.9

Figure 1 shows daily precipitation, maximum temperature, minimum temperature, and average water vapor pressure from the Urbana climatological station for the period June 15 - August 25. During this period, there were only 2 days on which more than 10 mm of rain were received. Daily maximum temperatures reached or exceeded 35 °C on 21 days. During the early part of this period, both water vapor content and daily minimum temperatures were unseasonably low, but more seasonable values of both variables were experienced during the latter two-thirds of this period.

Figure 1 also shows a plot of B and B_p averaged over the midday period of 0800-1600 CST on measurement days and the weekly soil moisture measurements for three layers (0-15 cm, 15-50 cm, and 50-100 cm). These measurements are expressed as a percentage of the plant available soil moisture. At the beginning of the experiment, soil moisture was very low in the top layer with no available water for plants. The values rose in response to the July rains, but fell again in August. In the lower two layers, soil moisture was also low and fell continually with little available by the end of the period.

During the first half of July, measured Bowen ratio values were much higher than the potential values, indicating higher sensible heat and lower latent heat fluxes than would be expected over a well-watered surface. The rain in late July lowered the Bowen ratio to near the potential value during the last week of July (although $B < B_p$, this may be the result of uncertainties in the measurements or in the calculation of B_p). However, the dryness after July 25 resulted in an eventual return to high Bowen ratios as measured in mid-August. During both the early July and mid-August periods, the corn was severely wilted, indicating moisture stress.

b. Implications for atmospheric energy and water budgets

It is interesting to consider the impact of this change in the surface energy budget on the overlying atmosphere. The difference between the measured and the potential ET was integrated over the daytime period. During the first half of July and the middle of August, the calculated differences are the equivalent of about 2.5 mm/day or 75 mm/month. This value is about two-third's as large as the long-term average precipitation rate for July (see Table I) and is about half of its potential ET.

A similar calculation was made for the sensible heat flux, integrating the differences between measured and potential values over the daytime period. Again focusing on early July and mid-August, the calculated differences represent an excess local atmospheric heating rate of about 4 MJ/m^2/day. Assuming that this energy is uniformly distributed over a mixing depth of 2 km (e.g., Kaimal et al., 1976), this represents a temperature increase of about 2°C/day in excess of normal heating.

A cursory examination of the atmospheric water budget during mid-summer points to the importance of ET as a source of water vapor. Two studies (Rasmussen, 1968; Portis and Lamb, 1989) of July upper air data provided relevant vertical profiles of monthly average convergence/divergence of water vapor. Rasmussen's (1968) study covered the entire eastern United States for 1961 and 1962 while the Portis and Lamb (1989) analysis was restricted to the heart of the U. S. corn belt (a box bounded by 81.0° W, 97.0° W, 36.5°N, and 44°N) for the years of 1975, 1976, and 1979. The contrasting rainfall patterns of these years are described in Peppier and Lamb (1989). Rasmussen's (1968) analysis showed a net convergence of water vapor over the eastern United States for the 100-90 kPa layer with divergence above 90 kPa. The Portis and Lamb work was less conclusive showing divergence throughout the profile in two years and lower level convergence in only one year.

A general monthly water budget will then be written as

$$\frac{w}{t} = C_l + ET - D_u - P \qquad (3)$$

where w = mean water vapor content in vertical column
C_1 = integral of water vapor convergence at lower levels
D_u = integral of water vapor divergence at upper levels
P = precipitation

Since changes in mean water vapor concentration are small during mid-summer, lower level convergence and ET must be approximately balanced by upper level divergence and precipitation. Table II summarizes the relevant results of the two studies. Areally-averaged values of precipitation were calculated. An estimate of ET, calculated as a residual of C_1, D_u, and P, is also given. The average value of the ET estimates is very close to the average July free water surface evaporation (140 mm) obtained by Farnsworth et al. (1982) at the Urbana site. The results in Table II suggest that ET is the major source of mid-summer water vapor in the Midwest with lower level convergence (import) being much smaller. Therefore, interannual variations in mid-summer ET caused by soil moisture anomalies clearly have the potential to significantly affect precipitation.

Table II. Water vapor budget estimates (mm/month).

Month	C_l(layer)	D_u (layer)	P	ET
July 1961, 1962 (Rasmussen)	10 (100-90 kPa)	32 (90-25 kPa)	124	146
July 1975 (Portis and Lamb)	0	91 (100-30 kPa)	56	147
July 1976 (Portis and Lamb)	0	58 (100-30 kPa)	84	142
July 1979 (Portis and Lamb)	13 (92-78 kPa)	37 (100-92 kPa) & 78-30 kPa)	129	153
Average	6	55	98	147

The severe dryness of the early part of the growing season was widespread in the Midwest For instance, the states of Michigan, Ohio, Indiana, Illinois, Wisconsin, Iowa, Missouri, and Minnesota received less than 50% of their average precipitation during May and June (see Figure 2). Thus, large areas had experienced unseasonably large depletion of soil moisture reserves prior to the July-August period of maximum moisture demand. Therefore, the results presented here are qualitatively representative of a very large area, perhaps 2×10^6 km^2.

4. **Conclusions**

It is difficult to separate the effects of global scale atmospheric forcing and regional scale surface layer forcing on atmospheric circulation patterns. However, the measured changes in the surface energy budget during the 1988 drought appear to be sufficiently large to constitute a significant element in reduction of precipitation and the observed persistence of the 1988 drought. The reduction in ET was significant when considering the overall mid-summer atmospheric water vapor budget and may have extended the period of deficient precipitation. The increase in sensible heating significantly increased near-surface air temperatures and presumably contributed to the maintenance of the upper level ridge which was a dominant feature of the synoptic situation during the summer.

This year was unusual in the unprecedented intensity of the spring dryness in the corn belt and therefore the observed 1988 reduction in ET may be a rare event. However, the observed summer weather was qualitatively similar to some GCM scenarios for the future midwestern climate under "greenhouse" warming conditions (e.g., Schlesinger and Mitchell, 1985). The water vapor budget analysis in this paper strongly suggests that a proper treatment of the surface energy budget/soil moisture problem is critical to the development of scenarios for future mid-summer precipitation.

5. **Acknowledgements**

I thank Diane Portis and Peter Lamb for supplying their vertical profiles of water vapor convergence/divergence and James Angel for his assistance with the field measurements and the data analysis. I also thank Peter Lamb and Scott Isard for their reviews of this manuscript. Parts of this work were supported under NSF Grant ATM 85-20877 and NOAA Grant NA87AA-0-CP119.

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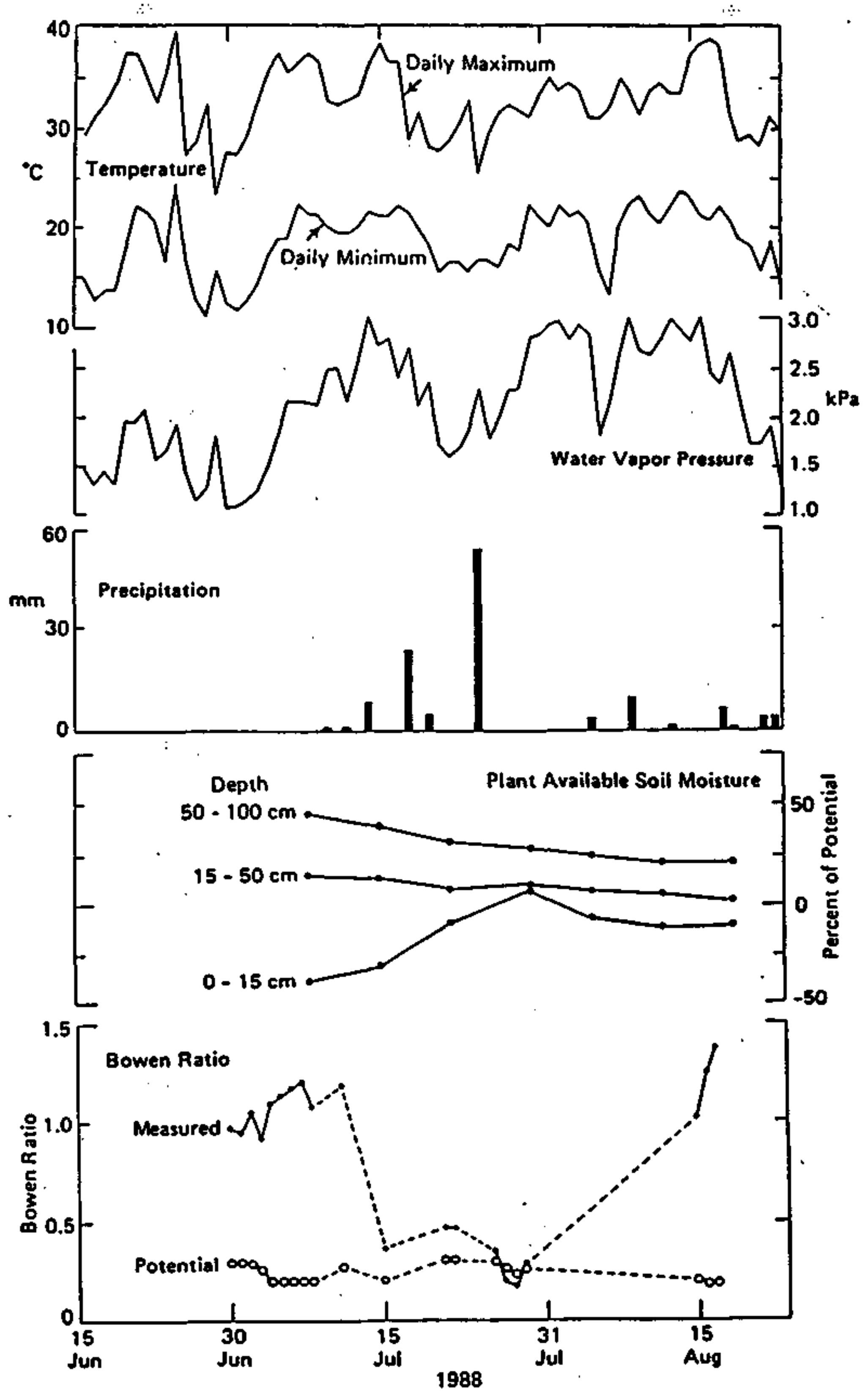

Figure 1. Daily values of maximum temperature, minimum temperature, water vapor pressure, soil moisture content, measured daytime Bowen ratio, and calculated values of the daytime potential Bowen ratio. Dashed lines indicate that there were missing days between measurements. Soil moisture is expressed as a percent of the plait available soil moisture where 100% represents the drained upper limit and 0% represents the wilting point.

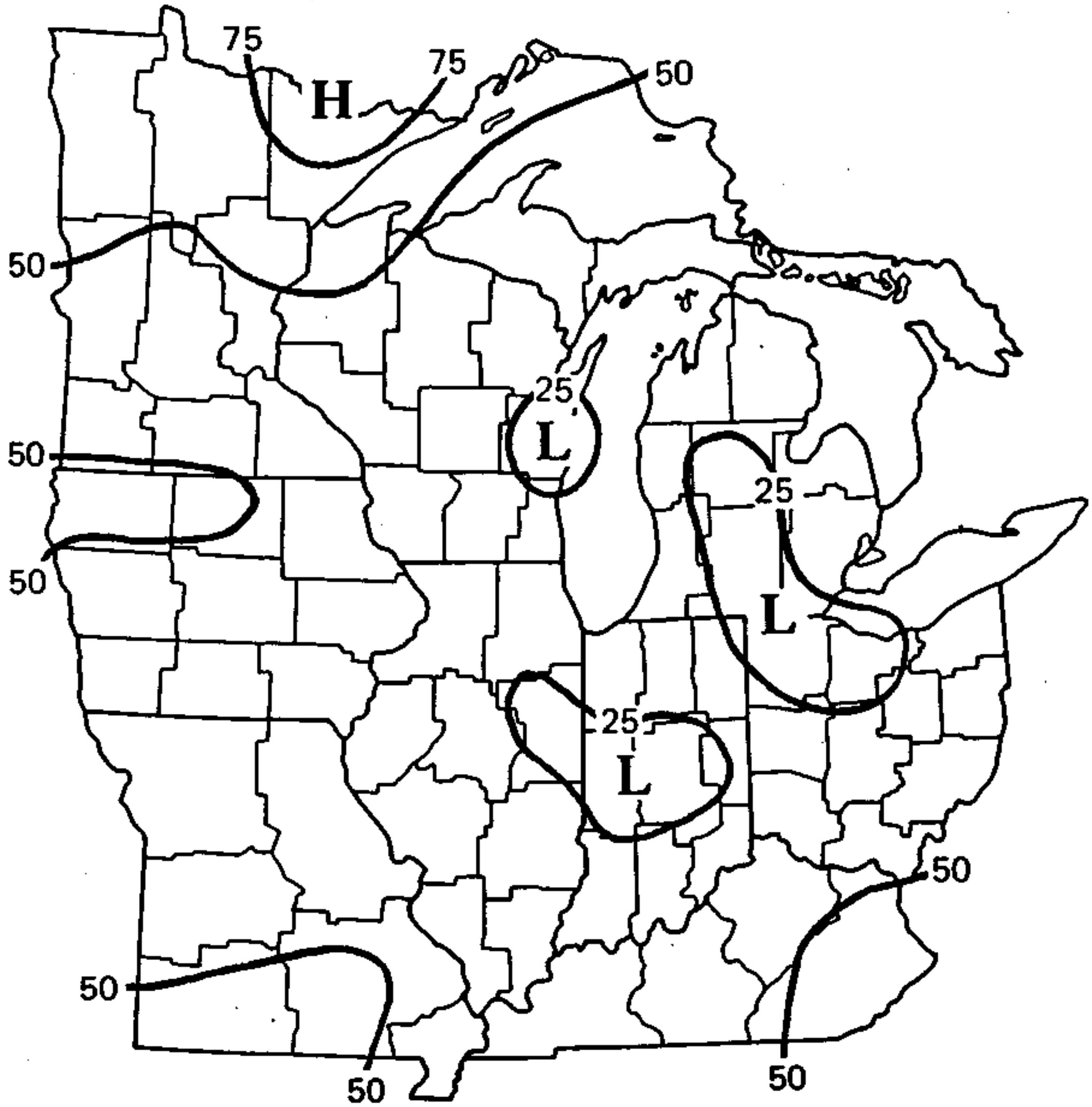

Figure 2. Spatial patterns of midwestern United States precipitation for May-June 1988 expressed as a percent of the 1951-1980 normals.

A PERSPECTIVE ON THE 1988 MIDWESTERN DROUGHT

by
Kenneth E. Kunkel and James R. Angel
Midwestern Climate Center
Climate and Meteorology Section
Illinois State Water Survey
University of Illinois
Champaign, IL 61820

1. Introduction

The drought of 1988 had widespread impacts in the midwestern United States. Crop yields were reduced significantly. Barge traffic on the Mississippi, Missouri and Ohio Rivers was severely disrupted. Municipal water supplies in some communities were reduced to critically low levels. In the face of these and other serious impacts, it is worthwhile to examine the climatological severity of this drought. For instance, was this drought comparable to the worst droughts in this century, as was frequently stated in news reports? Or, alternatively, were these serious impacts at least partially the result of a lack of flexibility in our socioeconomic system and in the experience of decision makers to adapt to serious drought

This analysis encompasses the nine-state region of Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. This includes approximately 68% and 62% of the U. S.'s corn and soybean acreage, respectively (USDA, 1987). The analysis was based on the daily temperature and precipitation data collected by the National Weather Service's cooperative observer climatological network. This is a dense network that now includes about 1500 stations in the region, which corresponds to an average separation distance of about 30 km in an area of about 10^6 km^2. Each state is separated into 4-10 climate divisions. For some of the results presented here, climate division averages were used; this is simply the arithmetic average of all stations in that division. Historical climate division averages for individual months were obtained from the National Climatic Data Center (NCDC) for the period 1895-1987.[2] Region-wide (9-state) average values were estimated by calculating an areally weighted mean of the climate division averages.

2. Description of 1988 Drought

Table 1 shows the region-wide monthly precipitation for January-September of 1988 as a percentage of the 1951-1980 normal precipitation. Precipitation was somewhat below normal in the early part of the year, but deficits became larger as summer approached. May and June were extremely dry, with the region receiving only about a third of the normal

[2]Because of the lack of available digitized climate data for years prior to 1931, the climate division averages for that period were estimated by NCDC from statewide averages using regression formulae based on 1931-1982 data. These earlier climate division values are therefore somewhat less reliable.

rainfall. July was somewhat wetter as a result of rains in the last ten days of the month, but still significantly below average. August was near normal; however, most of this rainfall occurred in the latter half of the month, too late to be of significant help to crops. The most unusual feature of this drought was the extreme dryness in the spring. It is very unusual in the Midwest for a dry period of this length to occur in the spring. The practical impact on agriculture was that the early crop development in May and June rapidly depleted the soil moisture reserves. By July, when crops reached their stage of maximum moisture usage, soil moisture reserves were severely depleted.

Figure 1 shows the spatial patterns of precipitation as a percentage of the 1951-1980 mean for the prime growing season of April-August 1988. Virtually the entire area received less than 75% of average precipitation. An area in the heart of the corn belt, (eastern Iowa, northern Illinois and western Indiana) received less than 50% of average precipitation. The climate division averages for April-August 1988 were compared with the historical climatic division averages for the entire 1895-1987 period. Figure 2 gives the rank of April-August 1988 precipitation as compared with the 93 years of historical records. A rank of 1 indicates the driest. Of the 75 climate divisions, 55 have a ranking of 9 or lower, which puts 1988 in the driest 10 percentile of years for those climate divisions. Ten divisions experienced their driest April-August period on record. These were located in eastern Iowa, southern Wisconsin, northern Illinois, and western Indiana.

Figures 3 and 4 show similar rankings for two other periods, May-June and June-August, respectively. The May-June period was the driest of this drought episode while the June-August period constitutes the traditional summer season. About 50% of the entire 9-state region (41 divisions) experienced the driest May-June on record. More than 85% had values in the driest 10 percentile. The June-August period was relatively wetter. However, 26 divisions (36%) were in the driest 10 percentile with 5 divisions experiencing their driest June-August on record.

Figure 5 shows the deviation of average temperatures from the 1951-1980 mean temperatures during June-August 1988. Northern sections were typically 2-3°C above average, whereas southern sections were 1-2°C warmer than average. These mean values mask the fact that the daytime maximum temperatures were much more above their averages than were the nighttime minimum temperatures. Figure 6 gives the rank of 1988 temperatures compared to 1895-1987 historical data. A rank of 1 indicates the warmest on record. Fifteen divisions in the northwest sectors experienced their warmest summer ever, while 54 divisions were in the warmest 10 percentile (a rank of 1-9).

To provide an area-wide measure of the severity of the drought, region-wide precipitation averages were computed for the periods April-August, May-June, and June-August and compared with similar averages from the 1895-1987 historical data. A similar average was computed for June-August temperatures. Table 2 lists the driest 10 years for the three periods and the warmest 10 years for June-August The year 1988 appears high on each list. In fact, for the May-June period, 1988 was easily the driest year of the 94-year record. For the other two periods, only a few of the 1930's drought years were drier. In terms of summer temperatures, only 1936 was warmer.

A common measure of drought severity is the Palmer Drought Severity Index. For each drought episode of this century, the month with the maximum number of climate divisions in the severe or extreme drought category was chosen and ranked according to the number of climate divisions in severe or extreme drought (Table 3). In only three previous drought episodes have there been more extensive areas of severe or extreme drought.

The prominent position of 1988 on these lists, along with the results presented in Figures 1-6, lead to the following conclusions:

1. The 1988 drought was the worst short-term drought in the Midwest since 1936.

2. In this century, only the droughts of 1930, 1933, 1934, and 1936 have equalled or exceeded the combination of heat and dryness experienced in 1988.

3. Some of the driest areas in 1988 were in the heart of the corn and soybean belt

3. Climatological Probabilities of Drought Recurrence

The drought continues to have impacts on water supplies in the fall and winter of 1988-1989 with river flows and reservoirs well below seasonal averages. Although top soil moisture levels have rebounded in some areas, other areas (particularly Iowa, northern Missouri, western Illinois, and southern Minnesota) have received below normal cool season precipitation. It is therefore meaningful to ask what are the chances for recurrence of summer drought in 1989. Since current precipitation forecasting techniques are not reliable beyond 3 months, an analysis of the historical data was performed. For each climate division, precipitation data were separated into 3 equally probable categories: above normal (wettest 1/3 of years), normal (middle 1/3 of years), and below normal (driest 1/3 of years). For the 30 driest summers (excluding 1988), we counted the number of times that the following summer experienced precipitation in each of the 3 categories. Figure 7 shows the result in terms of the probability for a below normal summer to follow a below normal summer. If the process were random, then the expected value would be 33%. Much of the region have probabilities in the 30-40% range. Parts of northern Wisconsin, western Missouri, and western Minnesota have probabilities of greater than 40%. However, because of the small number of samples (30), a chi-square analysis indicated that only values of around 50% or higher are statistically significant (at the 10% level). No areas have statistically significant probabilities of back-to-back dry summers. Although not shown, there also were no areas experiencing statistically significant probabilities for wet summers to follow dry summers. If we restrict our attention to the four driest past summers (1936, 1930, 1933, and 1976), the following summer was dry in two cases (1931 and 1934), normal in one case (1937), and wet in one case (1977); again, there is no strong tendency. In summary, there is no strong indication in the climate record as to the potential conditions following a summer drought

4. Conclusions

In conclusion, the drought of 1988 was of historic magnitude in the Midwest - the worst in over 50 years. In this context, it is not surprising that the physical environment was severely impacted and that parts of our socioeconomic system functioned poorly during the drought. However, the drought illustrated our vulnerability and lack of flexibility to extreme drought conditions.

5. References

United States Department of Agriculture, Agricultural Statistics 1987. United States Government Printing Office, Washington, DC, 1987.

Table 1 - 1988 monthly average precipitation for a nine-state midwestern region expressed as a percentage of normal precipitation.

Month	% Normal Precipitation
January	94
February	89
March	77
April	68
May	45
June	28
July	78
August	100
September	110

Table 2 - Driest and hottest years for various periods in a nine-state midwestern region.

Precipitation (mm)						Temperature (°C)	
April-August		May-June		June-August		June-August	
276	1936	80	1988*	161	1936	23.5	1936
309	1930	106	1936	180	1930	23.2	1988*
319	1934	120	1934	186	1933	23.2	1934
321	1988*	152	1911	221	1988*	23.2	1901
339	1901	152	1966	221	1976	23.1	1921
359	1976	154	1901	226	1913	22.9	1983
384	1971	155	1922	226	1910	22.8	1933
386	1925	157	1910	228	1901	22.7	1955
391	1913	159	1987	228	1922	22.6	1949
392	1895	160	1972	232	1918	22.6	1931

Table 3 - Number of climate divisions in severe or extreme drought conditions according to the Palmer Drought Severity Index.

Month	Number of Climate Divisions
July 1934	64
July 1936	63
December 1930	58
August 1988*	54
January 1954	50
January 1964	48

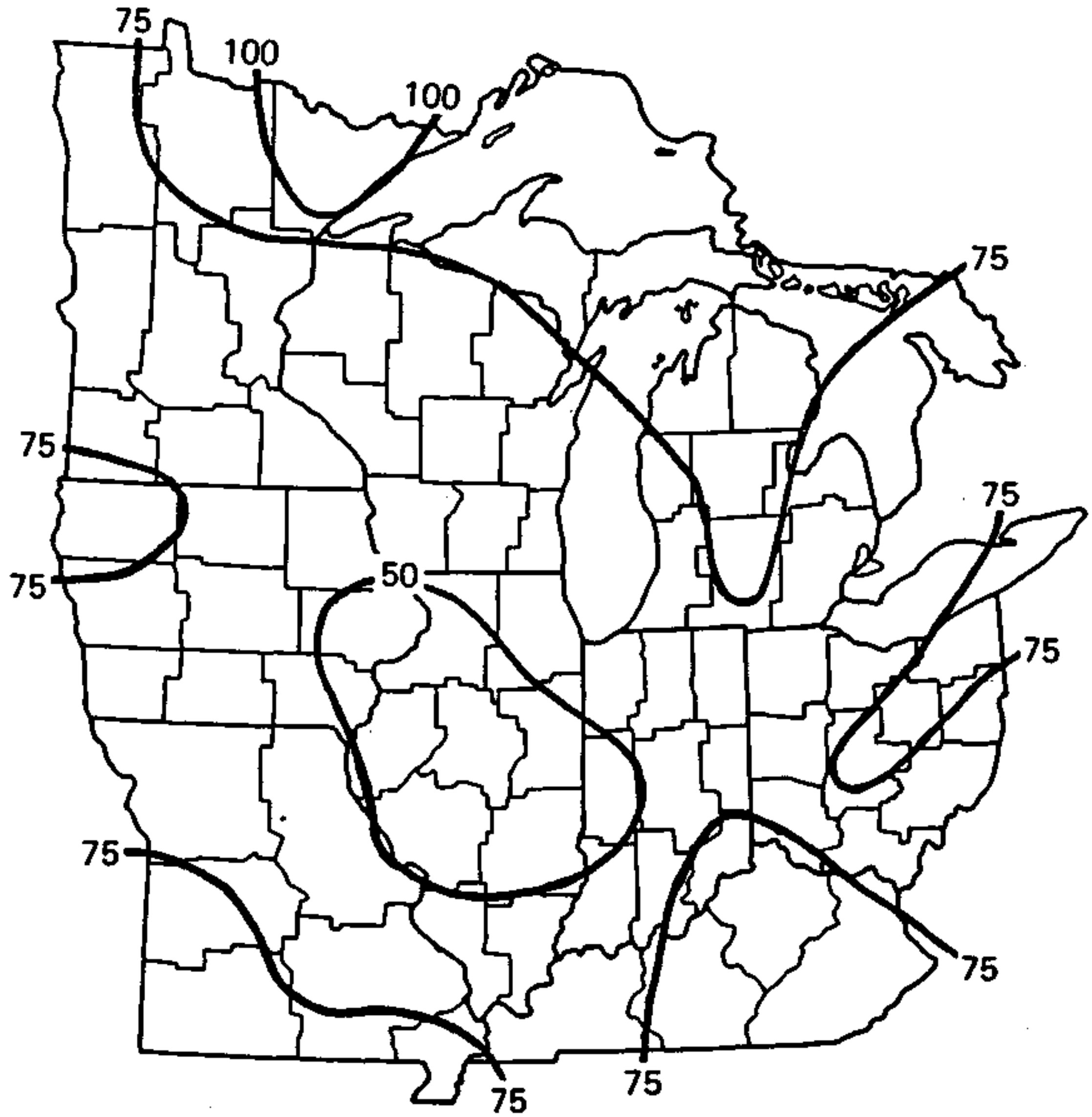

Figure 1. Percentage of normal precipitation for April-August 1988 in the Midwest.

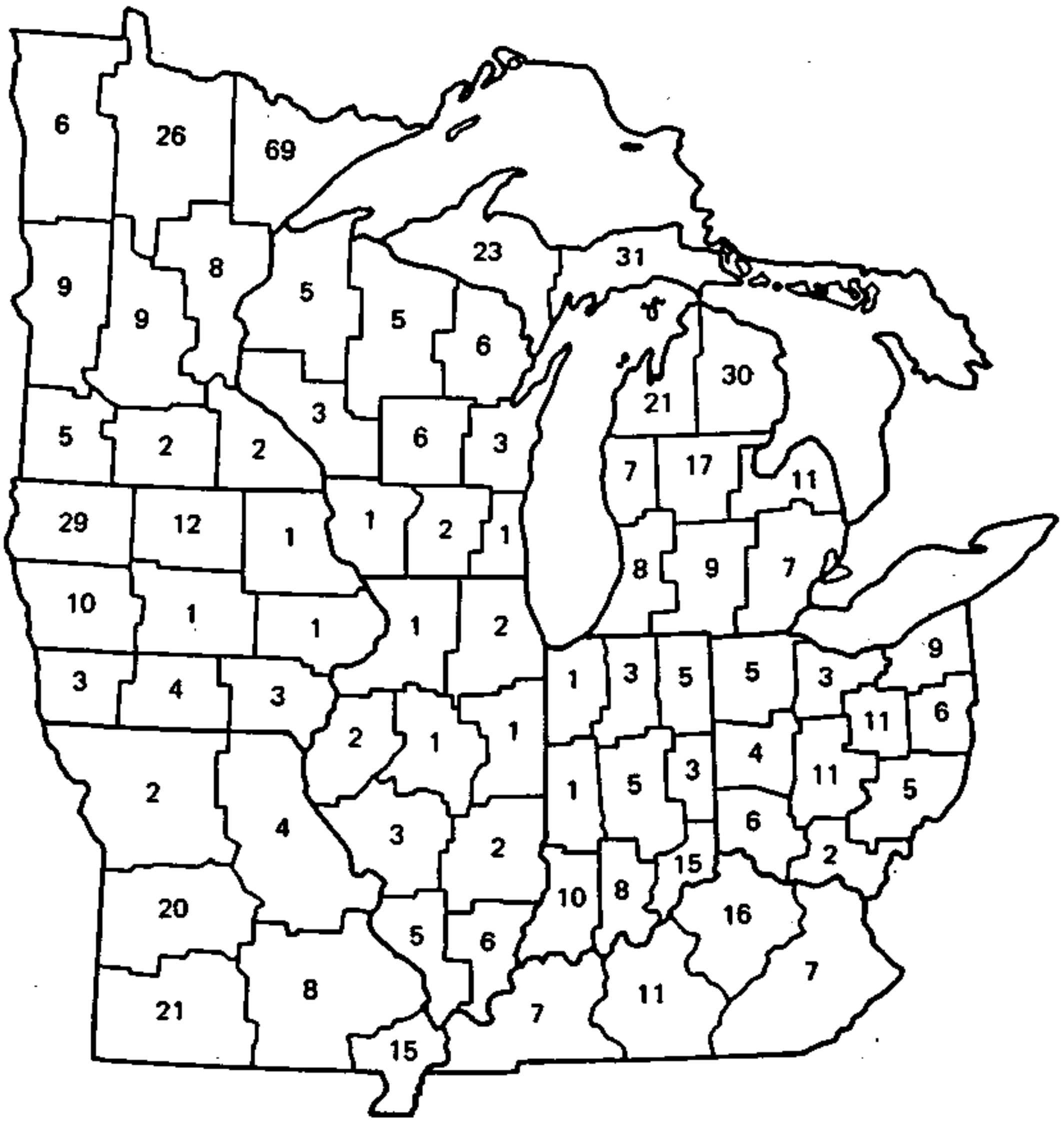

Figure 2. Rank of April-August 1988 precipitation compared to the 1895-1987 historical record. A rank of 1 indicates that 1988 was the driest year of the historical record.

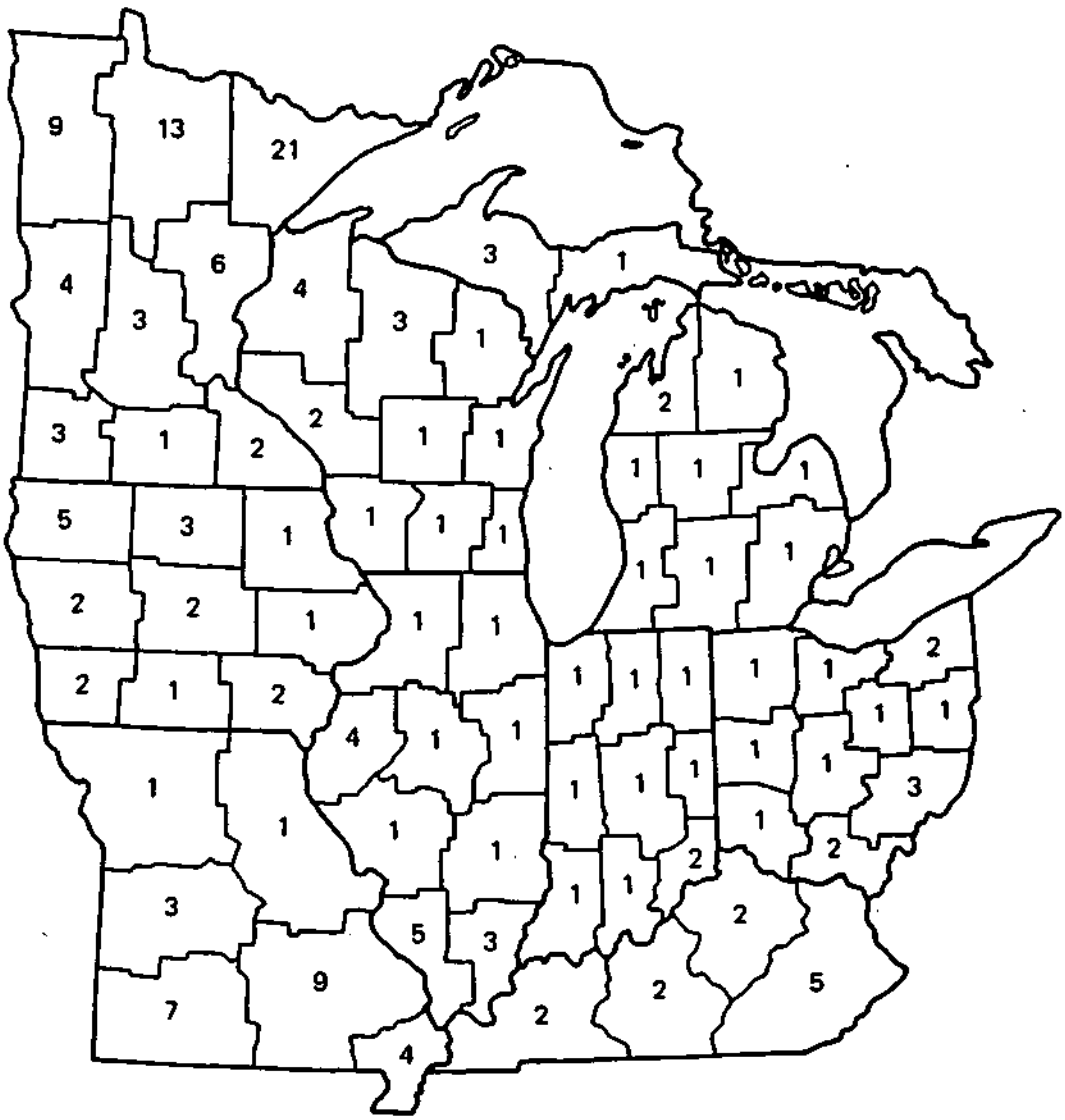

Figure 3. Rank of May-June 1988 precipitation compared to the 1895-1987 historical record. A rank of 1 indicates that 1988 was the driest year of the historical record.

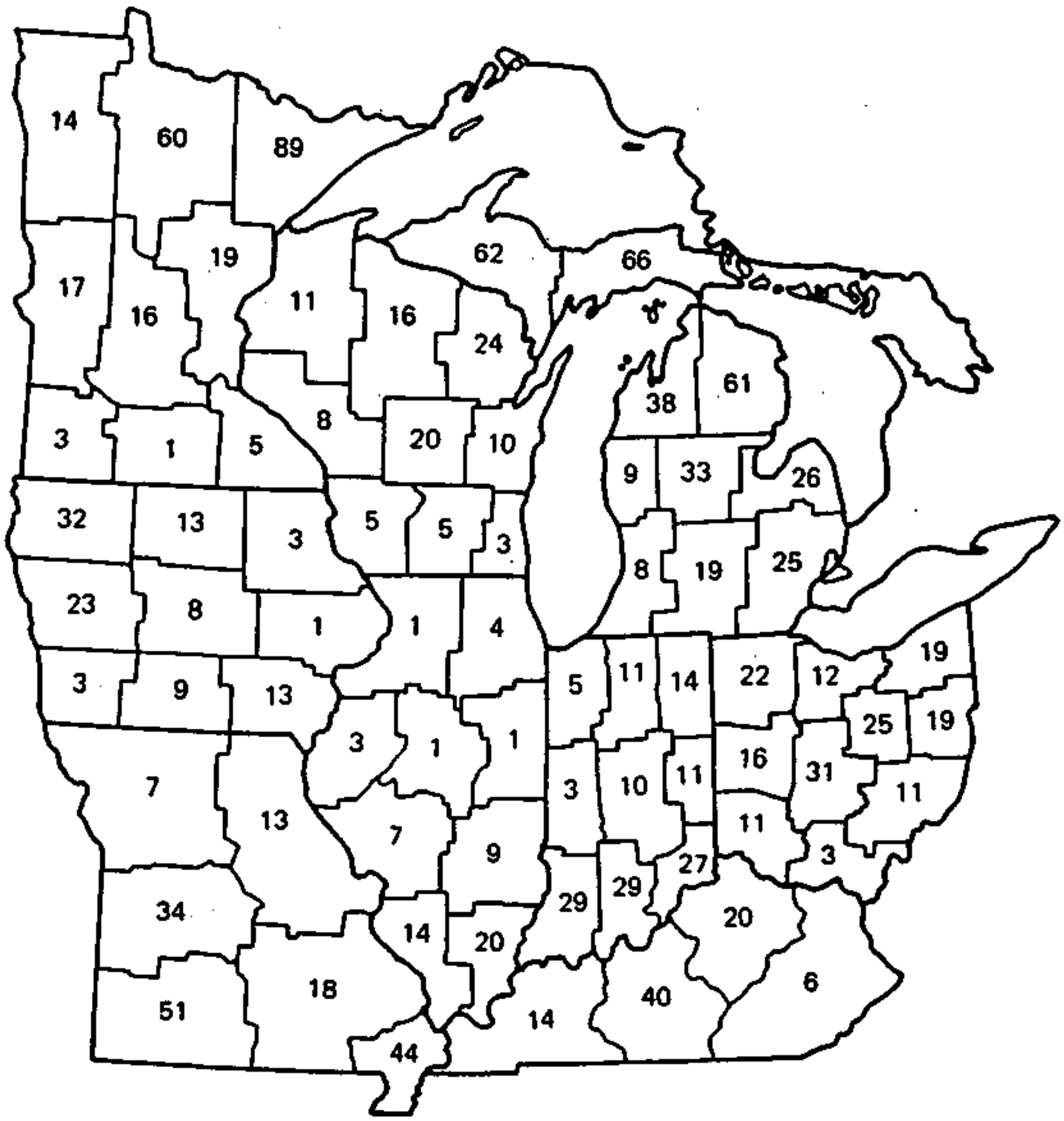

Figure 4. Rank of June-August 1988 precipitation compared to the 1895-1987 historical record. A rank of 1 indicates that 1988 was the driest year of the historical record.

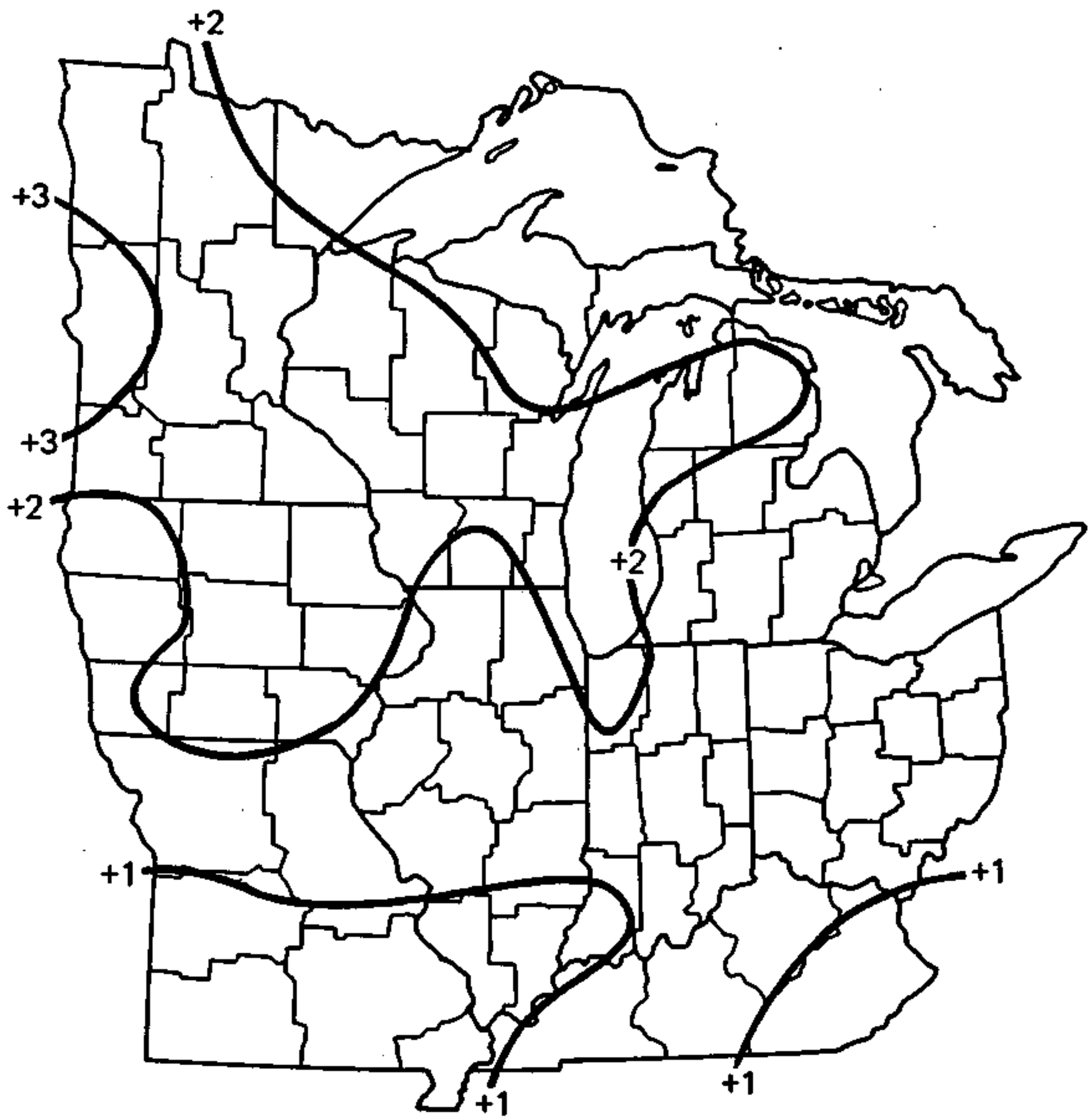

Figure 5. Deviation of the June-August 1988 temperatures from 1951-1980 averages for the Midwest.

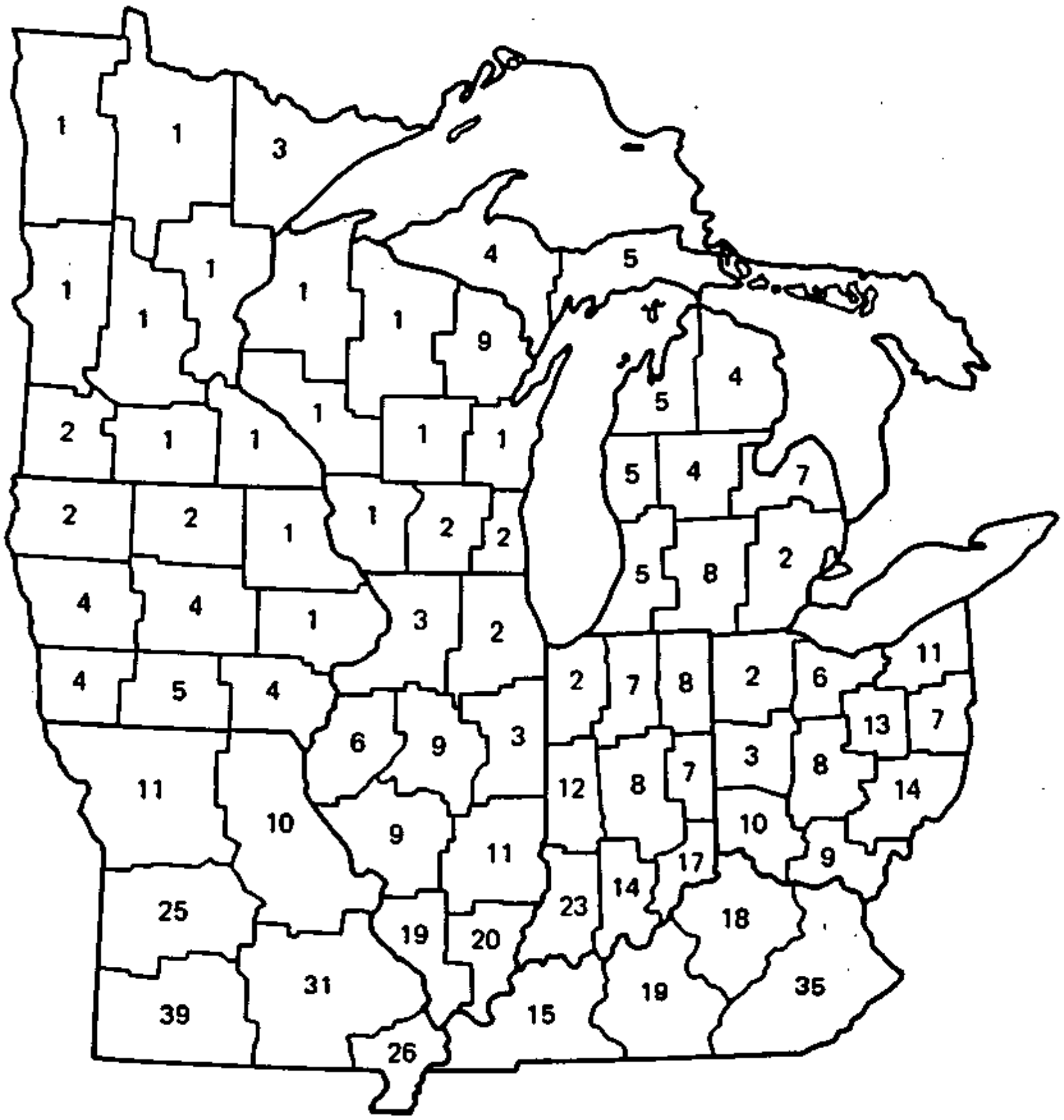

Figure 6. Rank of June-August 1988 temperatures compared to the 1895-1987 historical record. A rank of 1 indicates that 1988 was the warmest year of the historical record.

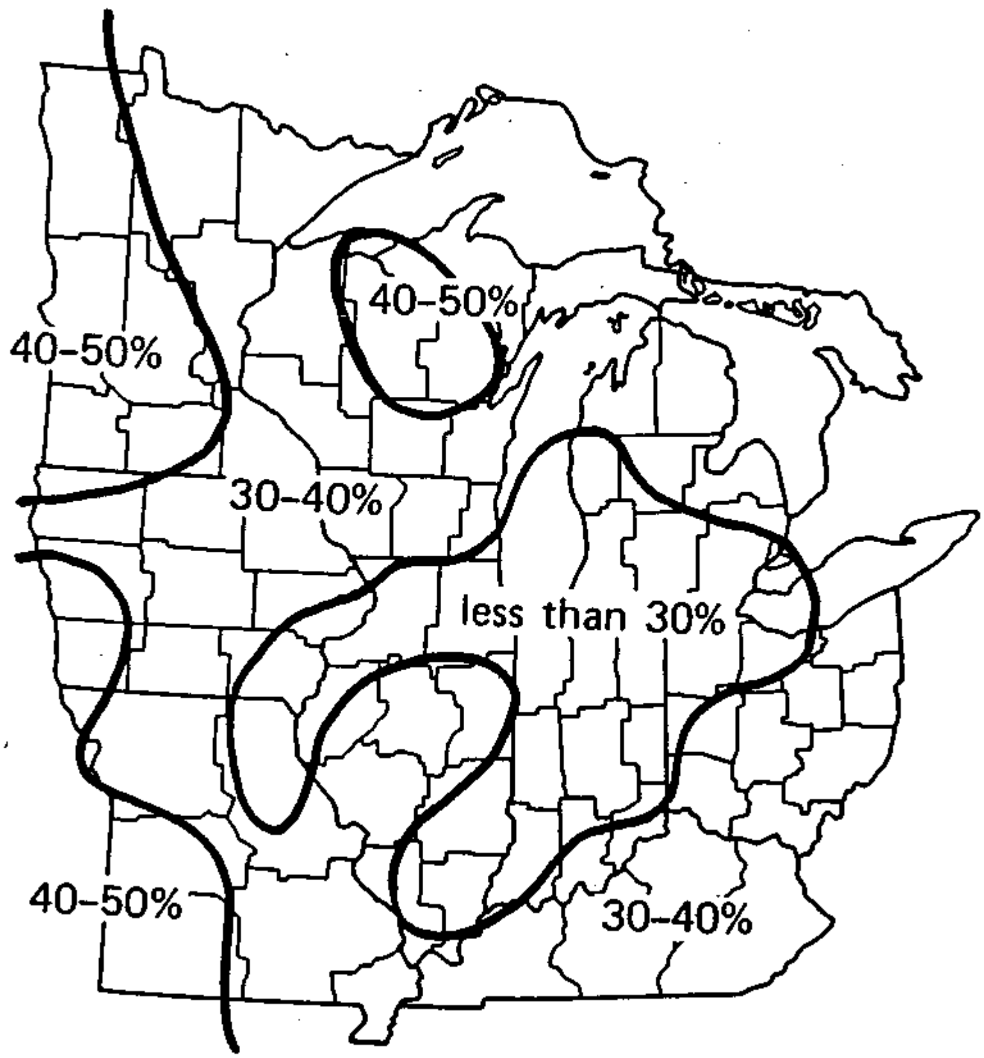

Figure 7. Probability of experiencing a dry summer following a dry summer. If there were no correlation, a value of 33% would be expected. Only values near and above 50% are statistically significant at the 10% level based on chi-square analysis.