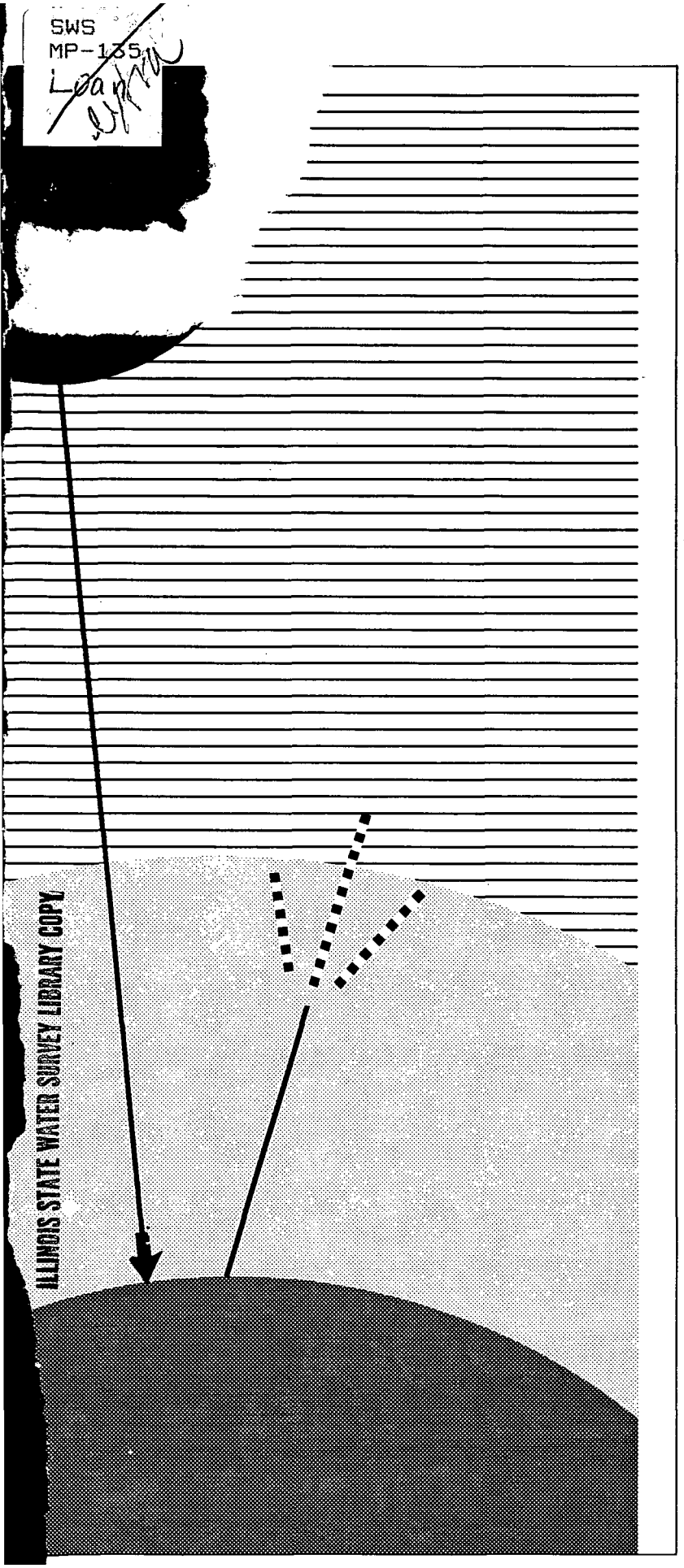

The Plan for the Illinois Global Climate Change Program

A Program To Provide Illinois with Comprehensive Information about Climate Change and Its Impacts on Illinois

Illinois State Water Survey
Champaign, Illinois

Stanley A. Changnon,
Program Director

November 1991
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OVERVIEW

This document presents a comprehensive plan for future research, monitoring, and informational efforts related to Global Climate Change and its potential impacts on Illinois. This plan has been prepared to help develop and guide the research and related monitoring endeavors at the Illinois State Water Survey. These research endeavors are designed for pursuance by Survey staff and by scientists at allied institutions and universities interested in jointly conducting the breadth of interdisciplinary investigations necessary to address this complex issue.

As a blueprint for future climate change research, monitoring, and informational activities, this plan is considered a "living document" That is, it will be updated every other year to keep its contents timely, both as to future plans and the progress on current activities.

This document is for use by three audiences. The first group is the Water Survey staff, those who will use the plan to help guide and pursue future research endeavors relating to climate change. The second group is scientists at allied institutions and universities that will do research with Water Survey scientists. The document is also intended to inform those who support the program of the research and monitoring efforts. For these audiences, this plan serves an umbrella document describing the rationale for the Water Survey's research program and the breadth of the research and monitoring programs. The plan provides the total programmatic scope, allowing one to better understand how an individual research project fits within the total Water Survey program addressing Global Climate Change.

Much of the research planned involves an interdisciplinary approach needed to address and answer the complex issues presented in the research agenda. This approach is particularly essential because significant parts of the research are focused on ascertaining the potential impact of weather and climate on various physical and socioeconomic systems. Conduct of such research efforts necessitates involvement of atmospheric scientists, chemists, hydrologists, and scientists of other disciplines.

The design of the Water Survey's Global Climate Change Program has been a staff effort. The dimensions of the program evolved from a series of individual and group discussions involving every interested scientist at the Water Survey. Coupling the results of these interactions with knowledge of the importance of the climate change issue to Illinois, has been the basis for writing the plan. Indeed, it is a "staff action plan."

The major components of the Global Climate Change Plan, as described in the subsequent text, are: 1) the research projects to understand climate change and measure its impacts, 2) monitoring efforts to better detect climate change and its effects, and 3) an informational endeavor to transfer findings and provide guidance to the public and private sectors.

Before presenting the plans for these components, three relevant issues are addressed. A short discussion about why the climate change issue is important to Illinois

is followed by a description of the aims of the Program, and by an explanation of the Water Survey's qualifications for conducting a major program addressing the global climate change issue.

INTRODUCTION

What Is the Climate Change Problem?
The potential for a future, unexpected shift in global climatic conditions has become widely accepted in recent years. Effects of increasing atmospheric pollution coupled with the research findings generated from climate models have revealed this potential. These models indicate that global warming of 3 to 4°C could occur within 30 to 80 years. Current models further indicate that central North America, and hence Illinois, would likely undergo considerable warming in all seasons and shifts in precipitation, with the net effect being drying.

We have long known that the earth's climate is not static. For example, the area that Dlinois covers has experienced thick glaciers during the Pleistocene ice ages and semitropical climates in earlier geologic periods. The reality is that the climate is always changing on some erratic space and time scales that defy interpretation. We know the forces that control the climate of a place...the sun and the latitude, the nearness to oceans, and shapes and dimensions of land forms, but we cannot predict how their interactive behavior shapes the weather of future months or the climate of future decades.

There is now reasonable scientific consensus that the continued loading of the atmosphere with trace gases such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs), and other trace gases will cause the troposphere (the lower portion of the earth's atmosphere) to warm. As a consequence of this warming, climatic conditions throughout the world would change; less certain is the nature of these changes and when they would occur. Still less certain are the rates at which the atmosphere might warm; the attendant rate of change in climatic conditions; whether transient climate changes will occur (for example, cooling in a locale before it warms); and whether the climate might change so that the frequency and severity of extreme events such as droughts, storms, floods, and freezes might be altered. Despite these uncertainties, it is highly likely that greenhouse-forced warming could have significant impacts on hydrology and therefore water resources, unmanaged ecosystems, agriculture, forestry, and fisheries, and in turn on the societies and economies that depend Upon them. Although the impacts would likely be beneficial in some regions, there is a serious risk that the world as a whole might be considerably worse off. Prudence would argue that we should mitigate the risk of climate change, but some argue that adjustment will successfully occur regardless of what the climate brings.

One thing is totally certain—future climate conditions, regardless of whether the greenhouse effect occurs, will be different in all respects from conditions Illinois has experienced over the past 150 years. For example, the weather of the 1970s was unlike that experienced in the previous 130 years, and it is safe to predict that what happens in the 1990s will be different from anything experienced in the past. It is thus prudent and wise to plan for future shifts in the climate regardless of the causes. New daily, monthly, and seasonal extremes

will occur, and the degree of variability of conditions between years and between decades will change. It is simply good business to be prepared for future shifts in the climate.

Why Should Dlinois Be Concerned?
How does the climate change issue affect Illinois? The critical policy issue here, and everywhere, is to find the mix of adaptation and mitigation measures that maximizes net social benefits of the efforts to deal with climate change. The great uncertainty about the costs and benefits of these two approaches, and the political struggle among the various interests with a stake in the outcome ensure that the choices about the mix of strategies will be anything but clear cut. These efforts must be international in scope; and the United States, as a source of 25 percent of all trace gases released to the atmosphere by man, will be an important player in both national and international policies.

Illinois faces the twin issues of having its physical-biological systems severely impacted by climate change, and having its industrial complex regulated by nationally driven efforts to mitigate climate change. We must understand how varying climate conditions would impact our weather-sensitive systems if we are to make wise decisions relating to state, national, and international policy.

THE ILLINOIS GLOBAL CLIMATE CHANGE PROGRAM

Goal and Objectives
The Global Climate Change Program (GCCP) has been established at the Water Survey to provide accurate and timely information to Illinois, the Midwest, and the nation about the potential future state of the climate, and how altered future climate conditions would affect Illinois. From this information, the public and decision makers, in both the private and public sectors, can effectively address proposed national and international means to ameliorate climate change, or proposed prevention, and how Illinois could and should try to adapt to climate change. Two kinds of adaptation to climate change exist. One response includes all those things people would be induced to do within the existing institutional and policy regime. The other response consists of institutional and policy changes that would be called for where and when the existing regime proved inadequate to deal with the impacts of climate change.

The scientific information generated by the Global Climate Change Program is a sound basis for helping to develop policy relating to climate change issues, and for planning for the consequences of changed climates in the future.

Illinois has already moved forward on this issue in several ways. The Water Survey has studied the climate of the state since the late 1940s under its mandate "to monitor and study the atmospheric and water resources of Illinois." As a result, the state of Illinois has more information about its climate conditions than any other comparable region of the world. Unfortunately much more information is needed, particularly about how climate fluctuations affect our hydrologic and biological systems and the state's economy.

The *Illinois State Water Plan,* as generated in 1983 by the state's 12 water-interested agencies, identified climate change and

related fluctuations like droughts among the state's 11 emerging major water-related issues needing attention. This far-reaching plan called for better monitoring and enhanced study of the state's climate and its future fluctuations.

Several actions resulted. The Water Survey, with state and private-sector funding, established the finest automated weather network in the nation. One of its central functions is to help detect changes under a multitude of climate conditions. Since 1983, the Water Survey has also pursued special research projects addressing certain climate change issues. These projects have been largely funded by federal agencies through peer-reviewed scientific research proposals prepared by Water Survey scientists. Some 15 such research projects addressing various theoretical and applied aspects of the climate change issue have been funded over the past eight years. One area of emphasis has been to analyze past climate fluctuations and to begin to develop data sets to help estimate the range of possible future climates or climate scenarios.

Significant research progress has been made, but major information gaps remain, such as how the climate could fluctuate and how these fluctuations would impact Illinois. We must better assess the effects of potential climate changes on the hydrologic cycle and other biological systems of the state. Second, we must assess the range and types of socioeconomic impacts that would ensue as a result of the climate-induced changes in the physical-biological systems. These activities are well suited to the Water Survey, with its diverse staff of climatologists, hydrologists, chemists, and agricultural experts. The Water Survey also has adjunct staff members from the University of Illinois with expertise in economics, geography, atmospheric sciences, and agriculture. Multidisciplinary teams can be formed to conduct these often complex studies of climate effects and impacts.

We must also put into place as quickly as possible, systems to detect global changes. Detecting the onset of a climate change and its effects is of great importance to action. Detection is made difficult because of the normally large year-to-year variability in Illinois' climate conditions. Unique means for monitoring change must be developed, such as monitoring slowly changing deep soil temperatures and ground-water characteristics in zones protected from pumping effects. These systems must be devised, installed, and kept operating and monitored over the coming decades. Here again, Water Survey expertise in instrument development, measurement techniques, data collection, and data interpretation will be invaluable.

Finally, we must continually translate our findings about climate and its impacts to the public and affected communities in the state. The topics of climate change and the greenhouse effect are fraught with scientific debate and misinformation, and much confusion abounds. Everyone, including the public and state policy makers, must be adequately informed if this Program is to fulfill its promise.

The Program's goal is to provide for Illinois a center of expertise addressing the global climate change issue with a three-way focus, including studies of climate change and its effects, monitoring of

climate-related environmental changes, and the timely dissemination of information about the issue.

The **objectives** of the Program are:

- To gain improved understanding of the climate of Illinois
- To describe past fluctuations in the climate and hydrologic cycle and to predict possible future fluctuations
- To investigate anthropogenic influences on weather processes and ultimately on climate conditions
- To determine and quantify how climate fluctuations affect the hydrologic cycle and other environmental systems using interdisciplinary skills
- To predict how future climate shifts can and will alter land surfaces, the hydrologic cycle, agriculture, and other weather-sensitive sectors
- To assess the impacts of climate-altered conditions on the socioeconomic structure of Illinois and the Midwest
- To promptly provide information developed from the above activities to Illinois decision makers, the general public, and the scientific community

The Water Survey's Qualifications To Address Climate Change

The Illinois State Water Survey was established in 1895 to "survey the waters of Illinois." For the past 96 years, the Water Survey has pursued tasks in three major areas: the collection of data on water resources of Illinois, the study of these and other data, and the transfer and interpretation of these data to interested parties. The initial thrust of Water Survey activities was on water quality issues, including drinking water and sewage treatment. By the 1930s the Water Survey's central mission had shifted from water quality and treatment to assessment of water resources, both in surface waters and ground-water supplies. By the 1950s a third area of measurement and research had developed: study of the atmospheric portions of the hydrologic cycle, including weather conditions, the climate, and the atmosphere's chemistry.

Monitoring Efforts

As part of these activities, Water Survey scientists and engineers launched projects to make special measurements of hydrologic and meteorologic conditions. The Water Survey has:

- Supported the costs of a dozen long-term streamgage stations operated in Illinois since the 1920s
- Operated a statewide network of shallow ground-water measurement stations since 1958, and monitored ground-water levels in several hundred deep wells in urban areas
- Conducted lake sediment surveys for 40 years
- Established a network to monitor sediment in streams in 1970
- Operated 14 dense raingage networks in different state areas since 1948, often lasting 5 to 10 years per network

- Measured the chemistry of wet deposition in rainwater at seven sites since 1978

- Installed and operated since 1984 a statewide climate network of 19 stations that measure all relevant weather conditions plus soil moisture

- Monitored air and precipitation chemistry at a benchmark site in rural central Illinois since 1977.

These have been monumental undertakings, and they now provide Illinois with unique data for use in better understanding its climate and how the atmosphere affects the state. These databases are unmatched anywhere in the world.

Research Efforts

The climate databases and expertise of Water Survey climatologists led to the establishment of the Midwestern Climate Center at the Survey in 1987. This Center, funded by the National Oceanic and Atmospheric Administration, serves a nine-state area centered on Illinois. The Center provides data and expertise on climate issues, and performs research directed at regional problems such as the drought of 1988-1989. Its ten-person staff and unique climatic databases include all climate-related historical information available for Illinois. The Water Survey also supports the Office of the Illinois State Climatologist, which includes a three-person staff. This Office performs studies of the Illinois climate and provides extensive advisory services to local and state agencies and the private sector.

Research on certain aspects of the climate of Illinois and the Midwest has been conducted since 1955. In 1965 these studies began focusing on the potential of local-scale climate change due to two factors. One involved the release of effluents, including heat and moisture, to the atmosphere from large power/industrial sources; and the second focused on the effects of large urban areas on weather conditions and climate. Special field programs covering a ten-year period were conducted at St. Louis and then Chicago, and at major power plants. They defined the dimensions of the influences of urban areas and power plants on the atmosphere. The urban areas were found to alter all facets of the local climate considerably, as well as the clouds, rainfall, and storminess extending 50 miles beyond these cities. By this process, Water Survey scientists were pioneers in the field of climate change due to human activities.

A third and recent area of climate research has involved multidisciplinary research to begin to define the effects of weather on agriculture and water resources. Particular attention has been given to the potential influences of weather modification on Illinois' crop yields and runoff. Assessment models were developed, and new methods of impact analyses were devised by Water Survey atmospheric scientists, hydrologists, agronomists, and affiliated economists and geographers. Collectively, these studies have resulted in a staff with excellent capabilities for addressing the climate change issue. This is now reflected in the numerous publications relating to climate, climate change, and climate impacts. These publications are listed in Appendix A.

In recent years, Water Survey scientists have conducted several projects dealing either wholly or partially with certain aspects of the climate change issue. These

projects are listed and described in Appendix B. They range from efforts to explain climate change to studies of selected impacts of changed climate. They also have included two analyses of ongoing research efforts conducted as a prelude to planning this program.

Informational Efforts

Informational efforts have also been conducted relating to climate change and its impacts. Three workshops have been designed, arranged, and partially supported by Water Survey funds with Survey staff presenting talks at each. One was held in 1988 with the Water Survey acting as co-host with the U.S. National Climate Program Office and the Canadian Climate Program Office. This three-day workshop brought together weather-sensitive groups from the Great Lakes Basin to be briefed on climate change as a basis for delineating potential key impacts and for identifying research and policy needs. This effort and the workshop report have helped define some of the research needs presented in this plan for Illinois.

A second workshop on climate change was held in conjunction with the National Crop Insurance Services in Kansas City in June 1990. Water Survey scientists designed the workshop and briefed weather-insurance industry leaders about the issue and how to cope with it.

A third workshop was organized in conjunction with the U.S. Environmental Protection Agency and held in Champaign during May 1991. It focused on analyzing research needs relating to climate change and forests.

Numerous scientific papers and several scientific reports describing research findings from recent and ongoing climate change research have been published (see Appendix A). An assessment of the climate change issue for public consumption was done in a paper prepared and published in *Illinois Issues* in 1990. The Midwestern Climate Center, in conjunction with the five other regional climate centers in the nation, prepared a statement about climate change for public dissemination in 1990. It describes the scientific status of the global climate change issue, defining the known and unknowns. These various actions—workshops and many talks at public forums and scientific conferences—help us understand what needs to be done, the type of information needed, and the need for a "state clearinghouse" for climate information. Public groups and decision makers have repeatedly requested a source for reliable, understandable scientific information on the climate change issue.

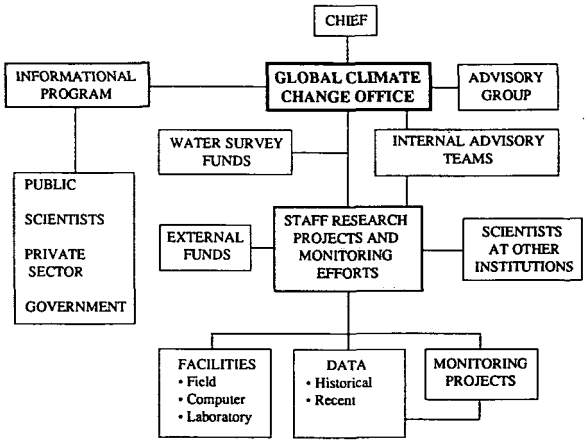
Also relevant to the Water Survey's qualifications on the climate change issue are the professional activities that staff have been asked to perform. Staff members have been invited to serve as members of national advisory boards dealing with climate change, including three advising major research programs of federal agencies, two advising national laboratories, and one advising a private research group on the dimensions of its climate research program.

Staff have been asked to provide testimony about climate change to Congress on three occasions during the past two years. Two staff members have represented climate expertise on panels addressing climate change and hydrology issues for the International Joint Commission, which handles

problems common to the United States and Canada. Water Survey staff also provided information to the National Governors Association (NGA) staff concerning the contents of the NGA's 1990 report on the global climate change issue.

Water Survey staff members recognized for their national expertise in the climate change issue have responded to numerous invitations to present talks before many scientific and policy groups. These have included midwestern agricultural leaders, heads of state agencies in the Midwest, groups of top farmers in Illinois and other states, water managers, utility leaders, financial advisors, etc. Numerous class lectures on climate change issues have been presented at Illinois universities and community colleges, as well as special seminars given in response to invitations at research and educational institutions in Illinois and elsewhere in the nation.

In summary, the Water Survey has a scientific presence on the climate change issue, both in Illinois and nationally; it has the enabling legislation and mandate to pursue the proposed activities in research, monitoring, and information services; and it has the staff talents and many of the facilities and databases necessary to pursue a broad and relevant program in global climate change for Illinois. To facilitate these efforts, a Global Climate Change Office has been established as shown in the figure. The following sections of the plan describe the future research projects that have been identified, the monitoring efforts needed, and the informational activities that will be pursued.



The Organizational Elements and Structure of the Illinois Global Climate Change Program

MANAGEMENT AND PLANNING FOR THE GLOBAL CLIMATE CHANGE PROGRAM

The Water Survey has established a Global Climate Change Program Office. It is the focal point for all programmatic activities relating to climate change and its impacts. The Office staff include a Director, an Assistant Director, and administrative support. They are responsible for ensuring that the functions of the Office are conducted. The functions of the Office are as follows:

- Assist in the design, conduct, and review of special hydroclimatic projects and other Water Survey data collection projects relevant to the Program.

- Facilitate the planning, integration, and conduct of research projects with Water Survey staff and with staff of other organizations.

- Assist and guide efforts to secure funding for projects within the Program.

- Conduct research on climate change including its effects on water resources, agriculture, and other sectors.

- Conceive and facilitate informational activities including preparation of special publications, scientific papers, public talks, and workshops concerning climate change and its impacts.

- Maintain timely internal communication about the program and ensure access to relevant data and publications on climate change.

- Review all Water Survey proposals for projects relevant to the climate change issue.

- Monitor external publications about the climate change issue, and arrange for staff attendance at important conferences and workshops.

- Plan and conduct a seminar series on global climate change involving experts from other institutions and those within the Water Survey.

- Prepare an annual report of program activities and accomplishments, and update the plan as needed.

The institutional structure of the Global Climate Change Program, including its Office and its other elements, is presented in the program outline.

To achieve the Program's objectives and perform the functions of the Office, the Director has established three standing advisory teams composed of staff members. These include the Implementation Team, the Climate Scenario Team, and the Information Team.

The **Implementation Team** assists the Program Office Director in the implementation of the plan and the individual projects, and helps develop ideas for the research projects and monitoring activities. Its staff represent major different disciplines including surface water, ground water, water quality, atmospheric chemistry, and climatology. They meet at the discretion of the Director.

The **Climate Scenario Team** assists by designing the critical research dealing with the physical and statistically based aspects of future climate conditions. They also serve as advisers to all Water Survey scientists in the planning and conduct of climate impact research. They meet at the discretion of the Director and include a climatologist, a meteorologist, and an atmospheric chemist.

The **Information Team** includes the Office Director, the Director of the Office of Extension Services and Operations, the Director of Publication Services, and the Head Librarian. This team will design and help conduct the informational activities of the Water Survey. The Heads of the Atmospheric Sciences, Chemistry, and Hydrolology Divisions will attend meetings and workshops concerning climate change, and help the GCCP Office staff in making presentations about the Program at in-state functions. The team will be convened by the Director of the Office.

Ad hoc planning groups will be formed to plan and promote multidisciplinary

projects, such as studies of diverse agricultural impacts, the experimental integrated basin studies, and regional projects.

A key aspect to the Program with its strong multidisciplinary flavor is the involvement of scientists (and institutions) in addition to those at the Water Survey. Several staff members of the University of Illinois are adjunct staff members of the Water Survey, and they possess skills that are valuable to the Program. Similarly, staff members at the other two scientific surveys, at the Department of Energy and Natural Resources, and at other state institutions, federal agencies, national laboratories, and state universities offer opportunities for collaborative involvement in the large, diverse research and monitoring program planned.

An **Advisory Group** to the Global Climate Change Program provides oversight and guidance to the dimensions and quality of the Program. Members of this group are from scientific and business communities of Illinois. The group is convened annually by the Director.

Program Funding

Funds for the Program are derived from a mixture of sources including state funds and those generated from external agencies and institutions through grants, contracts, and cooperative agreements. Funding agencies have included state agencies, federal agencies, and private entities and foundations. The broad, multidisciplinary flavor of the Program offers many opportunities for obtaining funds from diverse sources.

Allied Programs and Institutions

Several existing and emerging programs dealing with the climate change issue offer excellent opportunities for the projects of the Water Survey. These include the emerging long-term program to investigate the impacts and responses to climate change in the Great Lakes Basin. This is a U.S.-Canadian effort that has included the Director in the planning process.

Another emerging program that holds great relevance for the Survey's efforts in climate change research is the Continental-Scale International Project (GCIP). Its area of focus is on the central United States and the Mississippi River Basin because the area is considered to have world's best databases. GCIP is part of the Global Energy and Water Cycle Experiment (GEWEX) and is being developed by the World Climate Research Program.

Involvement in the Long-Term Ecological Research Program of the National Science Foundation holds potential for some of the monitoring and research projects envisioned. The environmental research of the Illinois Department of Energy and Natural Resources has supported climate change and irrigation research, and holds promise for future support. The Climate Systems Modeling Program of the University Corporation for Atmospheric Research (UCAR) is another program with potential for Survey involvement. The Water, Energy, and Biogeo-chemical Budgets (WEBB) Program of the U.S. Geological Survey holds potential for certain hydrologic research projects. WEBB will focus on measurements and research at five sites, and Illinois could be one.of these. The program "Education for Climate Change," designed to encourage involvement of graduate students in climate-related research, holds promise for educationally based research at the Water Survey.

Numerous in-state institutions and universities have staff with similar interests to those of the Survey's GCCP. Efforts are being made to include them in collaborative research and monitoring activities. In addition, other U.S. institutions with similar interests and potential for joint research efforts in climate change impacts include the Environmental-Societal Impacts group at the National Center for Atmospheric Research, the Natural Hazards Center at the University of Colorado, the nation's five regional climate centers, and several laboratories in the National Oceanic and Atmospheric Administration conducting atmospheric and hydrospheric research.

AREAS OF FUTURE RESEARCH

The assessment of research needed on climate change and its impacts in Illinois has been based on three factors: 1) familiarization with past and ongoing research at the Water Survey and at other institutions, 2) analyses to identify specific gaps in knowledge about how climatic conditions affect the hydrologic-biological systems and socioeconomic conditions in Illinois, and 3) the interests and expertise of the Water Survey staff and adjunct staff members from the University of Illinois at Urbana-Champaign.

A major literature search was conducted, and a special section has been established in the Water Survey Library to house the hundreds of publications that address the climate change issue. Members of the staff serve on several advisory bodies that guide and review the global change programs of several federal agencies, including the Environmental Protection Agency and the National Science Foundation, plus the climate research programs of the National Center for Atmospheric Research and the Electric Power Research Institute. Knowledge gained from these activities has been the basis for developing a plan of future research. The plan focuses on physical processes relevant to a changing atmosphere, descriptions of past fluctuations in the state's climate and water resources, and on the many potential effects of altered climatic conditions.

An analysis of research needs has identified four major programmatic areas for investigation:

- Investigations of atmospheric and hydrospheric processes relevant to a changing atmosphere
- Studies of past and potential future fluctuations in climatic and hydrospheric conditions
- Investigations of how climate conditions affect the hydrosphere, impact the socioeconomic structure of Illinois and environs, and the adjustments to these impacts
- Comprehensive, multidisciplinary projects seeking to understand and quantify the effects of a changed climate on regions important to Illinois

The climate change monitoring and detection program of the GCCP, which is described after the research section, also includes endeavors related direcdy to the study and interpretation of the monitored conditions—past, present, and future.

Investigations of Atmospheric and Hydrospheric Processes

The scientific research program of the Water Survey has long embraced studies of the physical processes involved in the hydrologic cycle. However, certain processes are not yet well understood. Reasons for these critical information gaps include the lack of staff suitable to address certain issues, inadequate understanding for hypothesis development, and the lack of equipment and facilities needed to address certain topics, such as how large cloud droplets interact to make rain or the rate of motion of water in deep aquifers. Eight areas of research needed have been identified, which will greatly improve our understanding of how the climate works and affects the hydrologic cycle.

1. Studies of land surface processes and atmospheric feedbacks that affect the water and energy budgets of Illinois and surrounding areas. Evidence is mounting that the drying associated with a developing dry period sufficiently reduces evaporation and transpiration to significantly reduce the amount of atmospheric moisture. In a developing drought, this reduction may be sufficient to reduce the development of clouds and the amount of rainfall, thus enhancing the drought, both in length and severity. Understanding such a process is critical to obtaining a better picture of a future potentially drier climate in Illinois.

2. Investigations of clouds and their effects on radiation. One of the major unknowns about climate change due to the greenhouse effect is the role that clouds will play by virtue of their effects on radiation, either to enhance the effects of trace gases or to ameliorate the warming effect. Studies of man-made cirrus clouds produced by jet aircraft, which frequently fly over the Midwest, offer an excellent opportunity to better understand how additional high clouds due to large-scale climatic change may affect incoming and outgoing radiation, as well as surface temperature. Also important is the need to gain understanding of the composition of aerosols that are active in cloud development. Studies of the Water Survey's unique, vast historical records of weather radar echoes would yield invaluable information on the temporal and spatial variations in the formation of "first echoes," that time when precipitation first develops in a cloud.

3. Investigations of precipitation development in the warm and cold seasons. A substantially changed climate will alter the amount and type of precipitation, but to predict with some confidence how this will occur requires an improved understanding of how precipitation develops in the cold and warm seasons. Attention has been given to understanding summer rainfall processes as a part of the research efforts aimed at purposeful modification of cloud and rain processes. This understanding of precipitation development is needed in all seasons, not only to predict what a future climate might produce, but also to improve our capability to modify precipitation conditions if the future regime is highly undesirable.

4. Studies of changes in air and precipitation quality. An altered climate will produce an atmosphere different than today's. We need to gain understanding as to how future air masses will act to enhance or worsen air quality. Currently, the frequent shifting of air masses in the Midwest with attendant strong winds help cleanse the atmosphere, but this condition could

change drastically. Of equal importance is the need to gain information about how an altered climate would affect the quality of precipitation. Would there be more or less acidic rainfall? Would visibility increase or decrease under different climatic regimes? Would we see more ozone alerts in our major cities?

5. *Investigations of the effects of a changed climate on fundamental chemical processes in the atmosphere and hydrosphere.* There is reason to believe that certain chemical processes now critical to the quality of the air and waters of Illinois will undergo changes in a climate with higher (or lower) temperatures. These shifts could slow or enhance chemical processes that affect molecular behavior or the rate of transformation of decaying materials.

6. Analyses of altered physical processes in selected watersheds and large water bodies. An altered climate that raises or lowers heavy rainfall rates would alter the rates of erosion, the stream transport of sediments and contaminants, and the deposition of these sediments. How these and other physical processes would be altered in basins composed of widely differing soils and physiographic conditions is not predictable with our current level of understanding, which is limited to a few locales in Illinois. A changed temperature and precipitation regime could alter the morphology of large lakes and rivers, and the processes by which this might occur must be explored and defined.

7. *Investigations of the effects of climate on ground-water levels.* A shift in climate to a drier or wetter regime will affect the movement of water in the ground. How a changed climate will affect the rates of permeability in the widely differing soils of Illinois, and the ultimate effect on shallow and deep ground-water levels cannot be accurately predicted from the existing knowledge.

8. Studies of existing modification of atmospheric processes due to land-use changes including urbanization and the concentrated release of heat, moisture, and effluents from industrial processes. These ongoing "experiments" that alter the atmosphere afford opportunities to gain knowledge about the unperturbed atmosphere and changes in the boundary layer, clouds, precipitation, and other surface weather conditions. We propose to further investigate unanswered questions about how large urban areas (Chicago and St. Louis) affect precipitation, including the study of nocturnal influences that appear to lead to significant increases in warm-season rainfall.

Past and Future Fluctuations in Climatic and Hydrospheric Conditions

The Water Survey has a wealth of historical data describing various climatic and hydrospheric conditions in Illinois. Many of these databases have not been subjected to analytical investigations to describe their inherent temporal variability, which is essential information for assessing characteristics of future climates in Illinois. Important to such descriptive investigations are associated causative investigations to explain the variations found.

Such studies will help us estimate future outcomes based on the weather conditions predicted by the ever-improving global and mesoscale climate models of the future. At this time, estimating future effects of a changed climate requires use of climate scenarios. Thus, a part of our research will

entail the development of scientifically sound scenarios of possible future climatic outcomes that include the variables essential for examining physical and/or socio-economic impacts. Four areas of research should be pursued:

1. Historical variations in atmospheric conditions. Data exist to examine the short and long-term variations in various atmospheric conditions, including precipitable water in the atmosphere, cloud cover and cloud types, and visibility. Coupled with the need for these investigations is a need to perform synoptic climatological analyses of surface and upper-air conditions over a long period. This will help provide an understanding of the fluctuations found in weather conditions, such as frontal passages, and will also be essential for helping to interpret the variations found in clouds, moisture, and other conditions.

2. Historical variations in precipitation and temperature conditions. Various combinations of wet/dry and cold/warm conditions over days, seasons, and years produce most of the impacts of climate realized in Illinois. In particular, hydrologically and agriculturally relevant conditions (e.g., freezing temperatures, heavy rains, prolonged hot periods, etc.) need to be analyzed. Past studies have not thoroughly documented the temporal dimensions of these critical conditions. For example, the frequency distributions of wet and dry periods of various durations (a season of up to ten years, for example), and having different intensities, have not been defined.

Anomalous periods of relatively warm and cool conditions over the last 100 years also need definition and explanation. Temporal fluctuations in rain events and in severe storms have not been delineated. Relevant to these descriptive studies would be the incorporation of the findings of the synoptic climatological analysis (above) to establish causation for the fluctuations discerned. It is also necessary to relate the frequency of these events to average conditions, including monthly, seasonal, and annual means in order to relate their incidence to outputs of the global climate models.

3. Historical variations in hydrologic conditions. The past variations in soil moisture at various depths and in shallow groundwater levels, as sampled in the Water Survey's network of wells across Illinois, and the changes found in riverine morphology, including streamflow and streamwater temperatures, need to be analyzed. A statistical definition of the temporal structure of these conditions critical to agricultural production and water supplies in the state is relevant for estimating their properties in an altered climate. The Water Survey possesses some of the longest records of these kinds in the nation.

4. Climate Scenarios. The global climate models are not yet able to provide climate estimates for the Illinois area that are considered sufficiently accurate in space and time to be used to analyze the effects of future climate shifts in Illinois. Using various approaches, climatologists have devised methods to create climate scenarios that are scientifically consistent.

Since the Water Survey's GCCP emphasizes studies of the potential range of impacts resulting from various future climates on state and regional scales, the Program requires research involving the design and development of climate scenarios that are

atmospherically consistent and embrace those weather conditions that cause physical and economic effects. One form of scenario to be used is historical analogs, and another is spatial analogs. Other approaches involve methods of adjusting climate data with outputs of global climate models. Fortunately, Water Survey scientists have several unique historical climate databases needed to create meaningful scenarios, plus the expertise to develop these. Their development requires interactions between atmospheric scientists and scientists involved in the impact studies, as described in the next section of the plan. The Midwestern Climate Center will serve as a clearinghouse for climate scenarios developed for the Midwest.

Climate Effects on the Hydrosphere and Socioeconomic Conditions, and Human and Institutional Adjustments

The greatest emphasis in the research efforts conducted as part of the Water Survey's Global Climate Change Program involves 1) defining and estimating the impacts apt to occur from future climate change and 2) assessing the ensuing responses and adjustments that may develop. Impact-focused studies are seen as critical for the wise development of state and regional policies relating to the climate change issue. Furthermore, research on impacts and the social adjustment to a changed world is getting only minimal attention in the federally supported research program on global change (National Academy of Sciences report, 1991). Assessment of research needs in the impact area revealed a distinct lack of knowledge about the quantitative relationship of weather conditions to many state activities. Yes, we know that weather impacts agriculture in a qualitative sense, but for example, we have no specific information about what a five-degree increase in summer temperature might do to the agribusinesses growing seed corn in Illinois and adjacent states.

The research needed in the sector-oriented impacts area falls within three types: those related to the hydrologic cycle and water resources, impacts on agriculture and vegetation, and potential human responses and adjustments to the estimated impacts of altered climate conditions.

1. Studies of effects on the hydrologic cycle and water resources. Unfortunately, very little definitive research has been done to relate climate conditions occurring over extended periods of time to many parts of the hydrologic cycle in Illinois or elsewhere. For example, one can identify a range of changes in water supplies due to shifts in climate, including the yields from reservoirs, ground water, and unregulated streams, or the quality of raw water. These translate to water management impacts such as system reliability, effectiveness of intersystem and interbasin connections, magnitude and control of demand, and the costs of system operation.

Areas defined as needing study and definition of their climate relations include: 1) wetlands, 2) stream and lake environments, 3) soil moisture and soil temperatures, 4) flooding incidence and magnitude, 5) ground-water recharge, 6) river morphometry, 7) water management structures and design, 8) drainage systems and water treatment plants at small to large communities, and 9) water-borne transportation. In each of these nine areas, we must define the quantitative relationships to climate conditions, and identify the sensitivities of

these physical systems and human endeavors to various conditions. We need to develop and improve existing basin-scale climate-hydrologic models for representative basins in Illinois. Furthermore, the relationship of climate conditions to streamwater temperatures needs to be defined, along with that for ice cover and river ice, and for streams in various regions of Illinois. Valuable shallow groundwater data collected over the past 35 years must be compared with monthly and seasonal weather conditions to develop models of their relationships for the various physiographic regions of the state.

A series of water resource problems relating to climate anomalies in Illinois during the last 30 years will be investigated in a series of "analog" type studies. Relatively recent well-documented anomalous events (e.g., fluctuations in Lake Michigan levels during the 1970s and 1980s, the cold winters of 1976-1980, the flooding and sediment problems on the Kankakee River in the 1970s, etc.) will be assessed to gain insight on the physical and economic impacts and the ensuing adjustments. These might include the types of social effects and institutional responses used to cope with a variety of climate aberrations. These should be multidisciplinary studies, and they are viewed as having great value in identifying coping mechanisms and in presenting information highly useful to water managers.

2. Climate impacts on agriculture and vegetation. Much of the weather-related agricultural research performed in Illinois over the past 25 years has been conducted by Water Survey scientists working with members of the College of Agriculture at the University of Illinois. These studies have focused on certain specific areas including defining the relationship of climate variables to corn and soybean production, the economic impact of weather altered by cloud seeding, and the effects of weather predictions on agricultural activities.

The Water Survey has the data and capabilities to address five areas where climate change in Illinois would have notable impacts: 1) effects on production agriculture and the farm environment; 2) effects on plant characteristics, crop yields, and the ensuing economic implications for farmers and agribusinesses in Illinois; 3) impacts on irrigation that would include expansion, demand modeling, and effects on water policies; 4) influence of changes in atmospheric circulation and temperatures on pest migrations and survival, and on the behavior of insecticides, herbicides, and fungicides; and 5) impacts of changed conditions on perennial plants throughout the state.

3. Human responses and institutional adjustments. Shifts in the hydrologic cycle and alterations in the state's biological systems will be translated into economic impacts, some as benefits and others as losses. These outcomes in turn will produce societal responses and adjustments to a changing climate. Some adjustment will occur through existing social systems and institutions; others will relate to institutional changes.

Water Survey researchers will examine the types of impacts generated in the water resource area and in agriculture to explore the potential types of social responses apt to occur. We will rely on studies of recent past analogs to estimate social responses. For example, responses to the wet decade

of the 1970s in Illinois and to the droughts of 1980-1981, 1988-1989, and 1991 will be used to gain insight as to possible outcomes under cooler, wetter conditions and under warmer, drier conditions. Local, state, and federal government reactions to these events will be investigated to examine the adequacy of existing institutions to respond to a changed climate.

Multidisciplinary Projects to Investigate Regional-Scale Impacts of Climate Change

Many of the above research endeavors are designed around understanding climate effects in specific physical areas like streamflow, and defining impacts in specific economic sectors. They may include study of the entire sequence, beginning with a changed climate, the ensuing effects on the physical system, and impacts to the economic sector/s, and finally the human adjustments. However, most of these will not address the effects and interrelationships across a broader, more complex world where a variety of impacts occur and many adjustments develop simultaneously.

More complex multidisciplinary assessments of climate change are needed for regions that are physically, economically, and socially homogeneous. Three such comprehensive regional studies have been identified to measure the wide range of effects apt to occur. Other regional studies can be conceived as research opportunities dealing with other state regions arise.

1. Studies of the Chicago Metropolitan Area. At least four aspects of climate change need to be investigated for the Chicago metropolitan area. First is an investigation of how altered climate conditions would affect 1) the use, availability, and treatment of water, 2) the levels of Lake Michigan and in turn the use of harbors and beaches; 3) handling of storm runoff; 4) raw and polluted water treatment and release; 5) water-borne transportation, and 6) anticipated changes in air quality. Second would be cross-cutting economic investigations related to changes in weather-sensitive industries including the power industry and the local producers of trace gases apt to come under federal regulations. Third is an investigation of the effects of a more stressful warmer climate on urban residents. Recent hot summers such as those in 1980 and 1988 led to more than 1,000 deaths in Chicago, many occurring in minority and elderly age groups. Fourth is an investigation of how these impacts and adjustments to a changed climate would affect the Chicago and suburban government agencies.

2. Investigations of the Great Lakes Basin. Water Survey scientists recognize that a changed climate in the Midwest would produce a myriad of impacts on the Great Lakes and Illinois. Thus, Water Survey leaders have been involved in the planning of a comprehensive, multidisciplinary research program, involving both U.S. and Canadian scientists, to define the effects of climate change on the basin, including human responses and institutional adjustments to cope with a changed climate. Areas of particular interest to Survey scientists include development of climate scenarios as input to basin hydrologic models to define changes in net basin water supplies and lake levels; the effects of changed basin conditions on the Chicago metropolitan area including lake shipping and recreational boating on shoreline erosion, on the movement of lake sediments and pollutants, and on the area's economy.

3. Studies of the Illinois River Basin. The Illinois River Basin encompasses roughly one-third of the state and is a well-recognized physical and economic resource. It is of immense importance to barge transportation, for urban and industrial water supplies, to the movement of effluents, and to a complex biological system that has evolved along the waterway. Studies of altered climates in this hydrologically complex basin are needed to define the many interactive impacts that would occur, including effects on water quality, water flow, flooding, wastewater treatment, water use, river-based recreation, river transportation, and the environmentally sensitive reaches of the basin's rivers. Econometric modeling could be used to estimate the range of economic impacts apt to develop under varying climate scenarios.

MONITORING TO DETECT AND MEASURE CLIMATE CHANGE AND ITS EFFECTS ON ILLINOIS

The federal government has long had the responsibility for measuring and monitoring the nation's natural resources, including weather and water resources. However, in the past 30 years the federal effort in measuring many critical conditions has decreased in extent and quality. Furthermore, many environmental conditions critical to an area like Illinois have never been measured. For example, the Water Survey played a prominent role in establishing a national deposition network to measure pollutants being deposited both by rainfall and by dry matter from the atmosphere. Water Survey scientists and engineers have pioneered the development of instruments to better measure physical conditions, including development of a state-of-the-science weather radar (the prototype for the 130 new NEXRAD radars being installed nationwide). During the 1980s, a statewide climate monitoring network was established to measure soil moisture and a host of other conditions not being adequately measured by federal weather networks.

As a result, the Water Survey has the scientific and engineering competence to design instruments and measurement programs needed to answer three critical questions:

- When will we know whether the climate change has begun?
- What is the magnitude and nature of the ongoing change?.
- How is the change being realized in key portions of the hydrologic cycle?

The Water Survey's monitoring efforts fall into two general categories: long-term (multi-decadal), continuing studies of select conditions; and short-term (e.g., five- to ten-year duration) concentrated site/region studies measuring many conditions in great detail. In both instances, an overriding objective is to collect high-quality data and to properly interpret these data. Thirteen monitoring projects have been identified.

1. *Establish and maintain experimental watersheds* to address various needs for water-related data in areas with major geographical differences. These would include: 1) the establishment of measurements on a few small streams for long-term sampling of effects on algae; 2) continued monitoring of the Cache River wetlands areas because of their unique physiographic and biological environments; 3) the rejuvenation of the highly valuable

water quality and sediment measurements on Court Creek; and 4) the establishment of a highly representative benchmark watershed with measurements of several relevant variables, including flows, sediment, water quality, erosion and sediment deposition, and biological indicators.

2. Initiate sedimentation surveys of selected lakes measured at five to ten year intervals to determine the long-term shifts in soil erosion and sedimentation. These surveys, coupled with findings from past surveys, will provide useful indices of change because their findings integrate several climatic conditions and should help reveal effects of climatic changes.

3. Monitor toxics in air and in precipitation at sites in Illinois and around the Great Lakes. This is of great importance in discerning effects of a changed climate on air and water quality. This includes a need for measurements of major ions, trace metals, and selected organics deposited in precipitation, and CFCs and selected organics in the air, along with continuous meteorological data at each site.

4. Monitor surface moisture and temperature conditions within selected basins across the state for five years. This provides ground truth for testing satellite-based measurements of these conditions.

5. Monitor hydrological and biological conditions in wetlands. Sampling must include the five fundamentally different types of wetlands important to Illinois.

6. Investigations of the aquifer recharge rates at a sandy soil erosion. A change in climate could well alter the rates in the major sandy soils of Illinois.

7. *Measurements of the deep soil temperatures* at selected sites. A long-term measurement program should be established in different Illinois soils established for this purpose.

8. Measurements of temperature fluctuations at different depths. Profile measurements are envisioned at one or more bore hole sites.

9. Monitor cloud reflectance and microphysical characteristics. This should focus on layer clouds, and monitoring should be done on an annual basis.

10. Sustain operations of existing networks. This includes the Illinois Climate Network, the Illinois Instream Sediment Network, National Atmospheric Deposition Program/National Trends Network sites in Illinois, and baseline streamgage measurements at selected sites with long records.

11. Develop new techniques and instrumentation for measurements of solar and incident radiation. These measures are relevant to future applications in solar and wind energy programs.

12. Monitor irrigation activities. Data collected over time on water use, number of irrigators, and areas irrigated across Illinois will reflect climate fluctuations and responses.

13. Investigate techniques to archive key perishable samples. Certain critical atmospheric and hydrospheric samples, such as water, must be retained in their collected state so that they can be analyzed for as yet unforseen future characteristics. Storage techniques need to be developed.

Of critical importance in this area of monitoring and interpretative study are continuing actions to monitor federal measurement programs for critical climatic and hydrospheric conditions. As in the past, the Water Survey must be ready to act to save endangered measurement programs or to encourage improvement in the quality of existing measurement efforts.

INFORMATION ABOUT CLIMATE CHANGE

The third important component of the Water Survey's GCCP is the provision of updated data and information on climate change to all impacted and interested parties in Illinois. **Illinois cannot make wise decisions about the climate change issue without high quality scientific and technical information about the subject.**

In designing the informational efforts, two aspects were considered: 1) the audience and 2) the tools needed to transfer information. The audience for climate change information is comprised of eight sectors:

- The general public
- Students in primary and secondary schools
- The climate-impacted business and industry sectors
- The scientific community of the state and nation
- Local, state, and federal government bodies and agencies
- Institutions closely allied with the Water Survey (other scientific surveys, universities, community colleges, the Department of Energy and Natural Resources, and other state agencies involved in water resources)
- Environmental groups
- The media

The tools identified for transferring information to these audiences are diverse. The methods to be used are listed below, along with the frequency of information transfer already accomplished for each approach.

- Workshops for specialty audiences (3 already conducted)
- Lectures and scientific seminars for scientists in Illinois (16 conducted)
- Scientific papers at conferences (55 presented over the past eight years)
- Internal talks by staff and invited experts (5 conducted)
- Special information publications for educational applications and for use by the general public (1 published)
- Talks at public meetings, service clubs, and special interest groups (several done)
- Special news releases to the media (4 released)
- Publications in the scientific literature (47 articles)
- Bibliographies based on climate-relevant publications (1 completed)
- Mobile exhibit describing climate change and impacts
- Video stories ranging from 1-15 minutes in length
- Information newsletter issued quarterly to interested parties
- Annual reports reviewing the program
- Articles about climate change in general interest magazines (1 completed)
- Lesson plans for primary and secondary education

Integral to the success of the Program is the timely flow of climate change

information as facilitated by the GCCP Office. This effort involves the Office of the Chief, the Library, the Information Team, and staff scientists interested in the subject. To facilitate the planning of projects and the ongoing research, the Library has established a special section containing all publications related to climate change and its effects. A key-word bibliography is maintained to provide staff and other scientists with easy access to the many documents on this subject. The Library prepares and issues a monthly listing of new publications relating to the topic.

APPENDIX A

PUBLICATIONS RELATED TO CLIMATE CHANGE[1]

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[1] The relationship has been defined as due to one or more factors:

1) to understand atmospheric or hydrologic processes related to climate change or variability,

2) to define effects of climate on some aspects of the hydrologic cycle and/or biological system;

3) to define impacts of climate on crops, society, economics, and/or policy; and/or

4) to describe changes in climate and/or hydrology [including quantity (or magnitude) and quality (chemistry)].

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APPENDIX B

PROJECTS RELATED TO CLIMATE CHANGE

PROJECTS DIRECTLY RELATED

Chemical Composition of Cloud Aerosols: Toward a Better Understanding of Cloud Chemistry and Climate Change

In the ongoing scientific debate over climate change caused by increases in greenhouse gases in the atmosphere, the role of cloudiness has emerged as a key factor that requires a better understanding. Much research has focused on the projected warming of the northern hemisphere due to increases in carbon dioxide ($C0_2$), largely emitted when carbon in fossil fuels is formed during combustion. A warming of the atmosphere also would increase the capacity of air to hold water vapor. This may result in greater cloudiness and, depending on optical thickness and attitude, these clouds may mitigate the projected temperature increases. Since clouds form on tiny aerosols called cloud condensation nuclei (CCN), any increase in CCN may also change cloud area or depth. It is widely held that over continental areas anthropogenic emissions contribute significantly to the CCN; and as a consequence, those emissions that contribute to warming from $C0_2$ may simultaneously contribute to the possible cooling brought on by clouds.

Direct measurements of the chemistry of CCN have not been reported because of the difficulty in collecting a sample mass sufficient for chemical analysis. This project has as its first objective the design and development of a device that will overcome this difficulty. Direct measurements of CCN chemistry will enable cloud modelers to include more realistic chemical processes in their simulations of cloud generation. This new understanding will improve our projections of future climate changes.

Monitoring Air and Precipitation Quality at a Benchmark Site in Rural Central Illinois

Long-term data for air chemistry, precipitation chemistry, and meteorological variables at a single site are infrequent in the literature, and this has complicated the assessment of trends in the United States. At a rural, east-central Illinois site where urban and industrial emissions are distant and well-mixed, routine measurements are being made in support of several long-term projects. Daily and weekly samples of wet-only deposition are collected for chemical analysis, as part of the Multi-State

Atmospheric Power Production Pollution Study (MAP3S) and the National Atmospheric Deposition Program/National Trends Network (NADP/NTN).

MAP3S began operations at the Illinois site in *1911,* and NADP/NTN started sampling in 1979. In 1988 measurements of particles and gases containing sulfur and nitrogen species were added as part of the National Dry Deposition Network (NDDN). Hourly average measurements of surface ozone, temperature, wind speed and direction, solar insolation, and surface wetness were also included in the NDDN measurement set. These meteorological variables, along with the gas and aerosol concentrations already mentioned, make it possible to infer the dry deposition of particular sulfates, gaseous sulfur dioxide, gaseous nitrogen dioxides, gaseous and particulate nitric acid and nitrates, and gaseous and particulate ammonia, using a model that parameterizes surface vegetative and other physical characteristics. This inferred dry deposition and the measured wet deposition make it possible to account for the total atmospheric deposition of the gases and aerosols resulting in acidic deposition.

Data from this rural site are used to study trends and how they compare to emissions changes, such as the reduction of sulfur dioxide from electric utility plants. Relationships of pollutant concentrations to wind speed and direction are studied as well, in order to understand the role of these and other meteorological variables in air and precipitation quality in central Illinois. Finally, data from these long-term networks, which use accepted methods and equipment, serve as a basis for the evaluation of alternative sampling strategies and equipment. This site can serve to evaluate how to monitor and interpret atmospheric chemistry variables to examine for linkages to climate change.

Climate Change and Agriculture

This project, funded by the National Science Foundation (NSF), has used models of crop development and on-farm decision making to determine the attributes that growing-season climate predictions would need to possess to have the greatest economic benefit for Illinois. The range of potential attributes includes the weather parameters dealt with, the periods for which the predictions are made, the lead-times for the predictions, and their specificity and accuracy. Related survey-type work is investigating the attitudes of agricultural decision makers toward climate prediction use.

The models are also being linked to macroscale econometric models of the Illinois and midwestern feed-livestock systems to assess the possible economic impacts on the Illinois agricultural economy of climate change induced by greenhouse gases. This long-term effort is currently examining the effect of aggregation across farms on estimates of crop-supply response to changing climate

conditions. Detailed Illinois data are used to specify alternative econometric models of corn and soybean supply (which incorporate the climatic variables of temperature and precipitation) at various levels of aggregation (farm, county, crop reporting district, and state). Comparisons across specifications will indicate how the choice of aggregation in modeling influences the measurement of impact of a changing climate. The results of the research should provide insights into the tradeoffs in measuring the effects of climate at various levels of aggregation, as well as the extent to which the level of aggregation may affect estimates of climate impact. In addition, the study is providing valuable information on methodology commonly used to assess a broad range of issues.

Climate Scenario Design for Forest Impact Analyses for Central and Eastern North America

Three approaches have been used to quantitatively design climate scenarios for use in impact-oriented climate change research. The project is funded by the U.S. Environmental Protection Agency. The first approach will generate purely empirical scenarios, based upon a newly-developed precipitation database, for specific sectors of society (i.e., agriculture, forestry, water resources) that may be impacted by a climate change. The second approach will use observational data (e.g., Illinois soil moisture) to develop methods for improving the detailed treatment of central North American soil moisture and surface hydrology in scenarios based on global climate models. The third approach builds upon the previous two by application of structural equation models to both spatial and temporal data. These allow for active interplay between theory, modeling, and estimation. The result will be a state-of-the-science set of climate scenarios that will help Illinois anticipate the possible effects of the future climate on both its own economic activities and those of the surrounding states on which Illinois is partially dependent.

Development of a Semi-Physical Model for Examining Solar Radiation in the Midwest

A number of papers on solar radiation (SR) published in the last two decades suggest that the SR climate of the Midwest, which includes the most important crop-producing area in the United States, has yet to be documented in detail. The network of SR measurements is sparse and lacking in longevity, particularly over the Midwest. Thus, to examine SR in this area, a radiation model was used to create a data set of 40 years of daily SR values for 53 stations in the Midwest.

The semi-physical model is based on standard meteorological data and includes the effects of Rayleigh scattering, absorption by

water vapor and permanent gases, absorption and scattering, absorption by water vapor and permanent gases, absorption and scattering by aerosols and clouds, and ground-to-cloud-to-ground reflectance. The model results were validated against four small samples (less than one year each) of SR measurements in Illinois, Ohio, and Wisconsin, and they also were compared with data from the four SOLar METeorological (SOLMET) stations in the Midwest. Results indicate very good agreement between modeled and observed SR, with mean absolute errors of around 8 to 12 percent of measured averages.

Monthly climatological maps of the Midwest show the influence on SR of the Great Lakes, elevation, atmospheric humidity, and urban industrial effects. Tendencies over the 40-year period at seven stations for four months show generally negligible increases for January, April, and July, except for a rather large increase in the means during July at Springfield, MO. Conversely, all seven stations showed decreases in SR for October, with five of the seven stations showing significant decreases, at the 90 percent confidence level, greater than one megajoule per square meter over the 40-year period.

Impacts of Altered Weather Conditions

An important facet of the research relating to anthropogenic climate modifications is the way these modifications affect physical and socioeconomic conditions in Illinois. Over the last four years, this research has included the development and testing of an econometric model looking at the effects of precipitation change on midwestern agriculture; the development of a basin-scale four-dimensional hydrologic model for measuring the pathways of altered rainfall; and the conduct of field (plot) measurements of effects of altered rainfall and temperatures on crop production. In the past year, this research has focused on the effects of altered rainfall on corn and soybean production, as measured in special controlled plots on the South Farms of the University of Illinois. The recent research has involved two major discoveries: 1) the temperature conditions for corn from planting until tasseling (late June) are extremely important to the ultimate corn yields; and 2) a given increase in rainfall at the time when nature is providing 1 or more inches of rain is much more effective in increasing yields than the same amount of rainfall increase under much lighter, rainfall. That is, a small increase in rainfall during moderate to heavy rains is much more critical than a large increase during light to moderate rainfall conditions. Also, the research has shown that rainfall increases are producing major enhancements of soybean yields. The plot-related research is to be continued to gather more information on yield behavior under different temperature conditions.

Inadvertent Weather and Climate Modification

An enhanced effort for the atmospheric modification research of the Water Survey has been to focus on the inadvertent, or accidental, effects of weather changes on clouds and precipitation. Earlier Water Survey research conducted during the 1970s was nationally famous in establishing that large metropolitan areas such as St. Louis and Chicago have major effects on clouds and precipitation, particularly during the summer season. Recent research has focused on the potential effect of St. Louis on fall, winter, and spring precipitation. This research revealed that urban influences on convective precipitation represent the major effects. Thus the seasonal effects are most pronounced in early fall and late spring when the St. Louis area precipitation is largely convective. In winter there are essentially no measurable urban influences on precipitation, due to the lack of convective rainfall.

This research has produced results that help us understand how the atmosphere can be altered to purposefully enhance rainfall, and also to understand the effects of altered precipitation on physical and socioeconomic systems. An increased effort in this area is planned to include further studies of nocturnal rain situations in the summer season, and to enhance our understanding of local and mesoscale human influences on climate conditions. All of this is very relevant to the issue of climate change facing Illinois and the United States.

Impacts of Climate Change in the Midwest

We are assessing the potential impacts of possible future climate change on Illinois and the Midwest. One area of concentration has been the potential impacts on the Great Lakes Basin. Methods of developing scenarios for the future climate were investigated. We have been monitoring the impacts of weather/climate conditions in the midwest since 1989.

Another area of study concerns the possible role that soil moisture depletion, due to a longer warm season, may play in reducing precipitation in the central United States. This was initially investigated by using the 1988 spring-summer as a possible analog for a warmer climate. Similar field studies were conducted in Illinois during 1991 We also study the results of research conducted elsewhere to further our understanding of the issue.

Illinois Climate Network

The establishment and operation of the Illinois Climate Network, a statewide network of 18 evenly distributed automated

weather stations, is designed to yield information of value to agricultural production and climate monitoring. The following stations were automated during the past year: Belleville, Brownstown, Carbondale, Dixon Springs, Olney, and Ina. This brings the total of fully operational stations to 17, with the previously automated stations of Champaign, DeKalb, Freeport, Kilbourne, Monmouth, Peoria, Perry, St. Charles, Stelle, Springfield, and Wildlife Park.

The variables monitored include solar radiation, wind speed and direction, precipitation, air temperature and humidity, and soil moisture and temperature. In addition to containing valuable information themselves, the data are also used to estimate potential evapotranspiration and plan water requirements, the results of which are used to provide irrigation scheduling guidance. The data are transmitted each night (by phone lines) to a Water Survey computer, where they are quality-controlled, archived, and subsequently made available to the public, including through press releases. A particularly important component of this project is the year-round manual monitoring of soil moisture which is performed twice monthly during March through October, and monthly during November through February. As a result of this effort, Illinois agricultural production is benefiting from detailed weather/climate information of a quality that is unsurpassed in the nation.

The data and information being accumulated, particularly the long-term climatologies of wind and solar energy, are also of great value for evaluation of alternative energy sources and for climate monitoring.

Diagnostic Studies of Growing Season Rainfall Fluctuations in Central North America

This recently terminated long-term NSF-funded project has examined many aspects of the growing season (May-August) rainfall on the region bounded by the Rocky and Appalachian Mountains, the Gulf Coast, and approximately 55°N latitude in Canada. The principal research thrusts involved were 1) identifying the most important spatial patterns of rainfall variation for 1949-1988; 2) quantifying the "local" climate system processes/conditions that contributed to the contrasting rainfall patterns of several recent distinctive individual years; 3) identifying the most important characteristics of the weather systems that produce the region's rainfall, especially in relation to the results obtained under (1) and (2) above; and 4) establishing the larger-scale climate system causation of the interannual variations of the rainfall. The project has furnished a broad array of information on the vitally important growing-season rainfall of Illinois and surrounding states. Parts of the results are germane to the crucial issue of whether growing-season rainfall in Illinois will be reduced in the future.

Climate and Flooding Fluctuations

Historical climate data and streamflow data are being analyzed to determine whether significant temporal fluctuations have occurred in the frequency, duration, and/or intensity of floods, and whether these fluctuations are related to fluctuations in pertinent climate variables. This study covers Illinois and eight other states in the Midwest and is focused on the 1921-1990 time period, and is funded by the U.S. Geological Survey.

The results have implications for the design and operation of water systems. In addition, this type of study is a necessary prelude to predicting the hydrologic consequences of future climate change. Results to date show significant fluctuations in the frequency of both floods and heavy precipitation events in Ohio and Illinois on a decadal time scale. These fluctuations appear to be well correlated spatially on a substate spatial scale; however, significant differences are apparent on a state and multistate scale.

Portions of the midwest including the northern half of Illinois have undergone increases in warm season flooding as well as the incidence of flood-producing rainfall events. Eastern parts of the midwest have undergone decreases in flooding events over the last 20 to 30 years largely as a result of fewer heavy rain events. Importantly, the incidence of heavy 7-day rainfall, those typically relating to flooding, does not relate well to whether the period of their occurrence was relevantly wet or dry. This means that global climate models which as yet indicate only seasonal shifts in rainfall quantity can not be used to infer of whether there will be increases or decreases in heavier rain periods capable of producing flooding.

Assessment of Impacts and Adjustments Relating to the Drought of 1988-1989

This research has focused on the continuing effects of the 1988-1989 drought on agriculture, water resources, transportation, and the environment in Illinois, the Midwest, and the nation. It has also included assessments of how the private sector and government agencies have responded to the drought. In one study, the impact of the drought on firms offering weather insurance was investigated. It was found that the rates did not properly represent the long-term likelihood of dry summers. Proper ways of incorporating climatic risks in establishing rates were proposed. The drought studies are relevant to climate change since increased droughts are predicted to occur in the future.

A second study investigated the role of soil moisture depletion in prolonging the drought by reducing atmospheric water vapor supplies. It was found that soil moisture depletion was probably larger than for any other drought of the past 40 years and

likely contributed to the length and severity of the drought. A third study quantified the economic losses and costs in the United States, which amounted to nearly $40 billion.

Severe Storms

This investigation has concerned extreme weather hazards studied on a national basis. This research analyzed storm hazards producing at least $100 million or more in losses. The historical fluctuations of these events from 1949-1990 in the midwest show a U-shaped distribution. The incidence of extremely damaging storm events was high in the 1950s, low in the 1960s, and 1970s, and high again in the 1980s. The general distribution of storm frequencies in the midwest indicates that the incidence is greatest during 5 to 10-year periods which are relatively warm, as were the 1950s and 1980s. Interestingly, the greatest storm intensity as well as frequency occurred in the 1950s which was a hot/dry period. Storm intensity or amount of damage per event was not nearly as high in the 1980s even though storm frequency was relatively high. The 1980s were generally a relatively warm and wet decade as opposed to warm and dry in the 1950s.

Assessment of Weather Impacts in Analog Years

As part of the Midwestern Climate Center's endeavors, a month-ending assessment was made, beginning in 1989, of the impacts of weather events by month. The data on climatic conditions and the weather impacts for the year 1990 were analyzed because of the anomalous nature of that year in the midwest. The general conditions for 1990 were extremely above normal temperatures and precipitation. This type of year, one potential analog for climate conditions of the future, exhibited an exceptionally large number of severe storms including tornadoes, flash floods, and winter storms. The most notable aspect of the impacts of the year were storm related damages with record number of persons killed and property damages being the second greatest of any prior year. Studies of the dates of last spring frost and first fall frost, done as a part of this research, revealed no relationship to the low monthly temperatures of May and September, a relevant finding related to the global climate models.

Climate Impacts and Issues Affecting the North American Great Lakes

Since Lake Michigan is a major water resource for Illinois, we have continued to investigate hydroclimatic issues affecting the lake levels of the Great Lakes. A recently completed study addressed issues concerning the predictability of lake levels on time scales of 1 to 24 months. Four problems were identified that affect the use of climate predictions and that limit improvements in hydroclimatic predictions for the basin. They include 1) lack of adequate understanding of the hydrologic system; 2) lack of direct and timely measurements of key conditions such as over-lake

precipitation and evaporation; 3) limited accuracy of climate predictions for 2 to 6 months ahead, and lack of predictions for periods beyond 6 months; and 4) user perceptions of predictive quality and lack of processes to integrate predictions into complex decisions. The greatest improvements in the accuracy of hydroclimatic forecasts for 1 to 6 months ahead will come through advances in climatic prediction skills and in the way they are integrated into the hydroclimatic models. This work will become very important for managing the lakes under a more stressed climate.

Other studies have addressed the impacts of the high water levels of the 1980s and those relating to the precipitous fall of the lake levels during the drought of 1988-89. These were utilized in an analysis of the society's sensitivity to fluctuating lake levels. The intense development of the Great Lakes Basin shore front housing and ports, coupled with the needs for lake transportation and the production of hydroelectric power have provided a series of competing demands. The effect are problems with any slight deviation of the lake levels around their individual averages. This research provides a basis for future lake research on climate change.

A third study related to the Great Lakes is concerned with climate analogs. Assessment of future effects and impacts of climate change on the Great Lakes requires estimates of future climate conditions, called climate scenarios. Thus, an essential part of the research into climate and Great Lakes involves development of climate scenarios. An analysis of climate analogs, historical periods which could be used to simulate future climates, has been conducted and a paper written.

A fourth area had involved continuing research planning of a major international research program involving the effects and adjustments to climate change on the Great Lakes Basin. . This effort began with a major International Workshop co-hosted by the Water Survey in 1988. Subsequent meetings and discussions over the last three years have been utilized as a basis for preparing the research plan for this international, multi-agency research program.

Climate Change and the Seasonal and Annual Ground-Water Balance

An interdisciplinary project is documenting the effects of climate change on shallow ground-water resources. Surface hydrology outputs from two global climate model experiments (one for control or present climate, and one for "greenhouse" or changed climate) are being used to drive a one-dimensional vertical moisture flux model (DRAINMOD) to show the effects of changes in precipitation, evaporation, and runoff on ground-water recharge and shallow water levels.

Observed precipitation in Illinois is being compared to equilibrium precipitation amounts from general circulation models of climate. Observed evaporation is also being compared to evaporation amounts in the climate models, and to evaportranspiration computed by DRAINMOD. Comparison of these quantities will allow us to simulate water levels with a greater degree of confidence.

PROJECTS PARTIALLY RELATED TO CLIMATE CHANGE

Monitoring of Air Quality and Local Meteorological Parameters in Support of the U.S. Department of the Interior's Materials Exposure Program

Cooperative research to evaluate material deterioration is in progress with the U.S. Geological Survey and the National Park Service. At the Washington, DC, West End branch library, a continuous set of measurements has been made since 1988 in support of the U.S. Department of the Interior's materials exposure program. This program evaluates the performance of a variety of building materials (such as stone and various metals) in a range of environmental exposures throughout the northeastern United States. Meteorological parameters, air chemistry, and sample surface temperature and moisture cycles are continuously measured.

Monitoring of Regional-Scale Dry Deposition via An Inferred Flux Method

A cooperative effort with the National Oceanic and Atmospheric Administration - Atmospheric Turbulence and Diffusion Laboratory is continuing at the Water Survey's Bondville Road field site in central Illinois. The project objective is to continuously monitor air quality and micrometeorological parameters of dry deposition as an aid to evaluating deposition models. The computed regional dry deposition rates have been used in assessments of total atmospheric deposition of sulfate and nitrate on regional, national, and continental scales.

Management of Great Lakes Atmospheric Deposition Sites

The ongoing monitoring of precipitation chemistry by the Great Lakes Atmospheric Deposition (GLAD) network is an important component of the U.S. Environmental Protection Agency's continued strategy to obtain information on the nature, sources, and magnitude of the air toxic deposition problem in the Great Lakes. Information gained from monitoring is to be made available to

others for research. Water Survey scientists continue to manage six GLAD sites in the state of Michigan. In general, we try to ensure the routing and proper collection of precipitation samples and their timely delivery for chemical analysis. A bimonthly newsletter is published.

Management of Data from the Central Analytical Laboratory of the National Atmospheric Deposition Program/National Trends Network

Because of its experience and expertise in the measurement of precipitation chemistry, the Water Survey serves as the Central Analytical Laboratory (CAL) for the nation's "acid rain" network, the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) . One goal of this program is to measure the composition of precipitation across a network of sites, so that its spatial distribution and variability can be determined and so that seasonal and long-term trends can be calculated.

Apart from the chemical analysis of the one-week samples collected at some 200 sampling stations, another key part of CAL operations is the management of the data. This involves a thorough review to assure the completeness and correctness of the data. Data are carefully verified to assure that numbers and observations have been reported correctly. Data are also reviewed to assure that the experimental controls and objectives of the measurement program have not been compromised. For the NADP/NTN measurement program, this means determining that the one-week sample sent to the CAL for analysis was exposed to the atmosphere only during precipitation, that specified standard operational procedures were followed in the field and at the CAL, and that samples were not grossly contaminated during sample collection or handling.

To facilitate this comprehensive review of the data, a full-time CAL/site liaison maintains active lines of communication between field site operators and CAL data management staff. The liaison gives advice on operational problems, seeks missing data and corrections for erroneous data, requests clarification where documentation of sampling problems is unclear or incomplete, and answers questions posed by the operators. Once this is completed, the data are reported to the state, federal, and international scientific communities, which summarize the data in various ways to address such questions as how source reductions in one area of the country may affect the wet deposition in another area, perhaps several thousand kilometers away, sensitive to "acid rain" effects. Since answers to these questions can affect costly control strategies in the future, the integration of the chemical analysis, data management, and site liaison functions at a single central laboratory, the CAL of NADP/NTN, is a cost-effective approach to providing consistent high-quality data.

Study of Atmospheric Pollution Scavenging

This project involves the operation of one of the nine sites for the Multi-State Atmospheric Power Production Pollution Study (MAP3S) rain sampling network. Wet-only rain samples are collected at all of the stations, and samples are recovered on an event or a daily basis. Samples are sent for analysis of the major inorganic anions and cations to a single laboratory, the Pacific Northwest Laboratory (PNL) in Richland, WA. Data are reported to the Atmospheric Deposition System (ADS), where they are available to the entire research community. An objective of MAP3S is to build a data record of chemical and meteorological variables at regionally representative sampling locations, so that hypotheses relative to the scavenging of airborne pollutants can be tested. Ultimately, a description of the key physical and chemical processes that link airborne pollutants to pollutants in clouds and precipitation is needed to evaluate a rational strategy to mitigate acidic deposition. MAP3S data continue to build our understanding of these key processes.

Additional research is being conducted to determine the impact of variations in aerosol size distribution on the chemistry of precipitation. To this end, optical aerosol size distribution data are being collected, along with supporting aerosol chemical composition measurements, in an attempt to correlate different distinctive aerosol size distributions with chemical composition. This determination is of interest because of the wide variations in aerosol size distribution observed during the course of only a few hours' time. These large variations may be responsible for large fluctuations in the event rain chemistry data.

An Experiment to Evaluate the Effects of Sampling Period Length on the Chemistry of Precipitation

Several regional and national networks designed to collect precipitation for chemical analyses are in operation in the United States and Canada. While some of these networks use the same equipment or the same laboratory procedures, each is different in some unique way. One important distinction is that some of the networks collect samples daily, some collect samples weekly, and one collects samples monthly. Several investigations have examined the differences due to sampling period length, but the results have not been consistent. Each of these studies has lacked at least one element of control, which may have affected the results. For example, in one study the collectors were installed so that both collectors would open and close at the same time, but different laboratories, using different procedures, measured the daily and weekly samples.

To overcome these shortcomings in previous studies, the Water Survey conducted a study in which the collectors operated in near-synchronous fashion, field procedures differed only in the sampling

period length, the laboratory was the same for all measurements, and the data were screened in the same way. Data from this study, conducted at an eastern U.S. National Atmospheric Deposition Program/National Trends Network site, are now being summarized. Some statistically significant differences have been found for ammonia in daily and weekly samples. Apparently ammonia in solution is not stable in all samples. Results from this study may be used to modify the protocols in current networks to stabilize the dissolved ammonia. These data may also be used to develop an empirical scheme to correct the data already collected. This will facilitate the pooling of data to analyze ammonia in precipitation spatially across regional or national borders, where different networks are in operation.

Ice Formation in Midwest Clouds

The alteration of summertime precipitation in Illinois would occur through stimulation of ice formation. The natural formation of ice in cumulus clouds remains a mystery. The goal of this study is to identify possible natural mechanisms of ice formation in convective clouds as an aid in planning future research. One outcome of the study was a proposal for joint experimental research with the University of Missouri in which their large cloud simulation chambers would be used to test several new ice initiation hypotheses. Ultimately, new knowledge about natural ice initiation in convective clouds will be applied to the climate change issue and to improving scientifically-based strategies for precipitation enhancement and hail suppression in Illinois.

Investigation of Warm Cloud Precipitation Processes

Rain production by coalescence of drops in convective clouds is one of the most important processes of midwestern summertime precipitation. It is this type of rain that caused the Chicago flood of two summers ago. Our weather modification research has also identified warm rain as a significant factor in Illinois precipitation. In 1985 we participated in an NSF-sponsored international field study on convective rainfall using a cloud physics aircraft. In 1990 we obtained more extensive measurements while participating in another NSF field program on the formation of rain bands that included use of Doppler radar data. Our analysis of the 1985 measurements has revealed the existence of giant raindrops and growth mechanisms for the rapid production of rain. Our new understanding of warm rain production will find practical uses in climate change research, in flood forecasting, and in radar-measurement of rainfall.

Frequency of Heavy Rainstorms

This project is a major updating of heavy rainstorm information for Illinois and eight surrounding states (Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin). The results of this research will provide valuable input to those attempting to solve engineering and scientific problems for which knowledge of the frequency distributions and other characteristics of heavy storm rainfall are essential. Information on the time-distribution characteristics of heavy rainstorms at a point and on small basins in Illinois is presented.

This study is also investigating whether the frequency of design rainfall events, at the 1-year to 10-year return intervals, has shifted over the last 80 years. The answer is yes; the last 40 years have had higher values than the first 40 years of this century.

A probing study was done to investigate potential for shifts in heavy rainfall events during significantly warmer periods which are either wetter or drier than the average conditions of the last 100 year. This study revealed that the extreme hot and dry periods of the past had notably decreases and heavy rainfall events at the 5-year and greater recurrent intervals. Similarly a geographical analog test of conditions in northern Illinois concluded that a shift to warmer and wetter conditions would bring a 20 to 25% increase in the 2-year and greater recurrent interval rainfalls.

Assessment of Uncertainty in Time-Related Capture Zones Using Conditional Simulation of Hydraulic Conductivity

A principal component of the wellhead protection program is the physical delineation of wellhead protection areas (WHPAs). A WHPA is defined by the USEPA as the area surrounding a well through which contaminants are reasonably likely to move toward the well, endangering the water supply. Of the many approaches suggested for WHPA delineation, the nominal ground-water time of travel appears to be the most appropriate criterion on which to establish protection zones around wells.

In a recent paper we demonstrated a numerical technique for determining time-related capture zones in nonuniform flow fields that could be used as WHPAs. However, this early work was deterministic in approach; it therefore did not consider the effects of uncertainties in knowledge of hydraulic conductivity on the resultant determination of the time-related capture zone of a pumping well. Recent research has built upon our early work to develop a stochastic approach to time-related capture zone determination, thus allowing a zone of uncertainty to be approximated for the capture zone boundary. Our stochastic approach is based on the conditional simulation of hydraulic conductivity. Conditional simulation of hydraulic conductivity

preserves the spatial correlation structure of the "real" hydraulic conductivity field as well as the measured, or known, values of hydraulic conductivity at sampling locations, thereby optimizing the use of available data. The results have significant implications regarding strategies for sampling aquifer properties for capture zone delineation and for interpretation of the effects of hydraulic conductivity uncertainty on capture zones.

Illinois Irrigation Investigation

Two irrigation studies (a statewide survey of irrigation farmers and a two-year field study of irrigation practices and water use at 275 representative sites in Illinois) have been completed. These serve to help ascertain the potential growth and use of irrigation.

Ground-Water Supply and Demand in Illinois

An updated analysis of ground-water supplies and demands throughout the state, by township, has been completed; the project was part of the efforts of the State Water Plan Task Force. A detailed report has been prepared showing past ground-water use patterns by region and projected ground-water uses for municipal industrial, and irrigation water uses.

Observation Well Network

A long-term activity of the Ground-Water program has been the collection of ground-water level data. The Water Survey is the only state or federal agency in Illinois that maintains a statewide observation well water-level monitoring program. Groundwater-level data are continuously collected from a statewide network of approximately 117 active observation wells. Historical data on 188 non-active observation wells are also available. Forty-nine of the active observation wells are equipped with continuous water-level recorders. Ground-water levels in the remaining wells are measured on a monthly basis.

Shallow ground-water levels in 20 selected observation wells in rural areas remote from pumping centers delineate both short-term and long-term trends of the shallow water-table levels under natural conditions. These water-table measurements were important as an aid to understanding the severity of droughts. The remaining observations wells are located near pumping centers to monitor the

response of local and/or regional aquifers to pumpage. These regions include the Metro-East, Peoria, and Chicago areas.

The geographic area termed "American Bottoms," which surrounds the Metro-East-region, contains 15 observation wells. These wells are used to monitor ground-water levels in a permeable sand and gravel aquifer system extensively tapped by large industrial and municipal ground-water users. In the Peoria area, 13 wells are maintained to monitor water levels in a sand and gravel aquifer system which yields large amounts of ground-water for municipal and industrial use.

Data from 40 observation wells are located in the northern one-third of the state. Twenty-three are deep sandstone wells, nine are shallow dolomite wells, and eight are sand and gravel wells. Twelve are equipped with continuous water-level recorders. Twenty-seven of the observation wells have been in continuous service for more than 20 years, including three in the Joliet area that date back to 1941 and 1942 and one at Crystal Lake that dates from 1950.

Illinois Water Use Inventory Program

A comprehensive program to inventory water use throughout the state began in 1978. The Illinois Water Inventory Program has been developed through the cooperative efforts of the Water Survey and the U.S. Geological Survey. The program was designed to collect data in three major categories: water withdrawal, water use, and water returns. The resulting database includes data on the locations and amounts of water withdrawn from surface and ground-water sources. The following categories are inventoried: Public Water Supplies; Self-Supplied Industries (Mining, Manufacturing, Electrical Power Generation, and Commercial); Rural (Domestic, Livestock, and Irrigation); and Fish and Wildlife Management.

The data collection strategy consists of annual surveys for the largest withdrawal categories (self-supplied industrial and public water supply). The quantity of water used for rural domestic, livestock, irrigation, and wildlife purposes is relatively small when compared to industrial use; however, these are the major water uses in a few counties. Sampling, field investigations, and the involvement of local agencies are used to estimate the total water withdrawal in rural use categories.

Illinois Water Inventory data are summarized geographically by counties and drainage basins as well as by various water use and water source categories. During 1988 Illinois public water supplies and self-supplied industry (excluding electric power generation) withdrew 3,306.2 million gallons per day (mgd) of water. Ground water provided 1,189.3 mgd, and surface water supplied 2,116.9 mgd. Rural demands and fish and wildlife demands were 485.9 mgd and 66.4 mgd, respectively. The largest water user, electric power generation (90.6 percent of the total withdrawal), withdrew 32,019.1 mgd including water for hydroelectric uses.

Long-Shore Currents and Suspended Sediment Measurements in the Southern Basin of Lake Michigan

The southern basin of Lake Michigan is subjected to extreme stress because of its proximity to large industrial centers and municipalities, and because of the input it receives from agricultural and industrial watersheds. The water, sediment, and inorganic pollutants discharged to the southern basin of Lake Michigan are distributed and dispersed by the long-shore currents and the lake circulation. Aerial photos demonstrate the existence of sediment plumes that appear to be dispersing in the near-shore zone. This research, funded in part by the Illinois-Indiana Sea Grant Program, was centered near Wilmette Harbor, Chicago. Lake circulation patterns and sediment in suspension were measured near Wilmette Harbor in 1989. Analyses of the velocity data for the harbor show that the velocity 1 meter above the lake bed ranges from about 1.0 centimeter per second (cm/sec) to 1.3 cm/sec at depths of 2.2 and 5.4 meters respectively. At both sites the water flowed in a southeasterly direction. The sediment concentration varied from 2 to 60 milligrams per liter.

Velocity data were also collected for several weeks at a Lake Michigan site where 8,000-year-old tree stumps are located. The water depth was 23 meters, and the two-dimensional velocity meter was installed 1 meter above the bed. At this site the average velocity for this period was 2.4 cm/sec and ranged from 1 to 9 cm/sec. The water was moving in a westerly direction. These data will be used in determining and evaluating long-shore transport and coastal shore protection within the southern basin of Lake Michigan.

Illinois Benchmark Network
Instream Suspended Sediment Monitoring Program

The Water Survey's instream suspended sediment monitoring program since 1981 has provided a means for gathering data on sediment transport in Illinois waterways. The program is designed to generate and manage a long-term database of annual regression parameters associated with the relationship between water and sediment discharge. Quality long-term data are essential to understanding the relationship between erosion and deposition of sediment, and the effects upon land surface, streams, lakes, and other bodies of water.

Since the beginning of the program, approximately 17,500 water samples have been collected. Laboratory analysis of these samples has determined their suspended sediment concentrations and suspended sediment particle size. Data collected by the Illinois Benchmark Network's instream suspended sediment monitoring program are presented in annual reports.

Influence of Wetlands on Watershed Hydrology and Hydraulics

The objective of this research is to analyze existing long-term streamflow records in Illinois to assess the influence of wetlands on watershed hydrology and hydraulics. Analyses of streamflow records of a number of streams may provide information on how wetlands influence the hydrology of the watershed. If watersheds with different ratios of wetland area to total drainage area behave differently, general relations can be developed between wetland areas and hydrologic parameters. If the hydrologic response of a watershed has changed over time, some of that change might be attributed to changes in land use, especially regarding the extent and drainage of wetlands, and to climate fluctuations.

Adequacy of Public Surface Water Supply Systems to Meet Future Demands

Ninety public water supply systems in Illinois rely on surface water sources for their supply. Continuing sedimentation in their surface water reservoirs reduces capacities and reliable yields, while demand for water typically has increased over time. The adequacy of these surface water supplies to meet future demands was investigated. The first three phases of a four-part study of these public water supply systems have been completed, and the fourth phase is in progress. The first three phases of the project include: 1) identifying all public water supply systems in Illinois using surface water, determining the populations served, and projecting future water demands up to the year 2020; 2) determining the streams and reservoirs used by the systems, projecting future capacities of in-channel reservoirs subject to sedimentation and, on the basis of expected future storage capacities, estimating reliable yields for these systems; 3) comparing the projected reliable yields of the systems' water supply source(s) to future demands and determining those systems which may face water shortages during future drought events.

On the basis of these investigations, it was determined that as many as 24 public water supply systems may experience water supply shortages during future droughts. These systems are currently being studied on a case-by-case basis, and possible alternatives for supplementing their current water supply sources are being evaluated. Various alternatives for augmenting water supplies include (but are not limited to) venting accumulated sediment from in-channel reservoirs, re-routing highly sediment-laden flows to reduce future reservoir capacity loss due to sedimentation; raising normal pool levels to increase storage; and developing other surface or ground-water supplies.

Review of Flood Modeling Methodologies

A literature review of the technical issues associated with rainfall-runoff modeling is being conducted to identify and assess the strengths and weaknesses of 1) hydrologic and hydraulic methods used to estimate flood hydrographs in Illinois; 2) precipitation and rainfall-loss inputs to the various models; and 3) the interpretation or frequency estimation methods used with the model results. The review is concerned with the class of rainfall-runoff models used to estimate flood hydrographs for stormwater management. Particular emphasis is placed on comparing standard rainfall-runoff models, such as HEC-1 and TR-20, to complex continuous simulation models, such as HSPF. These comparisons are needed in order to properly select a model for a desired application.

Areas will be identified for further research that can add reliability and accuracy to the present modeling techniques of stormwater management. Our review indicates that available models are generally more sophisticated than the available data used in the modeling process. Data inputs such as the representation of rainfall distribution on a watershed and the infiltration process continue to be major sources of modeling error. New methodologies also are needed for the frequency analysis of flood events in basins which have a significant amount of detention storage.

Integration of GIS, Remote Sensing, and Digital Evaluation Data for a Hydrologic Model

The Agricultural Nonpoint Source Pollution Model (AGNPS), which was developed by the Agricultural Research Service, was used as a test model for assessing nonpoint source pollution. The model has runoff erosion/sedimentation, and water quality components. Input data were obtained from three main data sources. The first source was the Illinois GIS databases, which include data on soil, land use, streams and water bodies, farm boundaries, monitoring locations, and land management practices. The second source was digital elevation model (DEM) data, which can be used to generate slope and drainage directions and to provide a three-dimensional display of the outputs from the watershed. The third data source was remote sensing data, which included satellite images and scanned aerial photographs. The approach was tested for two Illinois watersheds, and the results indicated that this approach was technically and economically feasible.

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The Illinois State Water Survey was founded in 1895. It is the primary agency in Illinois concerned with water and atmospheric resources. Research and service programs encompass the assessment and evaluation of ground, surface, and atmospheric water resources as to quantity, quality, and use. Scientific research anticipates and reacts to practical problems in the state of Illinois. Much of the Survey's work is facilitated by an extensive database collected and developed over the course of a century.

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