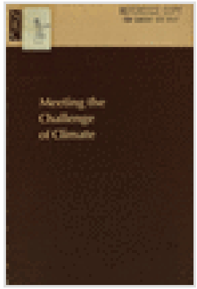

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Meeting the Challenge of Climate

Panel on Intergovernmental Climate Programs

Climate Board

Commission on Physical Sciences, Mathematics, and Resources

National Research Council

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NOTICE The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

PREFACE

In the National Climate Program Act of 1978, Congress authorized the establishment of programs of "Federal and State cooperative activities in climate studies and advisory services." Such cooperative activities, there defined as the "Intergovernmental Climate Program," were intended to help the entire nation meet the challenge of climate by helping to "expand and improve upon existing climate-related services to user groups throughout the Nation" (House of Representatives, 1978). The Climate Board established the Panel on Intergovernmental Climate Programs to assist the federal government specifically in the development of such a program.

Since the inception of the National Climate Program, the Climate Board has expressed the view that the intergovernmental climate programs should play a major role in the conduct of climate studies and the delivery of climate services. In its 1979 report, Toward a U.S. Climate Program Plan, the Board (then the Climate Research Board) emphasized the importance of such activities as a "channel of interaction between groups of users at state and regional levels and officials at national levels who are responsible for providing basic climatic data and services." In a subsequent report, A Strategy for the National Climate Program, the Board (1980) expressed considerable concern over the delay in initiating any intergovernmental activities and urged the "immediate implementation of exploratory programs" as the first phase of a three-phase implementation strategy. This approach has been adopted in the Five-Year Plan for the National Climate Program issued by the federal government in September 1980.

The Board also created a Panel on the Effective Use of Climatic Information in Decision Making, which produced a report on Managing Climatic Resources and Risks (1981). That report identified key user needs for climate data and information and made recommendations on how to improve the existing information-delivery system to meet these needs better. Among its conclusions was that a broad-based network of experts is critical to the application of climatic knowledge in many different activities. Intergovernmental climate activities were identified as the principal means by which public (federal, state, and local) and private resources could be harnessed to support such a network.

The Panel on Intergovernmental Climate Programs was formed with two major objectives:

1. To examine and document the need for and potential benefits from cooperative federal and state climate activities; and
2. To develop strategies for the implementation of coordinated intergovernmental climate activities at state, regional, national, and international levels. . .and make recommendations to improve the effectiveness of such activities.

Objective 1 is addressed in Chapters 2 and 3 of this report, and objective 2 in Chapters 4, 5, and 6.

As part of its study, the Panel solicited case studies of the effective use of climate information from a variety of individuals and groups, including state climatologists, private consulting meteorologists and climatologists, and selected government organizations. The Panel greatly appreciates the many detailed and thoughtful responses to its request. It also thanks the American Meteorological Society for permission to reproduce Meteorological Monograph No. 1, Wartime Developments in Applied Climatology, for use in its case-study solicitation and for permission to reprint the article, "Examples of Applications of Climatic Data and Information Provided by State Climate Groups," included as Appendix A to this report.

The Panel met three times between December 1980 and August 1981. The group is especially grateful to Panel member Thomas B. McKee for hosting the third meeting at the Colorado State University, thereby enabling several participants to attend the 1981 annual meeting of the American Association of State Climatologists. Thanks are extended to the latter organization and its members for permitting Panel members and staff to observe the annual meeting, which provided many useful inputs to the Panel's report. Inputs were also received from representatives of several different government agencies during the Panel's meetings, for which the Panel is grateful. These representatives included Peter Robinson and Norman Canfield of the National Oceanic and Atmospheric Administration, Kenneth Bergman and David Richtmann of the National Science Foundation, Robert Dale of Purdue University, Boyd Post and Norton Strommen of

the U.S. Department of Agriculture, and David McClintock of the Department of State.

Finally, the Panel gratefully acknowledges the substantial contributions of the Climate Board staff, notably Robert S. Chen, to both the substance and production of the report. Additional editorial assistance was ably provided by Jesse H. Ausubel.

William C. Ackermann, Chairman
Panel on Intergovernmental Climate Programs

CONTENTS

SUMMARY

The diverse climatic regimes of the United States constitute a significant natural resource. The variability of climate presents not only hazards and risks but also opportunities to improve the operation and productivity of many sectors of our complex society through wise use of available information about climate. Analyses of a number of case studies of successful applications of climatic information permit identification of a number of common needs:

1. Highly specialized and localized information in probabilistic form;
2. Easy access to data at several levels of summarization or aggregation;
3. Usable composite measures or indices tailored to individual applications;
4. Data other than the standard meteorological observations;
5. Compatibility in time and space resolution between climatic data and other types of technical, environmental, and social data;
6. Adequate spatial coverage of climatic data;
7. Current information, as well as historical data; and
8. Where available, climate forecasts.

Most applications of climate information are on a local or regional level, and a key role is played by experts experienced in local climate, data sources, user needs, and decision-making environments. Thus, decentralized climate services are essential to satisfy national needs, with both the public and private sectors playing important roles. Such services are best provided through a coordinated nationwide system of federal, state, and local climate services, both public and private, that are made up of local experts, state and regional climate programs, and federal activities.

The National Climate Program Office should take a leadership role in the development and support of a coordinated, nationwide system of climate services involving both the public and private sectors through collaboration with existing state and regional climate programs and by encouraging the further development of such programs.

- Initial exploratory work should be completed speedily.
- An equitable process for defining responsibilities should be initiated.
- Mechanisms for coordinating federal-agency participation should be implemented.
- State and regional climate programs should enter the intergovernmental climate program as full partners, motivated primarily by possibilities for improvements in access to data, expertise, and facilities.

These efforts could lead to marked improvements in climate monitoring; data analysis and quality control; research and innovation; coordination, communication, and referral; dissemination of information and delivery to users; education; and maintenance of a flexible, responsive, and accessible system for providing climate services to all sectors of our national economy.

1

INTRODUCTION

The vast territory of the United States encompasses many different climatic regimes, from deserts to humid river basins to Arctic tundra. We take advantage of these varied climatic resources in a myriad of ways in agriculture, industry, recreation, and many other activities. Fluctuations in climate such as droughts, or heat waves, or frigid winters can have widely differing impacts, beneficial or adverse, depending largely on local climatic and social conditions.

To a great degree, our economic and social activities are already well adjusted to local climatic conditions, especially to the wide variations in temperature and precipitation that characterize the seasons. Homes, buildings, and roads in northern parts of the country are generally designed to withstand severe cold and heavy snow, whereas those in southern areas are geared to milder winters and warmer summers. Particular crops are grown in regions for which they are well suited climatically, as determined largely by length of growing season, local temperature and precipitation, and soil and economic conditions. Lifestyles are closely adapted to local climate in the clothes we wear, the foods we consume, and the recreation we seek.

Nevertheless, there are still ample opportunities for improving our adaptation to climate, ranging from new methods to take advantage of climatic resources to better understanding the influence of human activities on local, regional, and global climate. These opportunities, the challenge of climate, may arise from many sources, including the following:

(a) Technological developments, such as solar and wind energy systems or new insulation methods, that generate new uses of climatic resources or better adaptations to climatic hazards and conditions;

(b) Social changes, such as altered population levels or policy decisions, that change the patterns of use of climatic resources (e.g., water supplies) or permit different ways of dealing with climate (e.g., insurance mechanisms and building codes); and

(c) Long-period climatic fluctuations or climatic changes on local, regional, or global scales, perhaps due to anthropogenic influences such as urban development or watershed modifications, that alter the mean climatic conditions or the likelihood of extremes to which society is currently adapted.

Opportunities such as these constitute a challenge to our society, because meeting them inherently requires timely, reliable, and balanced understanding of climatic, social, and technological conditions and capabilities. Yet the benefits of meeting this challenge, of helping society to adjust to climate in the most effective and efficient manner possible, are--and will continue to be--considerable. How such benefits can best be realized, through the cooperation and collaboration of a wide variety of groups at local, state, regional, and federal levels, is the focus of this report.

As in the earlier Climate Board (1981) report, Managing Climatic Resources and Risks, it is useful to clarify a few commonly used terms:

> A sharp distinction is made in this report between data--the numbers and symbols representing observations--and information--the interpretation of data for some specific purpose. Decision makers usually require information, although they may also need access to the original data. Also, weather is defined as a set of atmospheric conditions at a specified time. Thus, the term weather refers to events or episodes--a rain shower at 3:00 p.m. over the Washington Monument, a tornado located 100 miles west of Chicago at 6:00 p.m. Climate is the statistical description of weather over some past period or an estimate of what the statistical characteristics of weather will be over some period in the future. The latter can be usefully expressed as a probability distribution and is estimated from theory or from the statistics of the past. This information about climate, which is all that can be provided, is a substitute for the perfectly accurate weather forecast that we cannot have. Both weather and climate are different kinds of descriptions of the state of the physical climate system of our earth--the land surface, the snow and ice masses, and the turbulent ocean and atmosphere.

In addition to the above terms, it is useful to define climate services as both information about climate and its effect on human activities and assistance in avoiding or ameliorating undesirable effects or in enhancing desirable ones.

2

EXAMPLES OF THE UTILITY OF CLIMATE SERVICES

The wide variety of climate-related problems and the degree to which their resolution depends on a blend of climatic, technological, and social expertise are best demonstrated by example. This chapter thus contains descriptions of cases of past, present, and potential utility of climate services in such varied activities as agriculture, water-resource management, transportation and construction, and energy operations. Emphasis is given to benefits derived. The Panel's survey of climate applications was by no means comprehensive, and the cases described are not necessarily exemplary of the highest benefit/cost ratios nor are some highly climate-sensitive activities included, such as fishing, recreation and tourism, health care, and military operations and planning.* Rather, the cases were selected as representative of climate-related problems that have been significant in the past, may now be important, or are likely to grow in importance in the future. The reader is also referred to Appendix A, in which a large number of examples drawn from all over the continental United States are presented, demonstrating the ubiquity of

*See National Oceanic and Atmospheric Administration (1976) for a discussion of climate and fisheries; McKay (1976) for a review of climate's importance for recreation and tourism in Canada; National Climatic Center (1976) for a discussion of climate and health; and Jacobs (1947) for an examination of wartime applications of climate information, many of which have had civilian uses. White and Haas (1975) present a review of research on the impacts of and responses to natural hazards, including hurricanes, floods, lightning, tornadoes, hail, windstorms, frost and freezing, urban snow, snow avalanches, and drought. Also see Committee on Weather-Information Systems (1980).

climate-related problems. For a more complete literature review of the economic benefits of climate information, see Berggren (1975).

AGRICULTURE

The production, harvesting, processing, and marketing of agricultural commodities are the most climate-sensitive industries in our economy. Crops and food animals are generally adapted to a limited climatic range. Variations from normal can have serious adverse impacts. Climatic variables of importance include temperature, precipitation, solar radiation, growing degree days, soil conditions, relative humidity, windiness, length of the growing season, frequency of hail and storms, and often the dates of first or last occurrence of frost. In addition, many nonclimatic factors that influence crop and animal health and productivity, such as water availability, the ravages of pests, and fertilizer and feed prices, are climate-dependent to varying degrees. Thus, as emphasized in the report of the National Research Council's Board on Agriculture and Renewable Resources (1976): "the major cause of season-to-season variation in food production is the fluctuation of weather and climate." It is clear that improvements in climate information would be of great value to farmers in managing their resources better to optimize productivity and minimize losses. Several examples follow. They do not cover all climate applications for agriculture, for example, uses by national or international policy makers and market managers,* but they should give some appreciation of the nature and magnitude of opportunities available. For further details see Impact of Weather and Climate on Agriculture: A Selected Bibliography (National Climate Program Office, 1981).

Case 1: Scheduling of Crop Harvests

Climate information has been used for several decades to schedule plantings of such crops as peas and sweet corn so that crop harvests will be spaced for optimal utilization of harvesting and processing equipment. The concept is that the time to maturity for different varieties of these crops is a function of the cumulative exposure to temperatures above a base (40°F for peas and 50°F for sweet corn). This exposure is normally expressed

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*See, for example, Hill et al. (1980) and MacDonald and Hall (1980).

as "growing degree days." Thus, a producer can choose varieties to plant or can space plantings so that a desired schedule of maturation will occur based on the expected local pattern of temperature during the growing season. The concept was introduced by C. W. Thornthwaite for Seabrook Farms in New Jersey in the 1950's (Thornthwaite, 1953; see also, Maunder, 1970). It continues to have wide application for both growers and processors of peas and sweet corn in Michigan, Wisconsin, New York, and Minnesota. The value of the information is estimated at several millions of dollars per year.

Growing degree days are also useful for field corn production. Seed companies specify maturity times for different corn hybrids as a function of growing degree days. This helps in the selection of hybrids for various regions within the Corn Belt. Extension specialists in the Corn Belt recommend hybrids with ranges of cumulative growing degree days for maturation that are the most appropriate for selected regions. The earliness or lateness of a growing season is monitored for most regions. When planting is delayed, for example, the planting of earlier corn varieties or even a change to soybeans is recommended to minimize the risk of frost damage before harvest.

Case 2: Integrated Pest Management

Approximately one third of all agricultural crops worldwide are never harvested because of losses from pests such as insects, weeds, diseases, and nematodes. Both plants and pests are sensitive to climate and weather. There are many historical examples of the interacting effects of climate and weather on pests and related agricultural productivity, with large resultant losses. A few examples, documented in more detail in Climate and Food (Board on Agriculture and Renewable Resources, 1976), are listed here. The so-called "potato famine" in Ireland in 1848 stemmed largely from the interaction of wet weather and pests (late blight), which devastated that year's harvest and led to the starvation or migration of some one-and-a-half-million people. The hot weather of the 1930's in the United States favored wheat rust, while the associated drought hindered the growth of wheat. The result was the loss of several million metric tons of wheat in several of the years of that decade. The southern corn leaf blight of the 1970's decimated corn fields from the Gulf of Mexico to Minnesota. This blight occurred because of a combination of susceptible cytoplasm found in 85 percent of the corn seed and an unusually warm and wet growing season. The loss was estimated to be on the order of $1 billion. Aphids and the viruses that they carry often combine in warm and rainy spring or autumn weather to cause enormous losses in legumes, grasses, and vegetables, but during dry springs or autumns few aphids can be found and viruses are less severe or absent; in other words, climate can affect not only pests but the pests carried by pests. Changes in weather may also influence plant resistance to pests. Indeed, the effectiveness of pesticides is often dependent on weather and climatic conditions.

New strategies to combat plant pests take greater account of weather and climate conditions, among other factors, in determining optimal actions to reduce agricultural losses. Commonly known as "integrated pest management," these strategies attempt to incorporate real-time, on-line weather and climate information into planning and decision making. Simulation models of pests, crops, and climate are used to estimate improvements in crop production and economic worth if pests are eliminated by pesticide spraying at different times. For example, as documented in Climate and Food, a simulation model was able to demonstrate that early pesticide spraying of alfalfa to eliminate the weevil during warmer springs could increase the harvest value of the crop by more than $30 per acre.

Some specific economic values of climate and weather information in pest-management strategies for Michigan fruit growers can be given. The state has 145,000 acres of fruit. The frequency and cost of pesticide application vary. It is conservatively estimated that by using weather forecasts the fruit industry can save one spray application annually. The average cost of a single spray is $10 per acre for material and labor. This alone results in a decreased expenditure of at least $1.5 million. Weather services in many other states are of equal or greater value.

Case 3: Irrigation of Crops

Irrigation provides an excellent illustration of the value of climate information. As described in more detail in an earlier Climate Board (1980) report, A Strategy for the National Climate Program, irrigation in the United States has been growing rapidly, with over 60 million acres of land now irrigated, including some 7 million acres in Nebraska alone.

One major irrigation method is the center-pivot system, which relies on diesel fuel or equivalents such as liquefied petroleum gas and natural gas for power. In 1981, a single irrigation cycle cost between $6 and $8 per acre. During an average year in Nebraska, fuel consumption for a center-pivot ranges from 4500 to 10,800 gallons of diesel fuel equivalent. Since existing pivot systems number over 50,000 in the United States, annual fuel consumption approaches half a billion gallons of diesel fuel equivalent.

Excessive irrigation can be detrimental. Too frequent or intense applications of wastewater degrade soil and water quality, exacerbate the depletion of groundwater supplies, and reduce crop yield. Some farmers apply more water than necessary, sometimes double the amount needed.

Climate information can help farmers avoid overirrigation. Better scheduling from field to field is possible given knowledge of soil type and moisture conditions, crop type and stage of development, irrigation-system characteristics and efficiency, cumulative evaporation data and likely forthcoming precipitation and evapotranspiration, and weather or climatological forecasts several days in advance. It is estimated that in Nebraska the number of irrigations could be reduced by one to two per season using even primitive scheduling based on the above information. Thus, for Nebraska, costs could be reduced by $50 million to $100 million per season, with additional savings possible by further refinements of scheduling. Nationwide, cost reductions could approximate a billion dollars per year.

Case 4: Animal Agriculture

There are many relationships between livestock performance and climate. There are demonstrated needs for climate information in regard to poultry, husbandry, and the swine industry. One of the best understood relationships is the adverse impact of summer weather--excess heat and humidity--on the milk production of dairy cows. Climate information can be used to help assess the likelihood and level of impacts and evaluate alternative strategic and tactical management responses such as the investment in and operation of environmental modification equipment to limit losses. It is essential that appropriate and reliable climatic data be used in such assessments and evaluations.

Weather records from June 1 to September 30 during the heat wave of the South and Midwest in 1980 were reviewed to compare the impact of hotter-than-normal temperatures on the performance of dairy cows with normal summer milk-production declines. Production declines were greater than the worst expected in one year out of ten in Georgia, Missouri, Texas, Ohio, Tennessee, Oklahoma, and Arizona. Conversely, less severe to near-normal declines were noted for Idaho, Wyoming, California, and South Dakota. Since dairy production is concentrated primarily in California and the northern states (New York, Minnesota, Wisconsin, and Michigan), the adverse impact of the 1980 summer heat wave in the South was not important for total U.S. milk production. However, on a local and regional scale, milk production was markedly reduced.

The value of climate control to alleviate stress on dairy cattle can be assessed using climate data for 5-20 years. The statistics of summertime milk-production decline have been derived for cows at various production levels under normal environmental conditions throughout the United States. The declines that might be expected for cows provided with evaporatively cooled air or other climate-control practices have also been estimated. Comparison of the two sets of statistics provides an estimate of the potential benefits of climate control for a particular location and size of operation. This enables a dairy farmer to calculate benefit/cost ratios for a proposed installation. This method has been used by many dairy producers who otherwise would not have considered evaporative cooling as an option. The sale of evaporative-cooling equipment for dairy and other livestock housing has grown considerably in the United States in recent years.

Case 5: An Agricultural Climate Situation Committee in Nebraska

A Committee was established in the spring of 1981 under the auspices of the Cooperative Extension Service to provide up-to-date information and advice on current climatic conditions for Nebraska's agricultural industry. The Committee is composed of specialists in fields covering all important agricultural commodities produced in Nebraska and a journalist (writer). It includes a number of agronomists and soil scientists, a plant pathologist, an entomologist, a rangeland specialist, a forester, an animal scientist, and a veterinarian, as well as a number of climatologists and meteorologists.

The Committee assembles at 8:30 a.m. each Wednesday morning (in 1982 it will meet on Monday mornings) to review weather and climate data that have accumulated during the previous week. These data include the Weekly Weather and Crop Bulletin and the Monthly and Seasonal Outlooks produced by the federal government. Preliminary Crop Cards with temperature and rainfall reports from 60 selected cooperative climatological observing stations in Nebraska are assembled with the assistance of the Omaha Office of the National Weather Service (NWS). Data from 5 automated agricultural weather stations and from a network of 11 NWS first-order stations are assembled. Climatological analyses and summaries prepared in previous years are also available.

After a thorough review of the current weather-related agricultural problems, advisories are prepared. The journalist composes a press release during the last half hour before the

Committee recesses at 10:00 a.m. The press release is checked by a Committee member and released by about 2:00 p.m. That Committee member also prepares a tape recording for release to radio stations later in the day.

A brief look at the spring of 1981 illustrates the kinds of problems with which the Committee has dealt. The fall of 1980 was dry after a severe heat wave in 1980, and soil moisture was depleted in the top 5 feet (the root zone for most of Nebraska's major crops). The winter of 1980 was extremely dry and very warm. Hence, the spring began with depleted soil moisture throughout much of the state and with unusually warm soils. Dry surfaces early in the season tempted some farmers to plant earlier than normal. The Committee advised against such early planting by emphasizing that the probability of a killing frost remained great, despite the unusual warmth.

As the spring progressed with little rainfall, the Committee urged that corn farmers, particularly those on unirrigated land, hold open their options to plant alternative crops such as sorghum and soybeans that are generally more drought-resistant than corn.

Another result of the warm, dry spring weather was an unusually early break in winter-wheat dormancy. Although the Committee was fully aware of the potential vulnerability of the wheat to late spring frost because of this early break in dormancy, it could recommend nothing to minimize the risk. It did, however, alert state agencies to this potentially serious problem. Indeed, a sharp frost occurred in early May, when wheat was prematurely in flower, causing an estimated $100 million loss to farmers.

Sorghum appeared to be a good alternative to corn, since the spring continued to be dry. However, wheat fields in southeastern and south-central Nebraska were infested with chinch bugs. Sorghum is particularly vulnerable to this pest, and so, the Committee determined, sorghum planted near wheat fields would be particularly susceptible to attack as the chinch bugs migrated out of maturing wheat fields. Thus, where both corn and sorghum appeared risky, the Committee recommended that farmers plant soybeans.

The interdisciplinary structure of the Committee was particularly valuable in cases such as this. For example, the entomologist pointed out that land prepared for corn or sorghum might already have been treated with an herbicide antagonistic to all broadleaf plants such as soybeans. Thus, the Committee urged that farmers examine the herbicide treatment history before a decision to plant soybeans was made.

Rangeland in northern and western Nebraska was also extremely dry in the spring. Through June, hay harvest was almost negligible. The Committee encouraged ranchers to use

Extension Service assistance in locating supplies of hay or finding markets for their excess animals.

Trees in cities also showed serious moisture stress by early summer. Homeowners were advised to soak the area around their trees thoroughly rather than rely on the weekly half-inch lawn irrigation otherwise recommended.

This brief summary describes some of the events and agricultural problems that the Agricultural Weather Situation Committee dealt with from March through June. In late June good rains began, and the 1981 summer crop season was a good one. The Committee continued to function throughout the growing season. Notably, radio and television stations and newspapers throughout the state disseminated the findings of the Committee widely and regularly during 1981.

WATER-RESOURCE MANAGEMENT

Climate strongly influences both the supply of and demand for water. With respect to water supply, climate is a principal factor in determining the water resources of a region. Precipitation provides the major input to a watershed, except for sources of stored, "fossil" water such as the Ogallala aquifer in the central and southern Great Plains. Climatic factors such as insolation, temperature, humidity, and windiness govern water loss through evaporation and transpiration. Infiltration and runoff are substantially determined by soil type, physical condition, and climatic variables such as antecedent precipitation (soil moisture), temperature, and rainfall intensity. Water quality depends on the amounts of both water and pollutants; the distribution of pollutants is strongly influenced by climatic conditions such as prevailing winds, the occurrence of temperature inversions, and type and frequency of precipitation.

The effect of climate on demand for water may also be great. High temperatures increase both water use and evaporative losses for urban and industrial cooling and agricultural and domestic irrigation. Also, the widespread use of air conditioning during hot summers can significantly increase the use of electricity, which may in turn increase the need for water in hydroelectric facilities and in cooling towers at thermal electricity-generation plants. Unfortunately, these increased demands for water are often likely to occur simultaneously with reduced water availability.

Water, or the lack of it, may also be a hazard. Droughts can seriously affect all sectors of the economy, including agriculture, transportation, hydroelectric power generation, and recreation (see, e.g., Rosenberg, 1978; White and Haas, 1975). Similarly, floods also affect broad segments of the commonweal (see, e.g., National Science Foundation, 1980). Water in the form of river ice may also be a significant problem, causing tens of millions of dollars in losses annually in the United States from interruptions in navigation and power production and other problems (Ashton, 1979). Reservoirs and drainage systems require large investments and in many instances still have dangerous inadequacies (see, e.g., White and Haas, 1975). Short- and long-range planning to deal with these situations should involve climatological analyses.

Several different examples of the use of climate information to manage water supply and demand are given in this section. The reader is also referred to two earlier NAS reports, Climate, Climatic Change, and Water Supply (Geophysics Research Board, 1977) and The Atmospheric Sciences: Problems and Applications (Committee on Atmospheric Sciences, 1977), for multidisciplinary treatments of the subject.

Case 6: Judicial Allocation of Interstate Waters

There is a long history of controversy over the water that is allocated for diversion from Lake Michigan at Chicago by the state of Illinois. Several times within this century the U.S. Supreme Court has been called on to settle disputes between Illinois and the other states bordering the Great Lakes. The water diverted at Chicago is used for municipal water supply, dilution of treated wastes, navigation, and other purposes.

A Court decree in 1967 limited the amount of water diverted to an average of 3200 cubic feet per second per calendar year [United States Supreme Court, in Wisconsin v. Illinois, 388 U.S. 426 (1967)]. Part of the permitted diversion consists of precipitation and runoff. Year-to-year variations in precipitation required that a substantial reserve of the allocation be retained to meet unpredictable periods of excessive precipitation and runoff that might come at the end of the year. The result was relatively inefficient management of the permitted diversion.

A revised decree of the Court in 1980 permits flows to be averaged for periods of 40 years in consideration of natural climate variability and an apparent trend of precipitation increases due to urban effects (United States Supreme Court, in Wisconsin v. Illinois, modified decree, December 1, 1980). The effect of this revision will be to make it possible to supply Lake Michigan water to 56 new communities representing a population of some 1.5 million people. The mining of groundwater can be reduced and eventually brought into balance with the sustained recharge capability.

This recognition of climate variability has had benefits far beyond expectation to the citizens of Illinois and Wisconsin through improved water management and without increase in the long-term diversion from the common resource of the Great Lakes.

Case 7: River Development and Operations

Climate information is frequently used in planning for river development and conduct of river operations, although there have been instances in which better information could have been employed. For example, as documented in more detail in an earlier Climate Board report, Managing Climatic Resources and Risks (Howe and Murphy, 1981), and in the report Climate, Climatic Change, and Water Supply (Dracup, 1977), important legal and engineering decisions regarding the apportionment of water between basins of the Colorado River were made in the 1920's based on limited climatic records that turned out to be unrepresentative of the long-term riverflow. This has been a cause of continuing legal and political problems, including an international dispute with Mexico over water quality and amount, that have plagued the River's development ever since.

Climate data and information also have extensive utility in the development of seasonal forecasts of riverflow on which decisions are made regarding the allocation and pricing of water for irrigation, the use of water to generate electricity, and the management of fishery and recreational resources. Climate-based statistical forecasts have been used, for example, in the Columbia River Basin for several decades. New opportunities to use climate data and information still exist, e.g., through the development of detailed computer-based simulation models that explicitly incorporate climatic parameters (Fleagle and Murphy, 1981). According to one estimate, a 1 percent improvement in the spring flow forecast to the Portage Mountain Reservoir in Canada could result in about a $1 million reduction in annual operational costs (McKay, 1976). On the other hand, errors in forecasts from lack or misuse of climate information or other reasons may have substantial adverse impacts. As documented by Glantz (1982), the Bureau of Reclamation's project office in the Yakima Valley of Washington State made a forecast of extremely low water-supply availability for the area in 1977, based on a subjective adjustment of supply estimates that already contained significant technical errors. Because of the prior appropriation system for allocating water rights in the area, the low forecast induced some irrigators to take drastic and costly actions to save their investments. However, the shortfall predicted by the Bureau (but not predicted by two other federal agencies, the Soil Conservation Service and the National Weather Service) never materialized.

Case 8: A Drought Response Plan for Colorado

In recent years, the state of Colorado has experienced serious and costly water shortages. These shortages have been the result of changing conditions in water supply and demand arising from Colorado's relatively arid climate and its rapidly growing population. As population continues to increase and as climate and conservation practices fluctuate, a temporary reduction in water supply can be highly disruptive to normal activities in both urban and rural settings. Two consecutive years of significant reductions in precipitation in Colorado would likely have serious and far-reaching economic impacts.

A systematic and timely application of scarce resources, when utilized on the basis of a clear understanding of existing or potential impacts, can reduce the adverse effects of drought. Should a drought intensify to the point where broad-scale impacts exceed the state's response capabilities, an existing and effective state program for the mitigation of drought impacts can improve access to and delivery of federal assistance.

The Colorado State Government has developed a drought response plan to provide an effective and systematic means for the state to deal with emergency drought problems that may occur over the short or long term (State of Colorado, 1981). The plan consists of two distinct systems that operate in tandem to support the state government's response to a drought. One system supervises the assessment of drought conditions, and the second manages the state's response. The assessment system utilizes a broad range of information sources, gathers and evaluates data, and identifies problems that cannot be met locally. The response system deals with current and unmet needs that fall within the state's capabilities.

The planned pattern of response to drought is founded on an information system that continually monitors drought severity in terms of water-availability indices (WAI). If the WAI reach values less than a certain critical value, a Water Availability Task Force is activated by the Division of Disaster Emergency Services, which has responsibility for coordinating the drought response. These two groups monitor conditions closely until (and if) the WAI reach a still lower threshold. At this point, a Governor's memorandum is issued to activate eight additional Task Forces to assess drought impacts. The eight Task Forces, composed of state and federal agencies, focus on municipal water, wildfire protection, agriculture, commerce and tourism, wildlife, the economy, energy, and health. Information on impacts from all of these groups is brought together to determine when and what response is needed. Thus, the impacts determine the threshold for activating the response portion of the plan. If the impacts are great enough to exceed the capacity of normal response mechanisms, then the Governor proclaims a drought disaster emergency. This emergency status allows responses not possible through normal channels.

The drought response plan requires a significant use of current and historical meteorological and climatological data. Basic questions likely to arise include what the current conditions are, how fast conditions are changing, and what lies ahead. The first two questions need to be answered well, since they form the basis for answering the last question, which involves describing possible conditions up to a year in the future on small spatial scales. Drought in Colorado is a complex phenomenon that spans all seasons of the year and affects groundwater, soil moisture, mountain snowpack, reservoir storage, river flow, and other parameters. More than one drought- or water-availability index is needed for monitoring purposes. The WAI include data on precipitation, temperature, and soil moisture and also measurements of groundwater, reservoir storage, and river flow. The monitoring function of the Water Availability Task Force depends on a significant degree of coordination and cooperation among state and federal agencies. Groups currently involved include the Colorado Division of Disaster Emergency Services, Department of Natural Resources, and State Climatologist and regional offices of the U.S. National Weather Service, Soil Conservation Service, Geological Survey, Bureau of Reclamation, and Bureau of Land Management. The entire plan could not function without cooperation.

TRANSPORTATION AND CONSTRUCTION

Climate services have utility in virtually all modes of transportation and types of construction. From walking to launching vehicles into space and from building sidewalks to locating and constructing launch pads, we use our understanding of climate in the conduct of transportation and construction operations and in the design and maintenance of transportation and other infrastructures. Sidewalks, for example, are generally designed to permit adequate drainage and are generally installed during summer when concrete sets best. Spacecraft launch sites are located in areas with high probabilities of benign weather conditions, and launches are scheduled to take advantage of "windows" in which adequate weather conditions are expected to persist for sufficient periods of time. More generally significant in economic terms, of course, are uses of climate information by planners and managers of railroads, river traffic, highways, aircraft and airports, and construction firms. A variety of different examples follows.

Case 9: Runway for Anchorage International Airport

Climatological wind data are frequently used in the siting, design, and operation of airports and airport runways (e.g., National Climatic Center, 1975, 1981). However, considerable care is needed in collecting and analyzing such data because of the unusual characteristics of wind and difficulties in observations.

In Anchorage, a problem arose concerning whether to build a "crosswind" runway at a cost of $33 million, as described by Haggard (1980a). The Federal Aviation Administration (FAA) required that crosswind components greater than 15 miles per hour (mph) must be present 5 percent or more of the time for such a runway to be justified. The 7 years of data collected at 3-hour intervals chosen for analysis by the state of Alaska yielded a crosswind component of 15 mph or more for 5.88 percent of the time. The FAA therefore authorized construction of the runway. However, a plaintiff whose property values would have been affected by flights from the new runway filed a lawsuit that sought to restrain the FAA from spending federal funds for the runway. The plaintiff alleged that a more complete analysis of the wind data would indicate that the proposed runway did not meet the FAA crosswind standard and that, based on 17 years of wind data, crosswinds of 15 mph or more occurred only 4.8 percent of the time.

The project was halted, and a more detailed study of the winds was made. Wind data for all hours for a period of 23 years were employed. Among the factors considered were the representativeness of the observational site, the continuity of the observational techniques, the accuracy of the measuring equipment, the methodology used in the data analysis, and the relationship of the data to the operational application. The study computed the crosswind component in over ten different ways; only one of the methods used yielded a value less than 5 percent for crosswinds of 15 mph or more. The Federal District Court that heard the case therefore approved construction of the runway, which is now in use.

Case 10: Two Railroads Sued for Damage Caused by Flash Floods

Another case of the utility of climate services in transportation-related litigation has also been provided by Haggard (1980b). Two railroad companies were sued for some $20 million in damages by downstream industries for allegedly contributing to the severity of flash floods that occurred in North Carolina in 1977 by altering the natural flow of the streams by embankments, culverts, and other modifications. Thirteen people died during the flood, and damages totaled over $50 million.

Investigators analyzed in detail the events that took place during the flood. Rainfall data, satellite photographs, weather-radar photographs, and other information were examined. Data on the amount and timing of the precipitation on the tributaries that fed the flood were assembled. The radar imagery proved to be extremely helpful. It enabled the investigators to trace the runoff and estimate the flow from the tributaries into the main stream. Flood levels were found to be the maximum ever recorded. Although a gauging station had been destroyed, it was determined from the high water marks that the discharge was about 24,000 cubic feet per second, over three times the discharge expected from a flood of a 100-year recurrence interval and almost twice the previous record set in 1940.

One suit was resolved in favor of the railroad. Another suit is still pending.*

Case 11: Destruction of the Hood Canal Bridge

On February 13, 1979, extreme winds along the Hood Canal in Puget Sound, Washington, caused the collapse of a 1.75-mile-long, floating, pontoon-style bridge. Retrospective analysis by one investigator (Reed, 1980) demonstrated that sustained winds exceeded 70 knots and gusted close to 100 knots in the immediate vicinity of the bridge. However, maximum sustained winds at

*The case, which has now concluded, was Powers v. N.&W.R.R., Smithport, North Carolina. Trial was held in Superior Court in Jefferson, North Carolina, and the jury verdict was in favor of the defendant, N.&W.R.R. The second case, involving flooding on Hominy Creek west of Asheville, North Carolina, is still pending. It was filed in the General Court of Justice, Superior Court System, in the County of Buncombe, North Carolina. The case is titled "AKZONA INCORPORATED and all subsidiaries, affiliated, associated and allied companies, AMERICAN ENKA COMPANY, ARMAK COMPANY, ARMIRA COMPANY, BRAND REX COMPANY, INTERNATIONAL SALT COMPANY and ORGANON INC. as Plaintiff v. SOUTHERN RAILWAY COMPANY Defendant and Third-Party Plaintiff, v. Dewey C. Capps and wife, Teresa, American Vault Company, Inc., Bailey Z. Whitt, d/b/a O.K. Tire Company and O.K. Used Cars, North Carolina National Bank, Executor of the estate of James T. Chappell, deceased and Ann Chappell, Candler Furniture Company Inc. and Walls & Thrash Fuel Company.

other stations in the region did not exceed 49 knots, and peak gusts were generally much lower.

Data from a variety of sources were used in the analysis. These included satellite imagery; standard weather observations (e.g., barometric pressure and wind direction and speed) from National Weather Service, FAA, and military stations and from a Coast Guard ship that took shelter in the area; wind data from an air-pollution monitoring network; hourly average winds from a National Oceanic and Atmospheric Administration urban climatological station; wind measurements from a nearby prospective marina site; and wind data observed on the bridge and recalled by the bridge tenders (the actual strip charts were lost with the bridge). In addition, important information was derived from a map of the blowdown of trees at a nearby tree farm. Many of these meteorological and climatological data were not known to exist before the retrospective investigation, and some had been collected for only limited periods of time.

The investigator found that the high winds on this occasion were attributable to three major recurrent factors, which frequently produced anomalously high winds in the vicinity of the bridge site. First, a steep pressure gradient associated with a Pacific storm over Vancouver Island existed upwind of the nearby Olympic Mountains. Second, a mesoscale low-pressure system developed in the lee of these mountains, causing extremely steep pressure gradients of over 5 millibars per 10 nautical miles in the Hood Canal area itself. Finally, the orientation of the gradient was such that winds could accelerate greatly over a distance of some 3-4 miles of water. Notably, the second two factors are highly localized phenomena that could not have been predicted on the basis of standard meteorological and climatological analyses.

According to the investigator, the bridge had taken almost three years to build at a cost of some $27 million twenty years earlier and would now cost over $200 million to replace. Although wind stress had been taken into account in the design of the bridge, unrepresentative climatological data were employed. More sophisticated analyses could have revealed the occurrence of unusually high winds at the site and suggested design changes that would have averted this disaster.

Case 12: Highway Construction Operations

Climate services can be extremely useful in transportation and construction operations, especially in the scheduling of activities to take into account seasonal variations in weather conditions. For example, as documented by a Transportation Research Board (1978) report, Effect of Weather on Highway Construction, the highway construction industry is sensitive to weather and climate conditions such as precipitation, temperature, and wind. The degree of sensitivity is indicated by the considerable fluctuation in construction employment caused by the seasons: total employment during summers often trebles over winter levels, by one estimate.

Careful selection of construction tasks and alternative construction practices can substantially expand the ability to continue work under adverse weather conditions. For example, the clearing and grubbing of trees and underbrush can be performed with relatively little additional difficulty in cold weather and indeed has some advantages (e.g., hard, frozen ground and reduced fire hazard). Bituminous-treated bases can be used to protect exposed subgrades over the winter months and can make possible earlier resumption of work in the spring. If proper protection is provided, the quality of structural concrete work and structural welding can generally be maintained.

Many of the above practices have been developed using climatological data. To implement the practices will also require careful planning with the data. Indeed, quite a wide variety of climatological data may be necessary, as illustrated by Table 1.

The benefits of extending highway-construction operations into cold weather can be substantial for both contracting agencies and construction contractors, in many instances outweighing the additional expenses that may be required. Such work can reduce the costs entailed in protecting dormant work sites, providing temporary traffic-safety facilities, maintaining a work force in less productive tasks, laying off workers, and delaying the completion of work. The costs of delays, in particular, can be considerable, given high inflation and interest rates, expenses for insurance, and possible impacts on other projects.

ENERGY

Climatic variations can have substantial impacts on energy supply and demand. For example, the severe winter of 1976-1977 is estimated to have increased energy demand for heating by up to the equivalent of 350 million barrels of oil according to one author (Quirk, 1981a; see also, Quirk, 1981b). Such an amount of oil is about 10 percent of U.S. oil imports in 1977 and a significant portion of the increase in oil imports from 1976 to 1977. Reductions in hydropower attributable to drought that winter may have increased the demand for fuels from other sources by another 50 million barrels of oil equivalent. Actual consumption may have been somewhat less, as a result of conservation, curtailment, and transportation problems caused by

TABLE 1 Climatological Data Required by the Construction Industry (extracted from Table 3-1 of Russo, 1971)

CLIMATOLOGY - Monthly Normals, published and updated at specific intervals:

a. Number of days of measurable precipitation (≥0.01 inch).
b. Number of days of moderate to heavy precipitation (≥0.11 inch in any hour or accumulation ≥0.50 inch).
c. Number of days of measurable (≥0.01-inch liquid equivalent) snow or sleet.
d. Number of days of snowfall exceeding 2-inch accumulation.
e. Number of days of snowfall exceeding 4-inch accumulation.
f. Number of days of measurable precipitation (0.01 inch) during working day (8:00 a.m. to 5:00 p.m.).
g. Number of days of moderate to heavy precipitation during workday.
h. Number of days of measurable snow or sleet during workday.
i. Precipitation amounts.
j. Snowfall amounts.
k. Minimum and maximum temperatures.
l. Hourly temperatures.
m. Number of days of temperature above 90°F.
n. Number of days of maximum temperature below 45°F.
o. Number of days of minimum temperature below 45°F.
p. Number of days of maximum temperature below 32°F.
q. Number of days of minimum temperature below 32°F.
r. Number of days of "chill factor" exceeding cold index (1000).
s. Morning and afternoon "chill factor."
t. Number of days of "temperature-humidity index" exceeding 50 percent inefficiency level.
u. Morning and afternoon "temperature-humidity index."
v. Number of days of dense fog during workday.
w. Hourly frequency of dense fog during workday.
x. Number of days of wind speeds (excluding gusts) exceeding 15 miles per hour during workday.
y. Number of days of wind speeds (excluding gusts) exceeding 35 miles per hour during workday.
z. Hourly wind speed during workday.
aa. Extent of ground (or water) freeze.
bb. Date and range of dates of frost periods (or frozen-water periods) persisting through cold season.
cc. Date and range of dates of spring thaw (land and water).
dd. Morning and afternoon drying conditions.
ee. River flood stage.
ff. Monthly maximum river stage.
gg. Maximum river stage.
hh. Degree days.

the extreme cold (e.g., freezing of rivers) (McKay and Allsopp, 1980). Nevertheless, at the 1977 price of about $15 per barrel of oil, these impacts together may have amounted to added expenditures on the order of several billion dollars. The magnitude of these impacts suggests that improved understanding of climate's influence on energy supply and demand may be of significant economic value (Weiss, 1982).

The production and distribution of energy are also sensitive to climate and are likely to become more so in the future as supplies of energy are sought in ever more hostile environments and from sources like the sun and the wind. Information on climatic wind extremes is already valuable for the construction of electric transmission towers. Oil and natural gas pipelines, offshore oil platforms, and oil and liquefied energy gas tankers are increasingly being used in regions such as the Arctic with unusual climatic regimes. New coal and oil shale mining and processing techniques, including climate-sensitive restoration methods, will be employed in many remote areas of the West. The climatic resources of sunlight, wind energy, and hydropower are being tapped. For example, solar photovoltaic technologies already have many commercial applications at remote sites (e.g., buoys), and small-scale hydroelectric and wind installations have begun to spread throughout the United States (Deudney, 1981). Detailed climate data and information and often climate predictions will be particularly necessary and valuable in all of these activities, especially in ensuring efficient operations and minimizing environmental impacts. One major use will likely be in the design of storage systems to overcome periods of climatic variability (McKay and Allsopp, 1980). Several different examples follow.

Case 13: Offshore Oil and Gas Platforms

Much of the new oil and natural gas to be found in the world is likely to be in offshore areas. New fields are being found in the Gulf of Mexico and the North Sea. The North Atlantic Ocean offshore of the United States and Canada will probably yield substantial amounts of petroleum. Platforms to tap this petroleum must operate in hostile environments, and, since it takes on the order of 30 years to deplete a reservoir, they must be able to survive extreme variations in weather.

The importance of climate in the design, construction, and operation of offshore oil and gas platforms is illustrated by a platform recently installed in the Norwegian sector of the North Sea. This platform is designed to produce, ultimately, 300 thousand barrels of oil per day along with the associated natural gas. Located some 200 miles from shore in 500-foot-deep water, it houses 150 people, can store nearly one million barrels of oil, and can handle tankers every few days to move the oil to shore. Also on the platform are rigs to drill and service 40 production and injection wells and processing equipment to separate gas, oil, and water; compress the gas for reinjection into the reservoir; and cool the oil to sea temperature before storing it in underwater concrete tanks. A 75-megawatt electric power plant is required to run all the equipment. The total investment in the facility is about $1.5 billion and, as demonstrated by recent losses (The New York Times, February 16, 1982, p. 1), is almost entirely at risk.

The Norwegian platform is designed to withstand 100-year storms and wave heights of 100 feet. Recent climate data in this area are reasonably good but do not go back in time as far as desirable. Old barometric pressure data from shore or other points on land were used to calculate retrospectively (or "hind-cast") the wave heights that probably existed in earlier times.

When the sea bottom is firm, it is economical to construct platforms in Norwegian fjords by clustering together hollow concrete cylinders, float them by adjusting the water-air ratio in the cylinders, tow them to the proper location, and lower them to the bottom by admitting water. The platforms are heavy enough to withstand wind and wave action, and the submerged cylinders are used to store oil (except for three that rise above the sea surface and support the deck upon which most of the equipment is mounted).

The "tow-out" portion of this procedure is a critical operation, as it takes several days to accomplish and must be done in calm weather. In addition, although most equipment is installed before the tow-out because labor costs are much less on shore than offshore, some heavy equipment must be installed after tow-out using large derrick barges; this also requires relatively calm weather.

Climate forecasting is used to determine a "weather window" of several months for the whole installation procedure, and the best weather forecasting possible is required to control the daily and weekly operations.

The environment is not so hostile in the Gulf of Mexico as in the North Sea. Conditions in the North Atlantic offshore of the United States resemble those in the North Sea, but offshore of Canada they are worse because of ice and iceberg problems. In all cases, detailed climate and weather information is needed for localized areas. However, information derived for large areas or regions is necessary, as is information on specific sites.

Construction and operation of offshore and gas platforms might be noted as an area where there is definitely a need for a federal government role in standardization and exchange of data on an international basis.

Case 14: Reclamation of Mined Land

The reclamation of land strip-mined for coal in the western United States poses a difficult, interdisciplinary problem. The problem is to restore a viable ecosystem consisting of a complex web of biological, ecological, and hydrological elements and processes. Climate is clearly an important consideration as it affects virtually all aspects of an ecosystem. Lack of attention to climatic factors in reclamation activities can quickly lead to costly errors and even to failure of a reclamation project.

Detailed climate information can help managers of reclamation projects to avoid climate-related problems and take better advantage of the site's reclamation potential. For example, a study of one site in Colorado (McKee et al., 1981) revealed that the standard U.S. Weather Bureau map for the region surrounding the site gives a value for annual average precipitation substantially higher than that estimated using a more detailed interpolation of station values and taking into account the local climatology. Also identified were a number of limiting climatic factors such as the frequency of drought years and the occurrence of winterkill that would limit the types of vegetation capable of surviving. The climatological analysis further suggested a variety of measures such as repeated plantings, supplemental watering, and the use of snow fences to ameliorate anticipated problems.

Case 15: Solar and Wind Energy

Climate services may be of particular utility in the development and application of solar and wind energy technologies, which are expected to make a growing contribution to U.S. and world energy needs in the future.* For instance, climatological analyses can assist greatly in the design of active and passive solar buildings, not only in terms of providing data on cloudiness and incident solar radiation but also with regard to supplying information on diurnal and seasonal temperature patterns, humidity and precipitation, heat loss due to winds, and the occurrence of extreme climatic events. Especially useful for building design is information on the persistence of and

*For a recent review of solar, wind, and other renewable-resource technologies, see Supplement--Energy for Rural Development (Board on Science and Technology for International Development, 1981).

correlations between climatological parameters, e.g., the frequent association between cold temperatures and clear days with high solar radiation accompanying the arrival of a winter cold front (Architectural Design Branch, 1980).

Data on wind speed and direction are clearly needed to assess the potential of wind energy systems. However, wind characteristics can vary greatly over short distances and over long periods, making reliable estimates of the wind potential of a site or a region difficult. Knowledge of the local topography, the local surface roughness, and the height and exposure of both the measuring station used to collect wind data and the site of interest are thus critical (Elliott, 1979). As in the case of airport runways (Case 9), substantial investments may depend on the reliability of the wind data.

3

APPLYING CLIMATE DATA AND INFORMATION: AN ANALYSIS

The 15 cases described in the preceding chapter, plus the examples given in Appendix A, illustrate a variety of different past and potential applications of climate data and information in many diverse economic and social activities. A key question is whether any common elements exist in these examples regarding ways in which the data and information are generated, analyzed, interpreted, disseminated, and used. If such common elements do exist, they may suggest better ways of applying climate data and information in the future to help society better adapt to climate.

USER NEEDS

A useful starting point is the discussion in a previous Climate Board (1981) report, Managing Climatic Resources and Risks. As listed in Table 2, the latter report identified a variety of different user needs for climate data and information. Associated with each of the user needs is a proposed function of an ideal climate-information system designed to ensure adequate attention to the respective user need. (The reader is referred to the earlier report for a more detailed discussion of these needs and functions.) These eight needs and functions are clearly applicable to the examples given in this report. A brief comment on each of the needs and functions follows.

Need 1: Tailored Probabilistic Climate Information

As many of the examples demonstrate, the impacts of climate depend greatly on local climatic, environmental, and social conditions. In the Hood Canal Bridge example (Case 11), for example, a localized set of meteorological phenomena and orographic features led to the high winds that caused the bridge

TABLE 2 User Needs for Climate Data and Information and Corresponding Functions of an Ideal Climate-Information System Identified in the Report Managing Climatic Resources and Risks

Functions	User Needs
The system should provide climate information either in probabilistic form with measures of accuracy and reliability or in a form permitting knowledgeable users to compute probabilities and derive needed information.	1. Users need probabilistic climate information tailored to particular circumstances and consistent with climatological theory and practice.
The system should provide access to the range of unprocessed and processed climate data and ensure their documentation and quality.	2. Users often need access to a range of climatic data processed to different degrees and to details about how such data were gathered, stored, verified, and processed.
The system should facilitate development, testing, documentation, application, and comparison of usable measures of climatic phenomena.	3. Users need clearly defined and usable "measures" of climatic phenomena such as the wind chill factor, heating and cooling degree days, stability classifications, and wind roses.
The system should inform users of the observations available and ways to obtain them and should assist in the measurement and analysis of new parameters and the generation of synthetic data.	4. Users need observations of climatic parameters other than standard meteorological variables such as temperature, precipitation, relative humidity, and barometric pressure.
The system should provide information in flexible forms to ensure compatability for diverse uses.	5. Users need climate information that can be easily combined with other data or knowledge.
The system should provide information that accounts for climatic variability and possible climate changes in both space and time.	6. Users need sufficient data in both space and time to ensure reliable probabilitistic estimates and minimal sampling errors.
The system should provide up-to-date climate information, taking advantage of existing and new capabilities.	7. Users often need current climate information.
The system should facilitate development and testing of methods to increase the lead time and accuracy of forecasts and should assist users in evaluating tradeoffs between accuracy and lead time.	8. Users often need tailored climate forecasts in advance to permit appropriate planning and preparations.

to collapse. To deal with such impacts adequately requires detailed information on the likelihood of certain climatic conditions or events given a particular set of circumstances. Such tailored, probabilistic climate information is clearly an important element of legal work (e.g., Cases 9 and 10), operational decisions (e.g., Cases 1, 2, 3, 5, 12, 13, 14, and 15), and contingency planning (e.g., Case 8). Notably, the level of effort required for converting raw data to usable information may range from the relatively inexpensive but judicious extraction and interpretation of small amounts of data (e.g., Cases 4 and 12) to rather complex and costly manipulations of large data sets (e.g., Cases 9 and 13).

Need 2: Data Access

The runway decision in Anchorage (Case 9) is an excellent example of the need for user access to raw climatic data accompanied by detailed information on how such data were collected, processed, stored, and validated. As demonstrated by the range of values obtained for crosswind components, small changes in methods, assumptions, time periods, or other parameters may have important implications for the eventual use of data. Thus, it is clearly important for a user to be aware of the origins of and possible idiosyncrasies in particular sets of data or information and, if necessary, to be able to access the raw data in order to derive information specifically tailored to the application (or area) in question. Such access was crucial, for example, in determining that regional data might be misleading for a specific subregion in the case of the reclamation of mined land (Case 14).

Need 3: Usable Measures of Climatic Phenomena

A variety of easily understood, composite measures and indices of climatic conditions such as the wind chill factor, growing degree days, and heating and cooling degree days have proved to be of considerable utility in facilitating the application of climate information. For example, as discussed in Case 1, growing degree days are used by seed companies, farmers, and processors to help schedule crop planting and harvesting. Wind chill factors are often used in highway construction operations to assess working conditions (Case 12; see also, Transportation Research Board, 1978). Composite water-availability indices were developed for use as indicators of drought conditions in Colorado (Case 8). Heating and cooling degree days have wide application in energy management and architecture; however, as noted in an example from the southwestern United States in Appendix A, care is needed in defining the base temperature to ensure the applicability of the measure to specific locales. These composite measures are especially useful in conveying information about climate to those unfamiliar with meteorology or climatology.

Need 4: Nonstandard Climate Data

Many of the examples cited in this report involve climatic parameters other than the "standard" meteorological variables such as temperature and barometric pressure observed for weather-forecasting purposes. Solar radiation, soil moisture, evaporation, runoff, snowpack, windiness, wave heights, and icebergs are a few of the many different climatic parameters that may be of importance to human activities and for which widespread or long-term observations are often lacking. Indeed, as in the case of offshore platforms (Case 13), it may be necessary to reconstruct "synthetic" data for certain unusual climatic parameters (e.g., wave heights) based on available data. The need for nonstandard climate data is likely to grow considerably with the development and spread of new technologies such as solar and wind energy (Case 15) and deep-sea mining.

Need 5: Compatible Climate Data

Climate data and information are most often used in conjunction with other types of technical, environmental, or social data. In agricultural applications, for example, information about the response of crops and livestock to different climatic conditions is needed for climate data to be of use. Thus, it is important for climate data and information to be available in forms that are compatible with other kinds of data or are flexible enough to permit the derivation of compatible formats. In some instances (e.g., Cases 2 and 7), climate data can be incorporated directly into simulation models. In other instances, composite indices as discussed earlier may be sufficient (e.g., Cases 8 and 12). In any case, as with nonstandard climate data, the need for flexibility in data is likely to grow with new applications and technologies.

Need 6: Adequate Data Coverage

Climatic parameters such as temperature and precipitation often vary considerably over short distances or over short periods of time. Thus, a sufficient sampling of data is needed to ensure that derived information adequately represents the conditions of concern. Without adequate data coverage, major problems can arise, as demonstrated by the development of the Colorado River (Case 7) and the destruction of the Hood Canal Bridge (Case 11). Another important consideration is the possibility of climatic changes, such as those induced by urban expansion, that may affect the future applicability of climatic data (e.g., Case 6 and the example concerning gas and electricity forecasts in Phoenix in Appendix A).

Need 7: Current Climate Information

Many operational applications of climate information require continual inputs on current climatological conditions in making day-to-day, week-by-week, or month-by-month decisions, e.g., with respect to irrigation (Case 3) and pesticide spraying (Case 2). Of particular concern is the fact that the damaging impacts of climatic episodes such as droughts and heat waves often do not become substantial or apparent until the adverse conditions have persisted for days or weeks. Thus, current climate information that incorporates both the latest weather data and recent climatological data (e.g., on soil moisture conditions, reservoir levels, snowpack, and streamflow) is needed to provide users with the information on which to base real-time decisions on preventive or ameliorative actions. Should conditions change, these often costly actions could be averted or postponed. The provision of current climate information is built into the structure and procedures of the Agricultural Climate Situation Committee in Nebraska (Case 5) and the Colorado Drought Response Plan (Case 8).

Need 8: Climate Forecasts

In some instances such as the construction of offshore platforms (Case 13) or the purchase of environmental modification equipment for dairy cows (Case 4), forecasts of likely climatic conditions during some period in the future could have substantial benefits in terms of increased efficiency or reduced risks or costs. Indeed, forecasts several months in advance may be necessary to permit adequate time to take precautions or develop alternative strategies (Weiss, 1982). However, it is important to note that current forecast techniques have limited skill, if any, and could lead to unnecessary actions and expenses (e.g., the Yakima Valley example described in Case 7). Thus, much care is warranted in generating and applying climate forecasts in decisions (Weiss, 1982).

INFORMATION SYSTEM ELEMENTS

It should be clear from the above discussion that the needs of users and the corresponding functions of a climate-information system are diverse and complex. To satisfy these needs and functions successfully will likely involve at a minimum the following common elements:

- A thorough understanding of the climatic parameters and processes relevant to a particular problem;
- Data of sufficient quality and comprehensiveness to provide adequate information;
- The ability to combine climate data and knowledge with nonclimatic but related data and knowledge and to translate the results into tailored and easily understood information; and
- An understanding of the options available to enhance desirable outcomes and avoid or mitigate undesirable ones and of the decision-making context and time frame of the problem.

If any one of these elements is missing, the basic objective of dealing effectively and efficiently with climate may well be jeopardized. This point is clearly demonstrated by a number of the examples from the previous chapter and Appendix A in which one of the above elements was lacking or inadequate. For example, lack of a complete understanding of the regional climatology of wind certainly contributed to the inadequate design of the Hood Canal Bridge (Case 11). Unrepresentative data on streamflow in the Colorado River (Case 7) formed the basis for commitments to supply water that have in the long term proved unrealistic. Misinterpretation of climate data and knowledge by nonexperts occurred in the case of a regulatory decision regarding a power plant in Maryland (see Section 6 of Appendix A), almost causing unnecessary expenditure of millions of dollars. Finally, improved appreciation of the pattern of use of air conditioning in low-humidity desert regions led to a revision of the base temperature used in Arizona to calculate cooling degree days, resulting in considerable savings. As these four examples illustrate, each element listed above is potentially critical and should be considered carefully in developing mechanisms to respond to user needs for climate information.

The Agricultural Climate Situation Committee in Nebraska (Case 5) is an excellent example of an attempt to take all four elements into account. First, the committee includes climatological experts from within the state who work with other members on a continuing basis. Second, a wide range of data from local, state, regional, and federal sources is readily available to the committee, including long-term records and weather forecasts. Third, the committee membership includes experts in a variety of climate-related fields and a journalist whose task is to help the committee convey its findings to the public in an understandable form. Finally, the committee identifies current options and provides guidance on choosing between them on a weekly basis during the crop season and maintains contacts with the press and state agencies to ensure the timely dissemination of information and advice while agricultural decisions are being made throughout the state.

It is clear that many of the applications of knowledge of climate will be at a local or regional level. Successful provision of services in, for example, water resources or agriculture, must to a considerable extent be decentralized. Thus, fulfilling the four elements described above demands that a key role be played by local experts, people who are familiar with local climatological conditions, local data sources, local applications and user needs, and local options and decision-making processes. Both climatic factors and economic and social activities vary greatly between different areas of the country, creating diverse sets of climate-related problems. This diversity is especially evident in Appendix A. Thus, users of climate services need access to locally based experts. Without decentralized provision of climate services, one or more of the four elements may be overlooked, leading to the often costly lack of use or misuse of climate information, as in the case of a number of examples described in this report (e.g., Cases 7, 9, and 11).

The four elements of a successful response also suggest the importance of continuity. A local expert is likely to develop a more complete understanding of the climatology, the types of climate-related problems, and the options available in a particular locale or region with increasing experience in dealing with problems there. Such experience would also increase the expert's awareness of the data available in the area and its peculiarities and limitations. Indeed, data collected for one purpose are sometimes of considerable utility for other totally different or unexpected applications, as demonstrated by the retrospective investigation of the Hood Canal Bridge collapse (Case 11) and the use of precipitation data by the Bureau of Land Management described in Section 4 of Appendix A. Improved understanding of climate information and response options and their strengths and limitations by local users, decision makers, and communications personnel is also more likely to develop with continued interaction with local experts. This prior understanding may be especially useful in disseminating climate information and coordinating responses during emergency situations such as droughts and floods. Finally, continuity will clearly be important in maintaining the quality of generation, analysis, interpretation, and application of climate data and information, especially given the importance of consistent long-term data and the constantly changing uses to which they are put.

INFORMATION SYSTEM REQUIREMENTS

Based on the above discussion, it is possible to discern several requirements in the provision of decentralized climate services that would help to satisfy the needs listed in the beginning of this chapter and ensure that responses to climate-related problems are of the highest possible quality. Six major requirements identified by the Panel follow.

Climate Monitoring

The capability to make observations of climatic parameters is clearly important, both for addressing particular problems (such as irrigation scheduling, Case 3) and on a regular basis as a benchmark or reference (e.g., with respect to drought, Case 8, or to urban climate change, Case 6).

Data Analysis and Quality Control

Obviously, experts need to be able to convert data into usable information, taking into account relevant climatic and other factors and processes. Of particular importance is careful control over the quality and compatibility of data, which may have been gathered and analyzed for entirely different purposes in light of the specific application and local climatological conditions (e.g., Case 14).

Research and Innovation

The "tailoring" of climate information to suit particular needs and situations intrinsically implies the ability to use available data in an innovative, exploratory manner. Indeed, many of the basic, widespread uses of climate information and methods for dealing with climate problems have already been incorporated into standard practice, e.g., building codes, design standards, and farming practices, and therefore require little or no continuing input from climate experts. It is the nonstandard (or "not-yet-standard") opportunities to use or improve the use of climate information and develop new methods to deal with climate-related problems that generally pose the most significant challenges. Moreover, data collected and techniques developed for research needs often turn out to have widespread application (e.g., Case 4) and, vice versa, data collected and techniques developed for particular applications often have important research uses (e.g., Cases 10 and 11).

Coordination, Communication, and Referral

Many climate-related problems are interdisciplinary and require coordinated analysis and/or response by diverse participants (e.g., Cases 5 and 8). Also, climate-related problems need not follow either economic, social, and political boundaries or climatological divisions, so that the combined efforts of experts from different areas may be needed for the effective resolution of some types of problem (e.g., Case 7).

Dissemination and Education

Users of climate services such as farmers are in many cases widely dispersed, so that active dissemination of information is critical (e.g., see Case 5). Moreover, successful employment of the information may require sustained, regular, or strategic decisions, and payoffs may not be immediately apparent. Thus, it may be necessary first to educate users about the character of the services. Education may also include the education of experts in nonclimatic but related fields and the training of new personnel in climate applications.

Maintenance of an Adequate System for Providing Climate Services

An important long-term function is to assure that climate information and advice continue to be used effectively in present-day activities, despite changes in the gathering, handling, and analysis of data; in the activities themselves; or possibly in the local, regional, or global climate.

Continuing Tasks

Not all of these requirements can be fulfilled by individual experts. They are the major continuing tasks that need to be performed generally to ensure meeting the overall objective of helping society improve its adaptation to climate. How such requirements might be satisfied in a manner that supports the work of local experts is the subject of Chapter 4.

4

CONSIDERATIONS IN THE PROVISION OF DECENTRALIZED CLIMATE SERVICES

As discussed in the previous Climate Board (1981) report, Managing Climatic Resources and Risks, there are at least two possible--and potentially complementary--approaches to the provision of decentralized climate services. On the one hand, services can be provided by the public sector, either through existing networks such as agricultural extension services or through some new mechanism or network. On the other hand, private meteorological and climatological firms can provide tailored information and guidance for specific problems as they do now. It is useful to evaluate these two options in terms of the needs of users and the requirements for climate services described in the previous chapter.

PUBLIC-SECTOR CONSIDERATIONS

The public sector is of course itself a major decentralized user of climate services with substantial needs for tailored, probabilistic information, data access, usable measures of climatic phenomena, nonstandard and compatible climate data, adequate data coverage, current climate information, and climate forecasts. Climate information is used to help manage public lands (e.g., the Bureau of Land Management example in Section 4 of the Appendix), public facilities (e.g., Cases 7, 9, and 11), common resources (e.g., Cases 6 and 7), economically important industries (e.g., Cases 5, 12, 13, and 15), and responses to climate-related problems (e.g., Cases 5 and 8). It may also be used to help carry out governmental responsibilities such as those pertaining to pollution control, public safety (e.g., Case 9), judicial and congressional allocations of interstate waters, and as evidence in litigation (e.g., Case 6). Although in many instances these activities could perhaps be carried out largely by contracting work to the private sector, some in-house expertise is certainly justifiable to ensure continuity, quality control, accountability, coordination with other agencies, and responsiveness to agency needs. For example, public-sector organizations, e.g., state agencies or universities, might be in the best positions to coordinate the gathering of climatological data by state and local agencies and help in setting statewide policy in a situation such as that of a Colorado drought (Case 8). Private-sector organizations might encounter problems of conflicts of interest, inadequate authority, and insufficient resources and recognition from lack of continuity. This does not imply that private-sector consultants should not be used whenever possible to support the work of the public sector.

The public sector has also traditionally had important roles in support of the six requirements cited in the last chapter. The federal government automatically engages in climate monitoring through its provision of weather-related forecasts and other services. Other monitoring is performed or sponsored by various governmental agencies to help manage public lands and facilities, meet pollution-control requirements, provide benchmark references for regional or national purposes, or satisfy basic research or military needs. Similarly, as a large user of climate information, government must also have the capability to analyze data and ensure its quality. There are clear advantages to eliminating unnecessary duplication in data analysis and storage, to making sure that all available data are compatible and of adequate quality, and to disseminating data and information widely. An important public-sector activity is to ensure some form of centralized clearinghouse and referral services for climate data and information. Indeed the federal government has a virtual monopoly on many types of past climatic data in the archives of the National Climatic Center, and a continuous flow of such data is maintained to nonfederal institutions and users. In the area of research and innovation, government has generally supported basic research on climate and climate-related topics and to some extent more applied research, as in the case of agriculture. Such research support has yielded substantial public benefits (e.g., see Berggren, 1975; Committee on Atmospheric Sciences, 1977; Evenson et al., 1979; Committee on Weather-Information Systems, 1980; Climate Board, 1981). With respect to coordination, communication, and referral, the public sector cannot only facilitate governmental activities but also greatly assist entire industries (e.g., in agriculture, Case 5, and solar and wind energy development, Case 15). The public-sector role in dissemination and education arises principally from the tradition of publicly supported education in the United States, especially at the university level. However, there are also clearcut reasons for public-sector involvement in this area: the dissemination of data and information generated with public funds, the education of government or government-supported personnel in the availability and application of climate information, and the possible modification of activities and practices to meet regional or national goals (e.g., water or energy conservation). Finally, the public sector can assist greatly in ensuring that climate information and practices continue to be used as efficiently and effectively as possible by monitoring its own climate-related activities and those of others.

Existing public-sector networks of trained personnel such as those in state and county agricultural extension services; state agricultural experiment stations; municipal, county, and regional water managers; and weather-service personnel create many opportunities to increase the accessibility and application of climate information among many different users and potential users scattered across the United States. First, the networks can be employed to increase user awareness of the importance of climate information in solution of problems and of the availability of climate services to help deal with the pertinent climatic aspects. Second, experts in the networks can themselves be trained to recognize climate-related problems and handle them on their own or with the support of others. Third, climate services can be specifically tailored to the needs of users associated with the existing network, with special attention to ensuring that climatic data are compatible and integrated with other types of data used. Finally, such networks provide a feedback mechanism or a means by which user needs can be communicated to those responsible for providing climatic services or to those able to take appropriate policy actions.

As an alternative to or in conjunction with existing networks, an entirely separate network of climatological experts could be established. However, it is clear that a nationwide network able to meet the needs of all the many different and widely spaced users or potential users of climate services would be prohibitively expensive. On the other hand, some type of network of experts who can provide climatological support for other networks and for large users such as local, state, and regional government agencies may well be more practical and cost-effective. Such a network already exists in the form of state climate programs that are currently active in some states (see Changnon, 1981). This possibility is discussed in more detail in Chapter 5.

PRIVATE-SECTOR CONSIDERATIONS

Like the public sector, the private sector is both user and provider of climate services. Private individuals and firms in a variety of different industries have needs for services of the kind detailed earlier (e.g., as in Cases 1-4, 10, and 12-15). Many of these users already gather and process climate-related data to meet their own specific needs using their own personnel and resources. Frequently, however, private-sector users turn to private consulting firms or individuals with training and experience in meteorological and climatological areas (e.g., Cases 9 and 10). Such consultants can provide climate services that are more carefully tailored to specific user needs than would likely be justified or could be provided by the publicly supported expert. Moreover, the bidding and contracting process normally used in consulting work provides opportunities to ensure adequate responsiveness to the contractor's needs, quality control, cost minimization, and timeliness. These factors are likely to improve over time as consultants gain experience and versatility.

The private-sector role in meeting the six requirements given in Chapter 3 has been somewhat more limited than that of the public sector but is nevertheless significant. Private firms have generally provided equipment for climate monitoring and in some areas such as air-pollution monitoring have enjoyed continued dominance. With respect to data analysis and quality control, private-sector involvement has generally been restricted to the handling of smaller data sets, with responsibility for reducing the large amounts of raw meteorological data into more manageable forms left to the public sector. Increasingly, however, private firms are beginning to offer high-quality, specialized data sets for variables such as solar radiation, wind characteristics, and other nonstandard climate data. Development of such new kinds of data and information of course involves much research and innovation. Research and innovation are also intrinsic to combining climate data with other nonclimatic data or models, developing and applying synthetic or proxy data, and developing climate forecasts. In reference to coordination, communication, and referral, the private sector is perhaps less concerned with managing local, regional, or national responses to climate-related problems than is the public sector, but it is still likely to be interested in industry-wide practices and interaction between disciplines. Indeed, private-sector industry groups, whether user-oriented or representative of consultants, could perhaps play a key role in improving quality control, assuring accountability, maintaining liaison with relevant private and public bodies, and developing workable referral systems. Private-sector involvement in the dissemination of information and education of users will be closely tied to marketing practices, as it is clearly in a consultant's interest to inform potential clients of the likely benefits of the available services. Moreover, private firms provide excellent opportunities for training new experts in climate applications and would perhaps enhance the attractiveness of the field to prospective students. Finally, the private sector certainly has incentive to support and participate in the maintenance of an adequate system for providing climate services since it is clearly a major beneficiary of such a system in terms of quality control and data coverage.

At present, there does not appear to be a substantial number of consultants in the United States who specialize only in climate services, although some climate-related work is probably performed by firms that engage primarily in meteorological or other activities. Several reasons for this situation are possible, including the following:

Lack of awareness by users of the potential benefits of climate services;

Hard-to-define benefits of climate services because of the uncertain, complex nature of climate and climate impacts on human activities and the lack or complexity of cost-effective responses to mitigate impacts;

Potentially high costs for providing climate services caused by expenses for data gathering, processing, and analysis;

Lack of sufficiently large or reliable markets for climate services because of their "transient" nature, i.e., the need for consultants diminishes once a procedure for obtaining and using climate information has been developed and implemented;

The present inability to provide reliable climate forecasts that could greatly increase the utility of other climate services and generate a more regular market for consultants;

Lack of personnel with adequate training and expertise in both climatology and applied areas; and

Competition from the public sector, which may provide comparable services at a subsidized rate or without charge.

While it is not now possible to assess the relative importance of each of these reasons without more detailed study, it is clear that each could be an important obstacle in particular instances. A key issue is the respective responsibilities and areas of activity of the private sector versus the public sector. In any case, efforts to minimize these and other potential obstacles would likely help increase private-sector participation in the provision of climate services. Of course, additional, more positive actions might also be necessary or helpful, for example, directives within government agencies to use private climatological consulting firms whenever possible.

CONCLUSIONS

Both the public and private sectors play important roles in providing climate services in the United States. Neither sector alone can meet the many varied needs of all users. Further exploration and definition of public- and private-sector responsibilities are desirable. For example, questions about collection and provision of data and proprietary information warrant more discussion. Certain questions will need periodic re-evaluation. The balance of costs and charges between the private and public sectors will continue to be an issue. At this time, when climatic services are increasing, it is especially important that public and private groups be brought together in a way that takes advantage of the strengths of each sector. How this might be accomplished is the focus of Chapter 5.

5

A NATIONWIDE SYSTEM FOR CLIMATE SERVICES

In light of the discussions in the previous chapters, the Panel has come to the conclusion that a coordinated, nationwide system of federal, state, and local, public and private, climate services is needed. Such a system need not involve substantial new resources. It does require clearer definition of roles and responsibilities in the provision of services than is now the case. In the Panel's view, a more unified, nationwide system of climate services should consist of the following:

1. A wide variety of local experts in both the public and private sectors who are familiar with both climatic and nonclimatic aspects of problems and with available options;
2. A network of state and regional climate programs designed primarily to support local experts with easily accessed data, information, research, and referral services and that can also help meet state- or regional-level needs; and
3. Active federal participation, for example, by coordination of agency activities in the context of the National Climate Program and through identification of a limited number of key contact points for particular types of federal assistance (e.g., the National Climatic Center for data).

This is of course not the only possible model for a nationwide system but does represent the Panel's consensus as to an appropriate blend of local, state, regional, and federal participation that the Panel believes would best meet the diverse needs of users. Each of the above components is discussed in more detail below. For each component, some possible functions are suggested that are intended to be illustrative and not necessarily definitive or complete.

LOCAL EXPERTS

The effective delivery of climate services depends greatly on the participation and capabilities of local experts. These experts must be able to apply knowledge and experience about climate to the specific problems that face users and to develop workable solutions in a timely fashion. This places a considerable burden on experts to understand thoroughly both the climatic and the nonclimatic aspects of particular problems. Although the Panel sees no easy way of avoiding this burden completely, relatively straightforward institutional arrangements can certainly reduce the difficulty of developing high-quality, interdisciplinary expertise.

One approach, which also makes sense for other reasons, would be to take advantage of existing public or private networks of experts such as county cooperative extension services and state agricultural experiment stations. Since these networks already incorporate expertise in particular areas, climatological expertise could be brought in by a number of means (e.g., hiring new personnel, training existing personnel, or retaining consultants) and made available through the networks.

Alternatively, multidisciplinary teams could be established involving experts from both climatological and relevant nonclimatological fields. This approach has been taken in both the public and private sectors (e.g., Cases 5, 8, and 13). The effectiveness of such teams in developing interdisciplinary guidance should grow substantially with time.

In the course of providing climate services to diverse and decentralized users, it is clear that local experts will and should contribute to meeting the six requirements listed in Chapter 3. That is, they are likely to become involved to varying degrees in functions pertaining to climate monitoring; data analysis and quality control; research and innovation; coordination, communication, and referral; dissemination and education; and maintenance of an adequate system for providing climate services. For example, data collected for short-term, *ad hoc* reasons by a private firm may well be useful for longer-term monitoring and benchmark needs (e.g., Case 11). In working closely with particular data sets, local experts are likely to discover problems and limitations in data that might not otherwise have been detected (e.g., Cases 9 and 14). The application of climatic knowledge to specific problems is likely to lead to new and innovative solutions that might be extremely useful elsewhere (e.g., Cases 1 and 4). A local expert climatological consultant, although lacking in specific expertise or resources to address a specific problem, may be able to refer the user to other experts or groups with the needed expertise and resources. Since a local expert's job or profits may depend greatly on the amount of business available, incentive exists for such an expert to make sure that users and potential users are aware of successful instances of and potential payoffs from climate applications. Lastly, local experts will certainly be better able to provide high-quality, timely services if they are supported by a system responsive to their needs.

STATE AND REGIONAL CLIMATE PROGRAMS

State- and regional-level climate programs have been and will continue to be important in the acquisition and analysis of climate data and the provision of climate services. At the state level, or in some cases the regional level, a useful combination of the following is provided:

1. Expertise on local or regional climatic conditions;
2. Expertise on local or regional economic and social conditions sensitive to climate;
3. Access to local and state resources and decision makers in both government and the private sector;
4. Access to regional organizations and resources, including regional offices of federal agencies; and
5. Access to the federal government, including both Executive and Legislative Branches.

This combination of expertise and access is particularly critical in light of the great degree to which climate conditions and fluctuations interact with societal conditions, as demonstrated by many of the examples in this report.

Not all aspects of climate need to be or should be dealt with at the state level. Many states contain areas that are part of identifiable climatic regions such as watersheds, deserts, plains, mountains, and coasts. In areas like New England, many of the most important problems caused by climate are shared by all the states in that region, e.g., the sensitivity of their energy supplies to climatic extremes. Thus, some type of regional structure may be needed to help state climate programs and other interested parties deal cooperatively with common problems in the most effective and efficient ways possible. Notably, such regional structures need not be based on climatic regions; different groupings might be called for depending on the particular topic of interest and on the types of organizations and resources available. Regional programs could focus on, for example, common climate-sensitive problems in crop and livestock production, energy, water resources, or transportation. This would permit, among other things, the more effective use of existing regional problem-oriented networks such as river basin commissions, energy management organizations (e.g., the Bonneville Power Administration and the Tennessee Valley Authority), and regional research committees of the state agricultural experiment stations. Regional programs would also be likely to reduce the burden of communication placed on federal agencies, which would otherwise have to deal with each state program individually. It is clear, however, that regional climate programs should neither supplant state climate programs nor be required in every region. They should be formed only when they are wanted, when the need is clear, and when they serve the interests of their constituent users, especially state climate programs.

A state or regional climate program should consist of at least three components: (1) data management, (2) climate information services, and (3) climate-effects studies. The data-management component provides a base for the other components of the program. At a minimum, this component should encompass data acquisition, data analysis, and data resources. Data acquisition would involve both the acquisition of data from federal networks and the acquisition or inventory of data collected within the state; data analysis would include efforts to monitor data quality and maintain standards; and data resources could include both computer-generated products and library archives. Climate information services should include, at a minimum, a mechanism to establish user contacts, the capability and resources to respond to requests, methods to disseminate information, and a system to keep records of services rendered by user, use, and type of information. Some ability to evaluate the benefits of services would also be valuable. Notably, a capability to provide advice on climate to government would inherently result from the provision of information services. Finally, climate-effects studies would at least require the ability to integrate climate information with an understanding of local socioeconomic activities and conditions. In general, such studies should involve both the analysis of local or regional climate impacts and the development of suitable responses.

In terms of the six requirements identified in Chapter 3, state or regional climate programs clearly can and should play a leading role. A state or regional group familiar with both climatology and data needs is likely to be best able to develop a coherent program of climate monitoring that meets needs in an effective and efficient manner (e.g., Case 14). Careful analysis of climate data available from all reliable sources within a state or region by a single group would provide the most users with the information of the highest possible quality with the least duplication and expense (e.g., Case 5). Innovative ideas and practices developed for a particular application or locale could be adapted for more widespread applications or for the state or region as a whole. By the same token, new ideas and practices developed elsewhere could be adapted for use in specific applications or areas (e.g., in modifying the base used for cooling degree days in Arizona, Section 3 of Appendix A). A state or regional program would certainly be a logical place for coordinating climate activities throughout the state or region and for ensuring that users and experts within the area communicate and interact in the most efficacious manner possible (e.g., Cases 5 and 8). With respect to dissemination and education, a state- or regional-level group may provide excellent opportunities for interaction with state universities and other educational facilities and could also act as an educational resource for interested parties such as existing networks of agricultural experts or potential users. Moreover, such a group could itself be an ideal training ground for new climatological experts who could be directly involved in data collection and analysis, climate studies, and user services. Finally, a state or regional climate program is probably in the best position to judge the adequacy of climate services in meeting local, state, and regional needs and objectives.

FEDERAL PARTICIPATION

It is clear that a major role in a nationwide system of climate services must be played by federal agencies. In particular, the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, especially three of its suborganizations, the National Weather Service (NWS), the Environmental Data and Information Service (EDIS), and the National Climate Program Office (NCPO), occupies a key federal position. Other agencies of importance include the Departments of Agriculture, Energy, Defense, and the Interior and the National Science Foundation. These agencies not only provide basic financial support for climate data acquisition, analysis, and dissemination on local, regional, national, and international scales but are also prime users of climate data and information and important participants in many climate-related decisions at local, state, and regional levels. It must be emphasized that administrative actions by such agencies are as important as, if not more important than, major increases in funding. This needs to be stressed especially in the face of stringent federal economies.

Federal participation in supporting the delivery of climate services would have considerable benefits not only for users of such services but also for the agencies themselves in terms of meeting their mandates more effectively and efficiently. For example, in the case of the Colorado Drought Response Plan (Case 8), improved information and coordination at the state level including regional federal offices will certainly help both the state and the federal governments to make better determinations of the severity of drought impacts and of appropriate means of assistance. State and regional climate programs and local experts are likely to be important resources for federal activities, as demonstrated by the Bureau of Land Management's use of precipitation data maintained by a state climatologist (Section 4 of Appendix A) and the use of a private consultant in analyzing wind data at an airport (Case 9).

However, an important consideration is the plethora of federal agencies with overlapping and sometimes conflicting objectives and jurisdictions. Clearly, some coordination of climate-related activities at both regional and national levels could help to minimize confusion or conflicts that might otherwise arise. For example, with respect to the provision of data, the Panel believes strongly that the existing National Climatic Center (NCC) of NOAA's EDIS should be the single primary focal point for all federal data-analysis and quality-control activities. This would help to ensure consistent and complete data sets of the highest practical quality. Of course, other federal agencies should continue their climate-data activities for specific purposes, but these data should then be made available through a central clearinghouse or referral system managed by the NCC.

Another important area for coordination of federal activities is in water-resource management. Water problems are of concern to many different federal agencies, including the Bureau of Reclamation, the U.S. Army Corps of Engineers, the Soil Conservation Service, the NWS, the Bureau of Land Management, the Tennessee Valley Authority, and the Water Resources Council (e.g., see National Science Foundation, 1980, Appendix A). As demonstrated clearly by the forecast by the Bureau of Reclamation for the Yakima Valley in 1977 (Case 7), significant problems can arise that might be avoided through better coordination and communication among federal agencies and others, and not only in offices in Washington, D.C., but also in the areas in question. Because of their geographic focus, state or regional climate programs could clearly play an important role in resolving such problems. For certain widespread or persistent problems, it may be appropriate for a group at the national level, such as the Water Resources Council or the National Climate Program Office, to help combine the financial and intellectual resources of the diverse agencies with those of local, state, and regional groups to develop coordinated approaches.

Sometimes there would be benefit not only from greater coordination of federal activity but also from federal coordination of activity at other levels. Many water issues are appropriately handled at the state level. Indeed, the trend is to shift responsibilities back to the states. In such situations the responsibility at the federal level of government is to coordinate, for example, providing referral services to groups seeking information on past experiences similar to their own or on comparable situations elsewhere.

The federal government has carried out, and should continue to carry out, functions important to meeting the requirements listed in Chapter 3. For example, a long-term national network of consistent climate monitoring, such as is now maintained by NOAA, is critical to both local and national applications. Since much often-costly data processing and many quality-control procedures need only be performed once on a particular data set, federal sponsorship or participation would help to eliminate unnecessary duplication and ensure widespread availability of results. A limited number of repositories for large data sets managed by the federal government might also make sense. The federal role is also important in such areas as climate forecasting research because of the operational responsibilities of the NWS. Thus, in mandating Experimental Climate Forecast Centers in the National Climate Program Act, Congress provided for protection against inappropriate or premature use of experimental climate forecasts. As has already been noted for data and water resources, there are many opportunities for the federal government to ensure the coordination of climate-related activities at a national level; in addition, the federal government may be the logical level at which to manage or sponsor a nationwide clearinghouse or referral system. With respect to dissemination and education, the federal government can certainly contribute to training experts and increasing public awareness and use of climate services through its many different information channels and educational programs, as well as by virtue of its own provision and use of such services. Finally, the federal government should actively maintain an adequate system of climate services directed primarily toward needs at the national level.

SUMMARY

The discussion in this chapter of possible activities and institutional arrangements are intended as a rough guide to the kinds of participants and functions that might logically comprise a coordinated, nationwide system for climate services. <u>The</u>

primary conclusion of this Panel is that a nationwide system for climate services is needed. Such a system will not require substantial new resources. Most of the necessary components already exist. What will be needed is the blending of these components into a more coherent system that can efficiently and effectively provide climate services to the many different, widely scattered users throughout the United States.

6

RECOMMENDATIONS FOR ACTION

As noted in the Preface, federal and state cooperative activities were called for by Congress in the National Climate Program Act for the purpose of expanding and improving climate services at the local, state, and regional levels. Particular emphasis was given to ensuring substantial attention to user needs and "two-way" communication between the federal government and local, state, and regional groups within the overall framework of the National Climate Program. The basic focus of such efforts was seen to be the state, with recognition that groups of states might be more appropriate in some instances (House of Representatives, 1978).

The Panel firmly agrees with these conceptions. In particular, the Panel strongly believes that the National Climate Program Office should take a leadership role in the development and support of a coordinated, nationwide system of climate services involving both the public and private sectors. The system should build on state and regional climate programs with federal government and private-sector involvement. The focus should be the support of local expert climatological consultants who provide services to meet the requirements identified in Chapter 3. It is critical that those who administer the program seek to overcome the obstacles to increased private-sector participation identified in Chapter 4.

The Panel also believes that the strategy of a three-phase implementation of a program of cooperative activities, recommended by the Climate Board in 1979 (Climate Research Board, 1979) and adopted in part in the National Climate Program Five-Year Plan (National Climate Program Office, 1980), is still a valid one. This strategy set as a five-year target a "fully developed and functioning Intergovernmental Climate Program," preceded by three progressive phases. The first phase, involving the funding of selected demonstration or exploratory projects, is now in its second year. The second phase would initiate joint federal-state climate activities. The third phase would include qualified state programs. The Panel has the following recommendations for continued implementation using this strategy:

- The National Climate Program Office should complete the initial exploratory phase of its five-year program within the next year or two. The results of the demonstration projects that have been launched should be carefully evaluated, summarized, and widely disseminated. The results of these projects should be valuable in generating interest and financial support from federal and state agencies and local groups for developing a nationwide climate-services system.
- As part of beginning the second phase of its five-year program, the National Climate Program Office should take the lead in initiating an equitable process for defining responsibilities for participation in a nationwide system of climate services on the part of local, private-, and public-sector experts, state and regional climate programs, and the federal government. Representatives from all of these likely participants, plus representative users from different economic sectors, should be intimately involved in this process from the start. The objective should be to develop guidelines for participants to ensure the performance of functions necessary for adequate provision of climate services and to minimize conflicts and duplication. Discussion of the roles of components of the system in Chapter 5 might serve as a starting point.
- The National Climate Program Office should take the lead in coordinating federal-agency participation in the climate-services system and in federal-state cooperative efforts, through some type of interagency committee. The goal should be to clarify agency responsibilities for climate-related activities and make sure that agencies are coordinated in such areas as data collection, analysis, quality control, and access. An important task is to examine possible government-wide policies to promote cooperative climate services, e.g., agency consultation with state climate programs, use of private-sector forms for climate services, or joint funding of climate-related projects through the intergovernmental mechanism.
- In the third phase of its five-year program, the National Climate Program Office should focus on incorporation of state and regional climate programs into the nationwide climate service system, as originally conceived. However, the matching-grant provision of the 1978 National Climate Program Act need not be the major incentive for states to participate in the program; such a provision may not be necessary. The primary incentive for participation should be the benefits that state or

regional climate programs would derive from an active and effective system of climate services. These benefits might include improved access to federal data, computer networking, close interaction with federal agencies on problems of mutual concern, better communication between state and federal governments, and access to surplus federal equipment.

The Panel wishes to point out that the initiation of the second and third phases of implementation need not await the completion of the prior phases. For example, some regions may be able to enter the program before others and should not be required to wait.

In addition to these general recommendations, the Panel in the course of its deliberations has developed a number of suggestions regarding the delivery of climate services. The suggestions can be roughly grouped into the six different requirements identified in Chapter 3.

1. Climate monitoring. A major concern of state agencies such as park services, natural resource agencies, and environmental offices is the maintenance of the cooperative observers' network. This network is now the responsibility of the National Weather Service (NWS). The network, which has been shrinking in recent years, is the principal source of basic data in the states. The priority for its maintenance needs to be upgraded. Where possible, the cooperative efforts of the NWS and state or regional climate programs should be enlisted to persuade participating amateur observers to include other climatic parameters in their observations, as many have already done. Wind observations are a good example of this. In some critical areas where wind energy or pollutant transport is important, judicious expenditures by the government might well be justified. In some instances, the use of surplus federal stock of equipment should be offered to state or regional climate programs. The National Climate Program Office could perhaps act as a focal point.

2. Data analysis and quality control. The National Climatic Center (NCC) could assist the state or regional climate programs by speeding up the analysis, quality control, and dissemination of the monthly state climate data. At present, there is often a delay of over two months after the end of each calendar month before these data become generally available. The need for timely data is illustrated in several of the examples given in this report and is emphasized in the report Managing Climatic Resources and Risks (Climate Board, 1981). Indeed, a major improvement would be to enable those climate programs with access to computer terminals to tap into the NCC's data banks

(with suitable restrictions and cost sharing). This change, now readily achievable over telecommunication lines, should be vigorously explored. Considerable effort is also needed with respect to developing adequate and consistent quality-control procedures and data formats. Here, the expertise of existing groups such as the American Association of State Climatologists, the National Council of Industrial Meteorologists, and the American Meteorological Society should be tapped. The National Climate Program Office should attempt to bring these groups together to begin to look at these problems from a broad perspective.

3. Research and innovation. Improved communication and dissemination of new research results and techniques in a timely fashion is an important need, as professional journals tend to have substantial lag times in reporting results and are often not accessible or understandable to nonspecialists. A useful contribution might be for the participating federal agencies to report briefly on their recent climate-related research in some easily accessed regular publication such as the newsletter, The State Climatologist, published by the National Climatic Center. Close interaction with the research and applications components of the World Climate Program should also be encouraged.

4. Coordination, communication, and referral. The National Climate Program Office (NCPO) should have primary responsibility for meeting these requirements at the national level, while each state or regional climate program would be responsible for these at its respective level. However, the NCPO may be able to facilitate state or regional activities in this area by sponsoring exploratory studies and developing a model referral system. The NCPO should also take a lead role in fostering coordination and communication internationally, not only with national governments and international agencies but also with subnational governments such as Canadian provinces and U.S. and Mexican states.

5. Dissemination and education. Information about climate services tends to be disseminated only within communities of experts already familiar with the value of such services. The National Climate Program Office (NCPO) should encourage attempts to disseminate information and educate nonspecialists about climate services and their potential benefits. Of special value would be development of courses tailored to the specific needs of users or nonclimatic experts, e.g., farmers, agricultural extension agents, architects, and energy specialists. New media for dissemination and education, such as video systems, home computers, cable television, and telephone-based voice response systems, should also be explored. Existing dissemination channels, such as the publications Weekly Weather and Crop Bulletin, Monthly Climatic Data for the World, and The State Climatologist, should be maintained.

With regard to the training of climate experts in the delivery of climate services, the NCPO should sponsor a careful assessment of the ability of current programs in meteorology and related fields to train new personnel who are capable of working in the interdisciplinary mode required by many climate-related problems. This should include examination of the employment and professional opportunities for those interested in this type of work. Such an assessment may, among other things, suggest important institutional arrangements at the state, regional, and federal level to ensure that sufficient human resources are developed to meet future needs.

6. Maintenance of an adequate system for providing climate services. The need for alertness on the part of state, regional, and federal participants must be emphasized. New techniques and technologies such as integrated pest management (Case 2) and environmental conditioning for animals (Case 4) are constantly emerging, leading to new uses for existing climate data or new needs for unusual climate data. Activities such as mining and oil drilling are increasingly expanding into areas subject to extreme climatic conditions and events, with attendant needs for climate data and information. Many such activities will require increasing international cooperation and collaboration. The system should be aware of and responsive to emerging needs to the extent possible.

7

CONCLUSION

The basic message of this report is simple. Climate services have been growing in value and will continue to do so. The emergence of private meteorological and climatological firms is evidence of this trend; the emergence of innovative state programs, for example, in Colorado and Nebraska, is further evidence. The continuing participation of governmental bodies in provision of climate services is essential and unavoidable. Technological developments, changes in society, and variability and possible long-term changes in climate combine to suggest that the utility of providing increased climate services will grow. This panel believes that a more coordinated nationwide system to ensure effective and efficient delivery of climatic services makes considerable sense. The Congress clearly recognized this in passing the National Climate Program Act of 1978 and in specifically establishing the Intergovernmental Climate Program. Indeed, it is the Panel's belief that the success of the entire National Climate Program will be determined substantially by the degree to which it helps to improve and expand climate services across the nation.

The Panel firmly believes that the establishment of a strong program of federal and state cooperative activities is by far the best way to develop a system for climate services that will be accessible to and used by all sectors of the nation. Local, state, and regional groups and users must participate in the development process from the start. Particularly critical is the need to identify clear roles that ensure a coherent and equitable framework for all participants. Through the combined talents and efforts of a broad range of our nation's citizenry it will be possible to meet the complex, pervasive challenge of climate.

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APPENDIX A

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Examples of Applications of Climatic Data and Information Provided by State Climate Groups

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Abstract

The value of climate data and the information derived from the data still seems to be an unknown to many. Five persons engaged in providing climate services in different U.S. climatic zones have assembled a few widely different examples of recent uses of climate data and information. These help demonstrate the diversity of applications, and the value of the data and of those who can interpret them.

1. Introduction

There has been a growing awareness of the importance of climate to our national well-being, leading to the enactment of legislation in 1978 calling for a more focused and effective national program in climatology that would involve research, data collection, and services. One of the interesting ensuing debates over the dimensions of the national program has focused on the need and value of services element.

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We who have long been involved in the provision of climate data and information to users found this debate to be both frustrating and challenging. We came to the realization that examples of climate-related services, so routinely performed in recent years, were not readily available. To those of us who have been involved in state-supported climatological programs, often as state climatologists, it came as a considerable surprise that a) there was any question as to the use of climatological data and information by a wide variety of interests, and b) many scientists and decision-makers did not realize the types of services reflected in handling requests for climate data and information.

This document aims to illustrate only a few of the applications of climate data and information services provided recently in five different climatic regions: the Pacific Northwest, the southwest desert, the Rocky Mountains, the Midwest, and the East Coast. We were involved in an assessment of the National Climate Plan in July 1979. At this meeting, we prepared a list of examples of applications of climate data and information to serve a variety of needs. Some of these have been combined to form this document. We stress that they are only examples and do not describe, by any means, the extent of our individual services efforts. They merely demonstrate the variety of services provided in recent years to various users in our climate. Hopefully, these examples will prove useful to those in the nation who are deciding on the value and need of sustaining, and indeed increasing, the limited state programs attempting to provide climate services.

2. Examples: Northwestern United States

The state highway department in Washington reviews climatic data on an annual basis to determine schedules for bridge maintenance, especially painting. Temperature extremes, the occurrence and duration of freezing temperatures, and ice forms of precipitation are major climatic factors used in their schedule decisions.

On a winter day in 1979, pontoon sections of a floating bridge capsized in a windstorm. Climatic data were provided to aid in the assessment of the cause and engineering errors, and in planning the design of a replacement bridge.

Banks in this region regularly use climatic data, such as extremes of temperature, precipitation, winds, or snowloads, to determine risks on mortgage loans for real estate they are considering.

A national insurance firm recently established significantly lower blizzard insurance premiums for livestock than prevail in the Great Plains and Midwest. These were determined as a result of a probability analysis of blizzard occurrence in the state's livestock-producing counties.

A major manufacturer of aircraft, which normally performs its own environmental monitoring, was faced with the loss of surface instrumental data required for evaluation of a series of test flights for a new multiengine jet. Provision of substitute climatic data derived at low cost saved the company the sizable cost of a complete repetition of the test flight series.

An insurance firm applied data on averages, extremes, and durations of temperatures above selected thresholds to determine the need for air conditioning systems in its fleet of company cars to be used in western Oregon and Washington.

3. Examples: Southwestern United States

A major lumber firm was investigating the possibility of the commercial production of a type of plant that produces oil-bearing seeds. The firm needed to know the limits placed on production of this plant by temperature conditions in a large portion of the American Southwest. Climate information was derived and supplied, becoming one of the factors that entered into the final decision not to proceed in this venture.

A group of investors wished to identify those areas where grapes might be produced in Arizona. A major concern was the length of the frost-free season and the number of growing degree-day units available at several sites. On the basis of the information from a special study of climate data, decisions were made to proceed and where to purchase land to start a major vineyard.

An individual had been injured as a result of lightning striking a power company pole. The plaintiff's lawyer charged negligence on the part of the power company because it had not provided lightning arrestors on the poles. The attorney was furnished with a statement assessing the frequency of thunderstorms in the region, a factor leading to the case being settled out of court for $1.5 million.

The nationally promoted base for calculating cooling degree-day units is 65°F. However, climate impact research showed that in the desert region, the use of air conditioning does not begin until the average temperature is 80°F. The cooling degree-day values for all communities in Arizona were revised to the base of 80°F. This information is now the basis for the design of structures and systems for the desert region and has resulted in energy savings and major reductions in capital costs.

Forecasts of gas and electricity use are based on climatological data. For most purposes the data used are the national normals for the period 1941–70. However, in the Phoenix metropolitan region, minimum temperatures in the summer are now 5°–7°F higher than they were 20 years ago due to urban growth. It was found that projections of temperatures—hence, energy use for cooling—were more nearly correct if normals based on the most recent 10 years were used rather than the 1941–70 normals.

4. Examples: Western Mountain area of the United States

Farmers in Colorado were asking the governor to proclaim more than half the counties as disaster areas so as to qualify for federal relief assistance. Before taking action, the governor sought a quantitative drought assessment. The state climatologist supplied an interpretation of the drought with a historical perspective for all counties. As a result, the governor declared certain counties as disaster areas, and they got relief assistance. Other counties seeking aid were not so declared.

The Bureau of Land Management (BLM) developed a rangeland model that required a climatological description of precipitation in five-day time increments through the growing season. The only usable daily precipitation data bases were available at the state climatologist's office, and a study was made for BLM. The results have been used in the management of more than 10,000 square miles over the past two years.

5. Examples: Midwestern United States

Soil temperatures in a midwestern state are monitored daily in the spring. These are coupled, on a weekly basis, with historical frequencies of daily precipitation data to develop probability prospects for planting of corn. There are many benefits from savings in work-time, energy expenditure, and seed-fertilizer losses.

In 1979, the Illinois Commerce Commission was considering a rate increase request of three natural gas firms. The decision to decline a rate increase that would have cost taxpayers $182 million in 1980 was based largely on a climatic study of the recent winters by the state climatologist. Direct study costs, excluding the cost of 90 years of data collection at eight sites, were $6500.

Illinois has obtained permission from the U.S. Supreme Court to use a different procedure for accounting for the water diverted from Lake Michigan for various uses in Chicago, its suburbs, and northeastern Illinois. The key issue was to go from a one-year accounting of diversion (limited to 3200 cubic feet per second) to 40-year accounting, mainly because there is now general recognition of the wet and dry periods of climate and acceptance of the ever increasing amount of rain in Chicago due to urban influences. As part of this diversion request, a climatological design study of heavy rainstorms was made, since the diversion must include storm rainfall. The diversion was contested by Wisconsin, which claimed that data from certain precipitation stations were invalid. The Illinois state climatologist made an in-depth assessment of the correctness of historical precipitation records for northeastern Illinois, and also furnished proof of the 15% rain increase in Chicago due to urban effects. Climatological information played a major role in resolving this water allocation issue.

6. Examples: Eastern United States

Climatological information was supplied to a commercial firm to design and market a pollution control system, including a special air quality monitoring network. As a result, power companies were able to meet pre-1977 clean air standards and still derive annual fuel savings of $5–$15 million at a cost of 10% of the savings. The Clean Air Act Amendment of 1977 declared such a system could no longer be used and must be replaced by more expensive process controls or stack scrubbers.

Climatology of winds and ocean waves was used by a commercial firm to design and market a system to optimize the routine and scheduling of transoceanic shipping. The savings for a 40-ship fleet was roughly $4 million annually at a cost of about 10% of the savings.

In Maryland, a public utility was prepared, on order from a regulatory commission, to construct a multimillion-dollar system to diffuse hot water into the bay. Calculations based on erroneous interpretation of climatic data by nonprofessionals (frequency and duration of extreme wet-bulb temperatures) had indicated that a serious violation of antithermal pollution regulations would occur. A climatological investigation revealed the error in the interpretation of the temperature data. Millions of dollars were saved, along with the energy necessary to construct the system and operate it for the lifetime of the power plant.

7. Summary

These limited examples reveal a wide variety of uses in planning designs and decisions, in operating issues, and for assessing events. Among those served were commerce and industry (transportation, insurance, food and fiber production and processing, and banks), design engineers, the legal profession, utilities, municipal agencies, state agencies, federal agencies, and, last but not least, the public. Actual savings are known in some instances, but these examples clearly reveal a multitude of values, both qualitative and quantitative. ●