Post

WORKSHOP REPORT

NOAA's Environmental Watch Rep. 94.1

Information Needs for Precipitation-Sensitive Systems

AGRICULTURE
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
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CONTENTS

PREFACE

Water is basic to life. In today's complex society, water uses are many and demands for data and information about its distribution in space and time is growing rapidly. Most of the basic decision making actions with regard to precipitation-sensitive systems require the use of accurate, timely, and reliable precipitation data. The need for precipitation data and information products is at an all time high, while, at the same time, there are only limited means to carry out the task of collecting, archiving and delivering the necessary information.

In addition to NOAA's extensive precipitation observing systems there are many other federal, state, and local precipitation monitoring systems. We thought it appropriate to review the way NOAA's precipitation data are being collected, archived, and made available to the general user community in context with observing systems from other agencies. The convenors of the workshop were able to solicit participation of scientific and business users from four broad environmental and economic sectors: agriculture, forests and rangelands, water resources and hydrologic systems, and estuarine environments. The need for comprehensive, high quality, and timely data from these four areas reflected a broad set of issues from network design and practices to data archiving and distribution. The findings and recommendations of the various working panels presented in this report will serve as a basis for improving the quality and accessibility of precipitation data.

Robert S. Winokur, Assistant Administrator
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EXECUTIVE SUMMARY

FINDINGS AND RECOMMENDATIONS

Lack of a National Monitoring Strategy

A major problem that was identified relates to different observational precipitation-recording networks which have been set up to meet a specific agency or regional need, but are not coordinated and therefore, not part of a national monitoring strategy. A nationwide assessment is required to identify how the nation's precipitation measurement networks can be streamlined, improved, and made more efficient in the delivery of high-quality precipitation data and information is required.

Developing a National Precipitation Monitoring Strategy

The existence of various observing networks and archival systems in the U.S. obviates the necessity of establishing cooperative and interactive working arrangements among the different agencies charged with implementing the measurement programs and archiving of the data. Minimum standards should be established regarding instrumentation, metadata, siting, and archiving and exchange protocols. Particular concern was expressed regarding the gradual decline and antiquated state of NOAA's cooperative observing network, which has served as the backbone of the nation's precipitation measurement network for over a century. We should note that often, in studies of long-term climate changes, relative accuracy may be more important than absolute accuracy. Table 1 presents a summary table of the recommended spatial and temporal resolution needed to address the above issues. Since the requirements vary greatly from one topical theme to another, a key recommendation of the workshop participants to NOAA management is that an interagency task force be established to develop a mechanism to ensure that the nation's weather observing system, and in particular precipitation measure-

Table 1. Summary information on type of system or problem being addressed, temporal and spatial resolution of required data, length of record, accuracy, and data access time.

Issue	Temporal Resolution	Spatial Resolution	Record Length (yr)	Data Accuracy	Data Access
Flash Floods	Hourly	Dense	>30	High	Real Time
River Floods	Hourly	Medium to Dense	>60	Medium	Real Time
Water Supply and Hydropower	Daily to Monthly	Low to Medium	>20	Medium to High	Near Real Time
Ground Water Recharge	Daily to Monthly	Medium	>10	Low	Delayed
Urban Runoff and Pollution	Hourly	Dense	>30	High	Real Time
Wetland Management	Monthly	Medium	>30	High	Monthly
Drought Assessment	Daily to Monthly	Medium	>50	High	Monthly
Soil Moisture	Daily to Monthly	High	>30	High	Monthly
Land-Use Changes	Daily	High	>30	Medium to Low	Monthly
Climate Chg. Detection	Daily	High	>100	High	Delayed
Physical & Socio-Econom. Impacts of Clim. Change	Problem Dependent	Problem Dependent	>50	High	Monthly or Seasonal
Paloeclimate	Seasonal to Annual	Medium	Longer than Instrum. Recd.	Medium	Delayed

Definitions. Spatial Resolution: Dense - 1 station/25 km^2 High - 1 station/250 km^2
Medium - 1 station/2500 km^2 Low - 1 station/25000 km^2
Accuracy: High...$\leq$ 1% Medium...$\leq$ 5% Low < 10%

ment, is capable of delivering the information necessary to understand and manage these natural resources in the most cost-effective manner. The development of new data delivery systems to take advantage of new and emerging technology for electronic transmission of information should be considered in any assessment of the merits of integrating the various existing precipitation observing systems across the country.

Decline of NOAA's Cooperative Observing Networks

Accurate and spatially-representative precipitation data are required for the planning and management of various natural ecosystems in the face of intrinsic high climatic variability and the possibility of unprecedented anthropogenic climate change. In particular, high-quality precipitation data of high resolution is necessary to help predict some site-specific conditions, behaviors, and responses of these ecosystems to such changes. Particular concern was expressed regarding the decline in reliability and density of stations in NOAA's cooperative weather observing network.

Benchmark Stations and Long-term Commitment

A valuable recommendation from many of the panels is the concept of establishing and maintaining benchmark networks of observing stations whose observational programs are focused on specific problem-related issues affecting these precipitation-sensitive systems. For example, the Changnon and Easterling Agricultural Panel point out the need for a reliable benchmark of hail measurements. The Fox and Riebsame Forests and Rangeland Panel point out the need to develop accurate historical benchmarks of fire-weather records. The National Park Service, together with the newly established National Biological Service, has a critical need for climatic benchmark stations in order to assess past, present and future environmental changes in Park areas and to separate environmental changes that are human-nduced from natural ones. The usefulness of benchmark or reference observing stations is predicated on two key elements. One is the existence of a relatively long record of high-quality observations that are as free as possible from measurement and instrumental biases. A second is the ability of the responsible agency to maintain such a baseline of measurements over the long term. Although these requirements place major burdens on the operation of these stations, the utility of those records clearly justify the effort and expense necessary to maintain them.

Legal Requirements

Each of the four major systems (agriculture, forests and rangelands, water resources, and estuarine environments) has specialized requirements that are dictated by the time scale of ecosystem responses. High-quality precipitation data and information products are needed to effectively manage these resources under a variety of requirements, some of which are written into law. They include wildfire management, reservoir mangement, control of pollutants in estuaries, and the planting and harvesting of the nation's food.

High Resolution Data

The lack of high-resolution data was often mentioned as a significant shortcoming in a number of decisionmaking activities. The need for adequate spatial and temporal data coverage was emphasized as being critical to improving our understanding of the possible impacts of precipitation variability on a range of terrestrial and aquatic ecosystems.

Impact Studies Require High Resolution Data

Regional impacts of global climate change require long-term, high-quality observations. Station history information is critical in evaluating precipitation trends and shorter-term variations, and in order to make a proper connection to much larger-scale changes. In this regard, it is important to have accurate high-resolution records to test the regional climate change projections of global climate models known as general circulation models (GCMs). Global change studies require adequate regional coverage in order to assess the two-way feedbacks between regional surface features (e.g., land-use, vegetation distribution, etc.) and global scale features. Significant improvements in precipitation measurements will have an impact on ecosystem-response modelling, which is driven, among other inputs, by precipitation data. They are also invaluable in establishing "ground truth" information that are needed in the calibration of remotely-sensed precipitation estimates.

BACKGROUND

During May 4 to 7, 1993, a workshop titled "Information Needs for Precipitation-Sensitive Systems" was held in Boulder, Colorado. A total of 44 participants attended, representing both public and private sectors, including a representative from Working Group II (the Impact of Climate Change) of the Intergovernmental Panel on Climate Change. The meeting was organized to consider important issues related to the collection, archiving and dissemination of precipitation data and information. A key goal of the workshop was to promote and improve the exchange of information among researchers, private and public institutions, and state and federal agencies charged with the stewardship and management of the nation's land and near-shore resources.

The workshop focused on four broadly defined natural systems: agriculture, forests and rangelands, water resources and hydrologic systems, and estuarine environments. Participants were asked to focus on these four topics and to identify important issues related to the collection, access, and exchange of precipitation data and information products. Workshop participants were asked to evaluate the importance of various types of precipitation data and products with respect to scientific assessments, research, and resource management issues related to each of the above main themes. The issues considered are listed at the end of this summary.related to each of the above main themes. The issues considered are listed at the end of this summary.

Presentations and informal discussions were organized around each of the four major themes. Following several overview presentations by invited topic experts, the workshop participants split out into individual panels along the four thematic lines. The panels were charged with evaluating precipitation data and information requirements for their respective system. They were also asked to prioritize data and information requirements needed by the various sectors to manage and utilize these resources now and in the future, and to take account of specific needs related to changing environmental conditions, such as global climate change.

WORKSHOP ISSUES

Agriculture

■ Identify the periods and threshold levels of precipitation sensitivity which are critical determinants of crop yields;

■ determine the spatial and temporal scales of precipitation variability which are the most important determinants of agricultural production;

■ evaluate existing mechanisms used to transmit precipitation information to the agricultural sectors and make an assessment of potential future mechanisms to improve the delivery of that information;

■ conduct an overview of current agricultural policies which are most sensitive to or affected by precipitation variability at various space and time scales for the purpose of identifying crucial precipitation parameters needed for decisionmaking.

Forest and Rangelands

■ Identify the important spatial and temporal scales of precipitation variability which are important to forest and range systems;

■ determine what are critical moisture threshold levels associated with different types and degrees of ecosystem stress, and in particular as regards to the dynamical equilibrium of such systems, and impacts of precipitatiion extremes such as drought and extended wet periods;

■ assess some of the implications of past climatic variations and change in comparison with potential impacts of future climate change scenarios. Identify data and information needs impacting on specific management practices, such as wildfire suppression, grazing limits and recreational uses in the context of natural versus human-mediated ecosystem change;

■ evaluate the current state of the information systems that provide access to precipitation-related climate data, useful to forest and range researchers and managers.

Water Resources

■ Identify spatial and temporal scales of precipitation variability important to flood forecasting;

■ define the optimal density of observations needed to effectively assess temporal and spatial variability of precipitation at a range of system scales;

■ determine the critical observational requirements needed to assess climate change impacts on water resources systems at different spatial scales;

■ estimate the required accuracy of precipitation data as inputs to short- and long-term management of water resources systems.

Estuarine Environment

- Evaluate precipitation data requirements and timeliness of information delivery needed in the development of estuarine resources management strategies;
- evaluate precipitation data and information needs related to planning for potential short- and long-term effects of global climate change on estuarine habitats and wetlands;
- identify the most important types of regional precipitation data and information needed to distinguish regional patterns and trends, including seasonal changes, in the delivery of fresh water inflow to the nation's estuaries.

The remainder of this report comprises the individual contributions from each of the four working groups written by the topic leaders. Their summaries and recommendations follow. Key points which provide crosscutting links among the various natural systems are summarized.

ACKNOWLEDGMENTS

We express thanks to Sylvia DeCotiis for helping with the technical aspects of the workshop as well as the Workshop Report. Scott Miller and H. Armstrong Roberts produced the graphics and Michael Changery assisted in the review of this report.

ACRONYMS

ALDS	Automatic Lightning Detection System
ALERT	Automatic Local Evaluation in Real Time
ARS	Agricultural Research Service
ASAE	American Society of Agriculture Engineering
ASTM	American Society of Testing Materials
BLM	Bureau of Land Management
BRC	Blackwell Research Center
CAC	Climate Analysis Center
CDIAC	Carbon Dioxide Information Analysis Center
CIESIN	Consortium for Earth Science Information Network
EOS	Earth Observing System
HCN	Historical Climatology Network
IWE	Institute of Water Engineers
IWS	Illinois Water Survey
MRCC	Midwestern Regional Climate Center
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NFDRS	National Fire Danger Rating System
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NWS	National Weather Service
ORCA	Ocean Resources Conservation and Assessment
PDSI	Palmer Drought Severity Index
RAWS	Remote Automatic Weather Station
SCS	Soil Conservation Service
SNOTEL	Snow Telemetry
TERRA	Terrestrial Ecosystems Reasearch and Regional Analysis Laboratory
US BR	U.S. Bureau of Reclaimation
USDA-FS	U.S. Department of Agriculture- Forest Service
USDI	U.S. Department of Interior
WRCC	Western Regional Climate Center
WSR-88D	Weather Service Radar-1988 Doppler

PRECIPITATION-SENSITIVE SYSTEMS: AGRICULTURE

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I. INTRODUCTION

Agriculture represents the most weather-sensitive economic sector of the United States with 10 to 15 percent of the annual value of the nation's agricultural production lost due to various forms of detrimental weather conditions. Precipitation excesses and deficiencies are a frequent cause of loss, and precipitation is one of the major determinants of agricultural productivity, for both crops and livestock, in the United States.

Weather and climate data and information have long played a prominent role in the nation's agricultural activities. The U.S. Weather Bureau was established in 1893 as part of the Department of Agriculture. Its primary purpose was to provide farmers and agricultural experts with data to design farm practices and to understand relationships between weather and crops. The early use of the telegraph to transmit severe storm information between locales became the first means of predicting the advance of large crop-damaging storm systems across the United States.

In this century, weather predictions have become much more accurate, and now they are tailor-made, by the National Weather Service and by the private sector, for use by farmers and agribusinesses. The large agricultural research community uses historical climate data from NCDC/NOAA in a variety of studies of crops, livestock, pesticides, herbicides, and fertilizers. Certain agribusinesses and many farmers also now rely on year-to-date "climate" data available in near real-time at Regional Climate Centers to closely monitor the status of weather conditions. Importantly, today's farmer can now utilize more effectively these forms of information to guide planting, spraying, harvesting, and other farming practices.

A specialty group of 13 persons with varying expertise and interests in agriculture were convened during a three-day workshop to address the broad topic, "Information Needs for Precipitation-Sensitive Systems." The agricultural experts assembled at the workshop addressed the precipitation informational needs within a framework of issues/problems which agriculture faces and that involve the use of precipitation data and/or information. Ten major issues were identified. The ten issues were: 1) erosion and sedimentation, 2) land and water pollution and precipitation quality, 3) wetlands management, 4) damaging hailstorms, 5) severe winter storms, 6) high resolution climate and agricultural models, 7) information delivery, 8) data quality, 9) access to foreign data, and 10) precipitation indices. For each, the reason/s for selecting the issue were identified; the critical precipitation conditions were listed including their space and time dimensions needed to satisfy the issue; the sources (existing or potential) of the data needed; and a general measure of the accuracy of data required to address the problem. In the next section of this document, these ten issues and the findings for each are presented. They have been grouped under four major headings: Natural Hazards, Environmental Quality Issues, Research Needs, and Data and Information Needs.

An assessment exercise of this nature is limited by the time devoted to the topic and by the breadth of expertise which addressed the topic. The assessment was done through presentations by each expert present, and then group discussions were conducted over a three-day period in May 1993. The 13 participants who addressed the agricultural aspects fortunately represented a diverse set of interests. Representing the private sector were owners of two farms, four members of agribusinesses, and two persons who utilize climate data and information to provide guidance to agricultural interests. The group also included persons from state and federal agencies who generate and provide precipitation data for the public and private sector, and some who use the data in their own agencies. The group also included research scientists from the agricultural and atmospheric sciences.

A longer, more in-depth period of assessment involving an even greater diversity of expertise would undoubtedly have detected more issues and provided a more exhaustive definition of data/informaissues and provided a more exhaustive definition of data/informational needs relating to precipitation. However, we believe that what has been identified and described incorporates many of the critical issues and reveals a wide breadth of demands for precipitation data in the agricultural sector.

II. DATA AND INFORMATION NEEDS

A. Natural Hazards and Precipitation Information Needs

Information about precipitation is crucial in reducing the vulnerability of agriculturalists to certain weather- and climate-related natural hazards. Damaging hail and severe winter storms were identified as precipitation-related hazards that are neither adequately monitored nor well-managed.

Damaging Hail

A single hail storm can destroy most, even all, of a farmer's crop. Hail can also cause extensive damage to farm property, including damage to buildings, equipment, and the landscape. Historical information about the following aspects of hail storms is needed:

- Date of storm: Date of occurrence of hail will help establish periods of high and low probability of hail.

- Size of hail stone: Size of hail stone constitutes critical information in calculating extent of hail damage.

- Duration of storm: Duration of storm will also determine the extent of hail damage.

In regard to the above aspects of hail storms, the following precipitation information/data characteristics are needed:

- Temporal scale: Daily hail observations are necessary to capture individual hail events. The period of record for averaging hail observations should be as long as possible.

- Spatial scale: The potentially localized extent of individual storms requires a minimum observing network scale of the township size.

Accuracy of information: The main accuracy requirement is the measurement of hail stone size to within 5%.

Precipitation in Damaging Winter Storms

Winter storms cause extensive damage to crops that are in the field at that time and are a major stress on livestock. Ice storms are especially destructive for orchard crops such as peaches, apples, and in some cases, oranges. Snow and ice accompanied by winds and low temperatures impede livestock weight gain and increase calf mortality rates. Winter storms also account for severe soil erosion in the western U.S. Historical precipitation information about the following aspects of winter storms is needed:

■ Effective precipitation: Effective precipitation in the agricultural sense is the portion of total precipitation that remains in the soil and is available to crops. It is the best measure of precipitation for monitoring crops and livestock.

■ Ice thickness: The thickness of ice coating crops determines the weight load and hence potential for damage.

■ Form of precipitation: The form of the precipitation (i.e., ice, sleet, snow) is a major determinant of the potential for crop damage and livestock stress.

■ Storm intensity/duration: The intensity and duration of precipitation in winter storms is a major determinant of agricultural damage, especially for soil erosion.

In regard to the above aspects of winter storms, the following precipitation data are needed:

■ Spatial scale: The typically large size of traveling winter cyclones requires a less dense monitoring network than smaller summertime convective storms. The cooperative extension network is of sufficient density for monitoring such storms.

■ Temporal scale: Daily observations of effective precipitation, ice thickness, precipitation form and intensity, and duration of precipitation events are needed.

■ Accuracy of data: Medium accuracy of precipitation data is sufficient to monitor winter storms.

B. Precipitation and Environmental Quality

Precipitation is a driving factor in many environmental quality problems involving agriculture. Farmers are being pressured to take responsibility for preserving farm-related environmental values. Though there are several environmental problems in which agriculture plays a role, three particular ones warrant the attention of NOAA: soil erosion/run-off; wetlands preservation; and precipitation water quality.

Soil Erosion/ Run-off

Hill erosion and accompanying run-off are deteriorating valuable farmland in some areas and reducing water quality in off-farm water bodies. Sedimentation of streams and surface impoundments, and run-off of farm chemicals from the land to both surface and ground water are controllable, but better information is needed in managing such problems. The same is true of other erosion/run-off problems such as flooding. Historical information about the following aspects of precipitation is needed:

■ Rainfall intensity: Knowledge of precipitation intensity is critical in assessing the risk of flooding and estimating erosion rates.

■ Precipitation distribution: Information about the distribution of rainfall over time is also critical for better management of flooding.

In regard to the above aspects of soil erosion/run-off, the following precipitation data are needed:

■ Temporal resolution: Daily 15-minute precipitation observations are needed, particularly for monitoring flooding. The averaging period for such observations should be from 5 to 10 years.

■ Spatial scale: A high-density network of observing stations is needed, probably of the type foreseen in WSR-88D (approximately 4 km^2).

Wetlands Preservation

Wetlands are highly biologically productive areas and they help filter agricultural chemicals in farm run-off. The Food Security Act has mandated that a strong regulatory program oversee wetland preservation. Better information about precipitation is needed for wetland delineation. Specifically, historical information about the following aspects of precipitation are needed:

■ Precipitation distribution: The distribution of precipitation over a specified period is crucial to the delineation of wetlands.

■ Precipitation frequency: The frequency of precipitation events is important supplemental information to precipitation distribution.

■ Water table elevation: Also, important supplemental information to precipitation is information about water table levels.

Precipitation-Sensitive Systems

C. Research Needs for Precipitation Information and Data

Research aimed at detecting and modeling climate variation and change and the impacts thereof is highly dependent on extensive and accurate precipitation data and information. As modeling techniques and the demand for specialized precipitation information become more sophisticated, the mode of collecting and archiving precipitation must move in lock step. The construction, validation, and operation of high resolution models (e.g., climate, hydrological, crop) and the development of specially-tailored precipitation indices were identified as two sets of research activities that could benefit from improved precipitation data. High resolution models offer considerable promise in the development of climate scenarios and in the calculus of the impacts of climate variation and change. Specialized agriculturally-related precipitation indices, such as crop-specific drought indices, are proving extremely useful in tracing the effects of precipitation variation on agricultural productivity.

High Resolution Models

High resolution models, when used to investigate problems of global climate change, are developed in order to simulate processes at the regional scale (40 km^2). Those models may be independent of or "nested" within lower resolution global scale models. Crop models and models that simulate related environmental and hydrologic processes may be nested within climate models. The panel recognized that the needs of the modeling community are quite broad and too encompassing to itemize all of the various needs for precipitation information. Instead some of the unique needs are listed:

■ Serially complete data sets: In order to estimate the dependency structure of precipitation in high resolution climate models, precipitation data sets must be serially complete at all observing stations in the data set.

■ Ancillary precipitation: In addition to precipitation data, alternate variables measuring dewpoint temperatures and windiness are needed to validate the models.

■ Temporal scale: Precipitation data sets are needed at virtually all temporal scales ranging from hourly (diurnal cycle) to decadal and beyond. Information about extended period of dryness and/or wetness are also crucial in agricultural studies.

■ Spatial scale: Highly localized precipitation data will be increasingly necessary to validate the models as they achieve higher degrees

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Precipitation-Sensitive Systems

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Delivery of Data and Information

A major need for precipitation data, and information derived for n agricultural purposes, concerns the status of conditions during growing season on a day-by-day basis. Needs include:

■ Near real-time information: Near real-time data and value-adc products are available at some Regional Climate Centers, but t computer-based systems of delivery are not uniform, the degree user friendliness varies, and crop-specific products available differ.

■ Data sources: Data from various precipitation data networks are not centrally available and they need consolidation at accessible sources. Daily and weekly data from foreign nations are needed.

■ New products: Considerable new ''information'' could be derived using expert interpretations of real-time data, and user friendly weather-agricultural activity models plus expertise capable of interpreting conditions for farmers and agribusiness.

III. CONCLUSIONS AND RECOMMENDATIONS

The ten issues identified revealed a variety of needs for precipitation data plus many needs relating to precipitation information defined as various interpretations of data for specific applications of agricultural users. The needs assessment for agricultural applications revealed two general themes:

1) those related to precipitation measurements and data, and

2) those related to information about precipitation for agricultural purposes.

Precipitation Data

The needs for precipitation data embraced two regimes: data from existing data systems, and data from future systems. The important issues which surfaced relating to existing data systems included:

developed for WSR-88D systems across the nation. This type of information needs to be widely available to users.

■ Missing data: A problem for research and real-time applications is missing precipitation data. Methods for estimating missing values are needed for varying applications. NOAA should develop and present techniques for estimating missing data.

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Existing Data Systems

■ maintenance of the "Cooperative Network" and other NOAA precipitation networks at the current density of stations; sustainment of the quality control of these data, their archival, and meta data[1] ; and development of uniform estimation techniques for missing precipitation data.

■ enhancement of the collection, quality control, archival, and accessibility of data from surface networks operated by other (non-NOAA) federal and state agencies, and recommendations for making these available at Regional Climate Centers.

New and Future Systems

There were numerous needs for precipitation data from very dense grids, seen as impractical using raingages, but with an excellent potential now for availability with the new NOAA WSR-88D radar system. This system will provide precipitation data needed for many important agricultural needs (crops and livestock production, and environmental management). Attention will be needed to sampling frequency and data retention to meet the rain and hail data needs of agricultural interests. There are also needs for new instruments, and networks of these, to measure dew, thickness of ice due to freezing rain, and hailfalls (stone size and frequency).

Assessments of Precipitation Events

There is also a notable two-dimensional aspect to the precipitation data needed to address many agricultural issues. Agricultural interests often must focus on evaluating the representativeness of precipitation conditions during a recent period of a few years against the historical behavior of precipitation conditions such as major fluctuations and multi-decadal trends. This situation exists because many precipitation-sensitive aspects of agriculture vary continually over 1- to 10-year time periods, and often greatly spatially. For example, the development and use of seed varieties are undergoing constant evolution; farm practices are ever changing such as fertilizers, herbicides, and pesticides used; the farm economy and crop mix change; and government policies affecting agriculture also shift over time (and vary between areas).

This situation places demands on agricultural-climate experts' a) to interpret the agricultural effects during those discrete recent "sensitiv-

[1]*Meta data are factual information about the quantity and quality of data that has been gathered by observation or otherwise.*

ity" periods, and b) to relate the conditions of these discrete periods to the longer-term climate conditions. Further, each of these two different time period data requirements frequently have different demands for precipitation data as to spatial scales, temporal dimensions, and accuracy. For example, answering informational needs related to the hail hazard in the short-term (less than 5 years) requires extremely detailed hail data from a dense sampling grid (farm scale), whereas the need to assess long-term hail variability (~5 to 10 years) does not require data at comparable spatial densities. This situation reveals the need for benchmark locations so as to compare present and past conditions. This "moving target" aspect of data needs for agriculture underlies many of the agricultural issues herein identified.

Clearly, sustaining the existing NOAA data networks and calibrating new networks like ASOS against past instrumentation serve many of the needs for precipitation data at the longer time scales needed to "calibrate" recent conditions. However, pivotal to the data needs of agriculture is a much more dense measurement of precipitation for short duration (15-minute and longer) periods. Only the new NWS radar system can provide the spatial and temporal detail needed.

The needs for *information about precipitation* defined as data interpreted for various agricultural purposes, also embraced two broad areas. One area related to historical and year-to-data information presented in near real-time, or at any time, at the discretion of the user. The other related to climatologically-based interpretative predictions of precipitation-related conditions for 30 days to months in the future. Since climate and agricultural practices have distinct regional variations across the U.S., regionally-focused information and predictions should be accessible at regional centers.

Transforming Data into Informational and Climate Products

The provision of historical and year-to-date precipitation and other closely-related climate information embraces a range of interpretations designed to serve different agricultural purposes. These include input for the development of better climate models; of improved crop models, and of a variety of precipitation indices such as those relating to drought. An important consideration in many such products is their presentation in near real-time, easily accessible to users to facilitate decision making. There are needs for farmer application products as well as those for specific needs of different agribusinesses and the scientific community. There are roles here for both the government and private sectors to create these "value added" products.

In a similar vein, long-range climate-based predictions represent a highly desired and useful information product. These can be an integrated assessment of past weather conditions, analyzed in the perspective of historical climate data and ongoing physical conditions related to agricultural activities, and coupled with climatological probabilities of future conditions and/or the 90-day outlooks to generate a useful prediction of future agricultural outcomes.

An example is useful to illustrate this need and capability. In early May 1993 (the time of the workshop), the U.S. Corn Belt remained exceptionally wet and only 5 percent of the corn had been planted. The 30-day outlook for May was for wet conditions. This situation meant that farmers would seek to plant short-duration corn hybrids (which generally produce lower yields than long-season hybrids), Further, we know there was not enough short-duration seed available; therefore roughly 50 percent of the Corn Belt would be planted in long-season corn. Thus, half of the U.S. crop will run the risk of being damaged by early or even average freezes in the fall of 1993. The probabilities for this occurrence can be determined **now** for all portions of the Corn Belt allowing one to assess the risks of damage to the 1993 corn production. Collectively, this information indicates now the range of outcomes for the 1993 corn yield of the U.S. Corn Belt. It also allows farmers in various areas of differing climatological freeze risk to make decisions on which seed to plant. As U.S. agriculture approaches the 21st Century, NOAA must step forward and take a leadership role in the provision of these and other precipitation information alluded to in the foregoing discussion.

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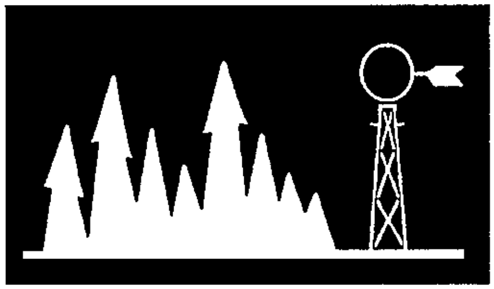
PRECIPITATION-SENSITIVE SYSTEMS:
FORESTS AND RANGELANDS



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1. INTRODUCTION

Researchers, managers, and policy-makers concerned with the health and productivity of America's forests and rangelands have long needed and used precipitation data. This is especially true of public lands resource managers in the Western U.S., which were the focus of this working group. Public lands officials must meet their management goals and mandates in a reliable manner despite large variations in ecosystems processes over time and space caused by climate fluctuations and the complex nature of semi-arid and arid terrestrial ecosystems. They are required, by legislation, to meet multiple goals under laws like the Taylor Grazing Act (1934); National Parks Organic Act (1916); Multiple-Use and Sustained Yield Act (1960); National Forest Management Act (1976); Federal Land Policy and Management Act (1976); Endangered Species Act (1973); and the Food Security Act (1985). Their ability to meet these goals is affected by changes in *both* the physical and social environments. In particular, climate variations affect resource outputs and qualities, and may affect managers' ability to meet specified goals (e.g., species preservation). Changes in public attitudes and desires affect the goals that managers are trying to meet; indeed, a common theme to forest and range resources management in recent years is how to deal jointly with environmental and social change, and this is reflected in our report.

The Goals of Forest and Range Management

Forest and range resource managers respond directly on a daily basis to climate--that is, they take strategic and tactical actions to intervene in natural systems that vary with climate fluctuations and with internal ecosystem processes. In some cases these variations are quite clear and dramatic, as when precipitation deficits increase forest fire frequency and intensity. In other cases, more subtle climate fluctuations must be considered; for example, national forest managers are required by the Forest Planning Act to chart resource outputs like timber, water, and wildlife *decades into the future*, and National Park managers are charged with maintaining natural preserves in perpetuity. Other laws mandate specific activities to produce resources while protecting the environment in areas as diverse as, rare animal species, soil erosion, forage production for livestock grazing, recreation, and water supply and quality.

The forest and range management environment is also changing rapidly, and these changes affect climate information needs. Public lands management is now at a historical crux that presages even greater demand for more, better, and specifically-tailored climate data, especially information on precipitation. This is because the traditional approaches to managing forest and range lands for "sustained yield" are being questioned by a public that wants more than short-term commodities from its lands, including more encompassing outcomes like ecosystems health and sustainability, biodiversity, naturalness, aesthetics, etc. Managers face the challenge of accomplishing these broader goals while maintaining a sustainable flow of commodities. Figure 1 illustrates this competing set of demands, where a third pole has been added to the traditional bi-polar tension between what people valued and wanted from forest and range lands, and the resource outputs that could be exploited. The new element, ecosystems health, reflects the change in public attitudes about resources generally called "environmentalism," which appears to be a strong public desire to have resource outputs and ecological well-being, simultaneously. As land management agencies seek to meet this emerging societal demand, they find themselves needing more and better data, and more and better science on how ecosystems interact with climate.

Thus, the goals of forest and range management are to intervene in ecosystems dynamics to meet social needs while simultaneously maintaining ecosystem health and sustainability. In this report, we will use the term "ecosystems management" to describe this new paradigm of forest and range management, demanded by the public and made necessary by emerging discoveries about elements as diverse as global warming and destruction of species.

The Role of Precipitation Information

A continuous history of precipitation information for as long as possible, including information about future values (ranging from short-term forecasts of hours to a day or two, to long-term

ECOSYSTEMS MANAGEMENT

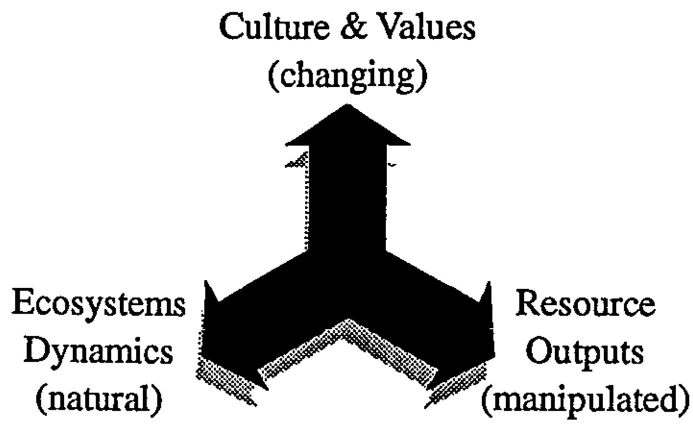

Figure 1

predictions of days to months) is critical to successful management of these resource outputs. Such products constitute the classic list of "multiple-use" components on public forest and rangelands. Forest and range management agencies have met these information needs either by relying on NOAA's weather and climate data systems, or creating their own. Precipitation information is especially important in the western U.S., where large tracts of public forest and range lands exist. Land managers, particularly in the western states, must often deal with ecosystems under stress, typically the stress of semi-aridity, aridity and hyper-aridity.

Besides meeting resource and environmental demands and mandates, land management agencies must also make their activities as *efficient* as possible. This quality will become increasingly important as the funds available for resource management become scarcer. Efficiency requires that the current piece-meal, stop-gap, narrowly-focused and incompatible climate data and analysis systems be replaced and that the agencies re-establish a cooperative, inter-linked approach.

Finally, the agencies have the dual responsibilities to *advance the science and understanding of natural resources* as well as to *monitor* key processes, like global climate change and its impacts, changing biodiversity, and changing land use and other effects of human activity on the land.

II. DEFINING CLIMATE DATA AND INFORMATION NEEDS

Forest and range managers intervene in ecosystems processes in order to balance social needs and values, resource outputs, and ecosystems health and dynamics. Climate data are needed in this balancing act to:

- help understand ecosystem changes over time (historical information at important sites);
- help predict site-specific conditions and ecosystem behavior, especially in terms of *resource outputs* like forage, water, timber, etc., and *ecosystems disturbances* like fire, pest outbreaks, and other extreme events. These activities are accomplished through a mixture of traditional practices, and new simulation models linked to new data-bases, and, in the future, *linked* climate and ecosystem models;
- help predict site-specific responses to manipulations meant to meet the three goals of land management

The necessary climate data must have certain qualities, including:

- inter-comparability: relative accuracy may be more important than absolute precision;
- accessibility: this has become a critical bottleneck at a time when data flow has increased and data management capabilities, while improving, remain somewhat outdated;
- improved geographical coverage: this is especially important in forest and range management in the western U.S. where data in mountainous terrain is generally poor, and where complex terrain creates complex climate-landscape interactions.
- appropriate temporal resolution and improved sensitivity to extreme events and other singularities: continuously recorded data could be transcribed at the minute and hourly scale, or tailored to the "storm-scale" or to a variable, "event" time-frame;
- be available for translation into carefully crafted, resource-relevant indices like fire danger ratings, drought intensity, watershed wetness, winter severity, etc. for purposes of forest, grazing, water and wildlife management.

Fire Management

Precipitation data needs in wildfire assessment and management are well-known and well-documented. Indeed, agencies responsible for wildfire management have very specialized needs for historical, real-time and predicted weather and climate information--needs so specialized in the Western U.S., in particular, that they have created their own networks and systems--the Remote Automatic Weather Station (RAWS) system and the Automatic Lightning Detection System (ALDS) both now chiefly operated by the BLM, in cooperation with the USFS and NPS.

Agency fire-related procedures include:

Fire program planning--long-term and seasonal preparation for fire suppression, based on historical data and season-to-date information; among other things, the National Fire Danger Rating System (NFDRS), based on recent climate data, is used to guide program planning.

Fire management--actual control and use of fire in prescribed conditions, based on immediate weather data and season-to-date data. Models used to make decisions about cost/loss relationships in fire suppression based on likely fire behavior and impacts;

Fire behavior analysis--Use of a complex mix of season-to-date, real-time, and predicted weather data to model fire behavior for suppression and prescribed-burn decisions.

Fire effects analysis--assessments of the ecological impacts of fire, the role of pest/disease in fire regime, and the potential for re-vegetation, soil erosion, runoff, etc. associated with burned areas.

Precipitation data are needed especially to:

- produce NFDRS outputs (short-term)
- assess fire behavior and conduct suppression (short- to medium-term)
- develop "fire management plans" (medium- to long-term)
- develop pest control plans (medium- to long-term)
- assist general vegetation management

Among the principal data inputs are:

- standard NOAA products
- specialized data from RAWS, ALDS, satellites, etc.
- site and fire-specific, short-term data from temporary stations, fire-crew measurements, etc.

1) **Spatial Scales:** Precipitation for fire management is needed at different times and for different operations, at three space scales: (a) regional or forest scale data is used for assessing geographical fire season severity and fire danger, and for imposing use restrictions (e.g., campfire bans); (b) watershed scale data is needed for calculating various indices of the NFDRS and for assessing the local length of fire season; and (c) local and micro-scale data are needed for assessing burning indices and making short-term fire management decisions.

2) **Temporal Scales:** Hourly and daily precipitation are used for calculating NFDRS indices at the watershed and broader regional scales. Note, however, that NFDRS needs "storm duration" resolution, and thus data at a finer scale than hourly is also needed. Local, and site-specific data are needed at the minute time scale to make real-time fire management decisions. Monthly and seasonal data are used at the regional scale to assess fire season severity and pest and disease prospects. Finally, data at the inter-decadal scale are used to assess plant mortality, species replacement, and overall forest health, all of which are important to fire management as well as broader ecosystems management, as discussed below.

3) **Data Delivery:** Real-time data are needed (often actually delivered to field command stations) throughout the fire season for all aspects of fire danger rating and for fire management decision-making. Delayed data on seasonal and annual precipitation, as well as historical time series, are used to assess overall fire potential, forest health, and forest change that affects fire regimes.

4) **Data Accuracy/Bias:** An important issue in forest climate data for all needs (fire as well as other resource analyses) is station longevity and exposure. Forest and range climate stations, because they are not near cities, airports, etc., are sometimes neglected in efforts to maintain the national climate data system. But, well-exposed observing stations that are representative of the important vegetation and fuel types in each USFS and BLM district are needed to assess fire potential. Many of these stations must remain fixed for many years if we are to properly assess natural variability and long-term trends, but this is difficult when attention most often comes to their products during extreme fire situations (e.g., 1988).

Drought Management

Forest and range resource outputs and qualities in the West are especially affected by precipitation deficiency. Historical and real-time precipitation data, translated into resource-relevant indices, are thus crucial to efficient and effective management. Drought is an especially difficult problem in the West, because of its pervasive qualities. Cumulative dryness affects all ecosystems and their abiotic environment. Soil moisture, groundwater, surface runoff, biomass production, and most ecosystems processes are affected by episodes of reduced precipitation. The 1988 drought in the Northern Great Plains and Rocky Mountains vividly demonstrated the difficulty of anticipating and assessing drought impacts on everything from forage production, to waterfowl survival, to wildfire prediction.

Precipitation data are the main ingredients of drought measures, ranging from the Palmer Drought Severity Index (PDSI) to various types of soil moisture or hydrological indices, to precipitation deficiency measures. Simple departures from "normal" are useful in some cases, but various indices (like the PDSI) have also been shown useful in forest and range management, though managers' experience with their use is relatively low.

1) **Spatial Scales:** Drought indices are best calculated at a watershed scale, recognizing that finer detail is needed for specific drought management activities like developing new wildlife water sources. However, current "watershed" climate divisions in the West are too large for useful data aggregation.

2) **Temporal Scales:** Drought indices are best calculated, for vegetation impact assessment, at the weekly to monthly time scale, which properly captures the cumulative, aggregate nature of drought effects. Hydrologic studies require longer time scales.

3) **Data Delivery:** The important need in drought index delivery is to get the information to decision-makers as soon after the calculating period as possible, and to deliver it in graphical and tabular form. Establishment of a weekly electronic bulletin board might be appropriate.

4) **Data Accuracy Bias:** Drought measures suffer less accuracy problems than point and time-specific precipitation data because they are cumulative indices that are relatively insensitive to a few missing or wrong data points. However, because of station siting, drought indices in the West exhibit a serious bias toward valley-bottom conditions. This situation, for example, made it difficult for forest managers to use the PDSI to assess fire danger during 1988, especially in the climate division encompassing Yellowstone National Park. Much of the Park is a high plateau, but most precipitation data in this

division come from stations at lower elevations.

Case Study:

The Bureau of Land Management (BLM) in Colorado has used the PDSI (calculated by the State Climatologist at a finer spatial scale than the typical climate division--see **Figure 2**) not only to plan livestock grazing, but to explain to grazing permit holders *why* a change in grazing plan is proposed (often including reductions in number of livestock or restricting the time that certain areas can be grazed).

Grazing is a seasonal use of available forage, and available forage is directly related to the timing and amounts of precipitation. Small, persistent precipitation deficiencies can accumulate into serious deficiencies in forage availability, or can set up conditions in which one season of traditional grazing pressure can damage resource qualities for several future years. In 1988-89, the Colorado BLM recognized that grazing conditions in the San Juan and Gunnison Basin resource management areas were being affected by cumulative drought conditions, and sought to reduce grazing pressure. Such decisions are very difficult and sensitive because drought conditions are subtle and may not be perceived by the people using the resource (thus, they may feel that use restrictions are not necessary). Unfortunately, a peculiar quality of western forest and range ecosystems is that once the effects of unusual climate conditions are obvious to most observers, it is too late to reverse or avoid resource damage. Management actions must be pro-active.

Range scientists felt that traditional grazing practices might harm the resource base in this situation, and ranchers using public rangeland were notified that forage conditions might be poor due to cumulative drought in the area. Many decided to reduce their stocking levels, to take "non-use" of their permits.

To be useful to this land management problem, the climate data had to have four key characteristics:

(1) the data had to be spatially relevant to the resource; in the West, this often means relatively fine-scale disaggregation that matches the complex terrain. At the least, the data or derived index had to represent a landscape unit like a topographic valley, a particular watershed, or a resource management area. Fortunately, in this case, the Colorado State Climatologist had established a finer-scale Palmer Index scheme in which the state is broken into 25 units rather than the traditional six.

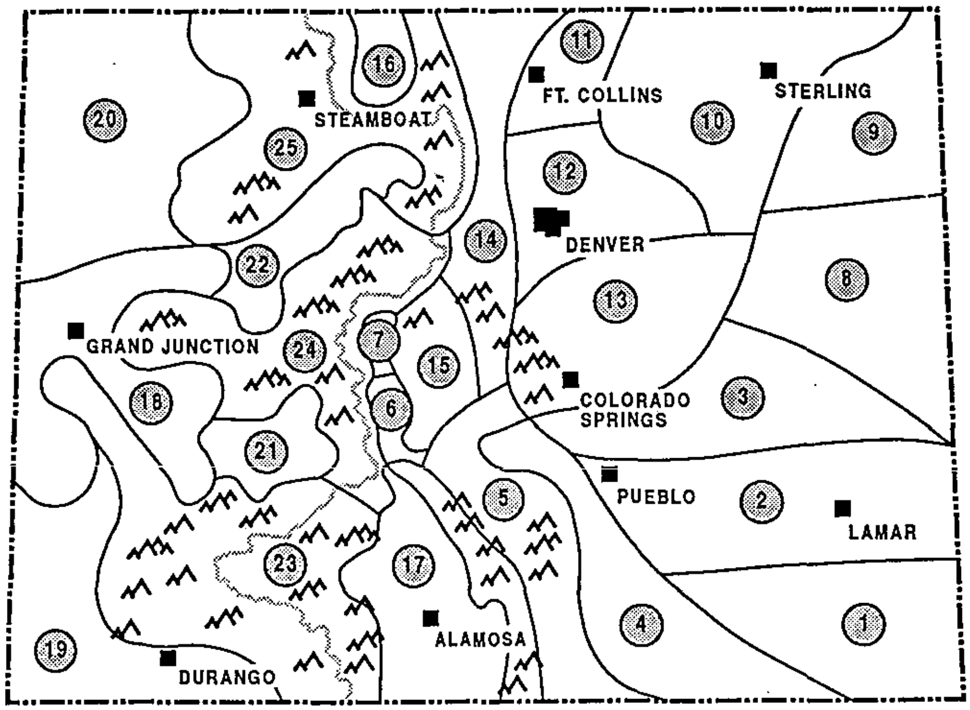

Figure 2

(2) The data and derived indices had to be available and accessible *when the resource management decision was to be made.* It would not be useful for range managers to learn that drought was deepening *after* they had made seasonal grazing determinations in the spring. In this case, the State Climatologist was able to calculate and communicate the drought indices to the BLM State Office as soon as the raw data were available. The state office was then able to advise district range managers in early spring, about two weeks before final forage utilization determinations were to be made.

(3) The information had to be relevant to the resource in question. That is, a scientific basis must exist to show that the climate index does indeed reflect resource outputs and qualities; and

(4) the data must be understandable and presentable to resource managers, users and to the public, because public lands management decisions are not made in a vacuum, but rather are scrutinized by increasingly sophisticated user and other interest groups (e.g., environmental groups). It is critically important that users affected by resource decisions made on climatological grounds are able to understand the reasoning and support for the decision.

Ecosystems Dynamics and Health, and Ecosystems Management

Drought and fire management represent specific needs at specific times, but a broader, more fundamental need for precipitation and other climate data in forest and range management is being created by the move toward "ecosystems management" (EM) by land management agencies. The notion of EM is to shift from management efforts meant to overcome ecosystem processes (e.g., fire and pest suppression), to approaches that work with the ecosystem and which use ecosystems processes as much as possible to achieve management goals. In some cases this means less overt intervention, in other cases it means emulating ecosystems processes in management actions, and in general it means maintaining ecosystems health.

The need for understanding ecosystems dynamics becomes sharper as EM is applied, causing a consequent increase in need to understand ecosystem-climate interaction. This is especially clear in the realm of vegetation dynamics and management.

Why Precipitation Data are Important

In general, the move toward ecosystems management will require greater amounts of climate data for establishing the "range of natural variation," setting base-lines, and assessing the feasibility of "desired future conditions." EM also means increased use of models - simulation models of range and forest ecosystems are increasingly used as tools for management, but require consistent, high-quality, spatially-resolved climate data.

Special attention is needed in western forest and range systems, because plants in arid and semi-arid environments are adapted to a wide range of climatic variability, especially in precipitation. However, the physiological response of both major and minor species in arid and semi-arid ecosystems to this range of variability is poorly known. Most plants that grow in upland areas in such water-limited systems tend to be drought-tolerant. The amount of their above-ground biomass is positively correlated with annual or seasonal precipitation.

There is little literature, however, indicating the ability of plants to tolerate extremes events and multiple years of precipitation anomalies. One hypothesis is that because most arid-system plants are tolerant of long runs of below-normal precipitation, they will readily adapt to a climate change that reduces precipitation. Perhaps, then, a basic change in climate to drier conditions will have little or no effect on individual species and plant communities (other than a lowering of above-ground biomass production) over periods of years to decades.

This sort of uniformitarian logic, however, may not hold in the case of extreme events, and given new insights into vegetation dynamics. Prolonged moisture stress may not shift plant communities toward new assemblages in a linear fashion but more in a stepwise or catastrophic fashion. Recent efforts have been made to model plant community "state and transition" dynamics. In these models of multiple-steady-states, cumulative climate pressure builds until a threshold is reached (perhaps with help from another disturbance, like grazing, or even release from grazing) and the vegetation community, after maintaining its original form for some time, changes drastically in a short period.

Unfortunately, the physiological response of species to large variations and/or extreme events in precipitation is not sufficiently well understood, to project the potential effects of climate change. Most current projections are based on linear notions and models that cannot readily incorporate stepwise and/or catastrophic change. We can only learn more about vegetation-precipitation relationships by studying them with long-term of records of both vegetation and climate.

1) **Spatial Scales:** As with most issues regarding precipitation relationships to western forest and range ecosystems, a major problem with current precipitation data is that they are not sufficiently dense to resolve the complex interactions of terrain and climate. While it may never be feasible to obtain ground-truth observations at the one-square-km resolution, it may be possible to develop a structured sampling system that does have such instrumental densities in key research watersheds, and from which extrapolations to other terrain setting makes sense. It may also be possible to utilize remotely sensed data to provide reliable information at sufficient density.

2) **Temporal Scales:** Daily data will be required to assess plant responses to climate, and, perhaps more importantly, data on extreme events is needed to examine plant threshold responses. Another typical weakness in the experimental site climate data is lack of soil moisture data. Soil moisture is a more direct control of plant growth than amount and pattern of precipitation. Precipitation and soil moisture data are especially needed during critical phenological periods, especially when seedling establishment occurs (different for different species).

3) **Data Delivery:** In many cases, resource and ecosystems management does not require real-time data, but uses data more in multi-year resource planning cycles, research on decadal-scale variability and monitoring of forest and range resources. The major exception is vegetation management during drought periods.

4) **Accuracy and Bias:** As with most issues regarding the needs for precipitation data in forest and range management in the western U.S., topographic and elevation bias is a big problem. Data networks are not sufficiently dense to match the complex terrain of the western states, and too few stations are maintained at higher elevations. This bias is a major problem that must be corrected.

Global and Regional Environmental Change

The prospect of human-induced global climate change, and the broader problem of overall global environmental change (GEC), provides the most profound motivation for improved and intensified use of climate data in forest and range management. Ironically, however, projected rates of climate change may make management based on historical climate data, and historically-derived relationships between climate and resources, less reliable. Past climate data, however, are still critical to constructing models of resource response to future climate scenarios.

Precipitation and other climate data are needed to:

■ understand ''natural'' ecosystem/watershed processes and relationships;

■ construct *vegetation distribution scenarios* as adjunct to climate change scenarios;

■ drive process models of *ecosystem and human interactions* with climate change (as is being attempted at TERRA, the Terrestrial Ecosystems Research and Regional Analysis Lab in Fort Collins, CO);

■ provide ground truthing for the Earth Observing System (EOS), and other remote sensing and measurement systems;

■ play a role in the *detection of climate change and its impacts*, both through the information conveyed in precipitation data, and in the conjoint analysis of precipitation and vegetation change;

■ develop response strategies to global change, using climate data as one ''leading indicator,'' linking it to changes in forest and range systems, and creating models that allow managers to test alternative responses under different climate and ecosystem scenarios.

1) **Space Scales:** Problems in western forest and range ecosystems management generated by GEC require a special effort to *link global and regional* scale data and models. Regional climate scenarios currently available are not reliable and cannot be used to drive process and management models at the regional scale. Fortunately, the western U.S. has been the focus of recent efforts to nest regional scale climate models, with more realistic earth-surface features, within global climate models. However, as with the global models, precipitation resolution will continue to be the a key model weakness, and we will continue to be unable to project, in a credible way, changes in critical factors like fire frequency, small watershed runoff, and plant community dynamics (e.g., seedling survival) that operate at relatively small spatial scales within the complex western landscape ecology.

2) **Time Scales:** It is still difficult to say what time scales are most critical in projections of climate change. In some sense, the discussions in the above problem areas all apply to the over-arching problem of GEC, but there is a special need to appraise, in the near-term, what scales make sense given the limitations of global climate modelling. A key limitation in GEC models, as we see it, is their inability to provide meaningful data on extreme events (those at the tails of statistical distributions), which are needed to examine ecosystem threshold responses.

3) **Data Delivery:** In many cases, resource and ecosystems management does not require immediate or real-time delivery of GEC model outputs. Rather, resource managers must be kept appraised of developments in global climate modeling so that they can request data as needed, as their own GEC research programs develop.

Along with "data" delivery in GEC issues must come "information" delivery. Outputs of GEC models must be accompanied by detailed guidance information designed to help non-climatologists understand the nature and limitations of global modelling outputs. GEC model output is not available from a central source in a form which enhances interpretation and application. Forest and range researchers must often make separate deals with global climate modelers to obtain model outputs. The few data sources, like NCDC, NCAR, and the CDIAC are attempting to fix this problem, but progress on a centralized source of GEC model output data, along with information on those data and how to use them, is slow.

A particularly vexing problem in GEC data delivery is the continuing release of slightly modified global climate model outputs that, for example, produce more or less global warming. While it is, of course, critical that model development occurs, it would also be useful to have sets of "benchmark" model outputs that the modeling community feels are reflective of the main features of global climate change and, thus, perhaps best for interim analysis and planning despite the knowledge that new model results will emerge at irregular periods.

4) **Accuracy and Bias:** A continuing problem in using GEC data in forest and range research and management is the difficulty of informing non-modelers about the biases and problems in the models. Different global climate models are parameterized, gridded, and spatially averaged in different ways, and output data reflect these biases in ways that users cannot readily know. Such changes as, for example, are derived from model projections for the benchmark doubling of CO_2 need to be properly scaled to the actual climate in different regions in order for the information to be of any utility for resource managers. A great deal of effort is needed to assess the comparability of data derived from the climate models and its uses in region-specific resources management.

III. RECOMMENDATIONS

Precipitation data are widely used by forest and rangeland managers and researchers. Present observational networks range in size from those with nation-wide coverage, such as the NOAA Cooperative Network, to localized, special-purpose networks of only several hundred hectares--as might be used by forest scientists. Data communications and access protocols vary among systems, and researchers in one agency or field of study spend considerable time finding out how to access data from other sources, and then often must maintain more than one access port and telecommunications hook-up. Finally, data archives often reside within the agency or specific research group, and are not widely available for retrospective research.

Creating an Integrated Surface Observing Network

Many networks were designed for specific purposes, requiring certain time and space scales. These networks are now being utilized for both research and management purposes which have different scale and measurement needs. Both the RAWS and the Soil Conservation Service's SNOTEL networks are examples of this situation. In other cases, networks designed for research purposes are now relied upon for operational needs, and vice versa. This can create conflict between primary and secondary data users and providers.

There is a great need to replace the current hodge-podge of systems with a comprehensive, integrated, nation-wide precipitation network that can meet the needs of many diverse groups trying to understand and base decisions on the interactions of precipitation and precipitation-sensitive resources like forest and range. This can best be facilitated by integrating current, and future, data collection efforts among the agencies, and maintaining system management within the climate research community. Cooperative data collection will ultimately lead to an enhanced system of precipitation observation that broadens both the user base and results in economies of scale among collection systems. A broader user base will expand and support appropriate data collection and delivery, which, in turn, will further enlarge the user base and improve our overall ability to answer critical questions about climate impacts on natural resources.

There is something of a trade-off between system integration and standardization, which is required to enhance overall system usefulness, and meeting the needs of a diversity of users. In practice, the evolution of a unified system will occur in parallel with an increase in user diversity. As a commitment emerges to achieve the kinds of data integration, quality and applicability that we envision, assessments can be made to refine standards, such as measurement precision and archival resolution, equipment type, exposure, density, geographic distribution, and archiving methods. Increased user diversity and demands will also require heavy emphasis on improved data accessibility. But, the benefits of a wholesale revamping of the current collage of systems will be substantial in terms of reduced time spent by users chasing unique data sets and continually designing and re-configuring narrowly-focused networks.

As minimum steps toward an integrated network design, we recommend that:

■ Current station locations must be preserved, especially for climate change analysis, and steps should be taken to provide comparative data for new stations. The NOAA Cooperative Network should be maintained at least at current levels, and special attention paid to the continuity and quality control for Historical Climate Network (HCN) stations and those important to long-term climate research. Current Experimental Range, Forest, and Watershed sites managed by the USDA and other land management agencies should be maintained, and certain abandoned sites in critical areas should be considered for re-opening to take advantage of their matched long-term precipitation and vegetation data. Current RAWS operated by BLM should be maintained or expanded into areas lacking other data sources.

■ Current geographical data gaps (higher elevations, sparsely-populated regions, etc.) should be analyzed and filled as efficiently as possible. That is, current knowledge of climate-terrain-ecosystems interactions in the semi-arid and arid zones should be used to design a spatial sampling design that meets emerging research needs most efficiently. Strategically-located, high-density networks in user-defined locations (particular watersheds, forests, terrain types, etc.) are also needed. Station placement should also meet needs for ground-truth in programs such as the next generation of weather radar WSR-88D, EOS, etc.

■ Precipitation data should be collected year-round at specific time intervals: the minimum need is for daily data, with a sub-network of hourly, breakpoint data, and continuous data. Specific instrument and archiving systems aimed at acquiring extreme events are also needed, perhaps not universally in the integrated system, but at least for some sub-networks. The "tipping-bucket" gages used in the BLM RAWS networks should be replaced with "weighing gage" technology.

■ Network design, and standardization of equipment, exposure, etc. should be developed in cooperation with existing standardization committees (ASAE, ASTM, IWE, etc.)

■ A new management approach is needed for the new system, perhaps by giving oversight responsibilities to an inter-agency committee that would consider the data and information needs of a broad cross-section of the user community, and make recommendations on how to best serve those needs in the most efficient and cost effective manner. The Regional Climate Centers could serve in this integration and oversight process.

Creating an Integrated, Standardized Data Telecommunications System

Data dissemination, both real-time and archival, should be through an on-line query system, such as Internet, in a user-friendly format. This is clearly an area of significant development needs, and as technology improves and expands, some organization should have the responsibility of ensuring that data are available in electronic formats (on-line, etc.). The Consortium for Earth Science Information Network (CIESIN) is moving into this role for the Human Dimensions of Global Change, and might provide a model for an on-line climate/resource information data system.

Creating Integrated, Accessible Data Archives

A move toward an integrated precipitation data system also requires an effort to retrieve, clean up, and make accessible data already collected from current and past systems. Global change research, in particular, requires retrospective data, but so do most attempts to relate climate to natural resources such as forest and range systems. It is important to address the issue of alleviating the backlog of data that is not readily available to the broader user community.

From the perspective of forest and range science, a special effort is needed to gather together, archive, and apply quality-control measures to matched climate-vegetation data sets, with attention to soil temperature and moisture, which are frequently neglected. Reasonably good long term records of climate and precipitation in arid and semi-arid regions exist in the relatively old Experimental Ranges, Experimental Forests, and Experimental Watersheds, operated chiefly by the USDA Forest Service and Agricultural Research Service. A recent report on the major experimental ranges in the West illustrates not only their value as long-term benchmarks, but shows that several are in disrepair. Two, the 'Desert Experimental Range'' and the ''Great Basin Experimental Range,'' have been closed for several years, but have data archives back to the 1930s and 1920's, respectively. Many others have been closed or essentially abandoned as budget-cutting moves, just when such data is increasingly needed for GEC research and ecosystems management. Data from these sites should be carefully archived at a centralized location, and made available to global change and ecosystems researchers. The same arguments apply to special observing systems set-up in small watersheds across the U.S. for various research purposes.

The main need in data archiving is for quality control and assurance, and this requires that equal attention be given to archiving meta-data about station history, instrumental, observation times, etc. Such ''data about data,'' or background information, can be as important as the raw data themselves, and must be archived in a similar manner and made accessible with the data.

A special effort should be made to establish archives for extreme event data, and data that allow researchers to examine threshold changes in ecosystems. This will require more communication between data archivists and ecologists.

Local Weather Generators

Global climate variations ultimately have their effects at the local scale, and while work on global models is slowly improving ideas about regional change, at the same time the absence of detailed local-scale weather information causes managers and researchers to "generate their own" data and information at the required scale. This results in a large variety of efforts to develop models that range in sophistication from fundamental physical models (mesoscale prediction models) to straightforward statistical interpolation and extrapolation. There is no uniformity or comparative quality control among these efforts, and, thus, there are large numbers of models being developed with little coordination. This duplication reduces the comparability of important local treatments of climate modeling and data generation.

IV. CONCLUSIONS: THE COSTS OF INACTION

It is not possible to quantify, in economic terms, the costs of *not improving* the nation's climate observing system simply because few studies have attempted to put a value on climate information. However, general problems associated with each of the major categories described above can be identified:

a) **Fire Management:** The obvious value of detailed precipitation data in fire assessment and management has been the force behind the development of the most extensive climate data-gathering systems in the western U.S. Despite these efforts, the same weaknesses noted above--especially data gaps and elevation biases of stations--still reduce our ability to assess fire danger. In particular, new fire behavior models, especially those that can simulate extreme fire behavior, like that observed in 1988, require more detailed climate data in time and space than is available from current systems. Fire analysts often circumvent this limitation by establishing temporary observing systems. Yet, our assessment is that these temporary systems should be permanent parts of a broader, integrated system, especially because other resource management areas also need information on storm-scale events and data from certain terrain and ecological settings.

b) **Drought Management:** Studies have shown that droughts are difficult to assess and respond to. Drought response and aid is often inefficiently applied due to lack of definitive drought severity and impact assessment. Drought mitigation in recent years (e.g., 1988) has run to billions of dollars in government response alone (private sector actions are less known), but drought severity data have not been available at time and space scales sufficient to assure efficient targeting of relief. The cost of not improving our acquisition and utilization of precipitation data, and their translation into drought indices and measures of drought impacts on ecosystems, is a continuing inefficiency of drought response.

c) **Ecosystems Health and Management:** The emerging notions of ecosystems management must be guided by better precipitation data or costly mistakes--management mistakes that will play out on the landscape for decades to come--will be made. Moreover, since resource outputs are tied to ecosystems health, limited ability to assess climate impacts on forest and range systems means limited ability to maintain commodity values. Finally, an integrated system should help us avoid some of the current duplication of effort by researchers and managers working on the interaction of climate and renewable natural resources.

Data that would allow climate/vegetation analysis are available at the relatively old Experimental Ranges, Forests, and Watersheds maintained by the federal agencies (mainly the USFS and ARS), but have not been examined in the comprehensive fashion needed to deduce long-term relationships and possible threshold responses. Moreover, the data bases from experimental sites are in danger of decay as funds for the sites are reduced. Unfortunately, the Experimental Watershed, Forest, and Range network is decaying due to lack of funds, and lack of action on this element of the nascent, integrated system will mean the loss of continuity important to long-term studies, and maybe even the loss of actual data and meta-data from existing, often informal, archives.

d) **Global Environmental Change:** Rapid, anthropogenic climate change offers a significant, if uncertain, threat to the quality and quantity of forest and range resources. Without better climate data, and knowledge about climate-resource interactions, our ability to mitigate and adapt to climate change, and perhaps even to take advantage of climate changes, will be constrained. Global climate change also elevates forest and range management to the global scale--ecosystems variables. However, precipitation is the most important input to these models.

Large scale water resource systems are multi-purpose in their objectives and their development. These purposes include provisions for flood control, water supply, hydroelectric power generation, navigation, water based recreation, fish and wildlife and water quality protection. These purposes can be categorized as having instream or offstream flow requirements. Water supply and sometimes hydroelectric power are considered to be an offstream flow requirement while the remainder have instream flow requirements.

The development sequence of large scale water resource systems can be divided into preliminary and final planning, preliminary and final design, construction and operation and management. Precipitation data are important to all of the development steps listed above.

The input for this contribution was derived from the discussions of the working group on water resources whose names appear at the end of this report. Inputs from the faculty of the CSU Department of Atmospheric Science are gratefully acknowledged.

Floods

II. DATA AND INFORMATION NEEDS

Control, Forecasts and Warnings

Most people are surprised to learn that floods are a leading cause of deaths and property damage from natural disasters in the United States. Every year, approximately 200 people die and billions of dollars of property damages occur due to floods in the United States. Flood control measures can be structural (e.g. dams and levees) or nonstructural (e.g. flood plain management). Floods can be classified as flash floods or riverine floods depending on how quickly they occur and their areal extent. The major problems specifically associated with flash floods is the urgent need for a timely forecast, the need for a rapid dissemination of a flood warning to those within the affected flood plain and the need for an evacuation of people within the flood plains.

The time scale required for flash floods is event specific but is usually sub-hourly. The space scale for quick response rain gages is dense. The precipitation record length needs to be sufficiently long, at least 30 years, to permit the analysis of the recurrence frequency of the precipitation and the flood event. The data accuracy required is high, plus or minus 5%, and the data access requirement is preferably in real time.

A flash flood warning network, called ALERT (Automatic Local Evaluation in Real Time) is being installed throughout the United States almost as a grass root movement and mainly by county flood control districts. These ALERT networks can be characterized as having standard hardware, software, rainfall/runoff models and radio frequencies. They are supported by vendors and a loosely organized informal support group that has quarterly local and annual regional meetings. One major problem with flash flood warning systems is that the flood event can occur before there is time to warn and evacuate the affected population, particularly in mountainous canyon areas. Therefore, there may be a need for denser networks of rain gages in mountainous areas susceptible to flash flooding.

Large scale riverine flooding is usually forecast by the National Weather Service via their River Forecast Centers. These centers are located at key points in the major river basins of the U.S. They have extensive computer hardware and software capable for determining the peak flowrate, the total volume and the time of occurrence of the peak event for riverine floods.

In conclusion, the precipitation data needs in the area of potential flood detection for riverine flooding are well met. In the area of flash flood detection the precipitation data needs are regionally adequate in some areas but are lacking in other areas. The cost of inaction regarding the delivery of timely precipitation data is increased loss of life and property damage from flash and riverine floods.

Water Runoff

Urban Storm Water and Other Pollution Runoff

Water runoff occurs in urban areas that have separate sewer and storm water systems. Storm water systems have received a great amount of attention in large part because they are the last significant sources of untreated waster water in the U.S. that discharge directly into various receiving bodies of water such as rivers, lakes and oceans. Other sources of pollution runoff occurs from mine tailings and agricultural fields.

The precipitation data requirements for pollution runoff are the same as for flash floods as discussed above. Whether or not the precipitation data needs are being met are very location specific, i.e. varies from city to city, and would be difficult to determine without a national survey.

The cost of not taking action regarding the delivery of adequate precipitation data would be the inability of water resource planning agents to determine the pollution loadings, i.e. the quantities of pollutants, associated with storm runoff volumes.

Water Supply

Agriculture, Municipal and Industrial

The continuous supply of cheap, plentiful water, of pristine quality, is perceived by most Americans as almost a God-given right. In the U.S. we are accustomed to drinking tap water without even thinking about whether or not adverse consequences will occur. Water for irrigated agriculture is also viewed as having to be cheap and plentiful or else grocery prices will rise and food supplies will diminish. Industries from electronics to steel and breweries require water of high quality and low cost. In order to accurately forecast water supplies a network of precipitation gauges are needed especially in the headwater regions of each basin unit or larger scale regions.

The time scale required for water supply needs is daily to monthly. The space scale is low to medium density. The record length to assess climatological benchmarks is low, normally 10 years is sufficient, but in order to establish an accurate baseline of the range of natural variability in such systems, particularly in regards to long-range planning activities, several decades of record, as a minimum are needed. The accuracy requirements are low, usually plus or minus 10%. Data access is near real-time, on the order of days is sufficient.

The cost of inaction in the adequate collection and dissemination of precipitation data for water supply purposes would be the inability of planners to assess the supplies of water available for future use.

Water Resources

Hydroelectric Power, Navigation, Water Based Rrecreation, Water Quality and Fish and Wildlife.

Each of the above listed water resource purposes is considered to be an instream flow requirement. That is, water does not have to be diverted from the stream or river in order to satisfy their flow requirement. However, sometimes hydroelectric power generation requires a temporary offstream diversion.

Accurate and timely precipitation data are required for each of these water resource needs in order to predict whether or not sufficient quantities of water will be available when they are needed. The precipitation data requirements for these five items are the same as for water supply, discussed above.

The cost of not having adequate and timely precipitation data available in these areas of water resource use is significant. The ability of water resource managers and hydrologists to predict, for example, the future seasonal flows available for hydroelectric power generation could result in the loss of millions of dollars of revenues from the sale of this power.

Groundwater

Groundwater Recharge

Groundwater recharge, as denoted here, is the purposeful application and storage of water on the land surface in such a manner that it will be able to infiltrate into the ground and percolate down through the porous media and reach the ground water table thereby increasing its volume. This is usually called artificial recharge.

The precipitation data time scale required for groundwater recharge is daily. The space scale is medium. The record length is 30 years or longer. The accuracy requirements are medium, usually plus or minus 10%. Data access is non-real time.

The cost of not providing accurate and timely precipitation data would result in the inability of water resource planners to predict the availability and quantities of water (e.g. when major storms and surface water runoff will occur) that may be used for groundwater recharge.

Climate Change Detection

Climate Change Detection and Assessment for Hydrologic and Water Resource Purposes.

To water resource engineers and hydrologists the detection and assessment of climate change is primarily a regional issue. The areas of interest are river basin in size unless large scale diversions from the river basin occurs.

The time scale required for climate change varies from daily to annual depending upon the final usage of the water resource subjected to the climate change. The space scale is medium. The record length needs to be at least 50 years. The accuracy requirements are problem dependent but can be considered to be high, plus or minus 5%. Data access is non-real time.

This is a significant problem in estuarine environments due to the large number and size of ungaged areas and is further complicated by the complex atmospheric dynamics characteristic of near coastal environments. Due to the inherent variability in flow direction of an estuary, placement of stream gages in the variable flow zone is limited. As result, virtually every system is to some degree faced with this problem. Bidirectional gages have been implemented but data analysis is complicated by the need for both astronomical and meteorological data against which to filter the data for freshwater inflow contributions due strictly to freshwater inputs.

In addition, land/sea interactions create a microclimate that dominates the weather over coastal regions. The sea temperature over the year changes relatively little and slowly due to the high thermal capacity of the water. By contrast the land in summer heats up rapidly by day, so the air inland becomes buoyant, less dense and therefore of lower pressure than the air over the sea. Low-level air moves from high to low pressure in the form of a cool onshore sea breeze. This convection process can initiate rainfall activity whose pattern and intensity of occurrence is often times difficult to capture and measure.

Solutions

The need exists for increased numbers of gaging sites, particularly within the ungaged portions of coastal watersheds. Given the size of the convective processes operative within these areas, an optimal spatial resolution of 50 sq mi providing data averaged over a daily time step would be suitable input for simulation models to estimate freshwater inflow amounts. An alternative requiring fewer gages would use a WSR-88D system to spatially extrapolate gaged results to the appropriate areas within the watershed.

To better refine pollutant inputs derived from urban runoff, gages are required within the urban area at a spatial resolution consistent with the dimensions of the probable storm type characteristic of the area. In addition, a program to determine an appropriate time step for sampling should be based on stratified comparisons between results using variable averaging periods.

Finally, a need exists to address the possibility of long term climate change on the amount and pattern of precipitation delivery. This requires data pertinent to the characterization of large scale synoptic weather features and possible changes. These analyses are best suited to address regional changes at the seasonal decadal to time steps.

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