Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation

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Abstract

Drought is a normal part of climate and occurs in virtually all regions of the world. Recent droughts have illustrated the vulnerability of all parts of the United States to extended periods of precipitation deficiency. Drought preparedness planning has become a widely accepted tool for governments at all levels to apply to reduce the risks to future events. In the United States, planning has been employed by local, state, regional, and tribal governments. In 1982, for example, only 3 states had developed drought plans. Today, 30 states have prepared drought plans and other states are at various stages of plan development.

Drought plans should contain three basic components: monitoring and early warning, risk assessment, and mitigation and response. A 10-step drought planning process illustrates how these components of a plan are addressed during plan development. Because of drought's slow-onset characteristics, monitoring and early warning systems provide the foundation for an effective drought mitigation plan. A plan must rely on accurate and timely assessments to trigger mitigation and emergency response programs. The monitoring committee's functions are discussed as an integral part of the drought planning process. An example of a new climate monitoring product, the Drought Monitor, is presented to illustrate how climate parameters and indices are being used in the United States to produce a weekly comprehensive assessment of drought conditions and severity levels.

Introduction

The economic, social, and environmental costs and losses associated with drought in the United States are significant. In 1995, the U.S. Federal Emergency Management Agency (FEMA) estimated annual losses attributable to drought at US$6-8 billion. Drought occurs somewhere in the United States each year, with an average of 12% of the nation (excluding Alaska and Hawaii) in the severe to extreme drought category. The maximum spatial extent of severe and extreme drought occurred in 1934, when 65% of the nation was affected.

Widespread and severe drought conditions in 1996 in the southwest and south central states, the recurrence of drought in 1998 in this same region and its expansion into the southeast, and the return of drought in 1999 to the southwest, southeast, and south central states and its expansion into the mid-Atlantic and northeast states have raised serious concerns about our nation's continuing vulnerability to extended periods of drought-induced water shortages. In 2000, drought again was widespread in the spring and summer months. It has resulted in severe impacts in three regions of the country: southeast and Gulf Coast, southwest and south central, and central and western Corn Belt states.

Our vulnerability to drought is quite different from that of many developing countries, where the primary concerns are centered largely on issues of food security and meeting the nutritional needs of the population, environmental degradation, and a retardation of the development process. In the United States, the economic, environmental, and social impacts of drought are substantial. Drought in 1996 resulted in serious losses in crop and livestock production and increased the incidence of forest fires and wildfires. Decreases in surface and ground water supplies affected public water supplies and water-based tourism and recreational activities. Energy demand also increased markedly in response to searing heat. These losses were estimated at nearly $5 billion in Texas alone (Boyd 1996); substantial losses also occurred in Kansas, Oklahoma, New Mexico, Arizona, Utah, Nevada, and Colorado. The rapid emergence of drought in 1998 following the strong El Niño event resulted in drought-induced wildfires in Florida and acute agricultural losses in Texas, Oklahoma, Louisiana, South Carolina, Georgia, and other southern states. Losses in Texas and Oklahoma were estimated at $5 billion (Chenault and Parsons 1998) and $2 billion (Thurman 1998), respectively.

Drought conditions that returned in 1999 in the southwest, south central, and southeast states have had a cumulative effect on economic and social systems and the environment. Drought in the mid-Atlantic and northeast states also had devastating effects in some areas. The economic impacts of the 1999 drought are likely to be several billion dollars. Drought events in 2000 have resulted in serious impacts on agriculture and municipal water supplies, especially in the southeast region, where drought has occurred in each of the past three years over most of Georgia and portions of Florida, Alabama, and South Carolina. It is too soon to know the extent of agricultural losses associated with this drought in the central and western Corn Belt. A dry fall, winter, and spring season over this area resulted in poor soil moisture conditions at planting, placing agriculture in a high-risk situation.

A critical component of planning for drought is the provision of timely and reliable climate information, including seasonal forecasts, that aids decision makers at all levels in making critical management decisions. This information, if properly applied, can reduce the impacts of drought and other extreme climate events. A comprehensive, integrated national climate monitoring or drought early warning system has been under discussion for some time in the United States (Wilhite et al. 1986; Riebsame et al. 1991; Wilhite and Wood 1994; Wilhite 1997a), but little action on these recommendations has taken place until recently. The wide range of data and information that is readily accessible to users via the Internet has made the development of an integrated climate monitoring system a more executable task.

The purpose of this paper is to discuss the current status of drought planning in the United States and illustrate the key role that drought early warning systems play in drought plans. This chapter will begin with a brief overview of some of the concepts of drought, how it differs from other natural hazards, and its characteristics. Understanding the unique characteristics of drought is crucial to establishing an effective and comprehensive monitoring and early warning system as one component of an effective drought preparedness plan. A planning methodology that has been applied in numerous settings in the United States and elsewhere and at various levels of government will be discussed. This methodology represents a step-by-step approach to developing a drought plan, including the creation of a drought monitoring or early warning system. A new national monitoring tool developed in 1999, the Drought Monitor, will be discussed because this approach integrates multiple indices and parameters in the assessment process and relies heavily on the Internet in product development and dissemination. The Drought Monitor has been widely accepted by decision makers and the media in the United States and is being used in drought assessment at the state and national level.

Drought: The Concept

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes (Wilhite 1992a). It occurs in high as well as low rainfall areas. It is a temporary aberration, in contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event. Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought year is unique in its climatic characteristics and impacts.

Drought differs from other natural hazards in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as a creeping phenomenon (Tannehill 1947). Although Tannehill first used this terminology more than fifty years ago, climatologists continue to struggle with recognizing the onset of drought and scientists and policy makers continue to debate the basis (i.e., criteria) for declaring an end to a drought.

Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed. Wilhite and Glantz (1985) analyzed more than 150 definitions in their classification study, and many more exist. Although the definitions are numerous, many do not adequately define drought in meaningful

terms for scientists and policy makers. The thresholds for declaring drought are arbitrary in most cases (i.e., they are not linked to specific impacts in key economic sectors). These types of problems are the result of a misunderstanding of the concept by those formulating definitions and the lack of consideration given to how other scientists or disciplines will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, drought declarations or revocations for eligibility to relief programs).

Third, drought impacts are nonstructural, in contrast to, the impacts of floods, hurricanes, and most other natural hazards. Its impacts are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. Emergency managers, for example, are more accustomed to dealing with impacts that are structural and localized, responding to these events by restoring communication and transportation channels, providing emergency medical supplies, ensuring safe drinking water, and so forth. These characteristics of drought have hindered the development of accurate, reliable, and timely estimates of severity and impacts and, ultimately, the formulation of drought contingency plans by most governments.

Drought severity is dependent not only on the duration, intensity, and spatial extent of a specific drought episode, but also on the demands made by human activities and vegetation on a region's water supplies. The characteristics of drought, along with its far-reaching impacts, make its effects on society, economy, and environment difficult to identify and quantify. This continues to represent a formidable challenge to those scientists involved in operational climate assessments.

Many persons consider drought to be largely a natural event. In reality, the risk associated with drought for any region is a product of both the region's exposure to the event (i.e., probability of occurrence at various severity levels) and the vulnerability of society to the event. The natural event (i.e., meteorological drought) is a result of the occurrence of persistent large-scale disruptions or anomalies in the global circulation pattern of the atmosphere. Exposure to drought varies spatially and there is little, if anything, that we can do to alter drought occurrence. Vulnerability, on the other hand, is determined by social factors such as population, demographic characteristics, technology, policy, social behavior, land use patterns, water use, economic development, diversity of economic base, and cultural composition. These factors change over time, so vulnerability will change in response to these changes. Subsequent droughts in the same region will have different effects, even if they are identical in intensity, duration, and spatial characteristics, because societal characteristics will have changed. However, much can be done to lessen societal vulnerability to drought. Improved understanding of a region's drought climatology will provide critical information on the frequency and intensity of historical events. Identifying the factors that explain who and what is at risk and why (i.e., the underlying factors behind the vulnerability) can lead to the development and implementation of a wide variety of mitigation actions and programs to reduce impacts from future drought events.

Drought Characteristics and Severity

Droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact. Many indices of drought are in widespread use today, such as the decile approach (Gibbs and Maher 1967; Lee 1979; Coughlan 1987) used in Australia, the Palmer Drought Severity Index and Crop Moisture Index (Palmer 1965, 1968; Alley 1984) in the United States, and the Yield Moisture Index (Jose et al. 1991) in the Philippines and elsewhere. A relatively new index that is gaining increasing popularity in the United States and worldwide is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993, 1995). The SPI will be discussed in greater detail in later sections of this chapter.

Another distinguishing feature of drought is its duration. Droughts usually require a minimum of two to three months to become established but then can continue for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event.

Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity shift from season to season. During the drought of 1934 in the United States, the area affected was approximately 65% of the country (see Figure 1). In the United States, it is unusual for drought not to exist in a portion of the country each year. A recent analysis of drought occurrence by the U.S. National Drought Mitigation Center (NDMC) for the 48 contiguous states in the United States demonstrated that severe and extreme drought affected more than 25% of the country in one out of four years.

Methodology for Drought Preparedness Planning

Drought planning in the United States has gained considerable momentum in the past two decades. Since 1982, there has been a rapid development of drought plans by state governments in the United States. In 1982, only 3 states (Colorado, New York, and South Dakota) had completed drought plans. Today, 30 states have drought plans in place and Texas, Georgia,

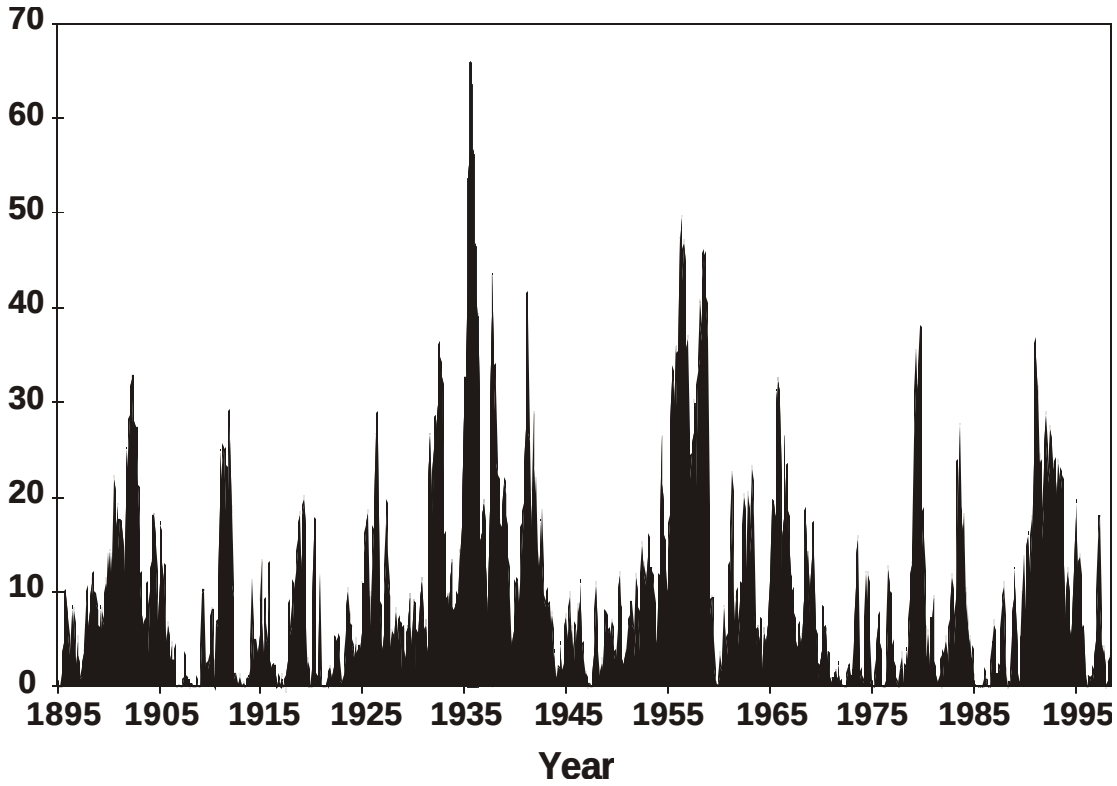

Figure 1. Percent area affected by drought.

Arizona, and Hawaii are in various stages of plan development. Most state drought plans are largely response oriented since they were first developed in the mid to late 1980s or early to mid 1990s. The exceptions are the plans of New Mexico, Utah, Nebraska, and Texas, in which greater emphasis is now being placed on mitigation. These four states will likely serve as models for other states. In the early years of state-level drought planning, Colorado's drought plan served as a model for others to emulate, and many states borrowed heavily from its organizational structure and operating procedures.

In 1991, a 10-step planning process for states in the United States was published as a methodology for plan development (Wilhite 1991). This process was intended to be generic and adaptable to the needs of any level of government in any drought-prone region. It has been widely disseminated at workshops and conferences in the United States and internationally as well as through the literature (Wilhite 1992b, 1996; Wilhite et al. 2000; UNDP/UNSO 2000). The influence of the planning process is clearly evident in plans that have been or are being developed at various levels of government in every drought-prone region. The original version of the planning process (Wilhite 1991), although recognizing the need for developing mitigation tools to reduce the impacts of drought, did not place as much attention on mitigation as is

warranted today, given the growing emphasis on risk management in addressing the impacts associated with natural hazards. When first published, this planning process focused more attention on improving governmental response to drought emergencies through development of greater institutional capacity directed at creating an appropriate organizational structure, improving monitoring capability, defining a more explicit decision-making authority for implementing response measures, and improving information flow and coordination between and within levels of government.

As vulnerability to drought has increased globally, greater attention has been directed to reducing risks associated with its occurrence through the introduction of planning to improve operational capabilities (i.e., climate and water supply monitoring, building institutional capacity) and mitigation measures that are aimed at reducing drought impacts. This change in emphasis is long overdue. Mitigating the effects of drought requires the use of all components of the cycle of disaster management (Figure 2), rather than only the crisis management portion of this cycle. In the past, when a natural hazard event and resultant disaster has occurred, governments have followed with impact assessment, response, recovery, and reconstruction activities to return the region or locality to its pre-disaster state. Little attention has been given to preparedness, mitigation, and prediction/early warning actions (i.e., risk management) that could reduce future impacts and lessen the need for government intervention in the future. Because of this emphasis on crisis management, society has generally moved from one disaster to another with little, if any, reduction in risk. In fact, many response measures instituted by governments, international organizations, and donors have actually increased vulnerability by increasing dependency on internal or external assistance. All components of the cycle of disaster management should be addressed in a comprehensive hazards mitigation plan, but greater attention needs to be placed on pre-disaster activities than has occurred in the past.

The goal of the 10-step planning process (Figure 3) is to derive a plan that is dynamic, reflecting changing government policies, technologies, natural resources management practices, and so forth. It is intended to serve as a checklist to identify the issues that should be addressed in plan development, with appropriate modifications. An overview of the steps included in the planning process follows.

In brief, Steps 1-4 (see Figure 3) of the planning process focus on making sure the right people are brought together and that they have a clear understanding of the process and what the drought plan must accomplish and are supplied with adequate data to make fair and equitable decisions when formulating and writing the actual drought plan. Steps 1 and 2 focus on the creation a drought task force (DTF) to supervise and coordinate plan development. When the plan is activated, the DTF will coordinate actions, implement mitigation and response programs, and make policy recommendations to the appropriate person or elected official and legislative body. A generic statement of purpose for a drought plan is to provide government with an effective and systematic means of assessing drought conditions, developing mitigation actions and programs to reduce risk in advance of drought, and developing response options that minimize economic stress, environmental losses, and social hardships during drought. The DTF should define the scope of the plan, the most drought-prone areas and most vulnerable economic and social

sectors, the role of the plan in resolving conflict between water users and other vulnerable population groups, current trends (e.g., land and water use, population growth) that may increase/decrease vulnerability and conflicts in the future, and principal environmental

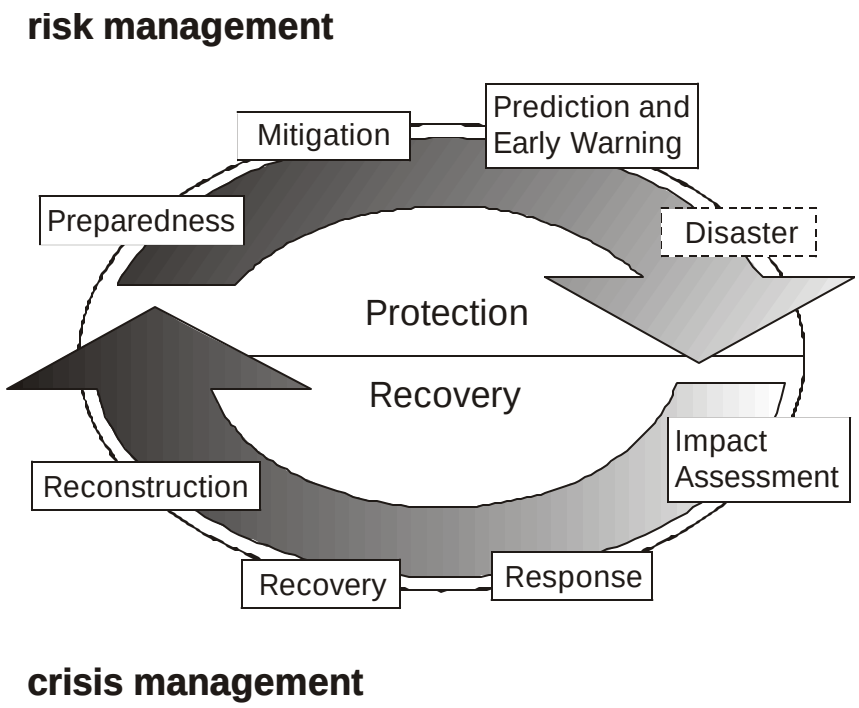

Figure 2. The cycle of disaster management.

concerns caused by drought. The DTF should identify the specific objectives of the plan, which will vary between countries and should reflect unique physical, environmental, socioeconomic, and political characteristics.

Step 1	*Appoint* a drought task force
Step 2	*State* the purpose and objectives of the drought preparedness plan
Step 3	*Seek* stakeholder participation and resolve conflict
Step 4	*Inventory* resources and *identify* groups at risk
Step 5	*Develop* organizational structure and *prepare* the drought plan
Step 6	*Identify* research needs and fill institutional gaps
Step 7	*Integrate* science and policy
Step 8	*Publicize* the drought preparedness plan, *build* public awareness
Step 9	*Teach* people about drought
Step 10	*Evaluate and revise* drought preparedness plan

Figure 3. The 10-Step planning process.

Steps 3 and 4 are directed at involving stakeholders in the planning process, resolving conflict, and conducting an inventory of resources available to the planning process. One of the goals of Step 4 is to complete a preliminary identification of primary groups or areas most at risk because of drought. In drought preparedness planning, making the transition from crisis to risk management is difficult because, historically, little has been done to understand and address the risks associated with drought. To solve this problem, areas of high risk should be identified, as should actions that can be taken before a drought occurs to reduce those risks. Risk is defined by both the exposure of a location to the drought hazard and the vulnerability of that location to periods of drought-induced water shortages (Blaikie et al. 1994).

Step 5 describes the process of developing an organizational structure for completion of the tasks necessary for preparing the plan. Since the focus of this meeting is on drought early warning systems, this step of the planning process will be discussed in greater detail because the establishment of a monitoring or early warning system is critical to the success of the planning process. Steps 6 and 7 detail the need for ongoing research and coordination between scientists and policy makers. Steps 8 and 9 stress the importance of promoting and testing the plan before drought occurs. Step 10 emphasizes revising the plan to keep it current and making an evaluation of the plan's effectiveness in the post-drought period. Although the steps are sequential, many of

these tasks are addressed simultaneously under leadership of the DTF and its complement of committees and working groups. The steps in the planning process are part of an integrated planning process rather than a list of discrete tasks. These steps represent a "checklist" of tasks that should be considered and completed as part of the planning process.

Drought Plan Development

Step 5 describes the establishment of an organizational structure for the drought preparedness plan. The drought plan should have three primary components: monitoring and early warning, risk and impact assessment, and mitigation and response. It is recommended that a committee be established to focus on the first two needs; the mitigation and response function can in most instances be carried out by the DTF after receiving input from the other committees. These committees will have their own tasks and goals, but well-established communication and information flow between committees is still a necessity to ensure effective planning.

Monitoring/Early Warning Committee

A reliable assessment of water availability and its outlook for the near and long term is valuable information in both dry and wet periods. During a drought, the value of this information increases. The monitoring committee should include representatives from agencies with responsibilities for monitoring climate and water supply, traditionally meteorological, hydrological, and agricultural services. It is recommended that data and information on each of the relevant indicators (e.g., precipitation, temperature, evapotranspiration, seasonal weather forecasts, soil moisture, streamflow, ground water, reservoir and lake levels, and snowpack) be considered in the committee's evaluation of the water situation and outlook for the country. The agencies responsible for collecting, analyzing, and disseminating data and information will vary according to each country's infrastructure. The monitoring committee should meet regularly, especially in advance of the peak demand season.

The primary objectives of the monitoring committee are:

1. Adopt a workable definition of drought that could be used to phase in and phase out levels of state and federal actions in response to drought. It may be necessary to adopt more than one definition of drought in identifying impacts in various economic, social, and environmental sectors. Several indices are available (Hayes 1998), including the Standardized Precipitation Index (McKee et al. 1993, 1995), which is gaining widespread acceptance (Guttman 1998; Hayes et al. 1999). The commonly used Palmer Drought Severity Index (Palmer 1965) is being replaced or supplemented as a monitoring tool in many states. The trend is for states to rely on multiple drought indices to trigger responses, which are calibrated to various intensities of drought. No single index of drought is adequate to measure the complex interrelationships between the various components of the hydrological cycle and impacts.

It is helpful to establish a sequence of descriptive terms for water supply alert levels, such as “advisory,” “alert,” “emergency,” and “rationing” (as opposed to more generic terms such as “phase 1” and “phase 2,” or sensational terms such as “disaster”). The monitoring committee should review the terminology used by other entities (i.e., local utilities, states, river basin commissions) and choose terms that are consistent for areas where there may be authorities with overlapping regional responsibilities. These alert levels should be defined in discussions with both the Risk Assessment Committee and the Drought Task Force.

In considering emergency measures such as rationing, it is important to remember that the impacts of drought may vary significantly from one area to the next, depending on the sources and uses of water and the degree of planning previously implemented. For example, some cities may have recently expanded their water supply capacity while other adjacent communities may have an inadequate water supply capacity during periods of drought. Imposing general emergency measures on people or communities without regard for their existing vulnerability may result in considerable political repercussions.
A related consideration is that some municipal water systems may be out of date or in poor operating condition, so that even moderate drought strains a community’s ability to supply customers with water. Identifying inadequate (i.e., vulnerable) water supply systems and upgrading those systems should be part of a long-term drought mitigation program.

2. Establish drought management areas (i.e., subdivide the state or region into more conveniently sized districts by political boundaries, shared hydrological characteristics, climatological characteristics, or other means such as drought probability or risk). These subdivisions may be useful in drought management since they may allow drought stages and mitigation and response options to be regionalized. Climatic divisions are the most commonly used subdivisions at the state level, but they may not be the most appropriate, given topographic features, land use patterns, or water use characteristics.

3. Develop a drought monitoring system. Most states already have a good data collection system for monitoring climate and water supplies and identifying potential shortfalls. Responsibility for collecting, analyzing, and disseminating the data is divided between many state and federal agencies. The monitoring committee’s challenge is to coordinate and integrate the analysis so decision makers and the public receive early warning of emerging drought conditions. On a national basis, much of this information has been compiled under the Drought Watch section of the NDMC’s web site (http://enso.unl.edu/ndmc/). Two new products, the Drought Monitor and Current Droughts Affecting the U.S., should be noted. This section is also linked to specific state web sites that illustrate how others are organizing information on drought conditions.

   Many states (e.g., Nebraska, Oklahoma, California) and other regions have developed automated weather data networks that provide rapid access to climate data. These networks can be invaluable in monitoring emerging and ongoing drought conditions.

These data can be coupled with data available from federal agencies to provide a comprehensive monitoring of climate and water systems. Data and data products should be disseminated on a timely basis in printed form and via the World Wide Web.

4. Inventory data quantity and quality from current observation networks. Many networks exist that monitor key elements of the hydrologic system. Most of these networks are operated by federal or state agencies, but other networks also exist and may provide critical information for a portion of a state or region. Meteorological data are important but represent only one part of a comprehensive monitoring system. Other physical indicators (e.g., groundwater and streamflow) must be monitored to reflect impacts of drought on agriculture, households, industry, energy production, and other water users. Helpful technology includes soil moisture sensors, automated weather stations, and satellite data such as digital data obtained from the Advanced Very High Resolution Radiometer (AVHRR), transmitted from a National Oceanic and Atmospheric Administration satellite. Satellite data is useful in detecting areas where moisture deficiencies are affecting vegetation growth.

5. Determine the data needs of primary users. Developing new systems for collecting and analyzing data is most effective when the people who will be using the data are consulted early and often. Soliciting input on expected new products or obtaining feedback on existing products is critical to ensuring that products meet the needs of primary users and will be used in decision making. Training on how to use or apply products in routine decision making is also essential.

6. Develop and/or modify current data and information delivery systems. People need to be warned of drought as soon as it is detected, but often are not. Information needs to reach people in time for them to use it in making decisions. In establishing information channels, the monitoring committee needs to consider when people need various kinds of information. These decision points can determine whether the information provided is used or ignored.

   A growing number of states have created web sites that contain current climate and drought-related information, including the state's drought plan and the responsibilities of key agencies. Some of these web sites are listed in Table 1.

Table 1. Drought-related web sites for various states in the United States.

State	Web Site Address
Montana	http://nris.state.mt.us/wis/Swsi/MTDrought2000.html
Nebraska	http://linux1.nrc.state.ne.us/carcunl
New Mexico	http://weather.nmsu.edu/drought
Oklahoma	http://www.state.ok.us/~owrb/features/drought.html
Pennsylvania	http://www.dep.state.pa.us/dep/subject/hotopics/drought/drought.htm
South Carolina	http://water.dnr.state.sc.us/climate/sco/drought.html
Texas	http://www.twdb.state.tx.us/DATA/DROUGHT/drought_toc.htm

Risk Assessment Committee

Drought impacts cut across many sectors and across normal divisions of responsibility for government ministries. These impacts have been classified by Wilhite and Vanyarkho (2000). Impacts are the result of exposure to the drought hazard (i.e., probability of occurrence) and a combination of economic, environmental, and social factors. Therefore, to reduce vulnerability to drought, it is essential to identify relevant impacts and assess their underlying causes.

Information on drought impacts and their causes is crucial for reducing risk before drought occurs and for appropriate response during drought. The membership of the risk assessment committee should represent economic sectors, social groups, and ecosystems most at risk from drought. The committee's chairperson should be a member of the DTF.

The most effective approach to follow in determining vulnerability to and impacts of drought is to create a series of working groups under the aegis of the risk assessment committee. The responsibility of the committee and working groups is to assess sectors, population groups, and ecosystems most at risk and identify appropriate and reasonable mitigation measures to address these risks. Working groups would be composed of technical specialists representing each of the sectors, groups, or ecosystems at risk. The chair of each working group, as a member of the risk assessment committee, would report directly to it. The responsibility of the committee is to direct the activities of each of the working groups and make recommendations to the drought task force on mitigation actions. The number of working groups will vary considerably, reflecting important impact sectors.

A methodology for assessing and reducing the risks associated with drought has recently been completed by the National Drought Mitigation Center (NDMC) (Knutson et al. 1998) and is available on the NDMC's web site at http://enso.unl.edu/ndmc/handbook/risk.pdf. The guide focuses on identifying and assigning priorities to drought impacts, determining their underlying causes, and choosing actions to address the underlying causes. This methodology can be employed by each of the working groups. This effort requires an interdisciplinary analysis of impacts and management options available.

The choice of specific actions to deal with the underlying causes of the drought impacts will depend on the economic resources available and related social values. Typical concerns are associated with cost and technical feasibility, effectiveness, equity, and cultural perspectives. This process has the potential to lead to the identification of effective and appropriate drought risk reduction activities that will reduce long-term drought impacts, rather than ad hoc responses or untested mitigation actions that may not effectively reduce the impact of future droughts.

Mitigation and Response Committee

Mitigation and response actions could be under the responsibility of the drought task force or could be assigned to a separate committee. The task force, working in cooperation with the monitoring/early warning and risk assessment committees, should have the knowledge and experience to understand drought mitigation techniques, risk analysis (economic, environmental, and social aspects), and drought-related decision-making processes at all levels of government. The task force, as originally defined, is composed of senior policy makers from various ministries and, possibly, representatives from NGOs. Therefore, they are in an excellent position to recommend and/or implement mitigation actions, request assistance through various programs, or make policy recommendations to the legislative body or the prime minister/president. Mitigation and response actions must be determined for each of the principal impact sectors identified by the risk assessment committee. Wilhite (1997b) recently completed an assessment of drought mitigation technologies implemented by states in the United States in response to drought conditions during the late 1980s and early 1990s. However, the transferability of these technologies to specific situations in other locations needs to be evaluated.

The U.S. Drought Monitor: An Example of Integrated Climate Monitoring

The need for a national drought early warning system has been acknowledged for some time in the literature as part of a more comprehensive approach to drought assessment and management. Following the creation of the NDMC, one of our first goals was to create a "one-stop shopping" section of our web site that would provide users with access to all of the information necessary to develop a timely and reliable climate and water supply assessment for their state or region. The development of the Drought Watch section was undertaken because no routine national or regional assessment was available. However, all of the components necessary to assess current climate and water supply conditions and the long-range outlook were becoming readily available on the World Wide Web. The goal of the Drought Watch section of the NDMC's web site (http://enso.unl.edu/ndmc/watch) is to provide users with first-hand climate and water supply assessments through products such as the Standardized Precipitation Index (SPI) and also to link to other sites that provide information on snow pack, soil/crop moisture conditions, ground water and reservoir levels, streamflow, fire danger, and seasonal forecasts. In the absence of a national assessment product, the NDMC sought to encourage users to examine products and resources available on the Internet. From these web sites, users could assemble the necessary data and information to assess current climate conditions and longer-range climate and water supply

outlooks. The popularity of this type of information has been reinforced over the past 5 years, as the Drought Watch section is the most-often visited of the NDMC web site.

The series of drought years that have occurred since the NDMC was established in 1995 has continued to raise the level of interest in drought planning and, consequently, the importance of effectively monitoring drought and delivering useful and timely information to a diverse set of users. To further that goal, the NDMC, U.S. Department of Agriculture's Joint Agricultural Weather Facility (USDA/JAWF), and the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA/CPC) created a joint drought monitoring facility in 1999. The purpose of this partnership was to develop new products collaboratively and bring together existing products under a new web site to provide users with "one-stop shopping." The intent of this new web site was to improve user accessibility to that information and, through the collaborative product development process and user feedback, to improve the quality (i.e., information content and ease of understanding) of climate-related products.

What has evolved from this collaborative effort has been a series of accomplishments that have significantly advanced the information available, its utility, and its resultant application by users to decisions that are climate sensitive. First, the Drought Monitor map integrates information from numerous indices and parameters in the determination of areas experiencing drought and the severity of that drought. A classification system for levels of drought severity has been developed that is similar to that available for hurricanes, tornadoes, and earthquakes. Drought levels are identified as first stage, severe, extreme, and exceptional. Areas that have experienced abnormally dry conditions over a period of time but have not yet reached a "drought" stage are also identified. These areas represent regions of concern or "watch" areas for future reference. An interpretive summary of each week's map is included.

Second, this assessment effort has successfully incorporated local and regional experts in a formal review of the draft map before release. This review group receives the map via an email exploder on Tuesday afternoon each week. This review group is made up of state climatologists, regional representatives of the National Weather Service and other federal agencies, regional climatologists from regional climate centers, hydrologists, and agricultural specialists. The advance review of this product by this group has helped to ensure the validity of the product by providing some ground truth for data analysis and interpretation, as well as for assessments of current impacts.

Third, the Drought Monitor web site also includes links to other web products. Products used in the preparation of the Drought Monitor map are linked, as well as forecast products. In addition, the web site includes information on how the map is developed and an archive of previous maps. The NDMC plans to animate these maps in the near future to help depict the changing nature of intensity and spatial extent over time.

Fourth, user demand for this information and the collaborative nature of product development have helped to spawn additional products in support of the development of this product. For example, the U.S. Geological Survey created a daily streamflow map that illustrates the status of

streamflow. This clickable map allows users to interpret streamflow conditions daily at the national, state, or local (stream gauge) level. This product has been extremely valuable in assessing the severity of drought conditions at the local and regional scale since streamflow is one of the first elements of the hydrological system to be affected by prolonged dry conditions. Below-normal streamflow is an excellent indicator of potential impacts on navigation, irrigated agriculture, municipal water supply, recreation, and fish and wildlife.

The first Drought Monitor maps were produced on an experimental basis in May 1999. Because of the severe drought that was affecting the eastern United States in August 1999, the Drought Monitor map quickly became an operational product. The product was released officially at a White House press conference in August and has continued to receive considerable publicity. Not only does it appear weekly in many local, regional, and national newspapers, it is also shown regularly on The Weather Channel. Although the product simplifies a very complex issue, it still seems to capture enough information in an easy-to-interpret format for a diverse audience. At release, it is widely used by commodity brokers in the United States and elsewhere. Since its unveiling, the Drought Monitor has been well received by people from a wide variety of backgrounds and trades. The media has been especially quick to pick up on and use the new product to inform their readers and listeners of current and changing drought patterns. Producers, commodity brokers, congressional delegations, and federal/state agencies also are using this product. Users like the simplicity and ease of use of the product (see Figure 4).

The Monitor consists of a color map (converted to black and white for this publication) showing which parts of the United States are suffering from various degrees of drought, and accompanying text. The text describes the current impacts, future threats, and predicted prospects for improvement. The Monitor is a synthesis of several scientific drought indices. It is by far the most user-friendly national drought monitoring product available. The Monitor is particularly well suited for use by mainstream media because it represents state-of-the-art scientific expertise, packaged as a timely, colorful, unambiguous map. Currently, the World Wide Web is the main means of distributing the Monitor. NOAA also distributes the Monitor through internal channels. The obvious advantages to using the web are that there are no distribution costs, and the information is instantly available, always current, and free. The obvious disadvantage is that not everyone has access to the web. Our focus to this point has been how to best disseminate the product in the most timely manner.

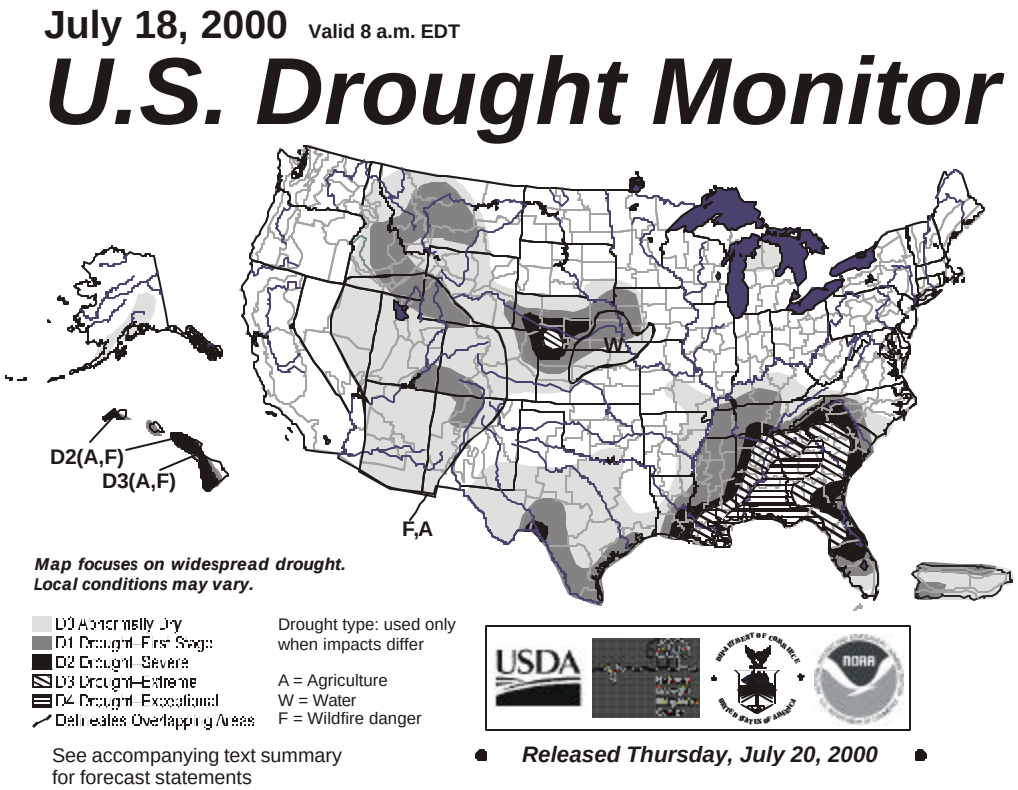

Figure 4. U.S. Drought Monitor.

No single definition of drought works in all circumstances, so water planners rely on indices or data that are most often depicted in map or graphic form to recognize droughts. The Drought Monitor relies on input from several key indices and ancillary indicators from different agencies. The final map is posted each Thursday morning at http://enso.unl.edu/monitor/monitor.html. The seven key parameters making up the current scheme are: Palmer Drought Index, Crop Moisture Index, CPC Soil Moisture Model (percentiles), USGS Daily Streamflow (percentiles), Percent of Normal Precipitation, USDA/NASS Topsoil Moisture (percent short and very short), and the remotely sensed Satellite Vegetation Health Index. The final color map summarizes all of this information in an easy-to-read format that captures where drought is emerging, lingering, and subsiding.

For the Drought Monitor, droughts are classified on a scale from zero to four (D0-D4), with zero indicating an abnormally dry area and four reflecting a region experiencing an exceptional drought event (i.e., comparable to the drought of record). The drought intensity categories are based on the six key indicators mentioned above as well as many supplementary indicators. The Drought Monitor summary map and narrative identify general drought areas, labeling droughts by intensity from least to most intense. D0 areas (abnormally dry) are either (1) drying out and possibly heading into drought or (2) recovering from drought but still experiencing lingering impacts or not yet back to normal or wet conditions.

The Drought Monitor also shows which sectors are presently seeing drought-related impacts. This is accomplished by assigning a label of A, W, or F. The "A" represents observed agricultural impacts on crops, forests, livestock, and range/pasture. Water (W), or hydrological, impacts are meant to show that the region is experiencing an impact on one or more components of the hydrologic or water supply system (i.e., streamflow, snowpack, ground water and reservoirs). "F" is used when abnormally high risks of fire danger are observed.

Two-week forecasts (5-day and 6-10 day) are used to determine which areas may see improvement or a worsening of conditions. Seasonal forecasts are also used in an informal way to identify areas that may see drought develop. These forecasts can generally illustrate what the trend looks like months into the future, especially when an El Niño or La Niña is occurring. Many teleconnections are found within certain regions of the United States depending on the ENSO phase. Some strong correlations do exist between dryness or drought in certain parts of the United States, depending on the season and whether or not we are in an El Niño or La Niña phase. The relationship is not nearly as strong, however, in the primary grain-producing regions that make up our corn and wheat belts. Another problem is addressing the non-phase year, especially in the summer. In fact, the summer months are the toughest to predict, regardless of whether an ENSO event is taking place. Models have improved and will continue to improve as computing power increases and the complex relationships that exist between our oceans, continents, and atmosphere are better understood.

The drought severity classification system that is currently being used in the preparation of the Drought Monitor map can be found at http://enso.unl.edu/monitor/archive/99/classify.htm. The system was intended to be flexible, allowing it to continually evolve by responding to and incorporating the latest technologies and data available.

Conclusions and Future Challenges

Reducing the risks and therefore the impacts associated with drought in the future requires that much greater emphasis be placed on preparedness and mitigation. Preparedness leads to greater institutional capacity to cope with drought events through the creation of an organizational structure that improves information flow and coordination between and within levels of government. Improving our level of readiness or preparedness for drought is about building institutional capacity at all levels of government, as well as improving coordination between levels of government. It is also about increasing the coping capacity of individuals, communities, and governments to handle drought events. Drought preparedness, coupled with appropriate mitigation actions and programs, can reduce and, in some cases, eliminate many of the impacts associated with drought.

This chapter described a drought planning process than can be followed in the development of a drought preparedness plan. A drought plan has three components: monitoring and early warning; risk assessment; and mitigation and response. The monitoring and early warning component of a drought plan is essential because it provides the foundation on which timely decisions can be made by decision makers at all levels (i.e., farmers to national policy makers). Given drought's

slow onset or creeping characteristics, monitoring all components of the hydrological system is the only mechanism we have for detecting drought's early onset and its potential impacts on sectors, regions, and population groups. This information serves as the basis for management decisions during both the developing and receding phases of drought, including the timing for the start-up and shut-down of mitigation and emergency response programs that are part of the drought preparedness plan.

Drought early warning systems face numerous challenges. First, data and information on climate and water supply, including seasonal forecasts, must be integrated to provide decision makers with a comprehensive picture or representation of current conditions and future outlooks. This will require much greater coordination between meteorological, hydrological, and agricultural services. Second, improved delivery systems must be developed to get information in the hands of decision makers in a timely manner. This will require a better understanding of user needs and their preferences on how this information is displayed or presented. The World Wide Web provides the most cost-effective and timely mechanism for information delivery, but this technology is not widely available in many countries. Appropriate delivery systems need to be employed. Third, potential users of climate information must be educated on how that information can be applied to reduce the risks associated with extreme climatic events such as drought. Improved communication between the developers and users of products must be established so that products are better suited to user needs and users understand how this information can be applied in the decision process. Currently, many products are not user-friendly and the value of this information is not fully appreciated.

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