Reducing Drought Risk: Bridging Theory and Practice

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Abstract: Drought events across the United States since 1995 illustrate the country's continuing vulnerability to drought. Officials are beginning to recognize the need for enhanced mitigation actions to reduce the increasing economic, environmental, and social impacts of droughts. One way to better understand a region's drought vulnerability and identify the appropriate mitigation actions to take is to conduct a drought risk analysis. However, drought risk can be a confusing concept for many planners. For this reason, a simplified, flexible framework for conducting a drought risk analysis is presented. This framework is based on a combination of natural hazards theory and interactions with a variety of drought planners in the field, and is intended to be a practical, action-oriented model to assist drought planners on a variety of political and geographic scales. Several case studies are also discussed to demonstrate the application of such a model.

DOI: 10.1061/(ASCE)1527-6988(2004)5:2(106)

CE Database subject headings: Droughts; Risk; Risk analysis; Planning; Models.

Introduction

Despite significant improvements in weather forecasting and warning systems, government programs, public education, and the development of new tools and technologies, the costs resulting from disasters around the world and in the United States are still high and rising, indicating growing societal vulnerability to natural hazards (Changnon et al. 2000; Wilhite 2000a; Bender 2002). A similar trend of increasing vulnerability exists with droughts (Changnon 1993, 2000) illustrated by recent droughts across the United States since 1995. From Fall 1995 into Summer 1996, parts of the southern Great Plains and southwestern United States experienced a severe drought that captured a large amount of attention from the media and policymakers. Parts of Florida, Georgia, South Carolina, Texas, and Hawaii experienced four consecutive years of drought from 1998 through 2001, the East Coast experienced a crippling drought in 1999, a record number of acres burned in wildfires during 2000, and the Northwest and northern Rockies faced a severe drought in 2001. During 2002, a severe and extreme drought existed along parts of the East Coast and in most of the Rockies and High Plains from Montana to Arizona and Texas.

In response to the rising costs of natural hazards, the United States Congress established the Natural Hazards Caucus in 2000 to better understand why the nation is increasingly vulnerable to natural hazards and to explore alternative courses of action (Natural 2001). According to the Caucus, the current federal-state-local relationship, which provides resources after a disaster and very few mitigation resources before, requires serious attention, and they believe that the emphasis needs to shift toward mitigation efforts to prevent citizens from becoming disaster victims in the first place. Mitigation in this context is generally considered to be the actions taken before a natural hazard event that would potentially reduce the negative impacts associated with the event. In 2002, the Federal Emergency Management Agency (FEMA) director, Joe Allbaugh, also called for a mitigation-driven philosophy, urging his agency to ''elevate prevention and pre-disaster mitigation from conceptual and educational ideas to actions that are applied in all of America's communities'' (Allbaugh 2002).

The concept of implementing mitigation to reduce natural hazard impacts has long been an important component of emergency management (Brenner 1997). For droughts, however, incorporating mitigation into planning efforts is a relatively new concept (Wilhite 2000b). Based on recent experiences, the National Drought Mitigation Center (NDMC) has learned that one way to identify appropriate drought mitigation actions is to conduct an overall risk analysis as part of drought planning (Wilhite et al. 2000). This approach makes sense, given that risk, mitigation, and planning for drought are so closely linked.

During a series of drought workshops in 1997 and 1998, organized by the NDMC and funded by the U.S. Bureau of Reclamation, there was a great deal of confusion among drought planners about the concept of risk and how to conduct a drought risk analysis. Therefore, the NDMC, along with assistance from members of the Western Drought Coordination Council, developed a framework useful for communities, tribes, and states conducting their own drought risk analyses. The main hypothesis presented in this paper centers on the concepts that (1) bridging drought risk theory with practical applications and (2) encouraging drought planners to conduct drought risk analyses are critical in helping to reduce the increasing impacts of drought. This paper addresses the theoretical aspects of drought risk and vulnerability and describes the process that the NDMC uses in communicating drought risk analysis to drought planners in the field. Three case

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Note. Discussion open until October 1, 2004. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on August 16, 2002; approved on September 10, 2003. This paper is part of the ***Natural Hazards Review***, Vol. 5, No. 2, May 1, 2004. ©ASCE, ISSN 1527-6988/2004/2-106–113/$18.00.

studies illustrate how officials have recently conducted risk analyses as part of their drought planning strategy.

Drought as a Natural Hazard

Throughout the world, drought ranks first among all the natural hazards in terms of the number of people directly affected (Obasi 1994; Hewitt 1997; Wilhite 2000a). Although considered a natural hazard, droughts differ from the other natural hazards in several ways. First, drought is a slow-onset hazard, often described as a creeping phenomenon, making it difficult to determine when a drought begins. Second, droughts do not have a universally accepted definition, causing confusion about whether a drought exists and its severity. ''What is a drought?'' needs to be defined specifically by region and activity. Third, although drought is not as physically destructive as most natural disasters, it can affect vast areas and cause a wide range of economic, environmental, and social impacts (Wilhite and Glantz 1987).

During the last two decades, the impacts from drought events in the United States have appeared to increase significantly without documented evidence of an increased number of droughts or an increase in their severity (Wilhite and Hayes 1998; Changnon et al. 2000). In 1995, FEMA published the National Mitigation Strategy, which estimated the annual loss from drought at $6–8 billion (FEMA 1995). Although previous studies have called for an increased emphasis on drought mitigation (GAO 1979; Wilhite et al. 1986; Wilhite and Easterling 1987; Wilhite 1993, 1997a), very few mitigation actions and programs were considered until the 1995–1996 drought in the southwestern United States finally caught the attention of policymakers. As a result of this drought, both the Western Governors' Association (1996) and a FEMA task force (1996) put together reports calling for enhanced mitigation efforts to deal with future droughts.

Since then, the Western Drought Coordination Council (1997–1999) and the National Drought Policy Commission (1999–2000) have emphasized the need for improved drought planning that includes mitigation strategies (NDPC 2000), while the NDMC continues its ongoing program emphasizing planning and mitigation. Following such advice, New Mexico, Texas, and Georgia developed drought mitigation plans in recent years. Nebraska, Utah, and Colorado revised existing drought plans to incorporate mitigation, while Hawaii is in the process of developing a drought mitigation plan. Native American nations, particularly in the southwestern United States (i.e., the Hopi, Zuni, Navajo, Kiabab Paiute, and Haulapai nations), have also engaged in developing drought mitigation plans. In all of these cases, the entities have conducted some form of a drought risk analysis to identify the appropriate mitigation actions.

Drought Risk Analysis

There is great confusion about natural hazard risk because of conflicting definitions and because it remains an abstract concept for a majority of the public (Alexander 2000). This paper, therefore, proposes a generalized framework to explain the issue of drought risk analysis (Fig. 1). Risk analysis for this purpose is defined as the process of identifying and understanding the relevant components of drought risk as well as the evaluation of the alternative strategies to manage that risk (Knutson et al. 1998). The framework is based on evaluating the hazard and deciding what to do about it, and can be represented as a combination of drought risk assessment and drought risk management. Other frameworks certainly exist, but the framework proposed here has been adopted because it balances many of the scientific concepts in the risk literature and is consistent with the interactions the NDMC has with officials and stakeholders around the world. It is important to understand that scientists and the public may use the term ''risk'' differently. Understanding the user's perceptions of risk and communicating concepts of risk in a simple and effective manner are critical to the success of a drought risk analysis. This requires awareness, flexibility, and continuing discussion. Another requirement of the risk analysis process is that it be as user-friendly as possible and, when possible, incorporate the input of stakeholders so that its results carry more credibility and user-based support (Mileti 1999; Flax et al. 2002).

Drought Risk Analysis

- I. Risk Assessment
  - A. Hazard Analysis
    - 1. Frequency
    - 2. Severity
    - 3. Temporal Trends
  - B. Vulnerability Analysis
    - 1. Impact Assessment
      - a. Social
      - b. Environmental
      - c. Economic
    - 2. Causal Assessment
    - 3. Temporal Trends
- II. Risk Management
  - A. Short- and Long-Term Mitigation Actions
  - B. Responsible Agencies
  - C. Action Time Table

Fig. 1. Drought risk analysis components

Drought Risk Assessment

Using the framework that risk analysis is the combination of risk assessment and risk management, the writers break down the specific components associated with each concept (Fig. 1). Because drought is a complex issue involving the supply and demand of water resources, and therefore both physical and social characteristics, a conceptual approach to risk assessment can be broken down into a combination of the hazard and vulnerability. Blaikie et al. (1994) originally represented risk as the sum of the hazard plus vulnerability (risk=hazard+vulnerability). More recently, risk has been represented as the product of the hazard and vulnerability (risk=hazard×vulnerability) (Knutson et al. 1998; Downing et al. 1999; Downing and Bakker 2000; Wilhite 2000a).

Hazard in these models represents the probability of occurrence or frequency of droughts; vulnerability represents the broadest concept of biophysical and social vulnerability in a region. Therefore, to reduce drought risk, there must be an under-

standing of the hazard using climatology, improved operational monitoring, an analysis of vulnerability to understand what people and sectors may be most affected by drought, why these impacts occur, and if these relationships are changing over time. Because of the product relationship, if there is no chance for the hazard or there is no vulnerability, the drought risk for that location is zero. For drought, there are very few places, if any, around the world where either component is zero, but this is not necessarily true for other natural hazards. For example, the likelihood of a tsunami in Nebraska is zero, making the state's tsunami risk zero according to the new equation.

Hazard Analysis

For droughts, hazard analysis revolves around an understanding of the frequency, intensity, duration, and spatial extent of drought occurrences, and if these factors are changing over time. This may be an easy or difficult task, depending on the length or availability of climatological records. For example, many Native American groups have expressed frustration over both the lack of historical data and the low density of weather stations on numerous reservations. The temporal trend is especially important for drought planning since planners may base their actions on more frequent and less-severe droughts, extreme droughts, or the drought of record for their region. For example, the drought of record along the front range of the Rockies, including the Denver metropolitan area, is the 1950s drought. Drought planners need to be aware that although multiyear droughts have not occurred recently along the Front Range, these longer-term droughts are a normal part of the Great Plains climate and need to be considered as part of a risk analysis (Woodhouse and Overpeck 1998). Drought planners in this area also need to recognize that the population characteristics and water-use patterns have also changed considerably along the Front Range since the 1950s, and will likely continue to change, affecting the level of drought impacts associated with various intensities of drought. The city of Denver, for example, incorporates many of these issues into their Drought Response Plan (''Drought'' 1997).

Vulnerability Analysis

Natural hazard researchers are most familiar with the hazard analysis component of risk assessment. However, many researchers stress that when evaluating hazard risk, vulnerability needs to be considered with at least the same degree of importance that is devoted to understanding and addressing the frequency and severity of other natural hazards (Blaikie et al. 1994; Cutter 1996; Pulwarty and Riebsame 1997; Downing and Bakker 2000). Confusion over the concept of vulnerability and its role in determining natural hazard risk may come from the many variations in vulnerability definitions. Variations in terminology associated with the meaning of vulnerability (e.g., sensitivity, resilience, susceptibility, resistance, capacity, potentiality) arise from different theoretical schools (e.g., political ecology, human ecology, physical science, spatial analysis), their subsequent methodological practices, and a great difference between hazards themselves and the regions chosen for case studies (Dow and Downing 1995; Cutter 1996). The definitions of vulnerability vary widely. However, most of them contain a common thread: they all agree that vulnerability shows the degree of susceptibility of society to a hazard, which could vary either as a result of variable exposure to the hazard or because of coping abilities (Wilhelmi 1999; Wilhelmi and Wilhite 2002).

Building on this common understanding, the framework presented here divides vulnerability analysis into three components: impact assessment, causal assessment, and a temporal understanding of these issues (Fig. 1). An impact assessment is essential to inventory the social, economic, and environmental sectors that are susceptible to drought impacts in a particular region. This allows the broad range of drought impacts to be examined and possibly ranked as high- and low-priority needs. This analysis may be based on the effects of more frequent and less-severe droughts, a drought of record, or whatever level of severity is deemed appropriate, based on the initial hazard analysis. Impact assessment subcommittees are usually established to research the relevant impacts for a given planning area. To assist such endeavors, several researchers have done quantitative and qualitative research on the impacts of drought (Riebsame et al. 1991; Easterling and Mendelsohn 2000; Wilhite and Vanyarkho 2000), while others have also included geographic information systems (GIS) in this type of analysis (Cutter et al. 1997, 2000; de Jager et al. 2000; Wilhelmi and Wilhite 2002). In most drought planning efforts, GIS and historical information may be used when available, but an impact analysis is often based only on the collective memories of the participants. More work needs to be done to incorporate research into planning efforts, but time, financial capacities, and expertise are often limiting factors.

A causal analysis allows tracing outward from each impact the multiple environmental, social, and economic underlying factors that contribute to the resulting impacts (Ribot 1996). In such a process, climatic events are placed among the many relationships that accentuate the negative consequences of drought. For example, an impact of drought may be that a city does not have enough water to meet consumer demands. Accentuating that problem may be the fact that the city did not heed forecasts and released too much water from storage, did not have any alternative water reserves, had older well pumps that broke down because of the extra use during the drought, or did not have water conservation plans in place. There are many ways to illustrate these causal linkages, such as impact tree diagrams, scenario building, or brainstorming sessions. From our experience, the latter seems to be the most prevalent when working with groups since it is the easiest and fastest, although not necessarily the best or most comprehensive method. In any case, by linking climate-associated impacts to causality, vulnerability analysis can provide a sound basis for policy since it is through responding to its causes that vulnerability can be effectively addressed (Ribot 1996). A clear understanding of local vulnerabilities, with stakeholder participation, and the potential impacts of hazards on communities is critical to making decisions about which mitigation actions should be taken (Mileti 1999; Pearce 2000).

Vulnerability is also affected by changes in technology, population demographics and behavior, and policies, and therefore temporal trends should be addressed in any vulnerability analysis (Blaikie et al. 1994; Changnon et al. 2000; Downing and Bakker 2000; Wilhite 2000a,b). This can be done by reviewing how drought impacts and causal factors have changed over previous decades as well as projecting them into the future. Such analysis provides a better temporal understanding of the problem and changing institutional and informational capabilities.

Several authors indicate that one of the challenges of vulnerability analysis is not simply the lack of recognition of the social, economic, cultural, and historical contexts of vulnerability but a general failure or unwillingness to put this recognition into practice (Whyte 1986; Pulwarty and Riebsame 1997). For example, Krannich et al. (1995) conducted a survey of residents in the San

Joaquin Valley in southern California and the Grand Valley in western Colorado in 1992. The survey revealed that even though the residents ''believe that a severe sustained drought is likely to occur within the next 20–25 years and that their communities would be seriously impacted by the event,'' the residents ''express little support for water management alternatives that would require shifts in economic development activities or in water use and allocation patterns.'' This issue of public complacency must be addressed to reduce the ongoing effects of drought in the United States and around the world.

Drought Risk Management

Risk management uses the information obtained through risk assessments to provide better ways for individuals and groups to reduce hazards or cope with their effects (Swaney 1996). Risk management actions must be evaluated in the context of numerous constraints: time, financial and personnel resources, geography, feasibility, the level and nature of development and vulnerability, and the attitudes and desires of the affected communities and property owners (FEMA 1995). Additional criteria for evaluating appropriate drought risk management actions could also include such concepts as legality, public acceptance, and liability. In recent years, sustainability has also been increasingly stressed as essential for creating more resilient systems and reducing the effects of natural hazards (Anderson 1994; Mileti et al. 1995; Mehta 1997; Mileti 1997, 1999). Overall, choices must be realistic, as well as socially and environmentally appropriate. This activity must also take place on a scale that is meaningful to those who must act, whether at the national, regional, or local level.

In response to recent droughts in the United States, states have identified numerous mitigation measures. Wilhite (1997b) assessed drought mitigation technologies, programs, and policies recently employed by these states and/or local municipalities. The mitigation activities identified were diverse because of regional differences in impacts, legal and institutional constraints, drought plans and institutional arrangements, and the wide range of state agencies responsible for drought planning and mitigation (Wilhite 1997b; Wilhite and Vanyarkho 2000). More than 50 specific actions identified by the state governments were classified into the following nine categories: (1) assessment programs; (2) legislation/public policy; (3) water supply augmentation/development of new supplies; (4) public awareness/education programs; (5) technical assistance on water conservation and other water-related activities; (6) demand reduction/water conservation programs; (7) emergency response programs; (8) water-use conflict resolution; and (9) drought contingency plans. Overall, states have made significant progress in the field of drought planning. However, most drought plans still emphasize emergency response rather than mitigation.

Wilhite (1997b) states that a thorough and systematic assessment of vulnerable sectors needs to be completed by each state to determine which mitigation measures are appropriate in each circumstance. The same holds true for local communities. A clear understanding of the type of hazard, its potential impacts, causal factors, and temporal trends is critical for making fair and effective decisions on short- and long-term mitigation actions. For each causal factor identified in the vulnerability analysis, a wide range of mitigation measures may be proposed and then weeded out by the limiting factors suggested previously (e.g., time, feasibility, cost, equity, sustainability). The result is a prioritized list of actions that are practical and sustainable for the user's particular region or situation.

However, risk management should not end with merely identifying the necessary mitigation actions. Mechanisms must also be put into place to ensure that they are carried out. The following two important steps are often left out of the process: (1) identifying agencies responsible for addressing each mitigation action; and (2) creating a timetable for implementing each action. Although there are no legal ramifications in most collaborative planning projects for implementation delays, establishing responsibility and timelines may place enough social pressure on the parties involved to keep the project moving forward. Finally, it might be helpful to estimate projected costs associated with implementing the mitigation actions. This would assist in determining the actions that could be done in the short term and the actions that would require additional funding sources. It would also assist in establishing an implementation priority for the mitigation actions.

Application of Drought Risk Analysis Methodology

The purpose for outlining this risk analysis process is to develop a strategy that individual communities, tribes, or states can follow relatively easily. This is especially important considering the current trend in the natural hazards community to move from national and regional risk and vulnerability analyses to local, community-based efforts with participation from stakeholders (Pearce 2000). Any methodology must be user-friendly for a wide variety of interests and knowledge levels.

To put these aspects into practice, the NDMC and members of the Western Drought Coordination Council developed a user guide, *How to Reduce Drought Risk* (Knutson et al. 1998). The guide was developed to assist states, communities, and tribes in conducting their own drought risk analysis. It attempts to transform theory into a relatively simple, practical step-by-step process for better understanding drought in a particular region and identifying appropriate actions for reducing its damaging effects. The NDMC has used the principles behind the guide to explain drought risk theory in workshops and consultations with a wide variety of drought planners throughout the United States and around the world. The guide is also available on the NDMC website (http://drought.unl.edu/ndmc) where it has been downloaded more than 20,000 times.

As part of the recent movement toward improving drought planning capabilities, several states and tribal governments have undergone some process of investigating their drought risk, identifying drought frequencies and severity, vulnerable sectors, and mitigation actions that can be taken to reduce drought impacts. Because of the NDMC's work with state agencies, much of this risk analysis has been based on the guidelines proposed by the National Drought Mitigation Center and the *How to Reduce Drought Risk* guide. The approach of each process was somewhat different depending on the available personnel, time, financial resources, familiarity with the risk analysis process, and successful models to follow. In addition, almost all of these efforts have taken place during a larger drought planning process, often with the help of the NDMC's 10-Step Drought Planning Methodology (Wilhite et al. 2000).

In 1998, New Mexico became the first state in the United States to analyze its drought risk and develop a drought mitigation plan. They were followed by Texas, Hawaii, and Georgia. Nebraska and Colorado have also revised their drought plans to incorporate mitigation actions as well. Meanwhile, tribal governments such as the Navajo, Zuni, and Hopi nations in the southwestern United States have investigated their drought risk and

developed drought mitigation plans, and other tribes are beginning their own drought risk analysis process. The three nations above incorporated more of the components into their risk analyses than did the states. Following are brief case studies of two states and one tribe that used the *How to Reduce Drought Risk* guide as a basis for the drought risk analysis.

New Mexico

In response to a severe drought in 1996, New Mexico completed a drought mitigation plan in 1998 (http://weather.nmsu.edu/drought/053102/). To develop a proactive plan that included specific mitigation actions, the state went through the important process of identifying their drought risk. New Mexico roughly followed the methodology suggested by Knutson et al. (1998), adapting the process to the available resources and relevant needs.

Risk Assessment

New Mexico began by completing a brief hazard analysis that investigated the historical trends of drought indices such as the *Palmer Drought Severity Index* and the *Standardized Precipitation Index*. These historical records of the indices were compared to drought impacts to determine if the drought indices did a good job identifying when the impacts occurred. A drought classification system was then established based on the drought indices, with five stages: normal, advisory, alert, warning, and emergency. The hazard analysis also identified a series of extended drought periods during the 1900s to illustrate that multiyear droughts are a relatively common characteristic of the New Mexico climate, which is important knowledge for the risk management component.

As part of the vulnerability analysis, New Mexico then organized four impact assessment subgroups representing the sectors most affected by drought in the state including (1) agriculture; (2) drinking water, health, and energy; (3) wildlife and wildfire protection; and (4) tourism and economic impact. The role of the impact assessment subgroups is to assess the current and potential impacts of ongoing or impending droughts anywhere within the state. However, the 1998 New Mexico Drought Management Plan had very little input from the public or stakeholder groups during the development of the plan. Instead, after a draft was produced, the state held public hearings at various locations around the state. The perception by the planners was that public participation during plan development would slow down the process, and the need for the state to have a drought mitigation plan was pressing as drought conditions continued beyond 1996.

The first step the subgroups took identified the major drought impacts occurring in each sector. The less obvious impacts were not considered, and part of the reason for this was that the subgroups essentially skipped the causal assessment and temporal trends components within the vulnerability analysis (Fig. 1). These less obvious impacts might have been identified if the state had had more time to ask questions related to vulnerability, such as why are these identified impacts taking place? What communities, people, or activities are particularly vulnerable to drought but not visible or obvious? What changes in the state in the past 25 years, or in the next 25 years, have changed or will change drought vulnerability?

Risk Management

The impact assessment subgroups also met to identify potential mitigation and response actions that could be taken to reduce or prevent drought impacts across the state. The resulting matrix of planned drought mitigation actions was the first of its kind developed by any state or government agency, and has become a model for other states. However, New Mexico also discovered that conflicts between environmental and other interests were surprisingly contentious because of the silvery minnow and other endangered species. These conflicts initially hindered the progress of the wildlife component of the Wildlife and Wildfire Protection Impact Assessment Subgroup (C. Caruso, personal communication, May 2002). In contrast, the wildfire component was well organized from the start because of a large amount of experience and common understanding among the participants in dealing with wildfires in the state.

The identified impacts, actions, and responsible agencies were placed into a four-part matrix that became part of the New Mexico Drought Mitigation Plan (http://weather.nmsu.edu/drought/053102/). No details about the methods for implementing the mitigation component were provided within the plan, however, so the state has had little direction in accomplishing the identified mitigation actions. Many mitigation actions can be accomplished when drought is not taking place. Otherwise, a state or organization must try to pick up its mitigation efforts where it left off when a new drought is imminent and attention is focused on drought again.

Nebraska

Nebraska followed a process similar to that completed by New Mexico when it revised its state drought plan to incorporate mitigation. Nebraska first developed a drought plan in 1986. In 1998, efforts began to update and revise the plan, and this process culminated in the Nebraska Drought Mitigation and Response Plan in 2000 ⟨carcunl.dnr.state.ne.us/docs/NebraskaDrought.pdf⟩

Risk Assessment

Although some drought hazard analyses had been done for Nebraska in the past, the state did not conduct a hazard analysis as it revised its plan. Nebraska also organized impact assessment subcommittees that reflected the sectors most affected by drought in the state: Agricultural, Natural Resources, and Wildlife; Municipal Water Supply, Health and Energy; Recreation and Tourism. Eventually, the Recreation and Tourism Subcommittee was incorporated into the first subcommittee because most of Nebraska's recreation and tourism revolves around the natural resources and wildlife in the state.

One of the differences between the experiences of Nebraska and New Mexico is that Nebraska attempted from the beginning to involve stakeholders within the risk analysis process. As the impact assessment subcommittees were being formed, participation was sought from a wide variety of state, federal, and local agencies; private organizations; and tribal governments. Nebraska is also unique in having private citizens as members on the state's drought task force.

Through a series of group discussions, the subcommittees assessed the state's vulnerability by identifying important impacts and potential causes for selected impacts. However, like New Mexico, no effort was made to look at the temporal trends that may have helped assess the dynamic nature of vulnerability across the state.

Risk Management

In terms of risk management, the drought subcommittees in Nebraska also created a mitigation and response actions matrix. A general list of responsible agencies was assigned to each group of potential actions, although no specific action timetables were suggested. However, having learned from the New Mexico experience, the drought plan specifically mentions that the subcommittees will meet regularly several times each year, with the intention of keeping the mitigation actions moving even when droughts are not a threat in the state.

As a result of the continued focus on risk management, Nebraska has implemented several mitigation actions that have been extremely successful. The Municipal Water Supply, Health, and Energy Subcommittee identified a need for developing a list of communities with vulnerable water supplies during drought. This list was developed during 2000. Since then, the state has been very aggressive in providing technical assistance to these vulnerable communities including holding workshops around the state. The state has also worked closely with several communities to identify sources of financial assistance from federal agencies for improvements that will reduce the communities' drought risk. This same subcommittee is preparing educational packets on homeowner water conservation that will be sent to all water suppliers around the state during the Summer of 2003 to send on to their customers.

In addition, the Agriculture, Natural Resources, and Wildlife Subcommittee worked closely with hay producers and ranchers in Spring 2000, resulting in a state-run hay hotline for ranchers needing to purchase hay that has been very successful in both 2000 and 2002. Both subcommittees in their risk analyses also identified the need to address the mental health dangers to farmers during droughts, and the state has organized a farm crisis hotline in collaboration with the Interchurch Ministries of Nebraska. This hotline has been very actively used in 2000, 2002, and early 2003. This subcommittee has also helped identify funding sources for improving the soil moisture monitoring network across the state. Soil moisture probes have been added to about half of the automated weather stations located across the state, and additional probes have been funded to be installed later in 2003.

Hopi Nation

The Hopi Nation, located in northeastern Arizona, retained a private consulting group to assist them in developing parts of their tribal drought mitigation plan. The risk analysis portion of the plan followed the methodology suggested by Knutson et al. (1998) quite closely in identifying mitigation actions that the nation can take to reduce their short- and long-term drought risk (S. Jones, personal communication, Septemeber 2001). This information is included within the draft Hopi Drought Plan, which was completed in 2000 but is still pending approval by the United States Congress (Hopi 2000).

Risk Assessment

The Hopi Nation's drought risk assessment process included undertaking both detailed drought hazard and drought vulnerability analyses (Fig. 1). As part of the hazard analysis, the nation completed a review of all the climate, natural resource, and social characteristics of the Hopi Reservation. This included an inventory and historical analysis of the local and regional weather and streamflow monitoring stations, as well as additional information about stock tanks and groundwater monitoring. The applications of various drought and remotely sensed vegetation-condition indices were reviewed as well as the applications of long-range forecasts and the relationships of precipitation with atmospheric phenomena such as El Niño. Finally, a thorough investigation of the drought-related resources available on the Internet was also conducted.

Based on the review of the Hopi Reservation's climate, natural resource, and social characteristics, the four areas that the Hopi considered to be most vulnerable to drought and to experience the greatest impacts were (1) range and livestock, (2) agriculture, (3) village water supplies, and (4) environmental health. The Hopi Drought Plan does not mention the use of public participation in their drought planning process. However, the plan does stress that the Nation will strive to incorporate community involvement regarding the best use of available resources during periods of drought and for implementing conservation measures.

A unique feature of the Hopi Drought Plan is the inclusion of current and proposed monitoring systems to evaluate not only changing climatic conditions, but also soil, vegetation, and water resources for farming, ranching, and domestic purposes. The drought plan describes establishing a network of approximately 60 transects to provide a detailed analysis of range conditions. The transects will be selected to represent major climates, soils, water resources, and land uses present on the Hopi Reservation, and will help to identify trends in vegetation health. These monitoring networks will not only help monitor and quantify the effect of drought impacts, but can also be used to assess the effectiveness of any mitigation actions that are implemented.

Risk Management

A list of short- and long-term drought mitigation and response actions were also proposed for each of the drought impact areas. For example, to mitigate range and livestock losses, the plan suggests that range management plans be completed for each range unit. To facilitate rotations and proper use of rangelands, the Hopi Range Management Plan also includes fencing and water-development projects for the unit range management plans. Water availability in these range units will be improved through a combination of rehabilitating surface-water impoundments, additional wells at key locations, improved water distribution from the supply point to multistock watering troughs, and other conjunctive uses. The Hopi planners hope these mitigation actions will decrease the vulnerability of the range and livestock economic sector.

In addition to identifying mitigation actions that will reduce the tribe's drought risk, the Hopi Drought Plan is unique in that it identifies the responsible agencies, provides a timeline to complete the actions, and provides a cost estimate for these actions. For example, an estimate of $12 million is given to upgrade the water supply systems of 12 tribal villages by improving pumping capacity, storage tank size, and pipe capacity. The tribe plans to seek these and other funding needs through a variety of agencies and sources while enhancing water conservation at the same time.

Conclusions

As illustrated by the case studies, different approaches for drought risk analyses were followed. New Mexico provided the important first model and several states and Native American nations have followed New Mexico's example including Nebraska and the

Hopi Nation. Nebraska took an important step by including public participation into its risk analysis process and has made some progress implementing several of the proposed mitigation actions. The Hopi Nation completed a thorough hazard and vulnerability analysis that assisted in identifying the short- and long-term mitigation actions the tribe needs to take to reduce their drought risk. Drought risk analyses will become less nebulous as more policymakers go through the process, sharing their experiences and providing additional models to follow.

In theory, drought risk is a complex concept so that the effort involved in making a thorough drought risk analysis may appear to be daunting to federal, state, and particularly local officials given the limited budgets and time resources that can be dedicated to this effort. The need to bridge drought risk theory with a relatively simple and applicable methodology to identify drought risk and determine appropriate mitigation strategies is clear. A general framework like the one used by the National Drought Mitigation Center, along with examples of how it can be applied, may provide officials with a workable methodology for completing a drought risk analysis.

The motivation for creating this framework resulted from the expressed needs of officials and drought planners. Each state and tribe that has conducted their own drought risk analysis has done it differently, based on their unique needs and insights, illustrating why the methodology needs to be flexible and adaptable. It is also important that the drought risk analysis remain as nonpolitical as possible. Public participation advocates stress that stakeholder involvement, if done correctly, is the way to keep the process nonpolitical. By getting all the principal stakeholders involved, potential conflicts can be identified and addressed. This inclusiveness will help avoid the potential situations where politics could derail the development and implementation of appropriate mitigation strategies.

Incorporating a drought risk analysis into a larger process involving other hazards, or within a large-scale water resources planning process, makes sense given the wide range of impacts resulting from a lack of water caused by drought. Such an overall goal could help local, state, or federal governments deal with a wide variety of issues putting societies at risk. In addition, drought risk and other hazard analyses should be a critical component of any focus on sustainability. Drought and other hazards certainly threaten national, community, and individual sustainability, particularly in the regions where societies are most vulnerable to disasters. Mitigation strategies that address multiple hazards, including droughts, may be the most cost-effective and successful in reducing the losses caused by droughts and other hazards in the future.

The proposed risk analysis framework is an initial version. The writers, along with the NDMC, continue to investigate issues of drought risk and adapt or amend the framework as needed. Additional opportunities will arise to assist governmental officials with drought planning and identifying their drought risk.

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