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Chapter 1 Drought as a Natural Hazard: Concepts and Definitions

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Chapter 1

Drought as a Natural Hazard: Concepts and Definitions

Donald A. Wilhite

Introduction

Worldwide, economic damages attributed to natural disasters tripled from the 1960s (US$40 billion) to the 1980s (US$120 billion) (Domeisen 1995). The 1990s have witnessed a continued escalation of economic damages, reaching US$400 billion through 1996 (Carolwicz 1996). Between 1992 and 1996, losses associated with natural disasters in the United States averaged US$54.2 billion per week (Carolwicz 1996).

The economic, social, and environmental costs and losses associated with drought are also increasing dramatically, although it is difficult to quantify this trend precisely because of the lack of reliable historical estimates of losses. White and Haas estimated in 1975 that the average annual crop losses associated with drought in the Great Plains region of the United States were about US$700 million. In 1995, the US Federal Emergency Management Agency (FEMA) estimated annual losses attributable to drought at US$6-8 billion (FEMA 1995).

More specific figures from recent drought episodes in the United States provide a clearer picture of the magnitude of drought losses and our continuing vulnerability. The southwestern and southern Great Plains states experienced dramatic impacts on agriculture, water supply, wildfires, transportation, and tourism and recreation in 1996 and 1998. For example, the impacts of the 1996 and 1998 droughts in Texas have been estimated at US$6 billion (Boyd 1996) and US$5.8 billion (Chenault and Parsons 1998), respectively. The 1998 drought in Oklahoma resulted in estimated agricultural losses of more than US$2 billion (Thurman 1998). These estimated losses in 1996 do not include losses that occurred in New Mexico, Oklahoma, Kansas, Colorado, Utah, Arizona, and Nevada. Likewise, significant losses also occurred in 1998 in Florida, South Carolina, Georgia, and Louisiana.

The estimated losses further illustrate the trend in vulnerability in the United States. Factors that may explain this trend are numerous; they include deficiencies in monitoring and early warning systems and the application of this information by decision makers, urbanization, population growth and regional population shifts to more drought-prone areas, outdated or inappropriate water management policies and practices, lack of contingency planning, fragmented responsibilities in water/drought management by government agencies, and poor coordination within and between levels of government. Thus, vulnerability is increasing in the United States despite dramatic technological advances and the availability of large financial resources (Riebsame et al. 1991). The series of drought years that occurred in the United States between 1986 and 1992, as well as severe drought conditions that prevailed in 1994, 1996, and 1998, has further reinforced the reality of the nation's vulnerability. What concerns many scientists and decision makers is the diversity and complexity of drought impacts and the low level of preparedness for future events. The ongoing debate about climate change and its potential effects on the frequency and severity of extreme climatic events is adding further to the concerns of scientists and decision makers.

The concerns about the trends in losses associated with natural disasters in developed countries are magnified when placed in the context of developing nations. Natural hazards result in significant loss of life and serious economic, environmental, and social impacts that greatly retard the development process. Figure 1.1 illustrates the trend of major natural disasters between 1963 and 1992, expressed as the number of disasters affecting 1 percent or more of the total annual gross national product. Figure 1.2 ranks these disasters by type, illustrating that drought, floods, and tropical storms were the most frequent disasters occurring during this period. The Centre for Research in the Epidemiology of Disasters (Blaikie et al. 1994) grouped natural disaster occurrence by decade and has shown that the number of droughts increased from 62 in the 1960s to 237 during the 1980s. However, these figures for drought are misleading. Drought is one of the most underreported natural disasters because the sources of most of these statistics are international aid or donor organizations. Unless countries afflicted by drought request assistance from the international community or donor governments, these episodes are not reported. Thus, severe droughts such as those that occurred in Australia, Brazil, Canada, Spain, England, the United States, and many other countries in recent years are not included in these statistics.

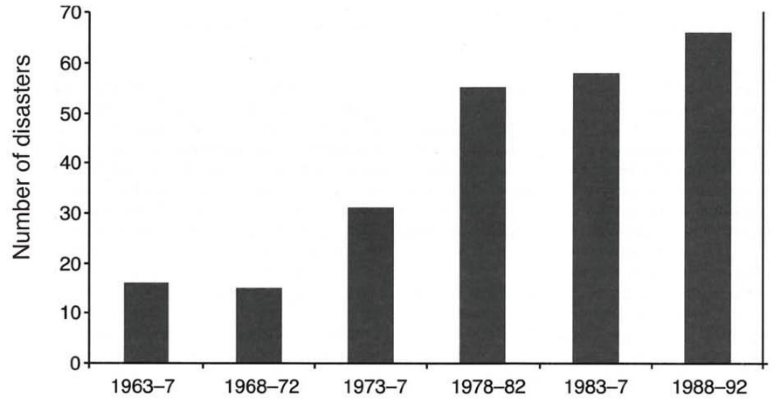

Figure 1.1. Number of disasters causing significant damage, 1963-92.* The figure was created from data provided by the UN/Secretariat, International Decade for National Disaster Reduction.

* = 1% or more of total annual GNP

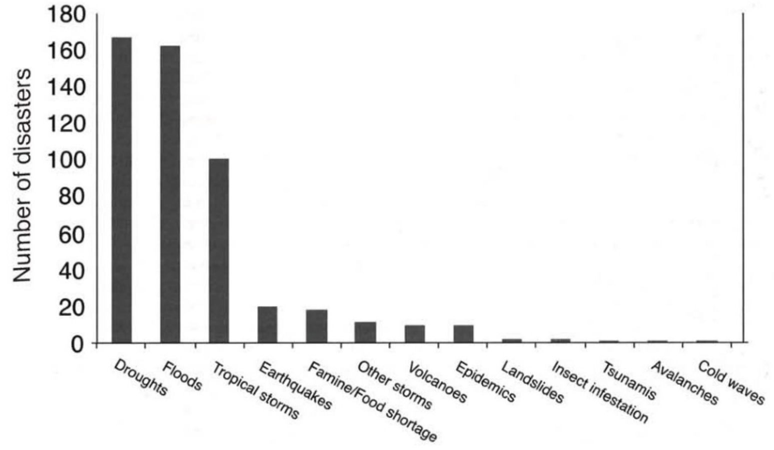

Figure 1.2. Disasters, by type, affecting 1 percent or more of total population, 1963–92. (Source as for fig. 1.1.)

Background

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman 1984). For example, in sub-Saharan Africa, the droughts of the early to mid-1980s are reported to have adversely affected more than 40 million people (Office of Foreign Disaster Assistance 1990). The 1991–92 drought in southern Africa affected 20 million people and resulted in a deficit of cereal supplies of more than 6.7 million tons (SADCC 1992). In the United States, the drought of 1988 resulted in estimated impacts of nearly US$40 billion (Riebsame et al. 1991), making this single-year drought the costliest disaster in American history. Drought results in significant impacts regardless of the level of development, although the character of these impacts will differ profoundly.

Drought is a normal feature of climate and its recurrence is inevitable. However, there remains much confusion within the scientific and policy community about its characteristics. It is precisely this confusion that explains, to some extent, the lack of progress in drought management in most parts of the world. The purpose of this chapter is to provide a foundation for the concept of drought that will help readers understand the complex aspects of this natural hazard as they are discussed in subsequent chapters. More specifically, the chapter will articulate the differences between drought and other natural hazards, the types and definitions of drought, and definitions of key components of the cycle of disaster management. Enhancing understanding of drought concepts should help readers understand why, according to Hagman (1984), the phenomenon is not better understood by scientists and policy makers. Through an improved understanding and awareness of the concept and characteristics of drought and its differences from other natural hazards, both scientists and policy makers will be better equipped to establish much needed policies and plans whereby vulnerability can be reduced or stabilized for future generations.

Drought: The Concept

Drought differs from other natural hazards (e.g., floods, tropical cyclones, and earthquakes) 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). Tannehill notes:

> We have no good definition of drought. We may say truthfully that we scarcely know a drought when we see one. We welcome the first clear day after a rainy spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to a drought as the last, but no one knows how serious it will be until the last dry day is gone and the rains have come again . . . we are not sure about it until the crops have withered and died.
>
> (Tannehill 1947)

Although Tannehill's book was written 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). For example, what is the significance of a threshold of 75 percent of normal precipitation over a period of three months or more? A definition of this type would be especially misleading for locations with a strong seasonal component of annual precipitation. 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 and spread over a larger geographical area than damages that result from other natural hazards. For example, a recent analysis of drought occurrence by the (US) National Drought Mitigation Center for the forty-eight contiguous states in the United States demonstrated that severe and extreme drought affected more than 25 percent of the country in twenty-seven of the past one hundred years. This represents an area of 750,000 mi^2 (1,942,500 km^2) or more.

Drought seldom results in structural damage, in contrast to floods, hurricanes, and tornadoes. 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.

Hazard events have been ranked by Bryant (1991) on the basis of their characteristics and impacts. This ranking is summarized in table 1.1. Key hazard characteristics used for this evaluation include an expression of the degree of severity, length of event, total areal extent, total loss of life, total economic loss, social effects, long-term impact, suddenness, and occurrence of associated hazards for thirty-one hazards. Although the ratings of the various hazards in table 1.1 are subjective, the overall rank is useful because it provides an integrated assessment of hazard characteristics and the relationships between hazards. Because of the intensity, duration, and spatial extent of drought events and the magnitude of associated impacts, drought ranks very high. One can make a cogent argument, however, that total loss of life associated with drought in this case is significantly overrated. Loss of life that is directly associated with drought is rare in most settings. The ranking by Bryant attributes loss of life because of famine to drought. This is inappropriate since the primary cause of famine in recent decades has been civil war or political strife, both of which heighten vulnerability to drought. Drought events disrupt food production systems and can be a significant natural trigger for famine.

Table 1.1. Ranking of hazard events by characteristics and impacts

		Grading of characteristics and impacts[a]								
Overall rank[b]	Event	Degree of severity	Length of event	Total areal extent	Total loss of life	Total eco-nomic loss	Social effect	Long-term impact	Sudden-ness	Occur-rence of associ-ated hazards
1	Drought	1	1	1	1	1	1	1	4	3
2	Tropical cyclone	1	2	2	2	2	2	1	5	1
3	Regional flood	2	2	2	1	1	1	2	4	3
4	Earthquake	1	5	1	2	1	1	2	3	3
5	Volcano	1	4	4	2	2	2	1	3	1
6	Extra-tropical storm	1	3	2	2	2	2	2	5	3
7	Tsunami	2	4	1	2	2	2	3	4	5
8	Bushfire	3	3	3	3	3	3	3	2	5
9	Expansive soils	5	1	1	5	4	5	3	1	5
10	Sea-level rise	5	1	1	5	4	5	3	1	5
11	Icebergs	4	1	1	4	4	5	5	2	5
12	Dust storm	3	3	2	5	4	5	4	1	5
13	Landslides	4	2	2	4	4	4	5	2	5
14	Beach erosion	5	2	2	5	4	4	4	2	5
15	Debris avalanches	2	5	5	3	4	3	5	1	5
16	Creep and soilifluction	5	1	2	5	4	3	5	1	5
17	Tornado	2	5	3	4	4	4	5	1	5
18	Snowstorm	4	3	3	5	4	4	5	2	4
19	Ice at shore	5	4	1	5	4	5	4	1	5
20	Flash flood	3	5	4	4	4	4	5	1	5
21	Thunder-storm	4	5	2	4	4	5	5	1	5
22	Lightning strike	4	5	2	4	4	5	5	1	5
23	Blizzard	4	3	4	4	4	5	5	1	5
24	Ocean waves	4	4	2	4	4	5	5	1	5
25	Hail storm	4	5	4	5	3	5	5	1	5
26	Freezing rain	4	4	5	5	4	4	5	1	5
27	Localized strong wind	5	4	3	5	5	5	5	1	5
28	Subsidence	4	3	5	5	4	4	5	3	5

29	Mud and debris flows	4	4	5	4	4	5	5	4	5
30	Air-supported flows	4	5	5	4	5	5	5	2	5
31	Rock falls	5	5	5	5	5	5	5	1	5

Source: Summarized from Bryant (1991)

a. Hazard characteristics and impacts are graded on a scale of 1 (largest or greatest) to 5 (smallest or least significant).

b. Overall rank is based on average grading.

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes. 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. Many people associate the occurrence of drought with most of Africa, India, China, the Great Plains of North America, and Australia; they have more difficulty visualizing drought in Southeast Asia, Brazil, western Europe, or the eastern United States, regions perceived by many to have a surplus of water. This fact emphasizes both the regional and relative nature of drought, a characteristic that will be discussed in more detail later in this chapter.

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. For example, Magalhães et al. (1988) have vividly pointed out the climatic differences between five consecutive drought years that occurred in northeast Brazil between 1979 and 1983, noting the critical linkages between the timing of rainfall and impacts.

Drought severity is dependent not only on the duration, intensity, and geographical 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, though not impossible, to identify and quantify.

Many people consider drought to be largely a natural or physical event. Figure 1.3 illustrates that, in reality, drought has both a natural and social component. 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 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, and social behavior. These factors change over time, and thus vulnerability is likely to increase or decrease 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, and subsequent chapters will discuss these actions from many regional and disciplinary perspectives.

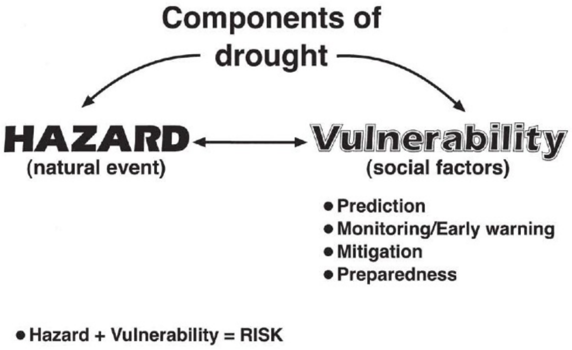

Figure 1.3. Components of drought.

Defining Drought

Because drought affects so many economic and social sectors, scores of definitions have been developed by a variety of disciplines. In addition, because drought occurs with varying frequency in nearly all regions of the globe, in all types of economic systems, and in developed and developing countries alike, the approaches taken to define it also reflect regional and ideological differences (Wilhite 1992). Impacts also differ spatially and temporally, depending on the societal context of drought. A universal definition of drought is an unrealistic expectation. Wilhite and Glantz (1985) concluded that definitions of drought should reflect a regional bias since water supply is largely a function of climatic regime.

Definitions of drought can be categorized broadly as either conceptual or operational (Wilhite and Glantz 1985). Conceptual definitions are of the dictionary type, generally defining the boundaries of the concept of drought, and thus are generic in their description of the phenomenon. For example, the Encyclopedia of Climate and Weather (Schneider 1996) defines drought as "an extended period—a season, a year, or several years—of deficient rainfall relative to the statistical multi-year mean for a region." These types of definitions are useful for furthering our description of the phenomenon but cannot be used to detect the onset of drought because of their lack of specificity. They do, however, incorporate the concept of the intensity and duration of the event and the need for regional bias.

Tannehill uses another conceptual definition that incorporates key elements of drought: a deficiency of precipitation from expected or normal that, when extended over a season or longer period of time, is insufficient to meet the demands of human activities, resulting in economic, social, and environmental impacts.

Operational definitions attempt to identify the precise characteristics and thresholds that define the onset, continuation, and termination of drought episodes as well as their severity. These definitions are the foundation of an effective early warning system. They can also be used to analyze drought frequency, severity, and duration for a given historical period. An operational definition of agricultural drought might be one that compares daily precipitation to evapotranspiration (ET) rates to determine the rate of soil water depletion and then expresses these relationships in terms of drought effects on plant behavior at various phenological stages of development. The effects of these meteorological conditions on plant growth would be reevaluated continuously by agricultural specialists as the growing season progresses.

Many disciplinary perspectives of drought exist. Each discipline incorporates different physical, biological, and/or socioeconomic factors in its definition of drought. Because of these numerous and diverse disciplinary views, considerable confusion often exists over exactly what constitutes a drought (Glantz and Katz 1977). Research has shown that the lack of a precise and objective definition in specific situations has been an obstacle to understanding drought, which has led to indecision and/or inaction on the part of managers, policy makers, and others (Wilhite and Glantz 1985, Wilhite et al. 1986). It must be accepted that the importance of drought lies in its impacts. Thus definitions should be region and impact or application specific in order to be used in an operational mode by decision makers. A comprehensive review of drought definitions and indices can be found in a technical note published by the World Meteorological Organization (WMO) (1975). Other sources, such as Subrahmanyam (1967), Glantz and Katz (1977), Sandford (1979), Dracup et al. (1980), and Wilhite and Glantz (1985), can be consulted for a thorough discussion of the difficulties in defining drought.

Drought has been grouped by type as follows: meteorological, hydrological, agricultural, and socioeconomic (Wilhite and Glantz 1985). Figure 1.4 explains the relationship between these various types of drought and the duration of the event. Droughts usually take three or more months to develop, but this time period can vary considerably, depending on the timing of the initiation of the precipitation deficiency. For example, a significant dry period during the winter season may have few, if any, impacts for many locales. However, if this deficiency continues into the growing season, the impacts may magnify quickly since low precipitation during the fall and winter season results in low soil moisture recharge rates, leading to deficient soil moisture at spring planting.

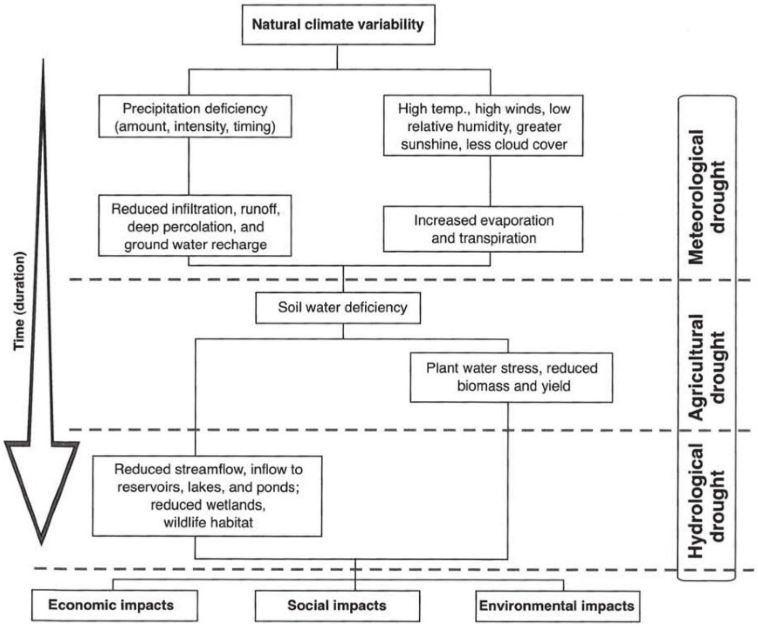

Figure 1.4. Relationship between various types of drought and duration of drought events.

Meteorological (or climatological) drought is expressed solely on the basis of the degree of dryness (often in comparison to some normal or average amount) and the duration of the dry period. Thus, intensity and duration are the key characteristics of these definitions. Meteorological drought definitions must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are climate regime dependent. For example, some definitions differentiate meteorological drought on the basis of the number of days with precipitation less than some specified threshold rather than the magnitude of the deficiency over some period of time (e.g., for Britain, fifteen days, none of which received as much as 0.25 mm of precipitation [British Rainfall Organization 1936]). Such a definition is unrealistic in those regions where precipitation distribution is seasonal and extended periods without rainfall are common. Most meteorological drought definitions relate actual precipitation departures to average amounts on monthly, seasonal, water year, or annual time scales. Human perceptions of these conditions are equally variable.

Agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration (ET), soil water deficits, and so forth. A plant's demand for water is dependent on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. An operational definition of agricultural drought should account for the variable susceptibility of crops at different stages of crop development. For example, deficient subsoil moisture in an early growth stage will have little impact on final crop yield if topsoil moisture is sufficient to meet early growth requirements. However, if the deficiency of subsoil moisture continues, a substantial yield loss may result.

The impacts of drought are crop specific because the most weather-sensitive phenological stages vary between crops. Planting dates and maturation periods also vary between crops and locations. A period of high temperature stress that occurs in association with dry conditions may coincide with a critical weather-sensitive growth stage for one crop while missing a critical stage for another crop. Agricultural planning can often reduce the risk of drought impact on crops by altering the crop, genotype, planting date, and cultivation practices.

Agriculture is usually the first economic sector to be affected by drought because soil moisture supplies are often quickly depleted, especially if the period of moisture deficiency is associated with high temperatures and windy conditions. The timing of rainfall during the growing season is critical in the determination of impacts. Crop or forage yields may be normal or above normal during a drought if rainfall is timely (i.e., coinciding with critical phenological stages) and effective (i.e., low intensity and high soil infiltration rate).

Hydrological droughts are associated with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater) rather than with precipitation shortfalls (Dracup et al. 1980, Klemeš 1987). Hydrological droughts are usually out of phase or lag the occurrence of meteorological and agricultural droughts. Meteorological droughts result from precipitation deficiencies; agricultural droughts are largely the result of soil moisture deficiencies. More time elapses before precipitation deficiencies are detected in other components of the hydrological system (e.g., reservoirs, groundwater). As a result, impacts are out of phase with those in other economic sectors. Also, water in hydrological storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., power generation, flood control, irrigation, recreation), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought, and conflicts between water users increase significantly.

The frequency and severity of hydrological drought is often defined at the river basin scale. Whipple (1966) defined a drought year as one in which the aggregate runoff is less than the long-term average runoff. Low-flow frequencies have been determined for many streams. If the actual flow for a selected time period falls below a certain threshold, then hydrological drought is considered to be in progress. However, the number of days and the level of probability that must be exceeded to define a hydrological drought period is somewhat arbitrary. These criteria will vary between streams and river basins.

The impacts of hydrological drought in an upstream portion of a river basin can also extend downstream as reduced streamflow may result in lower reservoir and groundwater levels at downstream locations, even though meteorological drought does not exist in this portion of the basin. Reductions in reservoir and groundwater levels in downstream portions of the basin may result in serious impacts on public water supplies, hydroelectric power production, recreation, transportation, agriculture, and other sectors. Conflicts between upstream and downstream water users may result, as has been the case in many river basins in the United States (see Opper 1994 for an example from the Missouri River

Basin). International water disputes often arise in situations where rivers transcend national borders, such as in the Middle East or between the United States and Mexico.

The discussion up to this point has focused on the distinctions between the types of drought during its onset or development phase. During the termination phase of drought, the interrelationships between these drought types may differ. Figure 1.4 is also useful in understanding the termination phases of drought. During drought onset, agriculture is usually the first sector to experience drought because soil moisture will normally be the first component of the hydrological system to be affected. When the rains return, however, soil moisture levels may dramatically improve, and over a short time frame. Thus, agricultural drought, particularly on rain-fed cropland, may end abruptly. Depending on the timing of these rains, however, impacts may linger because potential crop yields may already have been reduced substantially. Hydrological drought may continue for many months or years, since recharge of reservoirs and groundwater is a long process. For example, following the series of severe drought years between 1987 and 1992 in the Missouri River basin, it was estimated that four to five years of normal precipitation over the basin would be required to bring reservoirs back to normal levels.

Finally, socioeconomic drought associates the supply and demand of some economic good or service with elements of meteorological, hydrological, and agricultural drought. Some scientists suggest that the time and space processes of supply and demand are the two basic processes that should be included in an objective definition of drought (Yevjevich 1967). For example, the supply of some economic good (e.g., water, hay, hydroelectric power) is weather dependent. In most instances, the demand for that good is increasing as a result of increasing population and/or per capita consumption. Therefore, drought could be defined as occurring when the demand for that good exceeds supply as a result of a weather-related supply shortfall (Sandford 1979). This concept of drought supports the strong symbiosis that exists between drought and human activities. Thus, the incidence of drought could increase because of a change in the frequency of the physical event, a change in societal vulnerability to water shortages, or both. For example, poor land-use practices such as overgrazing can decrease animal carrying capacity and increase soil erosion, which exacerbates the impacts of and vulnerability to future droughts. This example is especially relevant in semiarid regions (e.g., South Africa, Australia) and in areas of hilly or sloping terrain (e.g., Lesotho).

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. The simplest index in widespread use is the percentage of normal precipitation. With this index, actual precipitation is compared to normal or average precipitation for time periods ranging from one to twelve or more months. Actual precipitation departures are normally compared to expected or average amounts on a monthly, seasonal, annual, or water year (October–September) time period. One of the principal difficulties with this (or any) index is the choice of the threshold below which the deficiency of precipitation must fall (e.g., 75 percent of normal) to define the onset of drought. Thresholds are usually chosen arbitrarily. In reality, they should be linked to impact. Many indices of drought are in widespread use today, such as the decile approach (Gibbs 1967, Lee 1979, Coughlan 1987) used in Australia, the Palmer Drought Severity Index and Crop Moisture Index (Palmer 1965 and 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 is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993 and 1995). A discussion of climatic indices for monitoring drought is included in several chapters in this volume in Part III (Monitoring and early warning techniques). For a comparison of several popular meteorological indices, see Olidapo (1985).

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. The five-year (1979–83) drought in northeast Brazil is a good case in point. In this series of years, 1979 and 1980 were both drought years in the classic sense (i.e., a significant deficiency during the principal rainy season). In 1981, the seasonal rainfall totals were slightly above normal, but the temporal distribution resulted in agricultural drought. In 1982, the rainfall totals were below normal, but the temporal distribution of precipitation was conducive to crop development. Agricultural impacts were less adverse. These four "drought" years were followed by the most severe drought year (1983) of the previous twenty-five years, with dramatic agricultural impacts (Magalhães et al. 1988).

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. In larger countries, such as Brazil, China, India, the United States, or Australia, drought would rarely, if ever, affect the entire country. During the severe drought of the 1930s in the United States, for example, the area affected by severe drought never exceeded 65 percent of the country (see fig. 1.5). By contrast, drought affected more than 95 percent of the Great Plains region in 1934. In India, the droughts of this century have rarely affected more than 50 percent of the country. An exception occurred in 1918–19, when 73 percent of the country was affected (Sinha et al. 1987). On the other hand, it is indeed rare for drought *not* to exist in a portion of these countries in every year. For example, figure 1.5 illustrates that in the United States, the percentage area affected by drought is often greater than 10 percent. Thus, the governments of these larger countries are more accustomed to dealing with water shortages and have established an infrastructure to respond, albeit reactively. For smaller countries, it is more likely that the entire country may be affected since droughts are usually regional phenomena—they result from large-scale anomalies in atmospheric circulation patterns that become established and persist for periods of months, seasons, or longer.

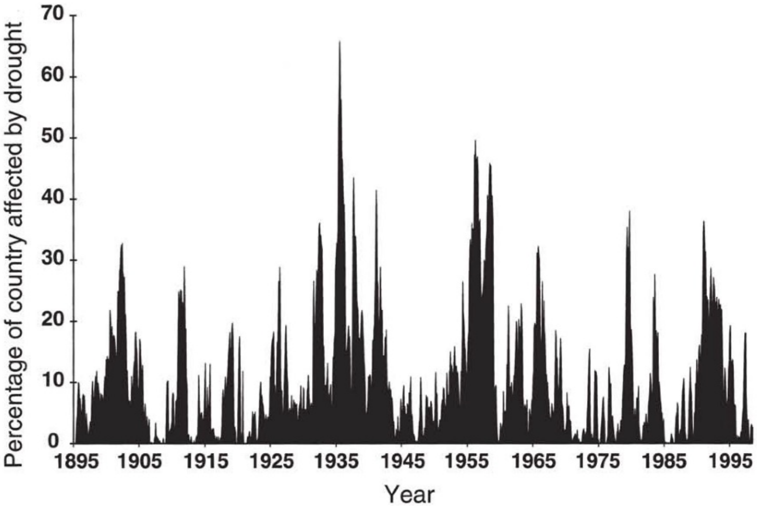

Figure 1.5. Percentage area of the United States (48 contiguous states) in severe and extreme drought (i.e., ≤–3.0), according to the Palmer Drought Severity Index, during the period 1895-1995.

From a planning perspective, the spatial characteristics of drought have serious implications. Nations should know the probability that drought may simultaneously affect all or several major crop-producing regions within their borders and develop contingencies if such an event were to occur. Likewise, it is important for governments to know the chances of a regional drought simultaneously affecting agricultural productivity in their country as well as adjacent or nearby nations on whom they are dependent for food supplies. In some instances, a nation's primary drought mitigation strategy may be to import food from nearby nations, ignoring the likelihood that a drought may have significant regional impacts on food supplies. Likewise, the occurrence of drought worldwide or in the principal grain-exporting nations, such as occurred during the ENSO event of 1982–83 (Glantz et al. 1987, Glantz et al. 1991), may significantly alter a developing country's access to food from donor governments.

Drought and the Cycle of Disaster Management

Although drought is a natural hazard, the term drought management implies that human intervention can reduce vulnerability and impacts. To be successful in this endeavor, many disciplines must work together in tackling the complex issues associated with detecting, responding to, and preparing for the inevitability of future events. Disaster management, of which drought management is a subset, requires that scientists and policy makers focus on both the protection and recovery/rehabilitation portion of the cycle shown in figure 1.6. In the past, the emphasis in disaster management has been placed largely on the response and recovery portion of this cycle, which explains why society has generally moved from disaster to disaster with little or no attention to mitigation, preparedness, and prediction and monitoring. This approach is commonly referred to as crisis management. This volume attempts to integrate all components of disaster management.

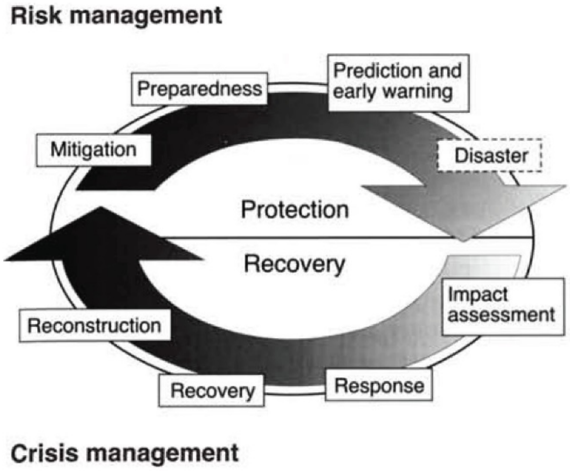

Figure 1.6. The cycle of disaster management

The remainder of this book will be devoted to the presentation of case studies for many countries and regions. These case studies will focus on the causes of drought and prediction methods, alternative monitoring and impact assessment methodologies, responses, and mitigation and preparedness strategies and technologies. For this reason, it is imperative that key terms be defined at the outset so that the reader understands each of the concepts highlighted by the disaster management cycle. Definitions of these and other key terms and phrases are given below.

> **Hazard** is the potential for a major incident. To elaborate, the term refers to the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon. Each hazard poses a level of risk that varies spatially and temporally and occurs with varying degrees of intensity and severity. Extreme natural events may affect different places singly or in combination at different times. Drought, from a meteorological perspective, is a natural event, and little can be done to reduce the frequency or severity of the event. A critical component of drought management is the characterization of the risk (i.e., drought climatology) associated with the hazard. The chapters included in the monitoring and early warning section (Part III) of this volume discuss the historical frequency and severity of drought events and operational monitoring programs to detect the onset or emergence of drought conditions.
>
> **Vulnerability** refers to the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. It involves a combination of factors that determine the degree to which someone's life

and livelihood is put at risk by a discrete and identifiable event in nature or in society. Vulnerability exists in a continuum from high to low and can be voluntary or involuntary. Vulnerability may exist because of high exposure to the hazard, sociocultural factors, or a combination of the two. This topic is treated in various ways by many authors in this volume. Chapter 45 by Tom Downing and Karen Bakker is a discussion of the complex issues associated with vulnerability.

Risk is the product of hazard and vulnerability. Exposure to the natural event (i.e., hazard) is relatively constant, but vulnerability is dynamic in response to changes in societal characteristics, including technologies, policies, population changes resulting in changes in demand, changes in social behavior, and so forth. Activities such as mitigation, preparedness, monitoring/early warning, and prediction are all directed at reducing the risk associated with future drought events either through a better understanding of the hazard or a reduction in vulnerability, or both.

Disaster is the actual historical event. Disasters can be the result of natural or environmental causes and can be human-induced. Greater emphasis on prediction, monitoring, mitigation, and preparedness can greatly reduce the frequency and severity of natural disasters. Many of the case studies included in this volume provide documentation of previous drought-related disasters III developing and developed countries.

Impact assessment refers to actions that allow for early estimates of the costs and losses associated with the occurrence of drought. Impacts are generally classified as economic, social, and environmental and are difficult to quantify because of their nonstructural nature. Methodologies or techniques for estimating impacts, and the reliability of those estimates, are highly variable from one natural hazard to another. Case studies of the impacts of drought events and methodologies for understanding and quantifying impacts are discussed in the section on impacts and assessment methodologies (Part IV).

Response refers to post-impact interventions by government and others that are usually implemented during or following an emergency and directed at saving lives, minimizing property damage, or improving or shortening the post-disaster recovery process. For drought, most response efforts are in the form of emergency assistance programs or low-interest loans. Response to previous drought events is discussed in many of the case studies presented in this volume.

Recovery and rehabilitation are actions or activities that restore critical life-support systems or return life to normal for persons in the affected area, such as transportation and communication services, emergency medical care, temporary housing, and water supplies. Many response, rehabilitation, and mitigation programs are directed at reducing impacts and minimizing recovery time.

Mitigation is short- and long-term actions, programs, or policies implemented during and in advance of drought that reduce the degree of risk to human life, property, and productive capacity. These actions are most effective if done in advance of the event. The types or forms of mitigation activities vary from one natural hazard to another. Drought-related mitigation actions are, for the most part, different from those used for other natural hazards because of the insidious nature of hazard. A first step in mitigation is the identification of the impacts associated with previous droughts and an assessment of whether these impacts (and others) are likely to be associated with future drought events. From this point, specific actions can be identified to reduce the impacts of future drought events. Part IV emphasizes the range of impacts associated with drought in various geographical settings as well as methodologies to quantify these impacts. Part V considers adjustment and adaptation strategies employed to reduce impacts and Part VI concentrates on preparedness methodologies, institutional arrangements/capacities, mitigation programs and actions, and policies that have been or could be employed to reduce the impacts of drought.

Preparedness refers to predisaster activities designed to increase the level of readiness or improve operational and institutional capabilities for responding to an emergency (e.g., early warning systems, operational plans). For drought, contingency plans are useful for denoting programmatic responsibilities; improving information flow on severity, impacts, and policies between and within levels of government; and coordination between levels of government.

Prediction refers to activities that provide users and decision/policy makers with advanced forecasts of the occurrence of drought. These forecasts can take many forms, but probability of occurrence (time, duration, and intensity or severity) is usually associated with the predictions. Forecast accuracy is highly variable between natural hazards and is particularly limited for droughts in most parts of the world. Lead time is an important consideration for drought forecasts as well, so decision makers are given ample opportunity to incorporate this information in planning strategies and the implementation of mitigation programs. There is also an important distinction between forecasts of meteorological drought and those of hydrological drought, especially in regions where snowpack is a critical element of the hydrological system. Information on the status of snowpack conditions can provide considerable advanced lead time for reliable forecasts of below-normal streamflow and reservoir levels.

Monitoring and early warning refers to activities that provide information that can be used to alert decision makers at all levels of the onset of drought. This information can be used by planners, emergency managers, policy and decision makers, and others to implement programs and policies that will help to reduce the risk associated with the hazard. Monitoring activities include the collection and analysis of data, data product development, and the communication of data products to decision makers and other users. Data includes not only physical data related to hazards but also social and biological data that assist in the definition of vulnerability. A comprehensive drought-monitoring system would include the collection of climatological data (e.g., temperature and precipitation) as well as streamflow, reservoir and groundwater levels, soil moisture, snowpack, and remotely sensed data from satellites. This information is useful in forecasts of agricultural and hydrological drought. Monitoring and early warning techniques, including the use of indices to track current drought conditions and to view them in a historical context, is the subject of Part III.

Summary

Drought is an insidious natural hazard that is a normal part of the climate of virtually all regions. It should not be viewed as merely a physical phenomenon. Rather, drought is the result of an interplay between a natural event and the demand placed on water supply by human-use systems. Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration.

Many definitions of drought exist; it is unrealistic to expect a universal definition to be derived. Drought can be grouped by type of disciplinary perspective as follows: meteorological, hydrological, agricultural, and socioeconomic. Each discipline incorporates different physical, biological, and/or socioeconomic factors in its definition. It must be accepted that the importance of drought lies in its impacts. Thus definitions should be impact- or application-specific and reflect unique regional climatic characteristics in order to be used in an operational mode by decision makers.

The three characteristics that differentiate one drought from another are intensity, duration, and spatial extent. Intensity refers to the degree of precipitation shortfall and/or the severity of impacts associated with the departure. Intensity is closely linked to the duration of the event. Droughts normally take two to three months to become established but may then persist for months or years, although the intensity and spatial character of the event will change from month to month or season to season.

The impacts of drought are diverse and generally classified as economic, social, and environmental. Impacts ripple through the economy and may linger for years after the termination of the drought episode. Impacts are often referred to as direct or indirect. Because of the large number of groups and economic sectors affected by drought, the nonstructural nature of its impacts, its spatial extent, and the difficulties in quantifying environmental damages and personal hardships, the precise calculation of the financial costs of drought is difficult. Drought years frequently occur in clusters, and thus the costs of drought are not evenly distributed between years. It appears that societal vulnerability to drought is escalating, and at a significant rate.

It is imperative that increased emphasis be placed on mitigation, preparedness, and prediction and early warning if society is to reduce the economic and environmental damages associated with drought and its personal hardships. This will require interdisciplinary cooperation and a collaborative effort with policy makers at all levels.

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