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Understanding the Phenomenon of Drought

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As the demands placed on water resources increase, society and industry become more vulnerable to the effects of drought. Having a better understanding of drought can enable hydroelectric project owners, operators, and developers to improve their planning for future drought risks.

By Donald A. Wilhite

Editor's Note: We've asked Donald Wilhite, director of the International Drought Information Center, to share current ideas and understanding of drought with Hydro Review *readers. Droughts of the late 1980s and early 1990s have had obvious and significant effects on many U.S. hydro projects. Any improvement of our understanding of the phenomenon can be useful for planning for the future.*—M.B.

The Bureau of Reclamation suspended operation of New Melones Dam, a hydroelectric plant near Modesto, California, in the early 1990s due to six years of drought and a lack of significant precipitation. The low level of the reservoir was apparent in the fall of 1991, when this aerial view of the dam's upstream face was photographed. The intake structure is visible on the right side of the photograph. (Courtesy of the Bureau of Reclamation)

The late 1980s and early 1990s will long be remembered for severe water shortages—a consequence of numerous consecutive years of drought over extensive portions of the U.S. In particular, many Americans will remember the 1988 drought for its wide-ranging economical, societal, and environmental effects. These effects went far beyond those normally associated with drought (i.e., reductions in agricultural crop yields). Increased incidence of forest fires, curtailments in barge traffic on the Mississippi and other river systems, reduced recreational opportunities, higher energy use in response to much higher-than-normal temperatures, and mandatory restrictions on municipal water use are among the documented effects of the 1988 drought. Hydropower production, too, suffered during 1988 compared to long-term generation averages. All regions throughout the U.S. except the Plains states experienced reduced hydropower generation, as illustrated in Table 1. [This table was derived from *Hydro Review's* Hydropower Generation Report database.—*Ed.*]

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During 1988, severe to extreme drought affected nearly 40 percent of the country; an additional 30 percent of the nation experienced moderate drought conditions. Although public awareness of the drought and its severity was raised dramatically during the spring and early summer months, the public's perception of drought quickly waned by late fall. The direct and indirect effects of the drought will never be known fully. However, the

Table 1: Hydropower Production by Selected U.S. Power Producers in 1988 Compared To a Ten-Year Average

Region and Producer	*Total Hydro Operating Capacity (in MW)*	*Ten Year Average 1983-92 (1,000 MWh)*	*Total Hydro Generation for 1988 (1,000 MWh)*	*1988 Hydro Generation Percent of Ten-Year Average*
Northeast: New York Power Authority	4,068	24,747	22,471	91%
South: Corps of Engineers	4,162	11,031	7,560	69%
Tennessee Valley Authority	3,346	16,871	9,620	57%
Great Lakes: Corps of Engineers	479	1,767	1,041	59%
Plains: Corps of Engineers	2,873	9,659	9,949	103%
Southwest: Bureau of Reclamation	4,472	15,744	11,304	72%
Pacific Gas & Electric	3,904	10,706	7,884	74%
Northwest: Corps of Engineers	13,093	55,794	48,507	87%
TOTAL/AVERAGES	36,397	146,807	118,335	81%

Source: *Hydro Review's* Hydropower Generation Report database.

costs and losses have been estimated at nearly $40 billion.[1] Included in these costs are nearly $5 billion in federal drought relief, primarily to the agricultural sector. This large societal cost indicates that, despite all of our technological progress, our vulnerability to the uncontrollable phenomenon of drought continues.

To fully understand the magnitude of the effects of the 1988 drought, it is first necessary to understand its temporal characteristics (chronology of drought development). The reality is that the 1988 water shortages began several years earlier, in the summer of 1985. In August 1985, for example, severe to extreme drought existed throughout much of the West and in portions of the East. During 1986, conditions improved somewhat in the West, but deteriorated rapidly in the Southeast to become one of that region's worst droughts on record. Drought conditions continued during 1987, especially in the East and in the far western states of California, Oregon, and Washington. It was this series of droughts between 1985 and 1987 that led to the large accumulated water deficits in surface and subsurface water supplies before the spring of 1988. As the drought increased in intensity and spatial extent in the spring of 1988, the most immediate concerns were the potentially serious agricultural effects in the spring wheat-, corn-, and soybean-producing regions of the northern and central Great Plains and Midwest. By early summer, it became quite clear that the effects of the dry conditions would stretch far beyond the agricultural sector and the states in the nation's heartland.

As Figure 1 shows, the drought of the mid- to late-1980s did not end in the fall of 1988. It continued through the early months of 1993, when much above normal precipitation fell over most of the West. In February 1993, California Governor Pete Wilson officially pronounced an end to the six-year California drought, but called for continued emphasis on water conservation. He renamed the California Drought Response Office the Water Conservation Office.

Although the public's perception may be that the drought's end signals a return to "business as usual," the fact is that water is still in short supply in parts of California and other portions of the West are continuing to experience drought conditions. Water conservation will continue to be necessary as surface and subsurface water supplies slowly rebound with the return of more normal precipitation patterns. At the same time, it is likely that new areas of drought will emerge in 1993. After all, historical evidence shows that drought is a normal part of our climate and its occurrence is inevitable. Although some may consider the series of drought years between 1985 and 1993 unusual, Figure 2—indicating the percent of the U.S. experiencing severe to extreme drought between 1895 and 1991—shows that the most recent drought was not abnormal when recorded drought data in the U.S. is considered as a whole. The accompanying story provides details about how the severity of a drought is determined.

As important as drought has been to the history of the U.S., it will be equally if not more important in the future. As the recent droughts have demonstrated, technology has not reduced societal vulnerability. In fact, our vulnerability is expanding in response to the increasing demands of a growing population on limited water and other natural resources.

An Overview of Drought

Drought differs from other natural hazards such as floods, tornadoes, hurricanes, and earthquakes in several ways. First, it is a "creeping phenomenon," making its onset and end difficult to determine. The effects of drought accumulate slowly over a considerable period of time and may linger for years after the termination of the event. This represents an important aspect of drought for the hydropower industry: it may take several years for reservoir levels to return to normal following consecutive years of 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 severity. Policy-makers often are frustrated by the inability of scientists or water managers to define drought in concise terms or to explicitly state whether or not a drought exists. This may lead to inaction on the part of decision makers. Third, drought effects are less obvious and are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of its effects and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards.

Drought is a normal part of climate for virtually all climatic regimes. It is a temporary aberration that occurs in high as well as low rainfall areas. Therefore, drought differs from aridity, since the latter is restricted to low rainfall regions and is a permanent feature of climate. The character of drought is distinctly regional, reflecting unique meteorological, hydrological, and socioeconomic characteristics. Many people have difficulty associating drought with areas of the U.S., such as the Southeast, that are considered to have a surplus of water. But, indeed, there can still be drought.

Drought needs to be considered relative to some long-term average amount of precipitation and evapo-

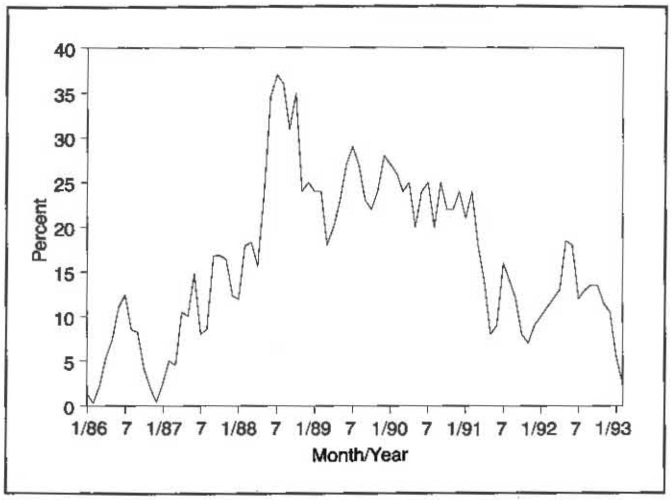

Figure 1: This graph shows the area (by percent) of the U.S. affected by severe to extreme drought between January 1986 to February 1993. The graph is based on data from the Palmer Drought Severity Index, in six-month intervals. Using the index, severe drought is identified as between –3 and –4. Anything less than –4 is extreme drought. (Information courtesy National Climatic Data Center, Asheville, North Carolina)

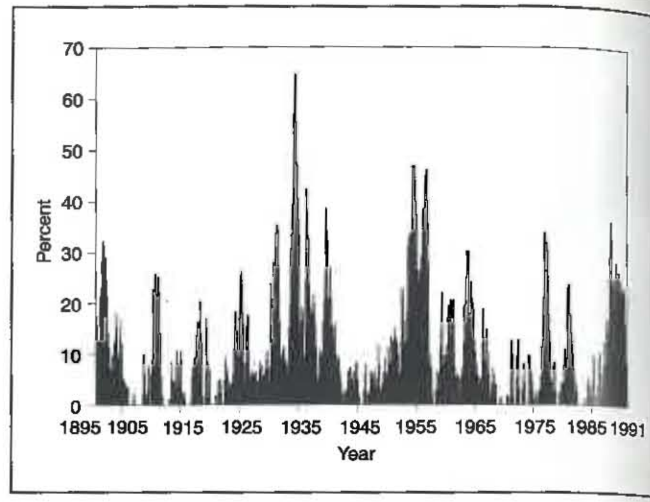

Figure 2: This graph shows the area (by percent) of the U.S. affected by severe to extreme drought between 1895 and 1991, based on the Palmer Drought Severity Index. (Severe drought is identified as between a –3 and –4 on the index. Extreme drought is less than –4.) (Information courtesy National Climatic Data Center, Asheville, North Carolina)

transpiration in a particular area, a condition often perceived as "normal." 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. Other climatic factors (such as high temperatures, high winds, and low relative humidity) often are associated with drought in many regions of the world and can significantly aggravate a drought's severity. Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, etc.) and the effectiveness of rains (i.e., rainfall intensity and number of rainfall events). However, drought should not be viewed as merely a physical phenomenon. It is the result of an interplay between a natural event (precipitation deficiencies because of natural climatic variability on varying time scales) and the demand placed on water supply by human-use systems. Societal vulnerability to periods of water shortage is always changing, reflecting our varying demands and water use priorities.

Various Perspectives About Drought

Because drought affects so many economic sectors and results in significant social and environmental effects, scores of definitions have been developed in a variety of disciplines. In addition, because drought occurs with varying frequency in nearly all regions of the globe, the approaches taken to define it reflect regional differences. Effects differ from one region to the next, and depend on the evolution of drought activities. Therefore, we cannot expect to derive a universal definition of drought.

Many disciplinary perspectives of drought exist. Each discipline incorporates different physical, biological, and/or socioeconomic factors in its definition of drought. But, all perspectives agree that the importance of drought lies in its effects.[2] Thus, definitions should be specific to the region and the effects in order to be used in an operational mode by water managers and other decision makers.

Drought can be grouped by type: meteorological, agricultural, hydrological, and socioeconomic.[2]

Meteorological drought compares the duration and degree of dryness in a region to the normal conditions for that region.

Agricultural drought occurs when conditions of meteorological drought affect soil moisture, evapotranspiration, and plant growth.

Hydrological droughts are concerned with the effects of precipitation shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, and ground water). More time elapses before precipitation deficiencies show up in components of the hydrological system, particularly for large river basins. Therefore, in large river basins, effects are out of phase with those in other economic sectors, and hydrological droughts usually lag behind meteorological and agricultural droughts. Also, water in reservoirs and rivers often is used for multiple and competing purposes, further complicating the sequence and quantification of effects. Competition for water in these storage systems escalates during drought.

Socioeconomic drought associates the supply and demand of some economic good to elements of meteorological, agricultural, and hydrological drought. Some scientists suggest that the time and space processes of supply and demand are the two basic elements of an objective definition of drought. For example, supply of economic goods (such as hydroelectric power, water, or hay) 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 exceeds supply as a result of a weather-related supply shortfall. This concept of drought supports the strong symbiosis that exists between drought and human activities.

Drought Characteristics and Severity

Droughts differ in three essential characteristics—intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of the effects of the shortfall. Intensity is generally measured by the departure of some climatic index from normal (for example, percent of normal precipitation) and is closely linked to duration in determining its effect. Actual precipitation departures are normally compared to expected or average amounts on a monthly, seasonal, annual, or water-year time period.

The most widely used method for determining drought severity in the U.S. is the Palmer Drought Severity Index (PDSI).[10] Developed in the mid-1960s, the PDSI is a meteorological index that evaluates prolonged periods of abnormally wet or dry weather. The index can be thought of as a hydrologic accounting system. The input to the system is precipitation. Outputs include evapotranspiration, runoff, soil infiltration, soil water storage, and deep percolation through the root zone to the ground water. The PDSI relates accumulated differences of actual precipitation to evapotranspiration, runoff, and soil infiltration to average precipitation for individual climatic regions. PDSI values generally range from +4 (extreme wetness) to –4 (extreme drought), although values above or below these thresholds are not unusual. Values near zero (+1 to –1) are considered to represent normal conditions. Figures 1 and 2 in this article are based on the PDSI. [*Hydro Review's* "Water Watch" department regularly includes information about soil moisture throughout the U.S. from the PDSI.—*Ed.*]

Another distinguishing feature of drought is its duration. Droughts usually take at least two to three months to develop, but can continue for several years. Droughts usually last longer in the interior of the U.S. than they do in the East or in the far western states, although the recent drought in California lasted for six years.[11] This finding is critical for hydro plant operators in these areas.

The percent of the total area of the contiguous U.S. affected by severe to extreme drought has been highly variable over the past century. The most widespread drought occurred in the 1930s—particularly 1934, when more than 65 percent of the country experienced severe or extreme drought. Using the percent of total area to define major drought episodes, significant areas were also affected in the 1890s, 1910, 1925 and 1926, 1953 to 1957, 1964 and 1965, 1976 and 1977, 1983, and 1988 to 1992. The 1930s, particularly 1934 and 1936, remain the most severe drought years on record for the northern and central Great Plains and Midwest. Until the recent series of drought years in the West, 1976 and 1977 was considered to be the drought of record for that region.

Causes and Predictability Of Drought

Empirical studies conducted during the past century have shown that drought is never the result of a single cause. Rather, it is the result of many causes, which are often synergistic in nature. Some of the causes may be the result of influences originating far from the drought-affected area. Drought researchers are studying the role of interacting systems, often called "teleconnections," in explaining regional and even global climatic patterns of climatic variability. Teleconnections are regional or global atmospheric patterns that reappear with considerable frequency in roughly the same form and often persist or recur throughout a month or season. These patterns tend to recur with enough frequency and with similar characteristics over a sufficient length of time that they help forecasters make long-range climate predictions, particularly in the tropics.

One teleconnection receiving a great deal of attention from scientists since the early 1980s is the El Niño/Southern Oscillation, usually called "El Niño." El Niño is the occasional invasion of warm surface water from the western equatorial Pacific Basin to the eastern equatorial region and along the west coast of South America.[3] El Niño events occur about twice every ten years, although the interval between two events is irregular. El Niño events have been linked to the widespread occurrence of extreme climatic events, such as droughts and floods, on virtually every continent.

The immediate cause of drought is the sinking of air (subsidence) that results in higher atmospheric pressure and compressional warming of the air, which inhibits cloud formation and causes lower relative humidity, leading to less precipitation. For regions under the influence of semi-permanent high pressure during all or most of the year, desert (arid) conditions result, such as in the Sahara and Kalahari deserts of Africa and the Gobi Desert of Asia. Most climatic regions, however, experience varying degrees of dominance by high pressure, often depending on the season. Prolonged droughts occur when large-scale anomalies in atmospheric circulation patterns become established and persist for periods of months, seasons, or longer. The extreme drought of 1988 affected both the U.S. and Canada.

How Predictable Is Drought?

Currently, it is difficult for forecasters to predict drought more than a month in advance. The potential to predict drought differs by region, season, and climate. Recent technological advances make drought forecasts more reliable today than a decade ago in some regions. In the tropics, for example, meteorologists have made significant advances in understanding the climate system. Specifically, meteorologists now know that much of the atmospheric variability that occurs over longer periods of time (several months to several years) can be linked to variations in tropical sea surface temperatures. Major global meteorological experiments are investigating these questions further. Improved predictability of El Niño episodes, for example, would profoundly influence seasonal predictions in the tropics and elsewhere. To date, empirical relationships have been developed for some tropical and near-tropical regions such as the Indian Peninsula and Australia. Further advancements will require major breakthroughs in the use of dynamic models that link ocean-atmosphere systems. Therefore, meteorologists do not believe that highly accurate forecasts are currently possible for all regions more than a season in advance.

The Effects of Drought

The effects of drought are diverse and often ripple through the economy. Thus, effects often are referred to as "direct" or "indirect." For example, a loss of agricultural crop yield resulting

from drought is a direct effect of drought. However, the consequences of that effect (e.g., loss of income, farm foreclosures, outmigration, or government relief programs) are indirect effects. Because of the number of affected groups and sectors associated with drought, the geographic size of the area affected, and the difficulties connected with quantifying environmental damages and personal hardships, the determination of the financial costs of drought is both difficult and imprecise. As Figure 2 illustrates, there are few years when drought is not affecting some portion of the U.S. It is also common to have a series of years with widespread drought followed by several years during which the spatial extent of drought is quite limited. For example, the decade of the 1930s was followed by a series of years in the 1940s in which severe to extreme drought was of limited spatial extent. This pattern has recurred several times since then. Therefore, direct and indirect losses may be extremely large for one or two consecutive years and then negligible for several years.

The effects of drought can be classified into three principal areas: economic, environmental, and social.

Economic effects range from direct losses in the energy sector and agricultural and agriculturally related sectors (including forestry and fishing) to losses in recreation, transportation, and banking. Other economic effects include increased unemployment and loss of revenue to local, state, and federal governments. Where activities are directly dependent on water resources, the economic effects of drought can include reduction in hydroelectric power, loss from fishery production, loss from recreational business, and loss to manufacturers and sellers of recreational equipment.

Environmental losses are the result of damages to plant and animal species, wildlife habitat, and air and water quality; forest and range fires; degradation of landscape quality; and soil erosion. Although these losses are difficult to quantify, growing public awareness and concern for environmental quality has forced public officials to focus greater attention on these effects.

Social effects mainly involve public safety, health, conflicts between water users, and inequities in the distribution of effects and disaster relief programs.

As with all natural risks, the economic effects of drought are highly variable within and between economic sectors and geographic regions, producing a complex assortment of winners and losers with the occurrence of each disaster. For example, decreases in agricultural production result in enormous negative financial effects on farmers in drought-affected areas, at times leading to farm foreclosures. This decreased production also leads to higher grain, meat, vegetable, and fruit prices, which have a negative effect on all consumers as food prices increase. Farmers outside the drought-affected area with normal to above normal production, or those with significant grain in storage, reap the benefits of these higher prices. To a lesser extent, this can also be true of hydroelectric production, where a drought in the northwestern U.S., for example, would result in the purchase of more hydroelectricity from B.C.

Hydro in British Columbia, Canada.

Ironically, in the U.S. the energy sector can economically benefit from drought and associated heat waves owing to increased energy requirements for refrigeration and air conditioning. For example, during the drought of 1980 and the accompanying six-week heat wave that extended from late June through the first week in August, total electric use averaged 5.5 percent above normal—costing $1.3 billion.[4] However, various segments of the energy sector are affected differently. While hydroelectric energy generation is reduced during extended droughts, replacement energy sources, such as fossil fuels, increase energy costs. These additional costs are subsequently passed on to the consumer. In the book *Drought Assessment, Management, and Planning: Theory and Case Studies,* it is estimated that the use of more expensive fossil fuels by electric utilities to replace drought-induced hydropower losses in California cost ratepayers $2.93 billion between 1987 and 1991.[5]

In California, hydroelectric power plants produce about one-third of the electricity used in a normal year.[5] However, this production may vary significantly between wet and dry years. During wet years, as much as 40 percent of the electricity used may come from hydropower. In 1988, record consumption of electrical power occurred in California, although hydropower generation accounted for only 17 percent of electricity production.[6] As a result of recent droughts, interest in large-scale interconnected power systems—such as between B.C. Hydro, the provincially owned utility in British Columbia, Canada, and the Bonneville Power Administration—has increased.[7]

In response to continuing hydrologic drought conditions in the Missouri River Basin between September 1992 and May 1993, the Western Area Power Administration (WAPA) has spent more than $39 million buying electricity that would have been generated at the six main stem power plants under normal conditions. [Under normal water supply conditions, WAPA typically would not need to purchase electricity from other suppliers.—*Ed.*] Hydropower generation forecasts for 1993 indicate record low generation with more energy purchases on the horizon.[8] Thus, while meteorological and agricultural drought may have ended or lessened in severity for some portions of the Missouri River Basin, the hydrologic drought (i.e., low reservoir levels) continues.

Societal Vulnerability To Drought

There is growing concern among scientists and policy-makers about society's increased vulnerability to drought throughout the world. Several factors contribute to this increase in vulnerability.

Competition for water and other limited natural resources is increasing because of increasing population. This increase in population puts added pressure on agriculturally marginal land to provide food and fiber. These marginal lands typically have a higher incidence of drought and are more vulnerable to degradation.

Changes in the distribution of population can result in greater distance

In early May 1988, the level of the Bureau of Reclamation's Hungry Horse Reservoir in Montana was significantly lowered in response to several consecutive years of below normal precipitation. As shown in this photograph, the water level dropped so low that a large sandbar developed.

between the location of people and the location of adequate water supplies. Movement of people to drier areas or from rural to urban settings strains society's ability to provide adequate water supplies. This concept is well illustrated in the U.S. by the movement of population to the West, especially California and Arizona.

Per capita demand for water typically increases with the level of economic development, straining water supply systems accordingly. This increased per capita demand is particularly evident in more developed nations, such as the U.S., but these trends are now being repeated in developing countries.

The costs and environmental concerns associated with constructing large reservoirs are slowing new water supply development projects. This narrows the margin between water supply and demand, increasing the likelihood of water shortages with less severe droughts in the future. As competition for water increases, so do the conflicts between water users. These conflicts escalate during periods of drought.

Environmental concerns are placing increasing constraints on our use of natural resources. For example, protection of fish and wildlife populations during water shortages requires new allocations of available supplies. Also, concerns about water quality—both surface and ground water—place constraints and added costs on the use of that resource.

These factors and others affect societal vulnerability to droughts and increase the need for both the public and private sector to use strategic planning to mitigate the effects of future droughts. Government response to past droughts has typically been reactive, using a crisis management approach. Such efforts do little to reduce vulnerability. In fact, providing drought relief can be a disincentive to managing resources on a sustainable basis.

To increase preparedness for drought requires improved coordination and cooperation within and between levels of government, as well as in the private sector. Several countries are now pursuing a more proactive risk management approach.[9] The approach includes the development of a national drought policy and plan aimed at reducing societal vulnerability to future droughts while also promoting sustainable, long-term resource management. This proactive approach is not yet widespread in the U.S.

Some Perspective about Preparing for Drought

Drought is a normal, expected climatic event. Vulnerability to drought, as noted in this article, is significant and increasing. Competition for limited water and other natural resources is increasing because of increased population pressure (i.e., growth and redistribution). Thus, drought-induced water shortages will be a more important problem in the future. Also, the uncertainty of future changes in climate, possibly resulting from increasing concentrations in atmospheric "greenhouse" gases such as CO_2 has led some scientists to speculate that changes in climate may result in an increased frequency and severity of drought in the future. Consequently, while there is a strong rationale for planning for water shortages based on current climate variability and trends in population and water use, any change in climate will further aggravate society's inability to cope successfully with extreme climatic events.

Both the public and private sectors

This corn, planted in late April 1988 in central Indiana, dramatically illustrates the effects of the drought on crop development. This photograph was taken in mid-July 1988, when a severe drought was still in effect.

must increase their level of strategic planning to be better prepared for mitigating the effects of future droughts. Government response to past droughts has typically been a reactive or crisis management approach; the development of higher levels of preparedness will require improved coordination and cooperation within and between levels of government and with the private sector.

Hydroelectric industry leaders would do well to understand the characteristics of drought. On a more general note, the U.S. needs to pursue developing a national drought policy and planning for minimizing the nation's vulnerability. □

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Notes:

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