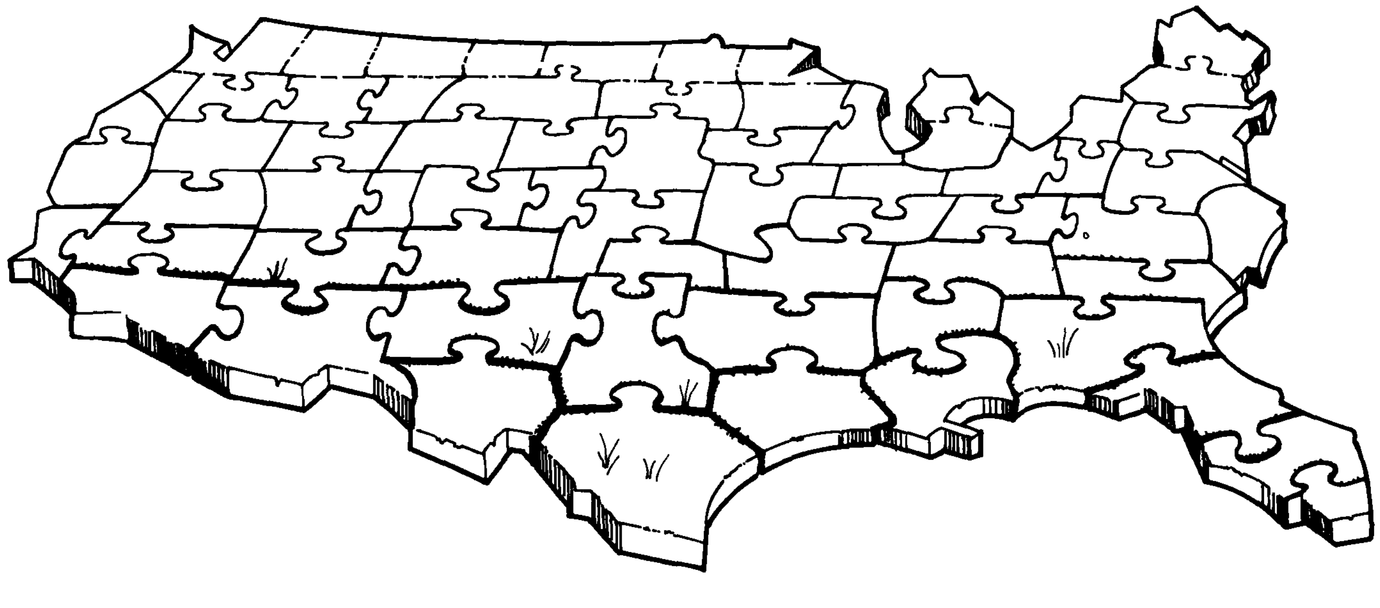
US Army Corps
of Engineers

The National Study of Water Management During Drought

A RESEARCH ASSESSMENT



August 1991

IWR Report 91-NDS-3

National Study of Water Management During Drought Reports

This report is the third of a series of reports which will be published during the study. Other reports:

<u>*Report on the First Year of Study*</u> *(IWR Report 91-NDS-1). The Corps of Engineers began the study after the severe droughts of 1988. The primary objective of the study is to find strategies to improve water management during droughts in the United States. The report explains how and why water is managed the way drought in the United States. The report explains how and why water is managed the way it is now, lists the impacts of drought, the problems in the current water management system, and the roadblocks to change for the better. It presents three recommendations which will be pursued in the remainder of the study.*

<u>*A Preliminary Assessment of Corps of Engineers Reservoirs, Their Purposes and Susceptibility to Drought*</u> *(IWR Report 91-NDS-2). The Corps Hydrologic Engineering Center in Davis, California used its **Reservoir Database Network** to link databases on Corps reservoirs, with databases which are maintained by other agencies for precipitation, drought, temperature, evaporation, and streamflow, recreation, and population. Assessments were made for each Corps division.*

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NATIONAL STUDY OF WATER MANAGEMENT DURING DROUGHT:

A RESEARCH ASSESSMENT

Prepared for

U.S. Army Corps of Engineers
Water Resources Support Center
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Many individuals have contributed to the writing and editing of this report. The principal authors contributed sections relevant to their expertise. Professor Gary D. Lynne of the University of Florida at Gainsville prepared the discussion on agricultural aspects of drought included in Chapter III and Appendix C. Professor Donald A. Wilhite, the Director of the International Drought Information Center of the University of Nebraska-Lincoln, prepared parts of Chapter II pertaining to the status of drought planning at the federal and state level. Dr. Dan Sheer, the President of Water Resources Management, Inc., prepared a section of Chapter IV on supply management measures. Dr. Ben Dziegielewski, an Associate Professor at Southern Illinois University and the principal investigator on this project with Planning and Management Consultants, Ltd., prepared Chapters I, IV, V, and the balance of other chapters. He also served as the editor of the report.

The principal authors wish to acknowledge the contributions of many people who provided the necessary information and helped in the preparation of the report. Professor Clifford S. Russell prepared very thorough and critical reviews of an earlier draft and made numerous suggestions for improving the clarity of the report and suggested significant improvements for the theoretical model for drought management. Two research assistants, Mr. Julio DalMonte and Ms. Nancy Hanna-Somers, spent many days collecting literature sources and preparing drafts of various sections. Mr. Jack Kiefer, an economist with Planning and Management Consultants, Ltd., helped with a review of loss measurement methods and the production of the final version of the report. The help of other investigators at PMCL, especially Ms. Eva Opitz and Mr. Russell Hinckley, are also appreciated.

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Finally, we would like to thank all persons whom we contacted for information on drought management at local, state, and federal levels of government, as well as many public and private water agencies.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

PURPOSE

The main purpose of this report is to describe this country's water resources management responses during drought and to highlight the critical inadequacies of national and regional policies for drought management. The report summarizes research on water management during drought and makes recommendations for additional research areas that offer the most promise for improving the drought management response at federal, regional, state, and local levels of government.

This report is part of a comprehensive study that has been undertaken in response to recommendations of the U.S. Army Corps of Engineers made after the drought of 1988-89. The President's budget included funds to begin a National Water Management During Drought Study as part of the administration's 1990 budget. Authority for the study is given to the Secretary of the Army for Civil Works (ASA(CW)) as provided in Sections 707 and 729 of the Water Resources Development Act of 1986.

The National Water Management During Drought Study follows several previous studies of the national water resources performed by federal agencies. These studies include:

1. First National Water Assessment (U.S. Water Resources Council, 1968)

2. Second National Water Assessment (U.S. Water Resources Council, 1978)

3. Northeast Water Supply Study (U.S. Army Corps of Engineers, 1971)

4. Office of Technology Assessment Study on Water Resources Modeling

5. U.S. Army Corps of Engineers Institute for Water Resources Water Supply and Conservation Planning Research Program (IWR Reports, 1979-Present)

The present study builds upon the information obtained in these studies in order to develop recommendations for further improvement in managing national water resources. The References section of this report provides bibliographical notes for the previous federal studies. Citations of specific studies including the IWR reports are provided throughout the remainder of this report.

The specific purposes of this report are:

(1) To formulate a conceptual framework for water management during drought, including definition of drought, drought adjustments, and criteria for drought management

(2) To identify the range of impacts of drought on society and describe the methods of measuring economic impacts on specific economic activities

(3) To characterize the vulnerability to drought of various regions of the country and summarize the present status of drought planning and management at local, regional, state, and federal levels of government

(4) To describe both the conventional and the innovative techniques for drought management and evaluate their documented or potential success

(5) To characterize the legal and institutional environments that influence drought management decisions

(6) To identify the requirements for designing and conducting drought preparedness studies for selected regions of the country

(7) To identify those aspects of drought management that need additional investigation and are likely to be the most productive areas for the study of drought

These specific objectives are formulated to allow the Institute for Water Resources of the U.S. Army Corps of Engineers to examine the current methods of responding to drought nationwide and to recommend a national strategy for better management of the nation's water resources during drought.

REPORT FORMAT

The remainder of this chapter defines a conceptual framework of the problem of drought. The subsequent chapters generally follow the objectives of this study as listed above.

Chapter II describes the vulnerability of various regions and economic activities to the adverse effects of drought. It also describes the status of drought preparedness at the local, state, regional, and national levels.

Chapter III reviews the experience and previous research on measurement of economic impacts of drought.

Chapter IV describes the legal and administrative environment within which the management of water resources takes place and describes a range of drought management techniques.

Chapter V describes the requirement for developing a national policy for water management during drought and includes an exemplary outline of work tasks for development of regional drought management plans.

Finally, Chapter VI contains the conclusions of this report and identifies the areas in which further research can enhance the ability of this nation to manage future drought events.

THE PROBLEM OF DROUGHT

There is and has been a continuous presence of drought in the global hydrologic cycle. For example, when the Great Plains is experiencing a period of abundant rainfall, other areas in the United States or elsewhere in the world may experience dry spells that can turn into severe droughts. The examination of tree rings suggests that droughts have always been present and that prehistorical drought events must have caused widespread famines in agricultural tribes.

The scientific approach to the problem of drought requires that the problem itself be precisely defined. Only precise problem definition will permit the scientist to pursue and possibly find the solution(s) to drought impacts. Unfortunately, the researchers of drought often confuse the various elements of the drought problem. Figure I-1 shows a general structure of the drought management problem. The left-hand side of Figure I-1 shows the sequence of the drought impacts. The right-hand side represents human adjustments to drought (or drought management). Each element of the drought impact sequence and drought management sequence depicted in Figure I-1 is discussed below.

THE DROUGHT IMPACT SEQUENCE

The Definition of Drought

The researchers of drought often confuse the definition of the "drought phenomenon" with the definition of the "problem of drought." The distinction between these two concepts is very important. In most cases, the physical phenomenon of drought can be defined without any difficulty. For example, it can be defined as "a shortage of precipitation" exceeding some x percent of average precipitation during a given period (e.g., month, season, year, or decade). The value of x cannot be established through empirical investigation, and it is usually arbitrarily set by the researcher. Typically, three types of drought are distinguished (Dracup, 1980):

(1) Meteorologic drought; defined based on the deficit of precipitation

(2) Hydrologic drought; defined based on low streamflow

(3) Agricultural drought; defined based on soil moisture deficiency

The drought literature contains considerable debate about the need for developing a universal definition of drought. It also contains a wide array of definitions developed over the years by many researchers. Examples of such definitions collected by Wilhite and Glantz (1987) are shown in Table I-1.

A major difficulty arises when one attempts to define the societal problem of drought. For example, the people of the state of California face the problem of drought not because this year's precipitation in California is less than normal but because there is not, or will not be, enough water to satisfy all the established and new uses of water in the state. Therefore, the "problem of drought" must be

FIGURE I-1
ELEMENTS OF THE DROUGHT MANAGEMENT PROBLEM

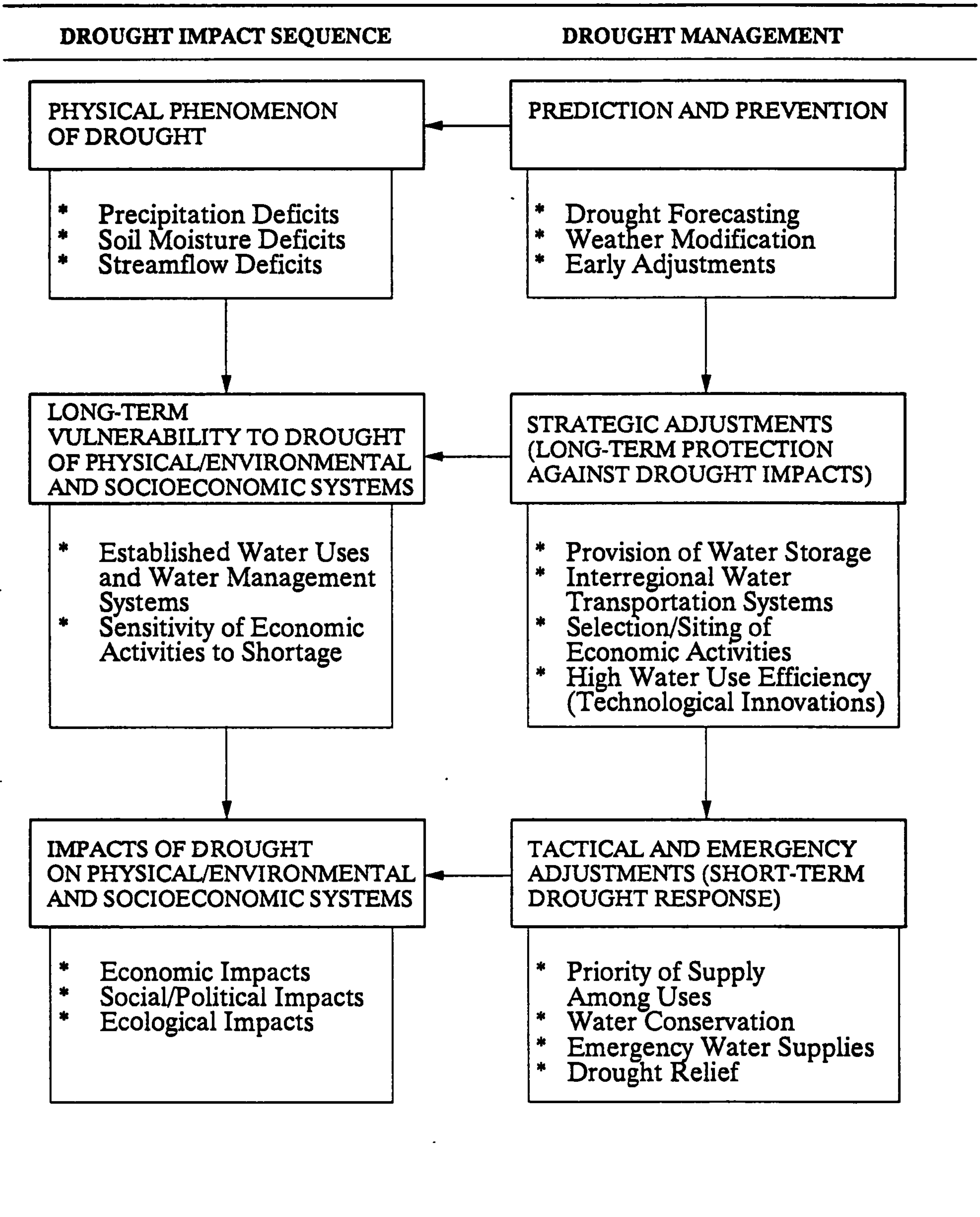


TABLE I-1

DROUGHT DEFINITIONS

Author[1]	Year	Definition
Meteorological Drought		
Condra	1944	A "period of strong wind, low precipitation, high temperature and, usually, low relative humidity." This definition applied specifically to drought conditions in the Great Plains area.
Levitt	1958	Expressed atmospheric drought as proportional to the vapor pressure deficit of the air.
Linsley et al.	1958	A "sustained period of time without significant rainfall."
Downer et al.	1967	A "deficit of water below a given reference value, with both deficit duration and deficit magnitude taken into account."
McGuire & Palmer	1957	A "period of monthly or annual precipitation less than some particular percentage of normal."
Palmer	1957	A temporary departure from the average climate toward drier conditions.
Palmer	1965	Developed the Palmer Drought Severity Index, which relates the severity of a drought to the accumulated weighted differences between actual precipitation and the precipitation requirement of evapotranspiration.
Gibbs & Maher	1967	Developed a drought measurement system by ranking monthly and annual precipitation totals and determining decile ranges from the cumulative frequency of the distribution, i.e., the first decile represents the precipitation values in the lowest ten percent of the distribution.
Lee	1979	Developed the Australian Drought Watch System, which uses deciles of precipitation to determine when droughts are developing. A severe drought is defined as a dry period not exceeding the fifth decile range over a period of three or more months.
Changnon	1980	Measured drought by comparing the amount of departure of precipitation from normal to the impact of the weather on the economy.

1. See Reference Section for list of individual references.

TABLE I-1 (Continued)

DROUGHT DEFINITIONS

Author	Year	Definition
Agricultural Drought		
Barger et al.	1949	Linked the severity of drought to impacts on corn crops.
Kulik	1958	Determined drought intensity by measuring the difference between plant water demand and available soil water.
Palmer	1968	Developed the Crop Moisture Index, which determines the severity of a drought based on the magnitude of the abnormal evapotranspiration deficit.
Heathcote	1974	A "shortage of water harmful to man's agricultural activities. It occurs as an interaction between agricultural activity (i.e., demand) and natural events (i.e., supply), which results in a water volume or quality inadequate for plant and/or animal needs."
Hydrologic Drought		
Linsley et al.	1975	A period in which "streamflows are inadequate to supply established uses under a given water management system."
Whipple	1966	Defined a drought year as one in which the aggregate runoff is less than the long-term average runoff.
Dezman et al.	1982	Surface Water Supply Index, which uses historical data and current figures of reservoir storage, streamflow, and precipitation at high elevation, etc., to form a single index number.
Socioeconomic Drought		
Hoyt	1936 and 1942	"When precipitation is not sufficient to meet the needs of established human activities." Also, droughts may occur when "in the economic development of a region man creates a demand for more water than is normally available."
Gibbs	1975	Amplified on Heathcote by defining demand as "dependent upon the distribution of plant, animal and human populations, their lifestyle and their use of the land."
Sandford	1979	Linked drought not only to precipitation but also to other factors that influence supply and to trends or fluctuations in demand.

Source: Beecher & Laubach, 1989, construct from Donald A. Wilhite and Michael H. Glantz, "Understanding the Drought Phenomenon: The Role of Definitions," in Donald A. Wilhite and William E. Easterling, eds., Planning for Drought: Toward a Reduction of Societal Vulnerability (Boulder, CO: Westview Press, 1987), 15-19.

defined from the perspective of human adjustments to drought. Accordingly, the real issue imbedded in the problem of drought is the social desirability of securing ample supply of water for all uses at all times. Through technological actions we have the ability to control the effects of a precipitation shortage. In more general terms, the need and level of drought, mitigation (i.e., reducing the adverse consequences of water supply shortages) may be determined by comparing the social, economic, and environmental impacts of drought with and without additional human intervention.

Within the social dimension of the problem of drought, Wilhite and Glantz (1987) distinguished socioeconomic definitions of drought in their compilation (Table I-1). Hoyt (1936), Gibbs (1975), and Sandford (1979) incorporate water demand into their definitions. Some definitions listed in Table I-1 under meteorologic, hydrologic or agricultural drought also refer to the presence of socioeconomic effects (e.g., Changnon, 1980; Barger, 1949; Heathcote, 1974; and Linsley et al., 1975).

Vulnerability to Drought

There are two main factors that affect drought vulnerability of socioeconomic systems at local, state, regional, national, and even international levels. The first factor is related to the risk of experiencing meteorologic drought. Although precipitation deficits can occur in any region of the globe, there are climatic and physiographic differences between regions that make some areas experience greater variability of precipitation than others. The available weather record with periodic droughts may be used for deriving probabilities of experiencing droughts of varying intensities (magnitude and duration) at any given location in the long run.

The second factor is related to the sensitivity of various socioeconomic systems to drought. For example, a dry-farming agriculturalist who operates on small profits and works large acreage is very susceptible to drought impacts. Small departures from normal precipitation (patterns and/or quantities) may force that farmer into bankruptcy. Similarly, urban economies consisting of activities that require a constant supply of large quantities of water may be very sensitive to shortages in water supply. This factor also includes the influence of the established water management system (e.g., reservoir operation rules, allocation schemes of water supplies among competing uses) on the sensitivity of some activities to a regional water shortage.

The Range of Drought Impacts

Droughts may have substantial economic, political, social, or even psychological impacts. During a drought, people cannot get all the water they demand (because of an actual supply shortage or an anticipation of a shortage as a result of drought) and, therefore, cannot achieve the same objectives possible with a plentiful water supply. With less water available some human activities become constrained, and the objectives are only partially satisfied or not satisfied.

A new category of drought impacts has been brought to public attention during recent droughts. This category includes the effects of drought on physical or environmental systems such as forest fires, reduced wildlife populations, wind erosion of soil, fish kills, and others. Some of these impacts ultimately will affect the socioeconomic systems.

Several schemes for classifying the various impacts of drought are found in the literature. Warrick et al. (1975 p. 35) devised a classification scheme for drought impacts that is arranged into four levels of a social system, as shown on Figure I-2. These effects show the extent of possible social consequences of drought. Warrick et al. (1975, p. 34) state that, in general, the more severe the drought, the greater the possibility that the effects will be felt at higher levels of the social system.

Two other classification systems of drought impacts can be found in the literature. One scheme attempts to classify all possible impacts into social, psychological, political, or economic categories that represent spheres of individual and social activities. Another scheme identifies ranges of impacts of social, political, and economic nature by economic sectors and other types of affected entities. Riebsame et al. (1990) developed a roster of drought impacts that itemizes many specific effects of the extreme drought conditions of 1988. These impacts are presented in Table I-2. They include the effects both of water shortage and of extreme heat (air temperature). Chapter III of this report considers economic impacts of drought on the agricultural and other sectors of the national economy.

The types of drought impacts found in the literature typically include the adverse consequences of drought. However, in some situations droughts may have positive effects as well. For example, it is possible that individual farmers may actually benefit from a drought if the elasticity of demand for some farm products is so high that a reduction of yield translates into an increase in farm income.

DROUGHT MANAGEMENT

Since prehistoric times, droughts have affected human activities and forced societies to develop ways of protecting themselves from drought-related disasters. Gilbert F. White and his collaborators (1970, p. 2) have developed a general classification of human responses to drought and other environmental hazards. These are described below.

(1) Folk, or preindustrial adjustments:

> Activities that involve a wide range of adjustment requiring modifications in behavior more in harmony with nature than control of nature; are flexible and easily abandoned; are low in capital requirements; require action only by individuals and small groups; and can vary drastically over short distances (e.g., movement of cattle and people to nondrought areas).

(2) Modern technological, or industrial, adjustments:

> Adjustments that involve a more limited range of technological actions emphasizing control of nature, are inflexible and

FIGURE I-2
RANGE OF SOCIAL CONSEQUENCES OF DROUGHT VIS A VIS SOCIAL SYSTEM LEVELS

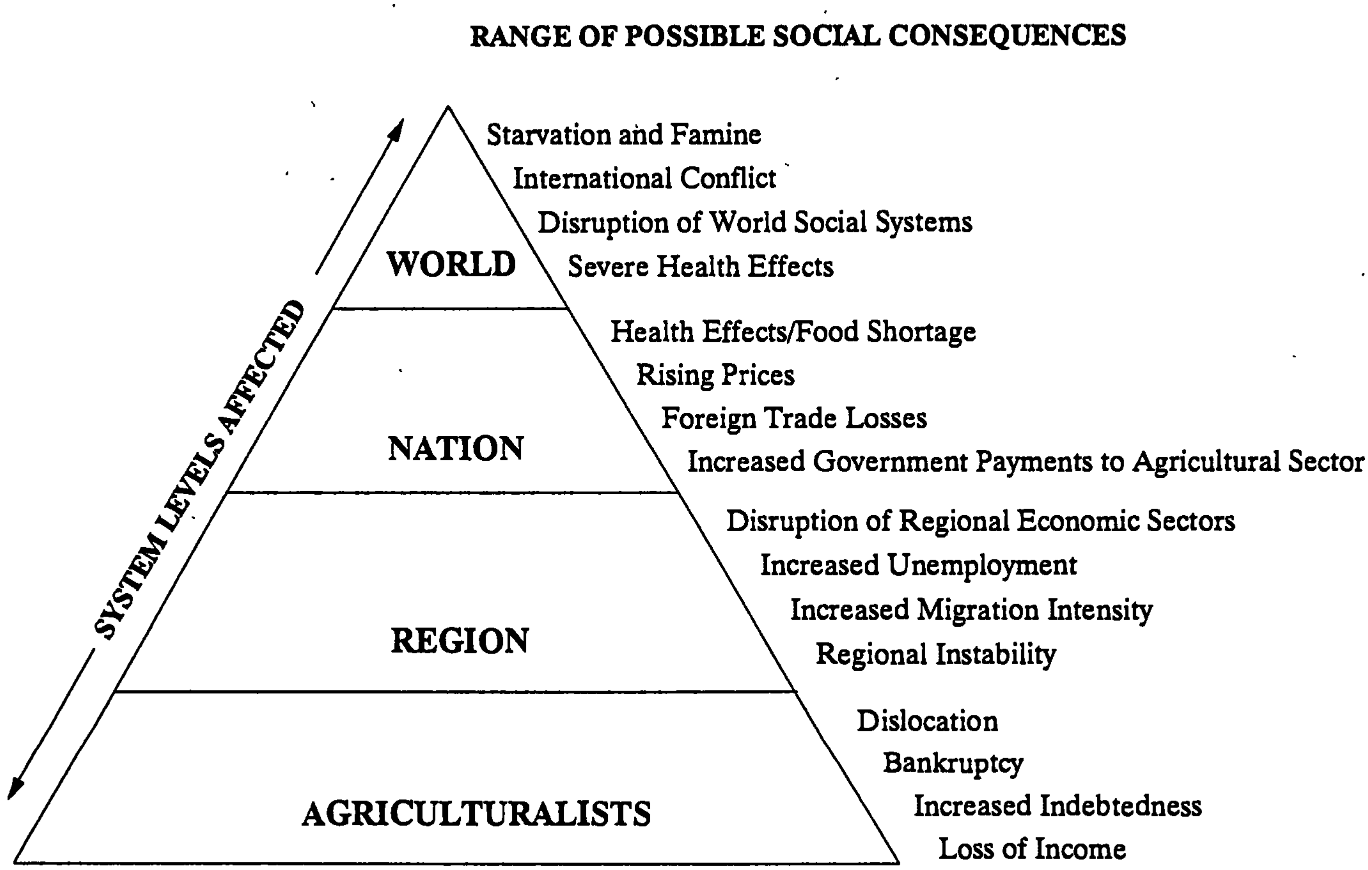


TABLE I-2

ROSTER OF IMPACTS OF THE 1987-1989 DROUGHT

A. Environmental
   1. Wildlife - reduced populations, food loss for migration
   2. Forests - major losses; fires, some growth stunted, seedling mortality
   3. Fish - major losses in low streams, and poor quality water
   4. Soil - increased wind erosion, especially northern Great Plains
   5. Water - reduced quality; low, warm flows; unable to handle industrial discharges and agricultural pollution
   6. Insects - some populations increased

B. Human Health (physical and mental)
   1. Deaths - number of persons totally or partly attributed to heat is in thousands
   2. Illnesses - increased asthma, heat stress
   3. Emotional problems - anxiety over heat stress, loss of income, higher costs for cooling, loss of recreational opportunities, concern over climate change

C. Agriculture
   1. Surpluses reduced
   2. Prices up for corn, soybeans, and wheat
   3. Farmers in drought areas hurt, those elsewhere helped economically
   4. Long-term impacts difficult to assess due to subsidies for exports and production
   5. Means to adjust to continuing drought available
   6. Commercial forestry hurt
   7. Increased crop insects and enhanced pesticide spraying

D. Transportation
   1. Rivers - barge traffic hurt
   2. Railroads - enhanced
   3. Great Lakes - shipping increased
   4. Airlines - fewer weather delays

E. Power Generation
   1. Record consumption of electrical power
   2. Hydropower generation reduced, costly fossil fuel substitutes required
   3. Brownouts, damaged electrical equipment, discomfort
   4. Increased income to most power companies

F. Commerce and Industry
   1. Rain insurance hoax
   2. All-weather peril insurance overwhelmed
   3. Recreation industry received less revenue
   4. Construction - fewer delays
   5. Shippers - higher costs

TABLE I-2 (Continued)

ROSTER OF IMPACTS OF THE 1987-1989 DROUGHT

G. Urban Areas
   1. Reduced water supplies
   2. Increased sickness and death of elderly from heat
   3. Increased water consumption
   4. Developed conservation procedures and penalties

H. Water Resources
   1. Low streamflows
   2. Lowered Great Lakes, reservoirs, and farm ponds
   3. Lowered groundwater levels
   4. New sources developed - wells drilled, piping for diversions
   5. Increased costs for water and sewage treatment
   6. Increased public awareness of water valaue and need for conservation
   7. Interstate conflict heightened

I. Education
   1. School hours reduced by heat

J. Government Operations
   1. Establishment of drought task forces
   2. Increased services and costs to government: river channeling, fire fighting, relief payments, etc.
   3. Concern over CO_2 as cause of drought
   4. Conflicts between states, especially over water
   5. National attention to planning for future droughts
   6. New legislation for drought relief

Source: Drought and Natural Resource Management in the United States: Impacts and Implications of the 1987-89 Drought. William E. Riebsame, Stanley A. Changnon, Jr., and Thomas R. Karl. 1990 Westview Press, Boulder, CO.

difficult to change, are high in capital requirements, require interlocking and interdependent social organization, and tend to be uniform, (e.g., construction of storage reservoirs and/or extensive irrigation systems).

(3) Comprehensive, or postindustrial, adjustments:

Adjustments that combine features of both earlier stages so as to involve a larger range of adjustments with greater flexibility and variety of capital and organizational requirements (e.g., combination of demand and supply management measures in drought mitigation).

An advisable general goal of current research on drought management would be to find ways to bridge the gap between the modern technological adjustments and the comprehensive (or postindustrial) adjustments to drought in the United States. Because the latter approach includes a large range of flexible adjustments, one could expect that the social economic and environmental costs of coping with droughts could be reduced.

The following sections discuss the human adjustments to drought under three broad categories: drought prediction and prevention, long-term drought protection, and drought preparedness and response.

Drought Prediction and Prevention

The present knowledge regarding meteorology does not allow the development of reliable long-term forecasts of weather and especially forecasts of drought events. However, there are some prospects for achieving a major improvement in describing the potential range of meteorologic and hydrologic variability. This improvement may be achieved by extending the existing climatological records through the analysis of the width of growth rings of trees. Also, substantial progress has been made in the research on causes of the drought phenomenon itself. The initial inquiry into this subject made by Tannehill (1947) was followed by the significant contributions of Namias (1953, 1960, 1968, and 1978) and Beran and Rodier (1985). The discovery of an apparent relationship between the sea surface temperature and continental weather, as well as the enhanced understanding of air-sea interactions, shows some promise for the development of meteorological procedures for forecasting drought within the next 10 to 20 years.

A reliable prediction of a major drought event would undoubtedly result in the avoidance of many adverse drought-related consequences. A number of early adjustments could be made to prevent water shortages. For example, flood control reservoirs could be kept full before the onset of the normally expected wet season to store water for drought. Hydropower production could be adjusted to maximize water storage and to make water releases coincidental with water demands. Finally, many economic activities could be modified to decrease water demands during the drought period.

The knowledge of an impending drought could also provide more impetus for precipitation management programs (i.e., cloud seeding) in order to increase the amount of precipitation before and during the drought. The latter activity represents a modification of the physical phenomenon of drought. The U.S. Bureau of Reclamation maintains an active precipitation management program in the western U.S. and with proper environmental safeguards could expand it in the future to significantly reduce the severity of droughts.

Strategic Adjustments to Drought

Recurrent droughts are a feature of the global climate and their effects are considered in planning for the provision of water for agriculture, urban development, recreation, navigation, and other activities. The simplest and often most efficient form of long-term drought protection is the provision of sufficient storage of water in times of high rainfall for use during periods of drought. Major river systems in this country include a significant amount of reservoir storage ranging from one to two years of average flow in the humid East, to three to five years of average flow in the arid and semiarid West. Also, significant amounts of runoff from small watersheds are retained in local lakes and reservoirs.

In addition to local and regional storage of water, the strategic (or long-term) protection against regional droughts can be achieved by developing interregional water transportation systems (i.e., aqueducts) that can import water from distant sources. Extensive regional and state water transportation networks have been developed in California, Florida, Arizona, and New York. Extensive regional "plumbing" can also facilitate the movement of water to locales with supply shortages.

Another type of long-term or strategic drought adjustment is evident in the selection of crops and farming methods in regions that face the risk of frequent droughts. Irrigated agriculture is an example of such an adjustment, especially in the humid regions of the country where the primary purpose of irrigation systems is to augment natural precipitation in order to reduce the risk of crop failure due to a short drought.

Finally, technological innovations also play an important role in drought protection. For example, drip irrigation systems in agriculture require only small quantities of water to achieve high crop yields, thus making agricultural production less sensitive to supply shortages. Also, the development of plant varieties that are resistant to drought represents a strategic adjustment to droughts.

The strategic drought protection measures represent long-term adjustments, since they tend to be permanent and cannot be implemented in response to ongoing drought. However, the impacts of an ongoing drought can be significantly attenuated by various short-term measures. Some of those measures are discussed below.

Tactical and Emergency Response to Drought

Many researchers of drought strongly recommend proactive drought management in contrast to reactive activities that are more characteristic of crisis management (Wilhite and Wood, 1985; Dziegielewski, 1986; Easterling and Riebsame, 1987; Riebsame et al., 1990). Drought preparedness represents an anticipatory approach to drought through preparing a detailed plan for prompt and efficient response to drought conditions. It is usually implemented by the development of formal (written) drought contingency plans. Such plans can be prepared at local, regional, state, or federal levels. One of the major objectives of the National Water Management During Drought Study is to develop such plans for various regions of the country.

There is a wide range of tactical measures than can be taken to reduce the adverse impacts of drought. The established water management system (i.e., operation regimes of water supply systems and the distribution or allocation of water among users) may not assure that the short supplies are utilized in a way that would minimize drought impacts. Priorities in allocation of water supply between various purposes of use can have major impacts in reducing the economic, social, and environmental costs of drought. Water conservation and emergency water supplies also can influence the balance of supply and demand and decrease or eliminate severe impacts of supply shortages.

Finally, if the tactical drought response measures are not sufficient, then some emergency measures can be introduced. Drought relief in the form of transfer payments to the drought-stricken regions can prevent the nationwide consequences of lost farm incomes and the resulting economic dislocations. These elements of drought management indicate that human adjustment to drought can greatly attenuate (or in some cases aggravate) the actual impacts of a drought event. Efforts to mitigate the negative impacts of previous droughts took many forms. For example, during the 1976-77 drought, cattle owned by South Dakota Mennonites were shipped to, and cared for, by Nebraska Mennonites (Miewald, 1978). State, regional, and national drought relief efforts were used during previous droughts to reduce the total economic impact. During the 1988 drought, the federal government provided more than $3.9 billion in aid to drought-stricken agricultural producers (Cloud, 1989).

DROUGHT MANAGEMENT CRITERIA

The available literature on the problem of drought has not established a coherent conceptual framework for drought management. The conceptual development of previous research often failed to appreciate the role of human decisions in creating many of the losses we call "drought costs." In order to facilitate the assessment of present knowledge of drought management, we offer the following conceptual framework.

Strategic and Tactical Adjustments to Drought

The structure of the drought management problem depicted in Figure I-1 provides a basis for building a general evaluation framework. First, we make a distinction between long-term (or strategic) and short-term (or tactical) adjustments to drought. Water agencies and communities decide on these long-term and short-term adjustments. The former are often, though not exclusively, structural (e.g., water storage reservoirs, groundwater recharge basins, aqueducts). The nonstructural short-term adjustments may include pricing systems, ongoing technological and public education. In the short run, water agencies and individuals decide what actions to take and when to take them, given the existing state of long-term adjustments, the recent history of precipitation/streamflow/soil moisture, predictions for near-term future patterns of these variables, and their preferences in terms of risk aversion.

In these circumstances, no entirely naturalistic conceptual framework can really help us think about the problem of drought. G. F. White and his students saw that drought losses were jointly determined by natural events and human adjustments, but their notion of human adjustments was the long run one mentioned above. This approach relied on the concept of minimizing the sum of costs plus expected losses as a function of some indicator (e.g., water use-to-safe yield ratio used by Russell et al., 1970). The idea that what is referred to as short run adjustment determines the sizes, temporal and spatial pattern, and distribution over industries and population groups of coping cost means that the previous approaches are inadequate.

Optimal Drought Adjustments

This newer, more comprehensive conceptual drought management model is shown in Figure I-3. According to Russell (1991), this relationship may be represented by the following simple static model:

$$\underset{P,S}{\text{Minimize}}\ [C(P) + D(P,S) + A(S)] \qquad (1)$$

Where

P = a parameter capturing the probability density function for drought events

S = a parameter reflecting success at reducing potential losses from a precipitation shortfall of given magnitude, i.e., success at "coping" with drought

C(P) = cost of long-term adjustments where $\partial C/\partial P < 0$ and $\partial^2 C/\partial P^2 > 0$

D(P,S) = expected damages as jointly determined by long-term decisions (choice of probability P) and short run coping success (choice of S) where

$\partial D/\partial P > 0$, $\partial^2 D/\partial P^2 > 0$ and $\partial P/\partial S < 0$, $\partial^2 P/\partial S^2 < 0$

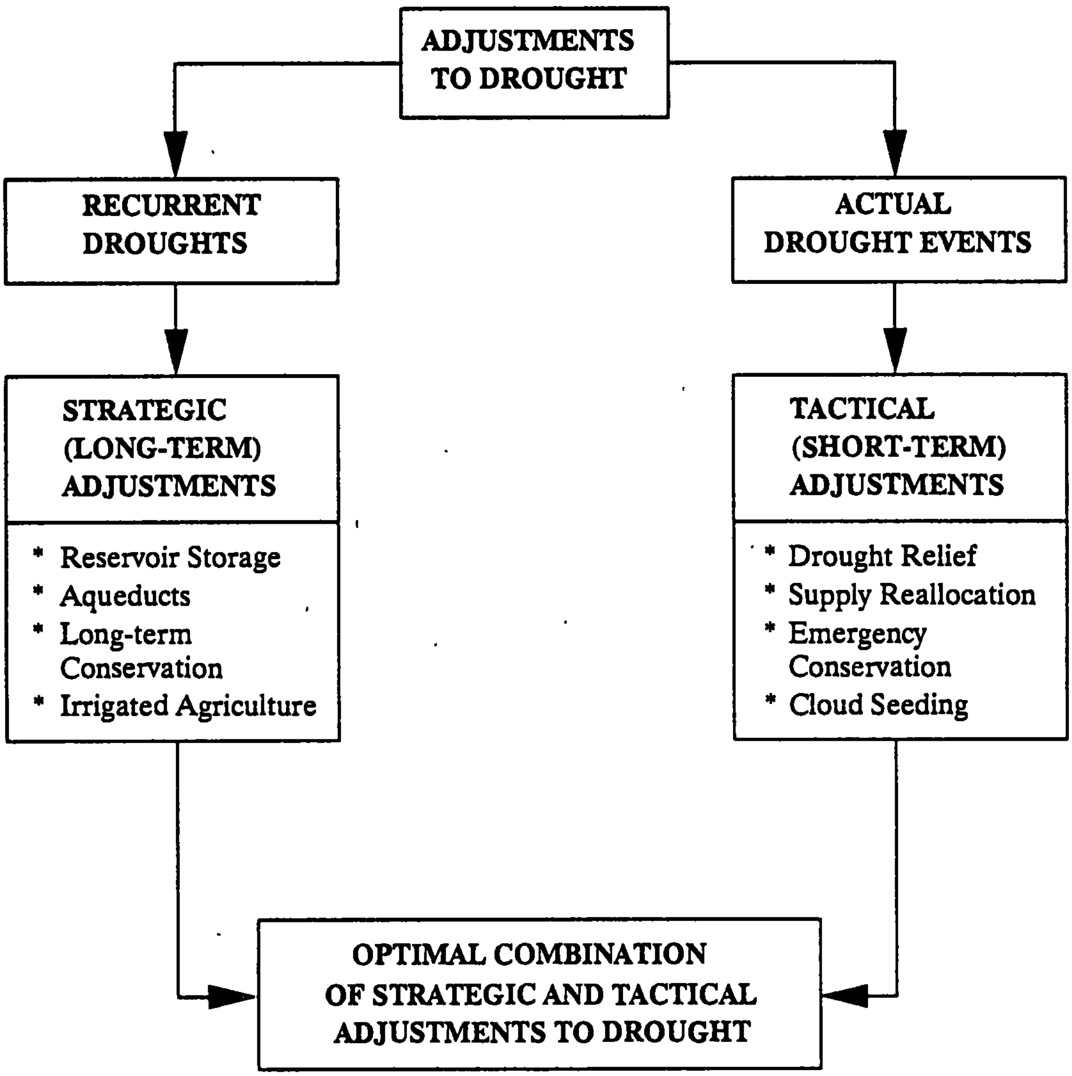
A(s) = cost of attaining S level of coping success where $\partial A/\partial S > 0$ and $\partial^2 A/\partial S^2 > 0$

The first order conditions, then, for optimal adjustments to drought risk are

$$\frac{\partial C}{\partial P} + \frac{\partial D}{\partial P} = 0 = \frac{\partial D}{\partial S} + \frac{\partial A}{\partial S} \qquad (2)$$

Since the expected damage D and its derivatives are assumed to be functions of both P and S, it will not in general be possible to pick P independent of S or vice

FIGURE I-3
STRATEGIC AND TACTICAL ADJUSTMENTS TO DROUGHT



versa. This captures the economic essence of the problem. If $\partial D/\partial P$ and $\partial D/\partial S$ were not functions of both P and S we would have the simple requirement that in both short and long run, marginal costs be set equal to damages avoided <u>and</u> these problems could be solved separately.

The optimization criteria stated in (1) and (2) can be incorporated into a general drought optimization model that would reflect growing demand and the need to make expansion path decisions in the face of (possible) economies of scale in the cost of long-term adjustments C(P). Furthermore, a dynamic programming model could be formulated to reflect some dynamic considerations such as when long-term choices foreclose or open up short-term choices or vice versa. However, formulating a truly dynamic model would not be easy. A simple version could be created that could take advantage of the results of optimal control theory. For example we could write:

$$C_t\ (P_t,\ S_t) \qquad (3)$$
$$A_t\ (S_t,\ P_t) \qquad (4)$$
$$D_t\ (P_t,\ S_t) \qquad (5)$$

and construct some relation between C_t and A_t analogous to the capital stock-investment relation in simple growth models.

ANALYTICAL FRAMEWORK

An analytical framework for the development and evaluation of national policies and plans for water management during drought should include four analytical steps: (1) assessment of vulnerability to drought, (2) measurement of potential consequences of drought, (3) evaluation of drought management options, and (4) formulation of a national drought management policy and development of drought response plans at national, regional, state, and local levels. Such a framework is shown in Figure I-4. The objectives of each step are briefly summarized below.

Assessment of Drought Vulnerability

The purpose of this step is to assess (1) the risk of meteorological drought, (2) the sensitivity of a region (i.e., economic activities) to water shortages during drought, and (3) the preparedness of local, state, and regional governing bodies to drought. Another element of this procedure is the assessment of long-term drought protection and the degree to which it influences the risk of experiencing shortages of water supply during drought.

As mentioned earlier, it is helpful to make a distinction between the "established water management system" and "water management during drought." The elements of "drought management" on Figure I-1 include both strategic and tactical adjustments to drought. All strategic adjustments are included in the "established water management systems." "Water management during drought" is used to denote the extraordinary actions that enhance the ability of the established water management system to manage an ongoing drought. Such tactical and emergency actions are depicted in Figure I-1 as "prediction and prevention" and "preparedness for response." Accordingly, federal drought relief payments, emergency water conservation, cloud seeding, and other similar actions would constitute "water

FIGURE I-4

AN ANALYTICAL FRAMEWORK FOR WATER MANAGEMENT DURING DROUGHT

STEP 1. ASSESS THE DROUGHT RISK, VULNERABILITY, AND PREPAREDNESS STATUS

* Assess the frequency and characteristics of drought events
* Assess the vulnerability of established uses and management systems to water shortages
* Assess the preparedness to drought at local, regional, state, and federal levels

STEP 2. PREDICT THE POTENTIAL ECONOMIC, SOCIAL, AND ENVIRONMENTAL CONSEQUENCES OF DROUGHT

* Identify social and economic activities affected by drought
* Estimate economic, social, and environmental losses for droughts of varying severities

STEP 3. IDENTIFY AND EVALUATE OPTIONS FOR WATER MANAGEMENT DURING DROUGHT

* Identify legal and administrative environments of drought management
* Identify the range of options for modifying the adverse impacts of drought
* Evaluate the feasibility, cost, and efficacy of specific management techniques

STEP 4. FORMULATE OPTIMAL DROUGHT PREPAREDNESS AND RESPONSE PLANS

* Define social, political, and economic criteria for drought management
* Formulate a national policy for drought response
* Prepare specific water management plans for water resources regions

management during drought." However, one should keep in mind that, in reality, water management during drought may be the principal shaping force for "established" or "strategic" water resources management.

The need for short-term drought response measures increases when permanent adjustments to drought are minimal or absent. Conversely, a sufficiently large investment in permanent drought protection can practically eliminate the need to prepare for shortages even during severe droughts. The optimization criteria described in the previous section should be used to select the optimal combination of the permanent and temporary measures. In order to find the optimal level of drought protection (i.e., permanent adjustments), it is necessary to measure the risk of water shortages during droughts. Russell et al. (1970) used a water-use/safe-yield ratio as an "index of water system inadequacy." Figure I-5 shows the interregional comparison of system inadequacy based on data gathered by the U.S. Public Health Service. It shows plots of 34 urban water supply systems comparing their historic average water use as of 1962 and the estimated safe yields of their supply systems. Definitions of safe yield vary from place to place, so the graph is an illustrative rather than a definitive indicator of vulnerability. In general the Southwest has the greatest safety measure, with about two-thirds of the population having safe access to twice as much water as they use.

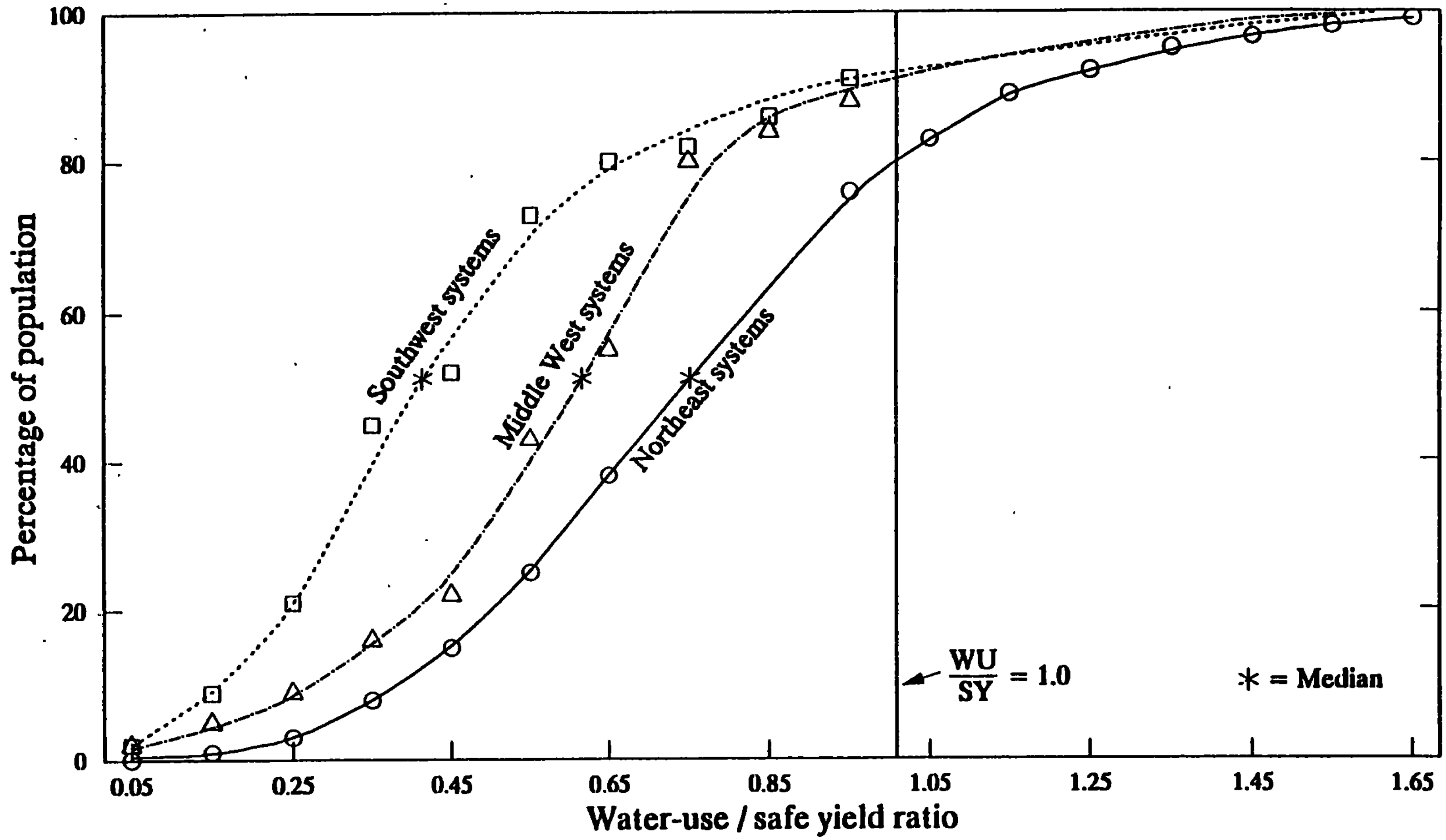
The concept of "safe yield" is defined using such statistical probability terms as "risk" and "reliability." According to the discussion provided in Dziegielewski and Crews (1986), the reliability of supply defines the capability of water sources to sustain a required level of supply (or provide required amounts of water) over time as the hydrologic input (e.g., reservoir inflows) varies both seasonally and annually. Specifically, assuming that the hydrologic variability can be described by a reasonably well known probability distribution and that a desired outcome (i.e., availability of required amounts of water) will take place with a probability of P, the term "risk" is usually used to denote the probability (1-P) of other outcomes. In applying risk to droughts, a related concept of "yield" (or "safe yield") is used. The safe yield is the output of a water supply system that can be maintained during a severe drought. The estimated probability of such a drought beginning in any given time period is (1-P). The value of P is used to define the "reliability" of the safe yield. For example, if the safe yield of 25 million gallons per day (mgd) can be maintained during a drought with a return period of 50 years, the "reliability" of this safe yield would be 98 percent. This implies that the risk of having a shortage of water in any given time period is 2 percent.

Measurement of Drought Impacts

Although a severe drought may have both economic and noneconomic (e.g., social, environmental) effects, the following discussion is limited only to the former. The sequence of drought impacts shown in Figure I-1 indicates that the total economic effect of a drought is a function of both drought severity, the level of permanent drought protection in place, and the short-run success of coping with the drought.

Drought severity measures the magnitude and duration of the precipitation/streamflow/soil moisture deficit. The conventional terminology used in the literature follows the definitions proposed by Yevjevich (1967). His definitions of drought characteristics (or parameters) rely on a statistical method

FIGURE I-5
INTERREGIONAL COMPARISON OF THE DISTRIBUTION OF POPULATION OVER THE WATER-USE / SAFE YIELD RATIO



Source: Russell, Arey, and Kates, 1970.

of analyzing a sequential time series of stochastic variables known as the "theory of runs." Figure I-6 illustrates the definitions of the three characteristics of a drought event: duration, magnitude, and severity. Drought severity is defined as the total deficit (the area below the base). Drought duration is defined as run length below average flow (or precipitation). Drought magnitude is defined as the average size of deficit (i.e., severity divided by duration).

In reality, the traces of monthly precipitation data (especially their departures from long-term averages) rarely follow the patterns shown by Yevjevich (1967). The run length (t_1) cannot be easily determined from such traces and it has to be arbitrarily selected by the researcher. Figure I-7 shows the analysis of drought events in Illinois performed by Changnon et al. (1982). The number of drought events depends on the duration used. Drought events for various durations are ranked in terms of their average magnitude, thus facilitating determination of statistical properties of these events. The groupings of drought sums in Figure I-7 indicate that between 1900 and the present, Illinois experienced three major droughts lasting 20, 15, and 5 years, and three annual droughts (i.e., lasting 1 year or less).

The greater the severity of a drought event, the higher are the potential economic damages. However, more severe droughts occur less frequently, and the most severe (and therefore least probable) drought events may be responsible for only a small portion of the drought damages that would accumulate over a long period of time.

The measurement of potential economic consequences of droughts during a prescribed planning period (e.g., a 50-year planning horizon) can be assessed for a given level of permanent drought adjustment (i.e., the established water management system) using the concept of "coping cost" (Dziegielewski and Crews, 1986). This coping cost is determined on the basis of the probability of water shortages and the cost of coping with them (including expenditures on coping measures A(S) in equation (1) and the residual economic losses $D(P_1S)$).

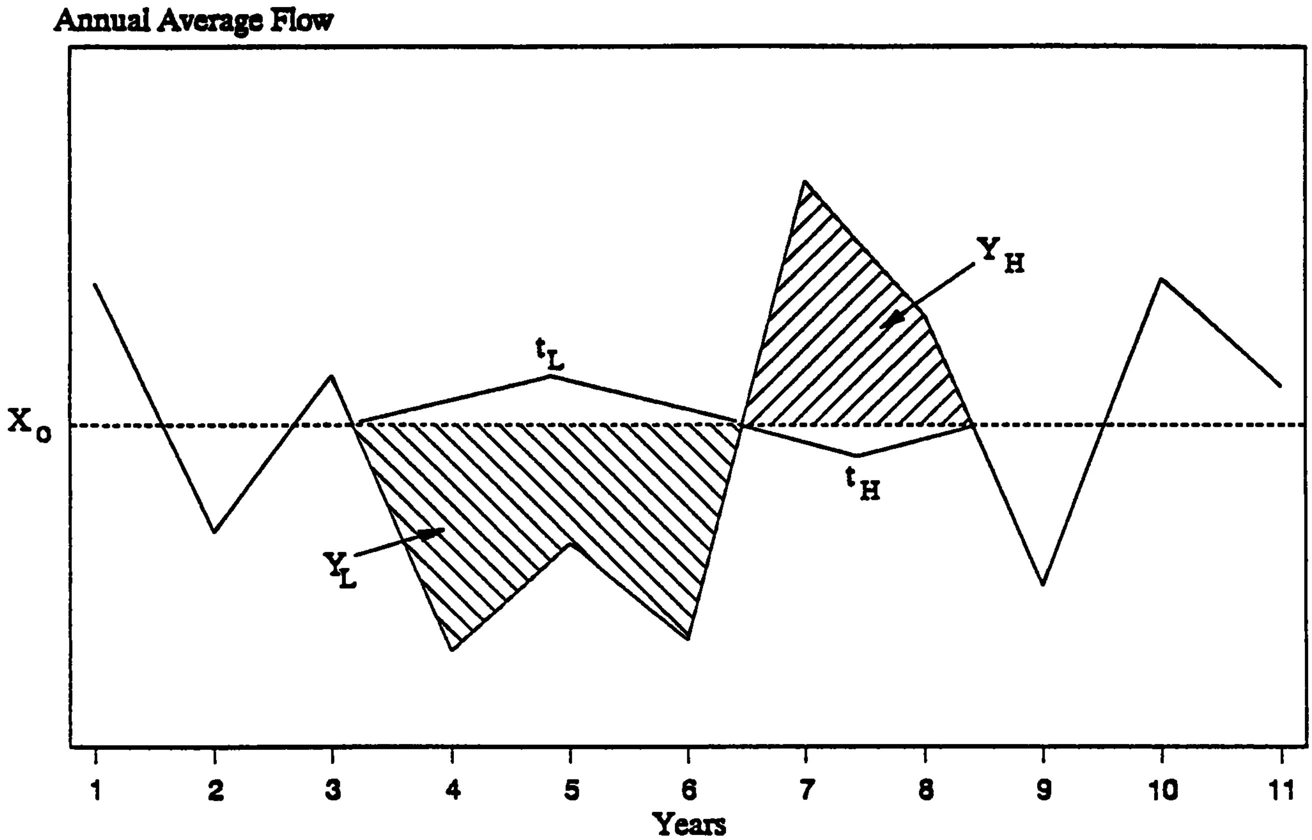
Evaluation of Options for Water Management during Drought

The short-term drought responses (both tactical and emergency) can be conveniently grouped into demand management and supply management techniques. The evaluation of these techniques requires the use of multiple criteria. These criteria differ somewhat between the two groups of measures.

Figure I-8 displays the various elements of the process that formulates alternative measures for short-term drought management. The three major stages of the process are (1) identification of possible measures, (2) a detailed evaluation of individual measures, and (3) final formulation of feasible alternatives. The purpose of the evaluation of individual demand-side and supply-side measures is to select an array of measures that are applicable and will be able to pass tests of technical, economic, legal, social, and political feasibilities.

Chapter IV provides a detailed review of both conventional and innovative drought management techniques.

FIGURE I-6
PARAMETERS OF THE RUNS OF A HYDROLOGIC SERIES



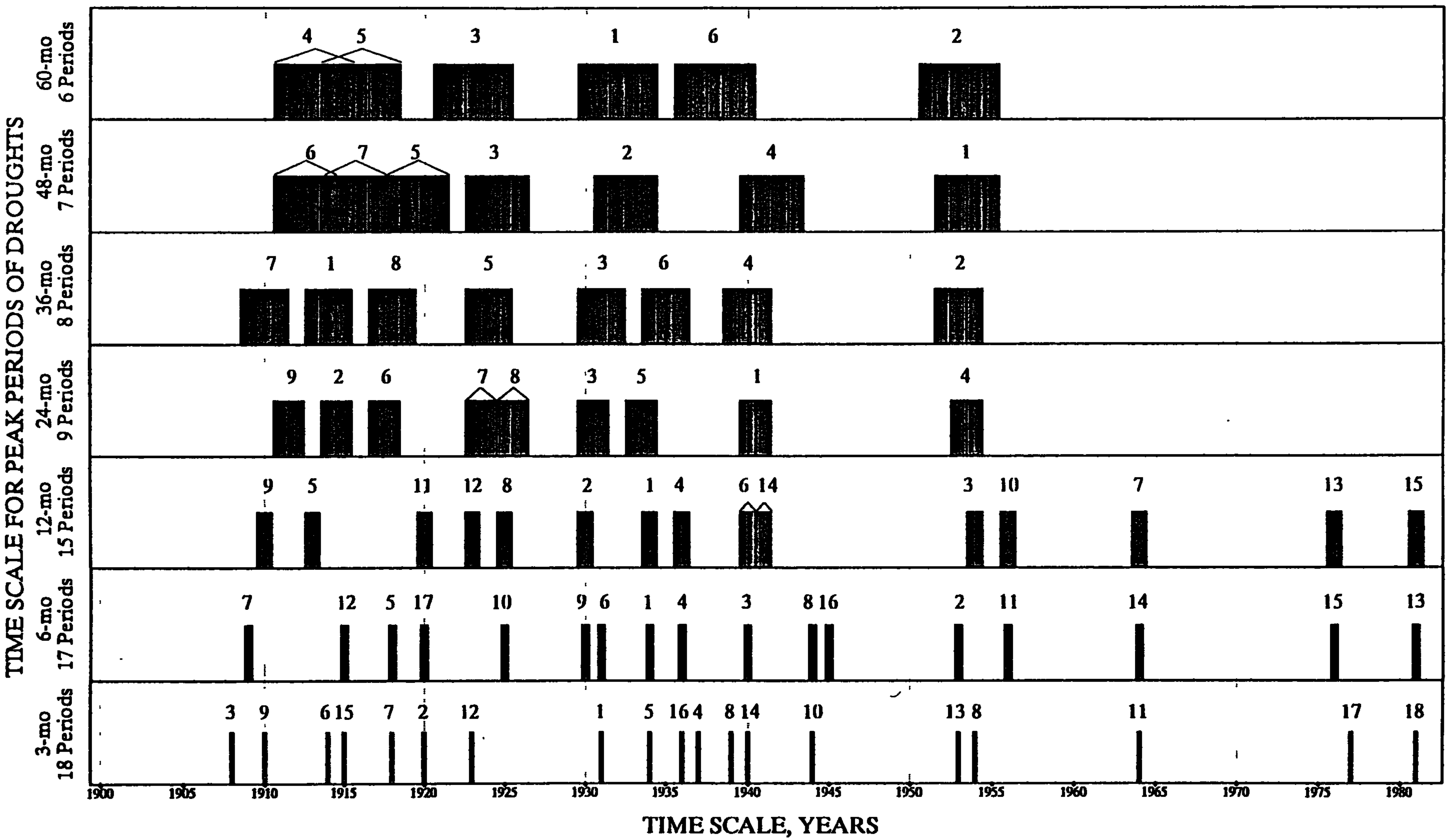
Runs Parameters:

Y_H = Run-sum above X_o
Y_L = Run-sum below X_o (drought severity)
t_H= Run-length above X_o
t_L= Run-length below X_o(drought duration)
Y_L/t_L= Drought magnitude

Source: Yevjevich, 1967

FIGURE I-7

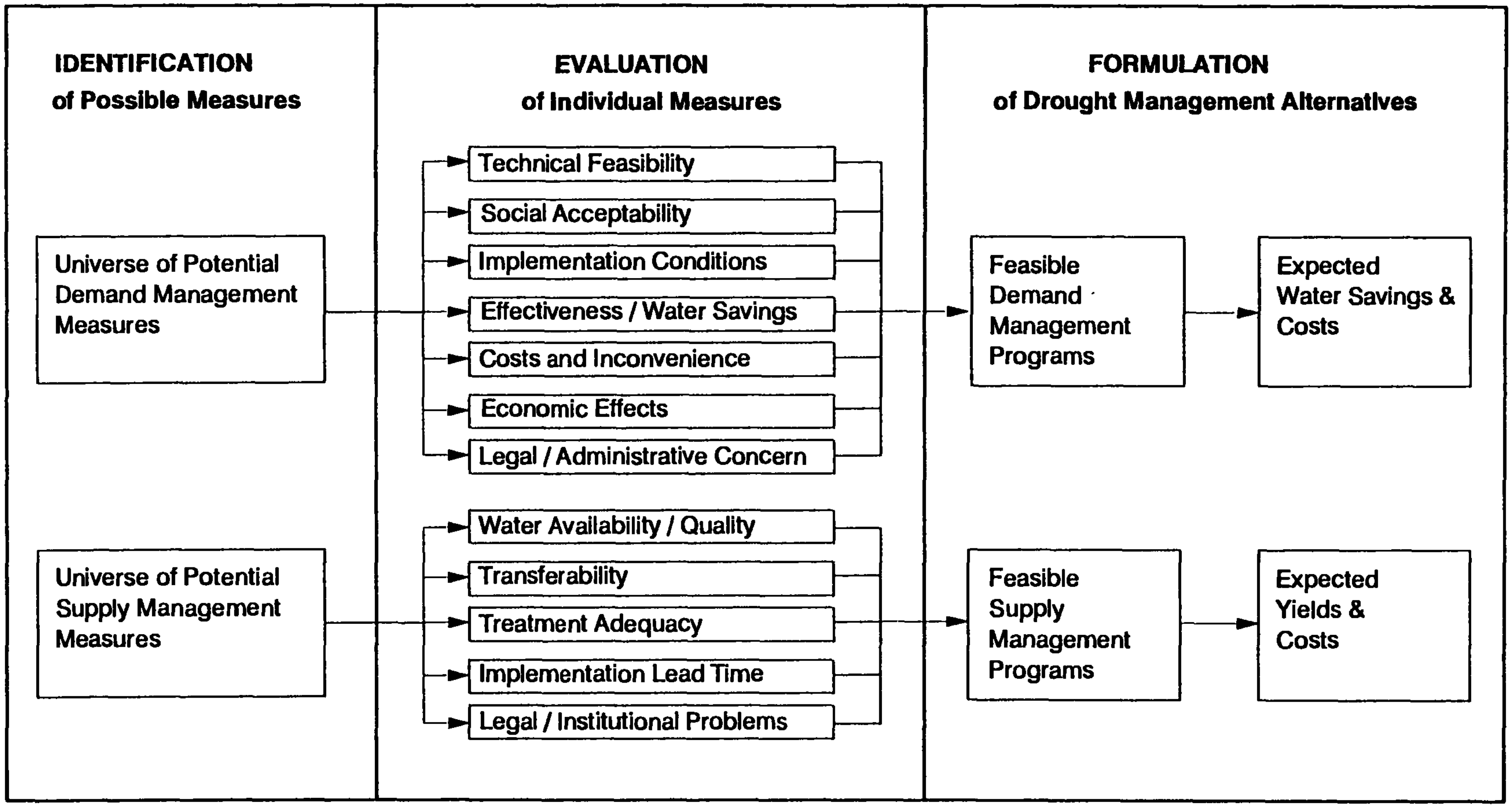
ILLINOIS DROUGHTS OF VARYING DURATIONS (1906-1981), WITH RANKINGS



Source: Changnon, 1981

FIGURE I-8

FORMULATION OF DROUGHT MANAGEMENT ALTERNATIVES



Formulation of Optimal Drought Preparedness and Response Plans

The final analytical step of drought management analysis is to formulate drought management proposals that can be used in formulating a national or a regional policy for drought response. Such proposals may include several drought management alternatives to be implemented together. The national drought management policy may be supplemented with regional plans for managing water during periods of drought.

II. DROUGHT VULNERABILITY AND PREPAREDNESS

The United States exhibits extreme variability in terms of its physiography and hydrography. Differences in susceptibility to natural disasters such as drought are a by-product of this variability. Although drought can occur in any region of the nation at any time, there may be differences in its characteristics and impacts.

While the potential for meteorological drought exists in every state, the vulnerability of a region or community to the effects of drought varies. The Great Lakes region can withstand extreme drought without experiencing public water supply shortages or disruptions, while the Southeast region may experience significant effects of a relatively minor drought event. Communities which are susceptible to drought have developed many ingenious ways of adjusting and responding to drought. While there have been many droughts, no community in the nation has ever gone without drinking water because of the presence of such adjustments (White, 1985). One might expect that the amount of time and energy devoted to drought protection by regions or communities may be a function of their vulnerability to droughts (both in terms of severity and frequency of drought events). Russell et al. (1970) found some evidence for such a relationship by using the supply-and-demand data for 1962 (see Figure I-5).

The first part of this chapter examines the susceptibility to drought of the various regions of the nation and the extent of drought protection present. The intent is to gain an understanding of where we stand as a nation when considering the hazard of drought. First, we consider ways of assessing drought vulnerability, then discuss what types of activities (e.g., urban, agricultural, environmental, or recreational) are most vulnerable to drought-induced shortages of water. The second part provides an assessment of drought preparedness at various levels of government.

ASSESSING DROUGHT VULNERABILITY

Throughout most of its history, the United States has treated the issue of providing adequate supply of drinking water almost exclusively as an engineering problem. With respect to cities, when an urban area grew to the point where the water supply base was seen as inadequate, new supply sources were sought and developed. Today, the issue of water supply shortage during drought is more likely to be considered from the perspective of the human adjustments to drought, where "the real issue is the desirability of providing ample supply of water for urban areas even during the periods of drought (Dziegielewski, 1988)." Accordingly, the vulnerability of urban areas to drought is often influenced by availability of both supply-and-demand management measures because of this shift in the "philosophy" of water management. Hopefully, this change will bring about significant reductions in the societal costs of drought protection.

REGIONAL VULNERABILITIES

As discussed above, there are a number of factors that affect the vulnerability of an area or region to drought. The attainable precision of such assessments depends on the availability of data. The desirable precision depends on intended use. The four drought regions as defined by Warrick et al. (1975) are reviewed in general, followed by an examination of the USGS water-use data to assess water budgets (comparisons of supply and demand) in the context of a region's vulnerability to drought.

Drought Regions

When considering drought vulnerability it is helpful to break down the nation into regions that exhibit similar climatic and physiographic patterns. Warrick et al. (1975) provide such a breakdown (Figure II-1) based on the "important characteristics of the physical drought subsystem," which they define as "the major physical and social parameters of the drought hazard." The regions are presented as:

(1) The arid, semiarid Southwest
(2) The semiarid, subhumid Midcontinent
(3) The humid East
(4) The Northwest

Warrick et al. (1975) suggest that these regions are not "discrete areas" and differences do exist within each in a meteorological and topographical sense "but on the basis of the duration of drought, other physical characteristics, and the differences in agricultural activity, important differences between each of the four areas can be readily discerned." These differences are discussed in the sections that follow.

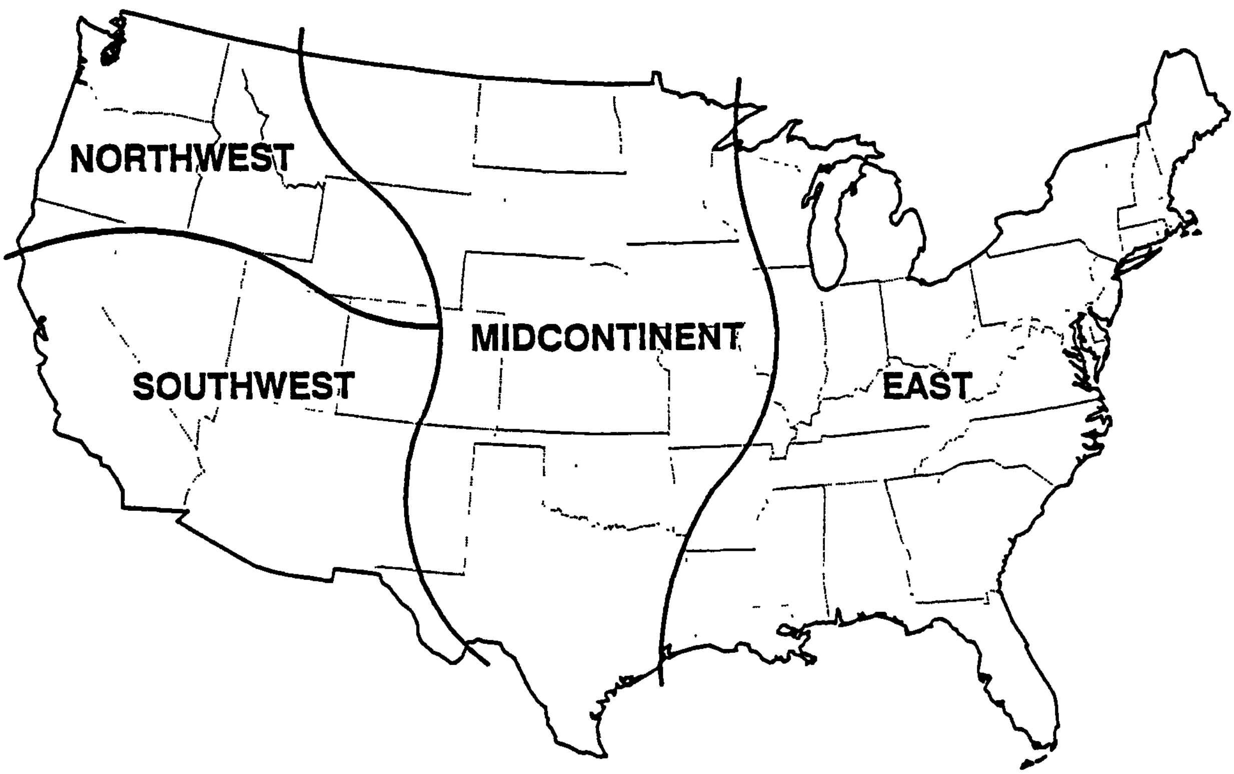
Water Resources Regions

In 1975 the United States Water Resources Council developed a breakdown of water resource regions based on major river basins of the United States (Figure II-2). The contiguous U.S. was divided into 18 regions allowing for a more specific estimation of drought vulnerability than the Warrick et al. (1975) scheme would provide.

Drought vulnerability can be assessed in many ways. There are not only physical (i.e., surface and/or groundwater supply) and climatological (i.e., precipitation, evapotranspiration) parameters that may be used but also socioeconomic factors such as the existence of drought contingency plans or the population and major economic base of a community. The United States Geological Survey (USGS) Circular 1001, Estimated Use of Water in the United States, (Solley et al. 1988) is used here to examine the water use characteristics of the 18 regions, mentioned previously. Water-use characteristics, together with hydrological factors, can be useful in assessing drought vulnerability of each region.

FIGURE II-1

PHYSICAL DROUGHT REGIONS OF THE UNITED STATES



Source: Warrick et al., 1975.

FIGURE II-2

WATER RESOURCES REGIONS OF THE UNITED STATES AS ESTABLISHED BY THE U.S. WATER RESOURCES COUNCIL IN 1970

Source: U.S. Water Resources Council, 1978, The Nation's Water Resources 1975-2000: Second National Water Assessment, Superintendent of Documents, Washington, D.C.

The Humid East

Figure II-2 shows that this region covers an area that includes all (or parts) of 31 eastern states. A common characteristic of this area is that annual precipitation exceeds evapotranspiration, and therefore soil moisture is relatively high. However, a number of major metropolitan areas in the region have experienced droughts of such severity as to cause major concerns. The northeastern drought of 1962-66 is an example of such an event, although the actual economic impacts of that event were relatively small (Russell et al., 1970).

The region's urban areas rely on surface-and/or groundwater sources that may be significantly affected by drought events of relatively short duration (annual). Furthermore, in many cities the problem of drought is manifested not in a shortage of water in the supply source but in increased demands on the pumping and treatment facilities due to increased water use during the drought. Many cities that are equipped to handle the increased demand on their systems may enjoy an economic benefit from a drought event as their increased pumping requirements imply increased revenue for the water supply agency.

Agriculture, in the humid East is periodically affected by seasonal, short-term drought events. Severe droughts, when they do occur, cause significant impacts to agriculture and economies associated with agriculture. The southeastern drought of 1986 and the regionwide drought of 1987-89 are examples of the impact that severe extended droughts may have in this region.

The Semiarid, Subhumid Midcontinent

According to Warrick et al. (1975), this region consists of all or part of 16 states that lie east of the Continental Divide and west of the Mississippi River. It is also a region that "is bisected roughly by the 2,000 foot contour and the zero index line, where precipitation received approximates moisture evaporated." This region is very vulnerable to drought (particularly its agricultural activities) because the variabilities in precipitation and temperature are extreme.

In terms of the most extensive and severe droughts the nation has experienced--those of the 1930s, 1950s, and recently the 1980s--the areas most heavily affected were part of this region. The economic losses absorbed by this region, and the nation, during those severe droughts were very high. As a result of the impacts that historic droughts have caused to this region, there is an increased emphasis on planning for recurring drought events. Decision makers in the region are more aware of the vulnerabilities of their particular systems to drought events of varying magnitude. Therefore, minor droughts of short duration may not have large impacts, since the area is more prepared for droughts in general.

The Northwest

This region of the country is subject to both high geographic and high temporal variability in precipitation. The region includes the rainforest areas along the coast and subalpine and alpine areas in the Cascade Range, and inland arid regions evolved as a result of adiabatic processes (those processes that occur without gain or loss of heat) in the atmosphere over the Cascades.

The increases in population of the urban centers such as Seattle and Portland have created the need to develop water conservation practices in the region. Warrick et al. (1975) suggest that the biggest drought threat to the region may be in terms of hydroelectric power-generating ability. The conflicting interests that are represented by hydroelectric-generating capabilities and increased public water supply needs can have tremendous regional economic, social, and environmental impacts. Planning for the eventuality of these conflicts takes on increased importance as a means of minimizing those impacts.

Agricultural regions east of the Cascade Range are susceptible to drought, although much of the area is irrigated farmland. Extended multi-year drought can reduce surface-water supplies to the point where production of agricultural crops will be severely affected.

The Arid, Semiarid Southwest

This region is similar to the Northwest region in that there is great variability in climatic types and precipitation rates throughout the area. It includes the Rocky Mountains and the Sierra Nevada and desert valley areas. The main sources of water for the region are the Colorado River and the snowpack of the mountain ranges.

In many ways this region is the most vulnerable to multi-year drought. The potential national impact of such a drought may be magnified in the future because of the continuing migration of the U.S. population to the region over the last several decades. The urban centers in this region have recognized the importance of adequate water supplies to their continued growth and prosperity and have put forth much effort to ensure future water availability. Since much of the present possible water supply has been allocated in the region, there is great need for demand management, both during normal weather and in response to drought.

ESTABLISHED WATER USES AND VULNERABILITIES

In addition to climatic and physiographic characteristics the vulnerability to drought of individual water supply systems depends on the type of sources of supply they use. In general, areas relying on surface water are inherently more vulnerable to drought than those areas that use groundwater. Streamflow and reservoir storage are affected by precipitation deficits faster and to a greater extent than deep groundwater aquifers. This section examines the proportions of population and agricultural activity relying on surface water for each of the river basin regions developed by the U.S. Water Resources Council in 1975. The irrigated acreage that exists within each of those same regions is also considered. Table II-1 provides an overview of the amount of surface water that is used for irrigation purposes. Since surface-water sources are more susceptible to drought, those areas that rely heavily on surface water for irrigation may be more vulnerable in the absence of long-run adjustments. Also the amount of irrigated acreage may be seen as a measure of an area's drought protection, although caution should be taken in that extreme drought may severely affect irrigated agriculture, since the availability of irrigation water is often dependent on reservoir storage. The data in Table II-1 do suggest there are several critical areas. Historically, these areas have experienced difficulties as a consequence of drought.

TABLE II-1

IRRIGATION SURFACE WATER WITHDRAWALS BY WATER RESOURCES REGION, 1985

Region	Percent of Irrigated Croplands (by Region)	Percent of Croplands Irrigated with Surface Water	Irrigation in Region Percent of U.S. Total
New England	2.6	84	0.15
Mid-Atlantic	2.7	60	0.11
South Atlantic-Gulf	13.8	47	1.24
Great Lakes	1.9	54	0.10
Ohio	0.3	53	0.15
Tennessee	0.5	89	.01
Upper Mississippi	1.4	18	.05
Lower Mississippi	18.0	24	1.02
Souris-Red-Rainy	0.7	48	.03
Missouri Basin	13.1	66	11.80
Arkansas-White-Red	13.0	22	1.46
Texas-Gulf	18.1	27	0.98
Rio Grande	47.0	75	2.74
Upper Colorado	74.4	100	5.25
Lower Colorado	99.3	58	2.68
Great Basin	72.6	84	4.56
Pacific Northwest	40.4	86	19.40
California	89.5	67	15.10
OVERALL	28.3[1]	59[2]	67.83[3]

(Figures may not add to numbers in the last row because of independent rounding.)

[1] Overall percent average of total cropland irrigated.
[2] Overal percent average of total cropland irrigated using surface water.
[3] Total water withdrawals for irrigation = 135,937 MGD.
Total surface water used for irrigation = 90,623 MGD.

Source: Adapted from Solley, W.B., Merk, C.F., & Pierce, R.R. (1988). Estimated Use of Water in The United States in 1985. U.S. Geological Survey Circular 1004.

In the western half of the nation, large amounts of surface water are used for irrigation. This is to be expected because the introduction of agriculture in the West was dependent on irrigation (precipitation in the area is less than evapotranspiration). Therefore, agricultural activities of the West may be considered to be directly dependent on water storage (both surface water and groundwater) and only indirectly on current weather patterns. In contrast, the East depends on natural seasonal precipitation for soil moisture. As a result, the short-term seasonal droughts are more likely to have impacts on agricultural production in the eastern half of the nation. The western agriculture will more likely be affected during more severe drought periods lasting several years.

The Upper Colorado, Pacific Northwest, Great Basin, Rio Grande, and, to a lesser extent, California and the Missouri regions, are all dependent on surface-water sources for a large part of their irrigation water needs. These areas account for a majority of the total water used for irrigation in the United States. These areas may also be considered to be the most susceptible to extended droughts.

Table II-2 shows the percent of the United States total population that relies on surface water for its public water supply by water resources region. Although there is great variability in the amounts and types of surface water that are used, the data demonstrate some systematic patterns. In the Mid-Atlantic region for example, 12.5 percent of the total U.S. population relies on surface-water sources. Much of this water is obtained from major river supplies and from reservoir storage that can be seriously affected during drought events. This region does not have the access to the essentially limitless freshwater supplies of the Great Lakes region.

The California region is certainly very susceptible to drought, although only 33 percent of the population relies on surface-water supplies because of uneven distribution of water throughout the state. Since some of the surface water that is available to the region comes from the snowpack in the Sierra Nevada, the region is afforded with some warning of when to expect inadequate water supplies. Water agencies in the region employ some of the most sophisticated, modern techniques of water supply/demand management to ensure the availability of water as a matter of general practice and not just as a response to periodic droughts. Other regions that may be of concern are the New England, Tennessee, Ohio, Upper Colorado, Arkansas-White-Red Basin.

The distribution of inadequate surface-water supplies among various regions is depicted in Figure II-3. It describes regions of inadequate streamflow that directly relates to surface-water availability. The regions with the most serious concerns are in the Southwest and the Great Plains, since much of those areas often experience a 70 percent depletion of streamflows during average years. The migration of population to the Southwest region adds to the concern about inadequate streamflow. Depletion rates may be expected to become even greater. However, intensive water management practiced in the area may allow continued growth to occur despite the lack of adequate streamflow supply. The figure also shows why the Great Plains region may have been affected in such a manner during recent drought events. The drought of 1987-89 was severe and in a region of the country that exhibits 70 percent streamflow depletion during average years, it becomes easy to imagine how heavily affected the area was (or <u>could be</u> in future drought events).

TABLE II-2

PUBLIC-SUPPLY SURFACE WATER USE BY WATER RESOURCES REGION, 1985

Region	Percent of Population Relying on Surface Water (By Region)	Population Served by Surface Water (Percent of total U.S. Population)
New England	74	3.93
Mid-Atlantic	73	12.50
South Atlantic-Gulf	44	5.73
Great Lakes	84	7.57
Ohio	70	5.52
Tennessee	74	1.12
Upper Mississippi	47	3.79
Lower Mississippi	30	0.90
Souris-Red-Rainy	48	0.11
Missouri Basin	56	2.46
Arkansas-White-Red	67	2.37
Texas-Gulf	56	3.94
Rio Grande	24	0.22
Upper Colorado	68	0.18
Lower Colorado	42	0.79
Great Basin	41	0.38
Pacific Northwest	59	1.90
California	33	4.08
TOTAL		57.5

(Figures may not add up to total because of independent rounding)

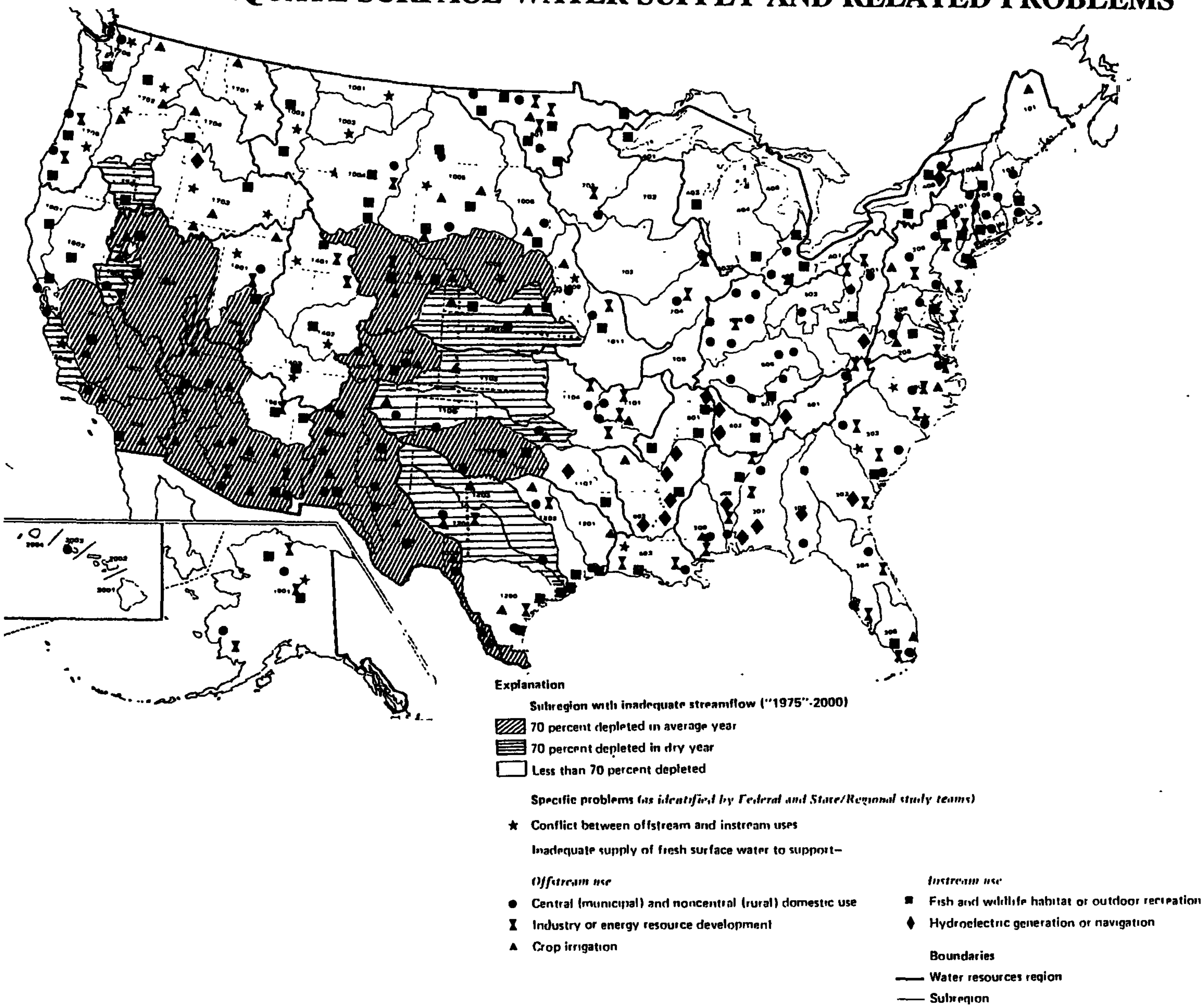
* Total U.S. population in regions served by public water supply systems = 195,542,000 persons.

** Total U.S. population relying on surface water = 112,373,000 persons.

Source: Adapted from Solley, W.B., Merk, C.F., & Pierce, R.R. (1988). Estimated Use of Water in The United States in 1985. U.S. Geological Survey Circular 1004 and The Nation's Water Resources 1975-2000. Vol 2: Water Quantity, Quality, and Related Land Considerations. 2nd National Water Assessment by the U.S. Water Resources Council, Dec. 1978.

FIGURE II-3

INADEQUATE SURFACE-WATER SUPPLY AND RELATED PROBLEMS



Source: U.S. Water Resources Council, 1978, The Nation's Water Resources 1975-2000: Second National Water Assessment, Superintendent of Documents, Washington, D.C.

Indicators of the Vulnerability to Drought of Selected Metropolitan Areas

The vulnerability of a metropolitan area to drought is, as discussed in this report, dependent on a variety of factors including physical infrastructure, economic base, climatic and geographic considerations, and institutional considerations. All of these factors make it difficult to make a precise determination of a city's drought susceptibility. Regardless of this, there has been a need to make assessments based on available knowledge. What follows is an example of one way of estimating the drought vulnerability of an urban center.

Table II-3 is a compilation of water-use data and safe-yield statistics for selected cities in the United States. The ratio of these two values provides a measure of vulnerability to drought. As the ratio gets closer to or exceeds the value of 1, the susceptibility of that city to major impact from a drought event becomes greater.

While the data used in Table II-3 is dated (almost 30 years old), it does provide an example of an indicator for assessing drought vulnerability. However, safe-yield estimates are difficult to obtain, making a national assessment on this basis very costly. Most recent information collected for the purpose of this study is shown in Table II-4.

Regional Differences in Vulnerability

While it is true that droughts can and have affected all regions of the nation, certain regions are at greater risk from drought impacts than others. These differences are likely to increase as a result of recent changes in the distribution of population and economic activities.

The Southwest region of the nation used to be a sparsely populated area that was impacted relatively little in drier than average years. Presently, major metropolitan areas exist in these desert regions that have already captured most available water supplies. However, the region has shown great ability not only to develop new sources and acquire new water rights but also to create conservation and demand management programs that allow the region to meet the needs of its metropolitan areas. The planners in those areas are well aware of their growing water demands and the possible effects that an extended drought could have on their communities. As a result, they are actively involved in drought contingency planning and are perhaps more prepared to handle droughts than other regions of the country.

Other regions that may be of most concern to the nation are the "heartland" or "breadbasket" regions that normally receive enough precipitation for production of agricultural crops. For these regions drought occurs occasionally, but rarely is it severe enough to bring about major long-term adjustments to drought.

When severe droughts do occur, each region will respond relying on any past experience to cope with the water shortage. While this generally is effective with most drought events, economic impacts may be magnified as a consequence of poor decision making and ad hoc responses to severe drought events. Detailed drought

TABLE II-3

WATER USE/SAFE YIELD STATISTICS FOR SELECTED CITIES AS OF JANUARY 1, 1962

REGION CITY	MAX. DAY WATER USE MGD	SAFEYIELD MGD	WU/SY	SOURCE
Northeast				
New York (plant #1)	1470	1495	.98	New York Watershed
Philadelphia (Belmont Plant)	108	700	.15	Schnylkill River
Springfield, MA (plant #1)	57	63	.90	Ludlow Reservoir
Washington, D.C.	104	506	.21	Potomac River
Southeast				
Atlanta (Hemphill Plant)	112	400	.28	Chattahoochee River
Mobile, AL	28	104	.27	Big Creek Reservoir
Tampa, FL	43	60	.72	Hillsborough River
Midwest				
Bismark, ND	11	259	.04	Missouri River
Chicago (source #1)	1513	unl.	-	Lake Michigan
Cleveland (MWD)	-	unl.	-	Lake Erie
Dallas (Boatman Plant)	104	124	.84	Grapevine Reservoir
Kansas City	45	unl.	-	Missouri River
Omaha	120	unl.	-	Missouri River
Mountain				
Albuquerque	78	-	-	67 wells
Denver (all)	299	25	11.96	Platte River
Salt Lake City (all plants)	141	21214	.01	creeks and rivers
Northwest				
(BMU) (Lafayette Plant)	25	200	.13	Pandee River
Portland, OR	190	275	.69	Cedar River and Bull Run River
Seattle	282	232	1.22	Morse Lake
Spokane	66	unl.	-	19 wells
Southwest				
Las Vegas (LVWD)	15	19	.80	Lake Mead and artesian wells
Los Angeles (MWD)	400	1100	.36	Colorado River
Phoenix (Verde Plant)	-	117	-	Verde River

Source: Municipal Water Facilities Communities of 25,000 Population and Over, As of January 1, 1962, 1962 edition. U.S. Department of Public Health, Education, and Welfare, Public Health Service Publication No. 661.

TABLE II-4

WATER USE/SAFE YIELD STATISTICS FOR SELECTED CITIES

City/Water Agency	Current Water Use, MGD	Safe Yield, MGD	WU/SY Ratio
1. Phoenix, Arizona City of Phoenix Department Water and Wastewater[1]	272	257	1.06
2. Indianapolis, Indiana Indianapolis Water Company[2]	102	112	0.91
3. Springfield, Illinois City Water, Light and Power[3]	19.3	28.8	0.67
4. Southern California Metropolitan Water District[4]	3,419	3,053	1.12
5. Denver, Colorado Denver Water Department[5]	197.9	266.0	0.74
6. New York City New York City Water Supply System[6]	1,533	1,290	1.19
7. Binghampton City, New York City of Binghampton Water System[7]	12.5	43	0.29
8. Merrifield, Virginia Fairfax County Water Authority[8]	78.9	54	1.46

Sources:

1 Phoenix Water Resources Plan--1990. City of Phoenix.
2 Dziegielewski et al. 1986. Optimal Drought Plans. Volume I (1984 conditions, 100-year drought).
3 Dziegielewski et al. 1983. Prototypal Application of a Drought Optimization (1990 conditions, 100-year drought).
4 Metropolitan Water District. 1990. Regional Urban Water Management Plan (1995 conditions, worst drought on record).
5 Systems Analysis for Wastewater Reuse, A Methodology for Municipal Water Supply Planning in Water-Short Metropolitan Areas. 1975 (updated in part to July 1977). Prepared by the Denver Research Institute, University of Denver for Office of Research and Development, U.S. Environmental Protection Agency.
6 Delaware-Lower Hudson Region Water Resources Management Study. 1987. Prepared by Hazen and Sawyer for New York State Department of Environmental Conservation (average demand based on calendar year 1984, and includes direct service, upstate counties, and the JWSC-Q franchise area; safe yield based on 1960s drought).
7 Eastern Susquehanna Sub-State Region Water Resources Management Study Report. 1986. Prepared by Weston for New York State Department of Environmental Conservation (based on 1984 demand and dependable yield).
8 Sheer. 1980. (based on 1984 water use and safe yield).

assessment and post-drought evaluation studies are needed in order to assess vulnerability of the various regions of the nation to drought events. Such studies can be used to develop useful and effective ways of deciding what human adjustments to drought should occur to minimize the costs of drought.

PREPAREDNESS FOR DROUGHT RESPONSE

The concept of drought preparedness evokes the image that institutions and agencies concerned with minimizing drought impacts have "action plans" in place which outline tactical actions once a drought has been identified. Due to the previously identified difficulties in recognizing drought severity and duration, initiation of those plans may be thwarted and replaced with a series of ad hoc emergency actions. This tendency toward crisis management, as opposed to risk management, may increase the ultimate costs of drought impacts; therefore it is important that plans be well designed and understood so that in the time of drought they can be implemented to minimize economic and other impacts.

The following section describes the current status of drought preparedness at various levels of government. Federal agencies have policies in place to offer a variety of assistance programs once the declaration of a national disaster or emergency has been made. State governments often take on the role of coordinating mitigation and relief activities during national or regional emergency situations. In recognition of the widespread impacts of drought, a number of states have developed contingency plans to guide decision makers through periods of water shortage. The local water supply managers' greatest responsibility is ensuring that reliable and safe water supplies are available to the public. Yet, it is at this critical level that the availability and sufficiency of drought plans seem most variable, thus contributing to the adverse impacts of drought.

A review of existing policies for agencies at the federal level, and the interstate and state levels, followed by a detailed analysis of the drought contingency plans of five selected states, are presented in subsequent sections. Those include a review of 21 individual states' responses and resultant impacts which are related to the drought of 1988. This information was developed by a survey conducted in December of 1988. This survey demonstrates the variability of impacts and responses that existed among states at that time.

FEDERAL WATER RESOURCES INSTITUTIONS

A number of federal agencies are directly involved in providing assistance during drought events. The types of aid available are often based upon previous experience with droughts and the accompanying impacts. The following sections describe current activities, policies, and programs that constitute preparedness for drought periods at the federal level.

United States Army Corps of Engineers

In areas deemed to be drought distressed by the Chief of Engineers, the Corps has authority to initiate a number of emergency (or last resort) efforts to relieve water shortages when all other options have been exhausted. The Corps' Districts may implement well drilling, truck in potable supplies, or transport water through small-diameter emergency water lines. The Corps may require that the emergency supply construction costs be paid by the user. The user is also responsible for obtaining all necessary state and local permits prior to drilling.

The maintenance of inland waterways for transportation and navigation is also a responsibility of the Corps. Dredging of major rivers in the nation to ensure navigability is a major responsibility of the Corps during drought emergencies. The Corps may also employ other means of managing waterways during drought emergencies, such as restricting river traffic or altering releases of water from upstream impoundments.

Coordination of regional water supplies through Corps projects is another activity which ensures the availability of water for municipal demands as well as for hydropower production, transportation, and maintenance of water quality.

The Corps has also been instrumental in the development of a drought contingency plan for the Savannah River Basin. The plan outlines policies and actions which can alleviate problems concerning competing water uses and ensure adequate water quality.

The Corps has initiated extensive research into the effects that low freshwater inflow into Chesapeake Bay may have. Maintenance of adequate freshwater inflow into the bay is vital to make sure saltwater intrusion will not degrade environmental quality. The diversity of aquatic life in the bay can also be severely affected when freshwater inputs from its watershed are reduced during droughts or increased during major floods.

Bureau of Reclamation, Department of the Interior

Federal reclamation projects are constructed under authorizing legislation promulgated by the Congress of the United States. Direct project beneficiaries are required to enter into contracts with the Bureau of Reclamation, which are the basis of repayment agreements. These same contracts also define the amount of water that will be delivered to water-user entities under both normal and shortage conditions.

The Bureau of Reclamation's ability to take special, drought-mitigating actions beyond the confines of existing contracts is generally limited by authorities granted under special legislation, such as the drought relief acts of 1977 and 1988. These acts provided short-term authority to take such actions as establishing water banks to facilitate sales of water from willing sellers to willing buyers, undertaking minor construction, performing special studies, and providing loans to water users. The particular drought-mitigating actions that are actually authorized are specific to each act of Congress. Nevertheless, even without special authority, the Bureau of Reclamation makes attempts to promote conservation of the nation's water resources by pursuing a variety of water conservation programs that may alleviate the severity of drought impacts.

United States Department of Agriculture

Farmers and residents of rural areas can be provided with many types of assistance in the event of natural disasters, including drought, by the U.S. Department of Agriculture (USDA). Coordination of efforts between USDA agencies and other federal agencies is provided by the USDA Emergency Programs Staff.

The severity of a disaster determines the types of assistance available: agency, secretarial, or presidential. At the request of a state governor, the level of disaster aid is decided for a county or state based on the decision of the Secretary of Agriculture or the President of the United States. Agencies under the direction of the USDA providing assistance to individuals during drought emergencies include the Soil Conservation Service (SCS), the Agricultural Stabilization and Conservation Service (ASCS), the Forest Service (FS), the Farmers Home Administration (FmHA), the Extension Service (ES), and the Federal Crop Insurance Corporation (FCIC).

Soil Conservation Service

Technical and financial assistance is available to retard runoff and soil erosion in order to reduce hazards from any watershed. Technical assistance is also available to rehabilitate land and conservation systems. The ASCS can provide cost-sharing assistance for such projects. The SCS may also make agency equipment available for use during declared emergency events.

Agricultural Stabilization and Conservation Service

Emergency services are available to livestock and grain producers through several programs administered by the Agricultural Stabilization and Conservation Service (ASCS). The programs were designed to assist producers during emergencies caused by natural disaster. The 1990 three-point program is outlined below:

(1) Emergency Haying and Grazing: During the 1990 crop year, grazing was authorized during the year except for a five-month consecutive period on Acreage Conservation Reserve and Conservation Use cropland that has been removed from production of annual program crops such as feed grains or wheat. Haying or grazing of these conservation acres could be permitted under emergency conditions during the restricted five-month period. The decision to allow the emergency use of the forage was made on a county-by-county basis when a natural disaster substantially reduced the growth and yield of livestock feed.

(2) Livestock Feed Program: The national Livestock Feed Program consists of several emergency assistance programs. The implementation of the programs can be initiated by the governor of individual states or by the Agricultural Stabilization Conservation (ASC) Committees. The decision on whether the program should be implemented is made by the Deputy Administrator, state and County Operations (DASCO), ASCS, based upon the recommendation of the state ASC Committee. The program was implemented on a county-by-county basis in 1990.

To be eligible for the program, a livestock owner must have suffered a 40 percent loss of feed production due to a natural disaster on the farm. This event must result in the need to purchase larger-than-normal quantities of feed for livestock eligible under the program including cattle, sheep, horses, mules, swine, goats, fish, and poultry. The livestock must have been owned at least six months or be offspring of eligible livestock. The animals may be eligible if owned for less than six months if purchased as part of normal operation and not to obtain additional benefits from the program. Fish and poultry have an eligibility requirement of only three months.

The ASC Committee for a county determines the dollar value of feed crops grown within that county. This value is used to determine the value of production loss and to value the current production available to feed eligible livestock during the feeding period under the program.

Assistance is available to livestock owners under the Emergency Feed Program, Emergency Feed Assistance Program, or the Prickly Pear Cactus Burning Program.

(3) Emergency Conservation Program: Emergency assistance funds are available under the Emergency Conservation Program (ECP) to provide cost-sharing funds to farmers and ranchers suffering serious damage to farmland caused by natural disasters. The funds may also be used to carry out emergency water conservation measures during severe drought periods.

The ECP only provides funds to solve new conservation problems created by natural disasters that are determined to impair or endanger the land or materially effect the productive capacity of the land. The damages must be determined to be unusual, not likely to occur frequently in the same area, and not to have existed prior to the disaster. The type of damage and its extent determine the level of assistance.

The ASC Committee of an individual county in consultation with the state ASC committee, is responsible for administering the ECP to eligible farmers for all disasters except drought. The Deputy Administrator, State and County Operators (DASCO) is responsible for administration of the program under severe drought conditions. The county committee may set cost-share levels of up to 64 percent, although lower levels may be set by the state and/or county committees.

Farmland damaged by wind erosion, drought, or other disasters is eligible for funds to remove debris, obtain emergency water supplies for livestock, restore fences, initiate farmland grading or reshaping, permit structure restoration, and employ water conservation measures. Additional projects may be approved by the state committees with the consensus of DASCO and the Agricultural Stabilization and Conservation Service (ASCS) if they are deemed necessary but not covered by the approved practices. Land having received severe damage three or more times in a 25-year period or at risk of damage more than three times in 25 years is ineligible for ECP benefits.

Forest Service

The Forest Service is responsible for setting priorities, establishing policies, and implementing formulated forest programs for the nation. During an emergency such as drought, the Forest Service may also provide fire protection and fire control and assist other federal and state agencies in suppressing wildfires. Technical and financial assistance can also be provided to state agencies to help prevent, detect, and evaluate the outbreak of disease or infestation by forest pests. The Forest Service may also undertake emergency measures to prevent downstream damage to life or property from watersheds damaged by natural disasters.

Farmers Home Administration

Under the Emergency Loan Program, low-interest loans may become available to eligible applicants having qualifying physical and/or production losses. These programs are established in counties declared to be in an emergency by the President or the Secretary of Agriculture on request of the state governor. Available funds may be used to cover actual losses to farmers, ranchers, and aquaculture operators. Farm property or supplies damaged in the disaster may be restored, replaced, or repaired using these funds. The producer may also utilize the loan to pay crop expenses incurred during the disaster year as well as the year following the disaster. Farm debts to creditors may also be paid with these loan monies.

Extension Service

The Extension Service provides informational and educational support to producers through the land-grant universities. They can provide information which may help farmers and ranchers protect themselves from hazards associated with disasters.

Federal Crop Insurance Corporation

The Federal Crop Insurance Corporation provides coverage for any unavoidable losses owing to any adverse weather conditions or damage from other natural disasters such as pest infestations, fires, and earthquakes. The producer can insure crops from 50 to 75 percent of yield, based on the verified production history of the farmer. The variability in productivity throughout the nation is reflected in the rate differentials established for specific counties or areas within counties and is adjusted for with the premium rates paid. However, participants must enroll prior to the beginning of crop year in order to assure the actuarial soundness of the program, otherwise the insurance program would be not different from other straight subsidy programs.

Tennessee Valley Authority

The Tennessee Valley Authority (TVA) is responsible for managing water resources in a 40,910 square-mile area concerning parts of seven southeastern states. The TVA has in place a Regional Drought Management Task Force which sees its mission as providing a mechanism for the expeditious exchange among the participating state and federal agencies of information regarding the drought situation, including but not limited to information about the probable drought impacts on natural and economic resources and their severity. The Task Force also serves to facilitate coordination among participants, their individual drought response actions, and plans to alert the public. The Task Force will further serve as a forum for the participants to obtain the views and assistance of other organizations and individuals, individual members of the public, industry, and environmental groups, when practical. In addition, the TVA Board has established four priorities of operation during drought events as follows: to maintain adequate water supply, water quality, navigation, and hydroelectric power generation. The four priorities are ranked in the order in which they appear.

Environmental Protection Agency

The Environmental Protection Agency (EPA) does not provide direct financial assistance to communities in preparing for, or responding to, drought. However, the EPA's mandate for environmental protection does provide it with a reason for concern for the possible negative environmental effects of drought and the ability of communities and states to prepare for drought events. EPA's main concerns are in the areas of provision of safe drinking water to meet federal standards, instream water quality, impacts of drought on wetlands, the use of water conservation as a technique to protect against drought, and the potential impact of climate change on the frequency and intensity of droughts.

The primary concern of EPA's Office of Drinking Water is that publicly supplied drinking water meets federal quality standards. The agency occasionally assists communities in handling water supply emergencies. States implementing the Safe Drinking Water Act have plans for water supply emergencies on file with the EPA.

Under the EPA's Wellhead Protection Program for public water supply wells, a contingency planning manual was prepared to assist affected communities. This publication contains information which describes techniques to be used when public water supplies are faced with emergencies arising from incidents of contamination. Many of these actions pertain to drought response and planning as well. The EPA also operates programs for wetland protection and instream water quality. The EPA also has initiated a program to encourage and assist communities in developing and implementing water conservation programs, where it is cost-effective and appropriate to do so. Another project has been developed to establish guidelines for wastewater reuse and reclamation processing. These programs can reduce the long-term effects of drought. Research is also sponsored by the EPA which investigates the possible impacts of climate change on water resources. The EPA believes that communities and states should consider the possible impacts of climate change on their water supply in their preparation for drought.

Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) is responsible for the President's disaster program under Public Law 93-288, the Disaster Relief Act of 1974. This act states that a major disaster or emergency declaration is based on "a finding that the disaster is of such severity and magnitude that effective response is beyond the capabilities of the state and the affected local governments." A determination is also made as to the assistance needs being beyond the assistance available through existing governmental programs. Additionally, states must spend a certain amount of their own funds to alleviate the effects of the disaster.

Under the Disaster Relief Act of 1974, the Federal Emergency Management Agency provides assistance which is designed to save lives, protect property, and preserve public health and safety. Grants are made through FEMA to state and local governments to repair and restore publicly owned real property and facilities. Generally, drought assistance from FEMA does not match the response given during other types of disasters, since it is FEMA's position that there are a sufficient number of existing programs and authorities at the federal level to manage most identifiable drought-related needs.

Small Business Administration

The Small Business Administration provides low-interest working capital loans to small agri-dependent businesses and cooperatives under the Economic Injury Disaster Loan Program. These funds become available for businesses to meet financial obligations due to natural disaster only when the Secretary of Agriculture designates a disaster and requests the SBA to implement the program. Loan assistance is available only to the extent that a business cannot meet necessary financial obligations or is unable to borrow funds from nongovernment sources as determined by the SBA.

Department of Housing and Urban Development

The Department of Housing and Urban Development has no specified drought policy in place at the current time. However, the agency has administered demonstration programs for home water conservation devices across the country (Maddaus, 1987).

United States Geological Survey

The Water Resources Division of the U. S. Geological Survey is responsible for assessing the water resources of the nation and for reporting that assessment to Congress and others. This responsibility continues during droughts, of course, when the Division collects additional data to document the impacts of the drought on the hydrologic system and to provide information to those agencies and officials that are involved in managing or allocating water resources.

Data Networks

The Division obtains a continuous record of streamflows at about 7,000 sites nationally. Many of these gauging stations are equipped with transmitting devices that send the data via satellite to central stations. These data provide the bulk of information concerning the occurrence of hydrologic drought. In every state, these records of streamflow have been statistically analyzed to determine the recurrence interval of low flows of given severity and duration. Thus, by comparing current data with information based on historic records, it is possible to assess the relative severity of a drought as it occurs.

At many sites on streams, water-quality data are also collected. Low flows tend to result in higher concentrations of undesirable constituents in water, such as nutrients and pesticides. Also, higher temperatures, often associated with drought, tend to decrease the dissolved oxygen in water, possibly resulting in fish kills or anaerobic biological activity. The Division also monitors the water levels in aquifers nationally. Thousands of observation wells are utilized to measure groundwater levels, either continuously or periodically. These data are particularly useful to managers during prolonged droughts in which groundwater is used for irrigation or for public or industrial supply.

National Water Conditions

In addition to providing current data to management agencies, the Division also publishes a monthly report summarizing the information obtained from the data networks. One of the features of this document, which is mailed to nearly 3,000 recipients, is a map of the nation, showing where streamflow is deficient or excessive. The report also contains streamflow, water-quality, and groundwater-level data for many index sites across the country.

Drought Investigation

The Division undertakes many projects to investigate various aspects of drought, often in cooperation with local, state, or federal agencies that need the information to better conduct their activities during droughts. Some of these projects are conducted before droughts occur to give managers information needed for planning. Others are conducted during droughts and often involve extra data collection and assessment.

While it may not be practical to describe all types of investigations that might be undertaken in support of drought management, a typical project might include extending drought-related statistical parameters to unregulated streams in a state or region. Regulators, for instance, could use this information to limit discharge permits to quantities that would not seriously affect water quality during drought. The Division stands ready to engage in drought investigations in support of other agencies if funding to support the additional work can be identified.

Coordination Efforts

The Water Resources Division has at least one, and possibly several, offices in each state. This grass-roots structure has often resulted in participation in drought task forces, management groups, and planning efforts. Division offices have assisted in the preparation of drought emergency plans, state water plans, and similar documents. They have served as local clearinghouses for hydrologic data related to drought. They have participated in groups charged with responding to the changing conditions during a drought. The Division has been able to respond to nearly every request for this kind of local support. They have also responded at headquarters level for participation in drought coordination and for assimilation and presentation of hydrologic information.

National Oceanic and Atmospheric Administration, Department of Commerce

The National Oceanic and Atmospheric Administration (NOAA) has many recording stations throughout the nation. Data are compiled with respect to temperature, precipitation, and climate patterns to develop informational support to a wide range of agencies. Weekly weather and crop bulletin reports are issued jointly by the USDA and NOAA. They include information on precipitation, temperature, crop moisture conditions, and drought severity indices for the nation. During the 1988 drought, a series of drought advisory bulletins were produced summarizing conditions and impacts. A notable contribution of this agency is the historical record that is continually reevaluated based on a number of data bases maintained by the National Climate Data Center. This historical record can be utilized to compare current drought conditions to other periods of known drought severity.

INTERSTATE AND STATE WATER RESOURCE AGENCIES

Regional and state water-planning agencies are responsible for much of the administration and policies for managing water supplies. The assurance of water availability is closely tied to federal legislation. The nature of water resources in the United States requires cooperative efforts on the part of states having access to a common resource base. The ability of contiguous regions of the nation to utilize a single watershed or groundwater basin demands policies for equitable allocation of such resources. The following sections describe several interstate water commissions that have developed methods ensuring adequate water supplies to relatively large areas of the United States under normal hydrologic conditions as well as periods of adverse conditions (floods or droughts).

Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) represents the cooperative efforts of the city and state of New York, the states of New Jersey, Pennsylvania, and Delaware, and the U.S. federal government to allocate water from the Delaware River and its tributaries. The Commission was formed in 1961. Prior to the adoption of the Basin Compact, the Delaware River water had been apportioned by the U.S. Supreme Court (Hansler, 1990).

The apportionment of the Delaware River was based upon the drought of record from the 1930s. Shortly after the Commission was empowered, it faced an even more severe drought during the mid-1960s. Water shortages and inadequate downstream flows created the need for emergency conservation measures along with a reevaluation of supply availability in the basin.

A drought contingency plan was incorporated into the Delaware River Basin Commission Policy in 1983. The contingency plan of 1983 set forth criteria which defined the differentiation among "normal," "drought warning," and "drought" conditions along with the scheduled reductions in water diversions from the basin, especially by New York City. Actions are outlined which ensure control of salinity levels based on measured flows at specified points upriver from the Delaware Bay. Amendments were made to the plan in 1984 and 1988 to coordinate operations of reservoirs within the basin. The DRBC approaches drought management from a regional perspective by adjustments in reservoir storage and release schedules, water conservation, and the addition of storage facilities.

Susquehanna River Basin Commission

The Susquehanna River Basin Commission (SRBC) was created as a result of a joint legislative agreement between the U.S. federal government and the states of New York, Maryland, and Pennsylvania. The Commission was established because of citizens' concern regarding water resource problems including flooding, drought, and water pollution. The SRBC Compact was signed into law by the President and approved by the participating state legislatures and the U.S. Congress in 1970. The Compact provides for "comprehensive planing, management, development, use and conservation of water resources," with the Susquehanna River Basin Commission acting as the administrative agency (Susquehanna River Basin Commission Compact, 1972).

The Commission adopted its first Comprehensive Plan in 1973, with its latest revision being completed in 1987. Although the Commission has not set forth a specific drought contingency plan, policy provisions are included in the 1987 plan which require the maintenance of water quality and supply during periods of low streamflow. There is also a policy goal set forth which calls for the development of an emergency plan that will protect public health and safety during water shortage events (Susquehanna River Basin Commission, 1987).

Savannah River Basin Drought Coordination Committee

In 1989, the U.S. Army Corps of Engineers published the Savannah River Basin Drought Contingency Plan. The Plan was developed to improve the coordination of activities and communication between agencies of the states of South Carolina and Georgia involved in water supply management issues concerning three Corps of Engineers' impoundments on the Savannah River.

The Plan provides for six water-use priorities including fish and wildlife management, hydropower, navigation, recreation, water quality and water supply. Specific provisions are discussed in the Plan with respect to the indicator to be used in assessing drought onset, specific procedures to be implemented once a drought has been identified, and an outline of committee action guidelines for management decision making.

Western States Water Council

Following the 1976-77 drought in the western United States, the Western States Water Council recognized the benefits of preventative action in minimizing drought impacts. A study was undertaken by the Council to assess the status of drought planning among 14 western states. Based on the results of a survey of western states, the Council developed a model plan for the region, recognizing that the diverse needs of participating states could not be met under one general regional plan such as the Delaware River Basin or Savannah River Drought Contingency Plans.

The Council published a model plan in 1987 setting forth the essential elements of a contingency plan, including monitoring and assessment procedures, operational processes with considerations for drought impacts to agriculture, fish and wildlife, recreation, water supply, power generation, and the economy.

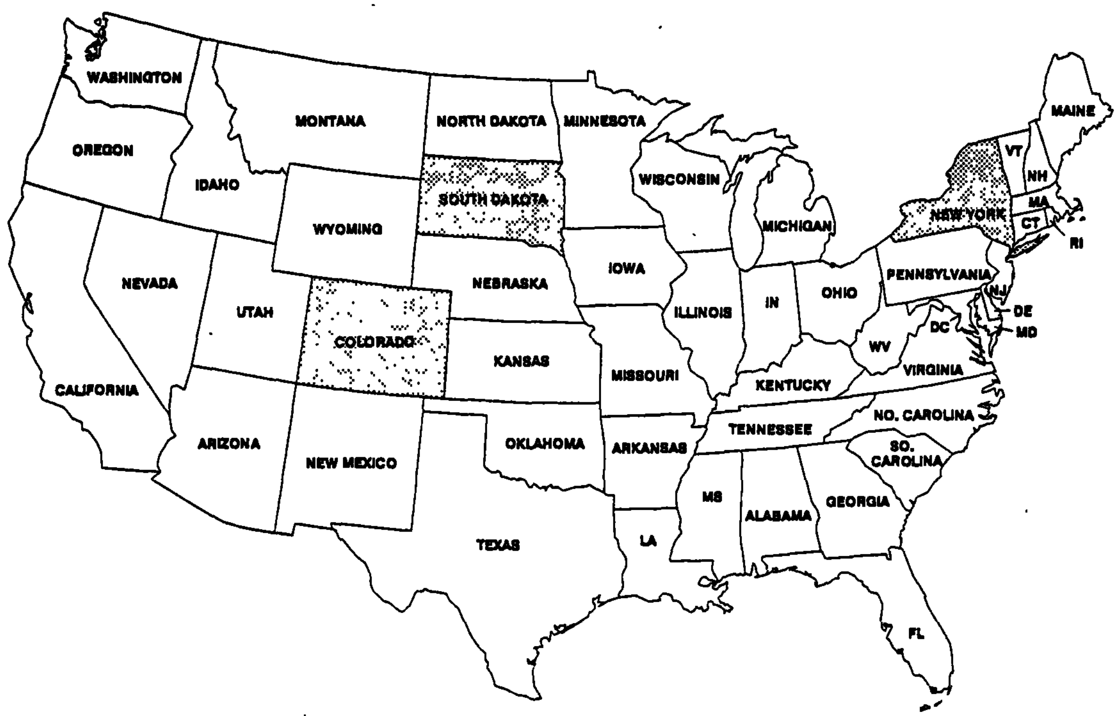
STATUS OF DROUGHT PLANNING: STATE GOVERNMENT

State governments in the United States have traditionally played a passive role in governmental efforts to assess and respond to drought. Generally speaking, they have relied on the federal government to come to their rescue when water shortages reached near-disaster proportions. For example, during the widespread and severe drought of the mid-1970s, no states had prepared formal drought response strategies. An evaluation of the response of three Great Plains states to the drought conditions of 1976-77 demonstrated a low level of preparedness and, consequently, an ineffective and poorly coordinated response (Wilhite et al., 1986).

The impacts from the drought of the mid-1970s and subsequent droughts, combined with the inefficiency of response efforts, generated considerable interest in the establishment of contingency plans in the early 1980s. However, survey of the states completed in 1982 indicated that only three states had developed plans: South Dakota, New York, and Colorado (Figure II-4). These plans differ considerably, reflecting the primary water management problems and concerns as well as the principal economic sectors affected in each state. The primary emphases of the South Dakota and New York plans are agriculture and municipal water supply, respectively, while the Colorado plan is multi-impact oriented. A more recent survey conducted in April 1988 and updated in June 1990 indicates that twenty-two states have developed plans, with one state (New Hampshire) in the process of developing a plan (Figure II-5). In addition, there are several states where action on the development of a plan is pending. A state-by-state breakdown of the status of drought contingency planning is given in Table II-5.

In general, state drought plans have certain key elements in common. Administratively, a task force is responsible for the operation of the system and is directly accountable to the governor. The task force keeps the governor advised of water availability and potential problem areas and also recommends policy options for consideration. Operationally, drought plans have three features in common. First, a monitoring system is established to coordinate the flow of information on water availability between state agencies, incorporating the data and information available from federal agencies as appropriate. The task force assimilates this information and issues reports and recommendations as appropriate. Second, a formal mechanism usually exists to assess the potential impacts of water shortages on the most important economic sectors. In some states this task is accomplished by a single committee, or more commonly, separate working groups are established to address each sector. Third, a committee or the task force referred to previously usually exists to consider current and potential impacts and recommend response options to the governor.

FIGURE II-4
STATUS OF DROUGHT PLANNING
1982



States with plans

FIGURE II-5
STATUS OF DROUGHT PLANNING
June 1990

States with plans
States developing plans

TABLE II-5

STATUS OF DROUGHT PLANNING: JUNE 1990

State	Agency responding	Does state have a drought plan?
Alabama	Governor	No. The state had a "prioritization/ action" plan, established by the Drought Task Force during the 1986 drought. A drought plan does exist for the Apalachicola-Chattahoochee-Flint basin
Alaska	Dept. Nat. Resources- Div. Land & Water Management	No.
Arizona	Dept. Water Resources	No.
Arkansas	Soil & Water Commission	No.
California	Dept. Water Resources	Yes. Annual contingency plans have been developed during the past several drought years to address water management alternatives if water shortages continue.
Colorado	Division of Disaster Emergency Services	Yes. Colorado Drought Response Plan.
Connecticut	Dept. Health Services	No. The Connecticut Plan (comprehensive water supply plan) requires each Public Water System to have a drought contingency plan.
Delaware	Dept. Nat. Resources and Environmental Control, Div. of Water Resources	Yes. Outlined in Management of Water Resources in Delaware: Water Conservation. The state also participates in the Drought Contingency Plan of the Delaware River Basin Commission.
Florida	Dept. Environ. Regulation	No. Florida does not have a formal drought plan, but the state is divided into water management districts that have developed plans.

TABLE II-5 (Continued)

STATUS OF DROUGHT PLANNING:
JUNE 1990

State	Agency responding	Does state have a drought plan?
Georgia	Dept. Nat. Resources	No. The state has Water Resources Management Strategy, which addresses water shortages and recommends actions to mitigate shortages
Hawaii	Governor's office	No.
Idaho	Dept. Water Resources	Yes. Idaho Drought Plan.
Illinois	Illinois State Water Survey	Yes. The Drought Task Force is co-chaired by the Director of the Division of Water Resources and the Manager of the Public Water Supply Section, Illinois Environmental Protection Agency.
Indiana	Governor's office	No. A task force was formed in 1988 but no formal plan has been developed.
Iowa	Dept. Natural Resources	Yes. A draft of the State Drought Response Plan was completed in early 1990.
Kansas	Kansas Water Office	No. A standing drought plan does not exist but a task force structure for monitoring and responding to drought is in place as a result of the 1988-89 water shortages.
Kentucky	Department for Environmental Protection	Yes. Kentucky Water Shortage Response Plan.
Louisiana	Governor	No.
Maine	Governor	Yes. Draft "plan of action" has been completed.
Maryland	Dept. Natural Resources	Yes. Response Plan for Drought and Other Water Shortage Emergencies.

TABLE II-5 (Continued)

STATUS OF DROUGHT PLANNING: JUNE 1990

State	Agency responding	Does state have a drought plan?
Massachusetts	Executive Office of Environmental Affairs	No. A drought plan was drafted in 1980-81 but was never finalized. Local officials are required to submit drought or contingency plans as part of a local water resources management plan
Michigan	Department of Agriculture	No. Department-level response plans exist as a result of the 1988 drought. Action is pending on a state drought plan.
Minnesota	Dept. of Natural Resources	No. A drought contingency plan for the Mississippi River was developed in 1988 in response to low-flow periods. This plan was developed by the Twin Cities Water Supply Task Force.
Mississippi	Governor	No.
Missouri	Department of Agriculture	No.
Montana	Montana Disaster and Emergency Services Division	Yes. Montana Water Plan--Section: Drought Management.
Nebraska	University of Nebraska	Yes. Drought Assessment and Response Plan.
Nevada	Governor	No.
New Hampshire	Dept. Environ. Services--Water Resources Div.	In process of developing a drought management plan.
New Jersey	Dept. Water Resources	No. Drought response is provided for in the state water plan, Emergency Water Supply Allocation Plan Regulations. The state participates in the Drought Contingency Plan of the Delaware River Basin Commission.

TABLE II-5 (Continued)

STATUS OF DROUGHT PLANNING: JUNE 1990

State	Agency responding	Does state have a drought plan?
New Mexico	Energy, Minerals & Nat. Resources Dept.	No.
New York	State Dept. Environ. Cons.	Yes. State Drought Preparedness Plan. The state also participates in the Drought Contingency Plan of the Delaware River Basin Commission.
North Carolina	Dept. Nat. Resources & Comm. Dev.	Yes. The Drought Plan was developed by the N.C. Division of Emergency Management.
North Dakota	Division of Emergency Management	Yes. North Dakota Drought Contingency Plan.
Ohio	Dept. Nat. Resources	Yes. Drought Preparedness and Response Matrix for the State of Ohio. The plan is coordinated by the Ohio Emergency Management Agency.
Oklahoma	Water Resources Board	No. There have been discussions and recommendations regarding the development of a drought plan but nothing is in progress.
Oregon	Water Resources Department	Yes. Drought: Annex to State Emergency Operations Plan.
Pennsylvania	Bureau of Water Resources Management	Yes. Pennsylvania Drought Contingency Plan for the Delaware River Basin. The task force established for the Drought Contingency Plan of the Delaware River Basin is expanded as necessary to include the remainder of the state.
Rhode Island	Dept. of Administration--Div. Planning	No. Comprehensive Water Supply Plan is being drafted; the Emergency Assistance Plan deals briefly with drought.
South Carolina	Water Resources Commission	Yes. South Carolina Drought Response Plan.

TABLE II-5 (Continued)

STATUS OF DROUGHT PLANNING: JUNE 1990

State	Agency responding	Does state have a drought plan?
South Dakota	Dept. Agric.--Rural Dev. Program	Yes. State Drought Recovery Operation Procedures.
Tennessee	State Planning Office	No. The Interim State Drought Management Plan was developed in 1987 but has not been finished.
Texas	Texas Water Dev. Board	No. The development of a drought plan has been discussed, but no action is pending.
Utah	Div. Water Resources	Yes. State Water Plan--Drought Relief section.
Vermont	Agency of Nat. Resources	No.
Virginia	Governor's office	Yes. The state has eleven basin water supply plans, summarized in Virginia's Water Supply--Statewide Summary. The State Drought Monitoring Task Force continuously monitors drought parameters and meets on an as-needed basis. Local governments have major responsibility for drought planning.
Washington	Dept. of Ecology	Yes. Drought Contingency Plan.
West Virginia	Governor's office	No.
Wisconsin	Dept. Nat. Resources	Yes. Drought Management Plan.
Wyoming	Dept. of Agriculture	No.

A summary of five state drought plans for Colorado, South Dakota, Ohio, New York, and South Carolina are presented in Appendix A. These states were selected because they represent several geographic regions and a wide variety of water supply and demand situations. Each plan is summarized on the basis of seven key features: (1) primary impacts addressed; (2) general plan structure; (3) plan components; (4) specific state assistance programs; (5) triggers for plan implementation; (6) primary authority; and (7) level of federal interaction and involvement in the function of the plan.

State-Level Actions by State Governments during 1988

In December 1988 a survey was conducted by D. A. Wilhite entitled Drought Assessment Response Activities of State Governments to determine the impacts and actions taken by state government in response to the severe-to-extreme drought that affected a large portion of the nation. The results of this survey were used in developing a summary report found in Wilhite (1990). The questions addressed to each of the states were as follows:

(1) What were the primary impacts of the 1988 drought in your state?

(2) Which geographic areas of your state were most affected?

(3) What types of interaction did your state have with neighboring states and the federal government?

(4) What types of mitigative actions did your state take in response to the drought?

(5) What are the current water availability conditions and the outlook for 1989?

(6) What action is your state taking if drought conditions continue into 1989?

Twenty-one states that responded to the survey represent a good cross-section of the drought-affected area. Responses, however, were incomplete in many instances. This occurred for two reasons. First, given the spatial variation in drought severity, all questions did not apply equally to each state. Second, answers to some of these questions are routinely not available. For example, quantitative estimates of the economic impacts of drought are seldom undertaken by the state or federal government. A summary of the specific responses to this survey is included in Appendix B.

For the purposes of this report, certain state actions taken during 1988 are worthy of special mention.

California: Organized a Drought Center to serve as an information clearinghouse on drought conditions, impacts, and response actions. Although this was not the first time such a center has been established by the state, it is a useful model for other states to follow during drought emergencies. The center prepared publications, organized conferences, surveyed water districts on the status of water supply, and assisted water districts with supply emergencies.

Delaware: Passed state legislation providing a state subsidy to farmers to purchase crop insurance.

Kansas: Kansas State University established a hay and forage hotline with the cooperation of the Kansas Farm Bureau and the Kansas Board of Agriculture.

Minnesota: Drought Task Force identified, analyzed, and proposed solutions to 25 drought-related problems. Recommendations were made to the legislature for action.

North Carolina: Division of Water Resources held a drought management conference to discuss steps local water managers could take in response to shortages, stressing the importance of local-state-federal cooperation.

Washington: State legislature mandated the development of a drought contingency plan by the Department of Ecology for incorporation into the State Comprehensive Emergency Management Plan.

State-level drought plans are often a reaction to immediate problems associated with water shortages in relevant economic sectors. The drought response actions implemented by most states during 1988 were short-term emergency measures intended to alleviate the crisis at hand. The lessons learned from recent droughts demonstrate that these actions have met with limited success. Hopefully, as states gain more experience in drought assessment and response, actions will undoubtedly become more timely and effective. As existing state drought contingency plans mature, their scope will broaden, addressing a wider range of potential mitigative actions that include a higher level of intergovernmental coordination. This will, in time, avoid or reduce the impacts, conflicts, and personal hardship associated with future drought. Unfortunately, previous experience teaches us that it is very likely that the plans generated in response to the 1988 drought will atrophy on the shelf and each new drought will be a learning experience.

LOCAL-LEVEL DROUGHT PREPAREDNESS

Many critical drought response decisions are made at the local level. Because of this the local-level water agency management plays a key role in determining the severity and types of impact that a particular drought may have upon a region. This section focuses on local-level response in recognition of the importance of its role in minimizing drought impacts.

The problem facing local-level decision makers' response to drought is the uncertainty in recognizing the necessity for a particular response at a particular time. Boland (1986) summarized this dilemma faced by decision makers as follows: "What you need to do [in case of drought] is, first of all, not obvious, although you may think it is. Also you don't necessarily know how to do it. Furthermore, you have probably never done it before. You can't do it alone. And, finally, you can't wait." Considerable research has been performed in an effort to alleviate these problems. Development of drought contingency plans is one way of reducing this uncertainty by providing guidelines to decision makers as to the proper times to employ measures and which measures to employ depending on the status of demand and supply.

This section reviews some past drought experiences in selected areas of the nation and describes the formal drought response plans for various localities. The factors that water utility managers consider important in responding to drought events are also discussed.

Local-Level Past Drought Experiences

A great variety of responses to actual drought emergencies have been documented. The types of responses depend on factors such as the size of water agency, the type of supply source used, and specific water demands which must be met (e.g., amounts of water used for outdoor purposes). Taking the drought situation into account, local decision makers take actions that they feel will guide the utility through the drought emergency with the least impact. Table II-6 summarizes various drought responses taken by some local utilities and details the outcomes of those decisions. There are several observations that can be made from the examples in the table:

(1) A public appeal for voluntary water conservation is usually the initial step taken, and in some cases, the reported reductions in water demand are as high as 20 percent.

(2) The same set of water-use categories, including lawn watering and car washing, are generally the first to be restricted or banned.

(3) When initial steps prove inadequate, a sequence of progressively stricter responses follows.

(4) Often a set of actions is implemented, rather than just a single measure.

(5) Estimated reductions of greater that 50 percent have been reported for very severe restrictions on water use.

(6) Some innovative strategies have also been identified, such as the Denver Water Board's increase in service area to encompass more water supply sources.

(7) Pricing is a rarely used rationing mechanism during drought events.

Another observation indicates that there tends to be an element of ad hoc response to drought situations as they arise. This may be due to a greater reliance on the managers' intuition than on data and information regarding the risk of shortages. In a survey of midwestern water utility managers, DalMonte (1991) reported that 76 percent of respondents who had experienced a drought year in the 1980s considered their decisions made in response to the drought to be adequate. Less than half (47 percent) of the managers surveyed had developed an ordinance or policy to respond to drought events because of lessons learned from previous experiences.

TABLE II-6
EFFECTIVENESS OF DROUGHT RESPONSE MEASURES IMPLEMENTED IN VARIOUS LOCATIONS

Location	Drought Response Measures	Outcome
City of Pawtucket, Rhode Island (Anderson, 1967)	(1) Ban on all use of water for watering lawns, car washing, and any unnecessary use when the reservoir supply dropped below 50 percent, (2) ban on the use of water for air conditioning without recirculation.	When both of these ordinances were put into force, they resulted in savings of up to 25 gallons per capita per day, or 16 to 18 percent of expected unrestricted municipal demand.
Washington Suburban Sanitary Commission, Washington, DC (Crews and Trieshman, 1979)	(1) Curtailing outdoor use, (2) reducing indoor use, (3) curtailing commercial and industrial use, and (4) severe restrictions imposed on all water use categories.	(1) Estimated savings of 5-25 percent in water use, (2) a 25-40 percent reduction was achieved, (3) a 40-60 percent reduction estimated, (4) over 60 percent reduction estimated.
New York City Water Supply System (Groopman, 1968)	Intensive appeals for voluntary conservation backed up by restrictions on nonessential uses. Appeals were made through the mass media, door-to-door solicitation, sound trucks, and handing out flyers and bumper stickers.	Water consumption decreased by an estimated 20 to 25 percent.

TABLE II-6 (Continued)
EFFECTIVENESS OF DROUGHT RESPONSE MEASURES IMPLEMENTED IN VARIOUS LOCATIONS

Location	Drought Response Measures	Outcome
Denver Water Board, Colorado (Miller, 1978)	(1) Increase DWB's service area to encompass more water sources, (2) reduce by 30 percent the number of new taps in various entities outside Denver, (3) mandatory water conservation program designed to limit the outside watering to a maximum of three hours every third day (supplemented by warnings, fines, and a massive public education program).	Water use over a four-month period (July-October) was reduced by 21 percent.
Salem, Illinois (Changnon et al., 1982)	(1) Water shortage alert declared by city officials and water district personnel (January, 1981); (2) requested voluntary cutbacks: (a) twice-a-week clothes washing, (b) twice-a-day toilet flushing per person, (c) five-minute showers, (d) bathtubs only 1/4 full, (e) no lawn watering, (f) checks on plumbing leaks; and (3) no mandatory restrictions were imposed on the public at any time.	Voluntary cutbacks by residents lowered demand from 1.6 to 1.0 million gpd or 40 percent below normal; by end of January, lake level recovered to within five feet of its spillway crest elevation.
Carlinville, Illinois (Changnon et al., 1982)	(1) City council shut off water to car washes (January, 1981); (2) prohibited residents from washing cars or watering lawns and gardens; (3) by mid-February, water was cut off to commercial water haulers; and (4) by April 27, the lake level began to rise and restrictions were lifted.	Conservation dropped daily consumption from a pre-drought average of 800,000 gallons to 675,000 gallons in April, 1981 (16 percent reduction); city planned to raise spillway at a cost of $500,000. This will increase the lake capacity by one-third (160 million gallons).

In another finding, DalMonte (1991) reports that utility managers ranked the consumer response to, and acceptance of, a particular conservation measure as the most important bit of information to be used in determining when to undertake a drought response action. Since the credibility of the water agency, in calling for conservation, is a major factor in the acceptance of a conservation program and utilities recognize the importance of consumer response to conservation program success, an organized, consistent means of employing conservation measures (i.e., drought contingency plan) becomes an important consideration in minimizing impacts from drought.

Structure of Local-Level Plans

A review of selected local-level plans was conducted by Dziegielewski et al. (1988) to examine the structure of existing drought contingency plans. The results of this review are summarized in Table II-7. From this, some conclusions may be drawn about local drought preparedness.

All of the response plans in the table are "phased." That is, they are implemented in stages in response to the increasing severity of a drought event. These phases are put into effect by certain triggering mechanisms which signal that a new phase of severity has been reached. These indicators of severity are predetermined as part of the drought contingency plan. The most frequently used triggers are reservoir levels, well-water levels, and the Palmer Drought Index. The study of midwestern water utility managers (DalMonte, 1991) found that increased water demand, increased media concern, and a drop in water levels were the three most common indicators of drought and drought severity for water agency managers surveyed.

The midwestern water utility managers survey found that utilities most often turn to demand reduction measures when acting to alleviate droughts' impacts. Voluntary conservation and the restriction of nonessential uses were the most commonly mentioned demand reduction measures followed closely by customer information and education through various media sources. This would be expected, since these measures are of a short-term nature, while system improvements and/or the acquisition of new water supplies are generally regarded as long-term responses. This apparent preference for short-term responses may be an indication of the nature of drought events in this region as discussed earlier in the chapter. That is, since climatic variability is not great, droughts are often short, seasonal events. Therefore, utilities tend to tailor their response to the characteristics of an average drought.

While this apparent tendency of tailoring drought response to average droughts is generally adequate, major droughts can have strong adverse consequences, since most utilities do not plan for these events. The severity of the 1987-89 drought on the Midwest is apparent in that 43 percent of all respondents were affected by drought in 1988, and 56 percent of all respondents were affected by drought at some point between 1987 and 1989. It would appear that different economic sectors bear the cost of different severities of drought. Water supply agencies are more likely to expend funds on combating minor or mild droughts. Severe droughts will likely lead to economic impacts to farmers and regional economies.

TABLE II-7

THE STRUCTURE OF EXISTING DROUGHT CONTINGENCY PLANS

No.	Location	Local, Regional	Authority/ Administrative Body	No. of Phases	Description of Phases/ and Triggers (Where Available)
1	City of Austin, TX	Local	City ordinance	4	1. Voluntary conservation 2. Water alert (falling reservoir levels, 70percent) 3. Water warning, 50 percent 4. Water emergency
2	City of Santa Monica, CA	Local	City ordinance	4	1. An amount in excess of 90 percent of amount used during base period, 1976. 2. Amount exceeding 85 percent of base period use. 3. Amount exceeding 80 percent 4. Amount exceeding 75 percent
3	City of Tulsa, OK	Local	Superintendent of waterworks and the commissioner of water and sewer	5	1. Winter months 2. Supply level adequate but distribution capacity is limited (e.g., 1 day's use = 130 mgd) 3. Supply level is such that current distribution capacity cannot be attained (e.g., 2 consecutive day's use = 130 mgd) 4. Supply level continues to deteriorate 5. Supply level drops so low as to constitute a danger to health, safety, and welfare
4	City of Amherst, MA	Local	Town of Amherst officials	6	1. Standard operating procedure--normal conditions 2. Formal declaration: when it is clear that a water supply shortage exists. 3. Implement ban on selected outdoor water uses 4. Request for emergency water from other communities 5. Reduction of less essential water use 6. Elimination of selected services

TABLE II-7 (Continued)

THE STRUCTURE OF EXISTING DROUGHT CONTINGENCY PLANS

No.	Location	Local, Regional	Authority/ Administrative Body	No. of Phases	Description of Phases/ and Triggers (Where Available)
5	City of Manchester, CT	Local	Public announcement	4	Drought watch: water levels are at 70 percent of normal seasonal capacity 1. 57 percent of normal 2. 40 percent of normal 3. 0 percent of normal
6	North Marin County Water Distrct for Novato Area, CA	District	Ordinance no. 6. district board of directors	3	1. Voluntary conservation 2. Mandatory rationing 3. Mandatory rationing until emergency is past
7	South West Florida Water Management District, FL	Regional (District)	Governing board of water management district	3	1. Moderate water shortage 2. Severe water shortage 3. Extreme water shortage
8	South Florida Water Management District, FL	Regional	Governing board of water management district	4	1. Moderate water shortage (< 15 percent reduction in overall demand) 2. Severe water shortage (<30 percent reduction in demand) 3. Extreme water shortage (<45 percent reduction) 4. Critical water shortage (<60 percent reduction)
9	North West Florida Water Management District, FL	Regional	Governing board of water management district	4	1. Moderate water shortage (< 15 percent reduction in overall demand) 2. Severe water shortage (<30 percent reduction in demand) 3. Extreme water shortage (<45 percent reduction) 4. Critical water shortage (<60 percent reduction)
10	Suwannee River Water Management District, FL	Regional	Governing board of water management district	4	1. Water shortage advisory (hydrologic conditions are abnormally low or low for the season) 2. Moderate water shortage 3. Severe water shortage 4. Extreme water shortage

TABLE II-7 (Continued)

THE STRUCTURE OF EXISTING DROUGHT CONTINGENCY PLANS

No.	Location	Local, Regional	Authority/ Administrative Body	No. of Phases	Description of Phases/ and Triggers (Where Available)
11	St. Johns River Water Management District, FL	Regional	Governing board of water management district	4	1. Moderate water shortage (<15 percent reduction in overall demand 2. Severe water shortage (<30 percent reduction in demand) 3. Extreme water shortage (<45 percent reduction in demand) 4. Critical water shortage (<60 percent reduction in demand)
12	City of New York Drought Conservation Plan	Local	Department of Environmental Protection	3	1. Drought watch (less than 50 percent possibility that reservoir system will fill up by June 1) 2. Drought warning (<33 percent possibility for full reservoir) 3. Drought emergency (avoid possibility of city's reservoir being drained)
13	City of Corpus Christi, TX	Local	City manager	4	1. Water shortage possibility 2. Water shortage watch 3. Water shortage warning 4. Water shortage emergency
14	Texas Water Development Board-Drought Contingency Plan	Local (city or utility)	Local ordinance	3	1. Mild drought conditions (possibility exists that water supply situation may become critical) 2. Moderate drought conditions (water levels are declining at a rapid rate) 3. Severe drought conditions (inability to provide certain services to the impairment of health and safety)

TABLE II-7 (Continued)

THE STRUCTURE OF EXISTING DROUGHT CONTINGENCY PLANS

No.	Location	Local, Regional	Authority/ Administrative Body	No. of Phases	Description of Phases/ and Triggers (Where Available)
15	City of Dallas, TX	Local	Mayor, city manager, or water utility director	3	1. Water watch (deliverable lake storage on June 1 falls below 50 percent in total connected lakes or 35 percent in the western lake system). 2. Water warning (deliverable lake storage on June 1 falls below 40 percent in total connected lakes or 25 percent in western lake system). 3. Water emergency (deliverable lake storage at any time falls below 35 percent in total connected lakes).
16	City of Round Rock, TX	Local	Round Rock city council	5	1. Water shortage alert (falling well level) 2. Voluntary water use curtailment (well level at 130 feet) 3. Mandatory water use curtailment (well level at 100 feet) 4. Price rationing (well level at 60 feet) 5. Termination of water shortage (based on water level in well)
17	City of Denver, CO	Local	Denver water department	5	Stage 1: voluntary conservation program Stage 2: mandatory conservation program Stage 3: progressive curtailment of water use Stage 4: more stringent restrictions on outside water use Stage 5: severe drought conditions
18	City of Philadelphia, PA	Local	Governor's proclamation	--	Prohibition of non-essential uses
19	City of Los Angeles, CA	Local	City ordinance	5	1. Prohibition 2. An amount in excess of 90 percent of base use 3. An amount in excess of 85 percent of base use 4. An amount in excess of 80 percent of base use 5. An amount in excess of 75 percent of base use

TABLE II-7 (Continued)

THE STRUCTURE OF EXISTING DROUGHT CONTINGENCY PLANS

No.	Location	Local, Regional	Authority/ Administrative Body	No. of Phases	Description of Phases/ and Triggers (Where Available)
20	City of Westminster, CO	Local	City ordinance	4	1. Warning--before summer irrigation season 2. Voluntary conservation (15 percent)--during summer irrigation season 3. Voluntary reduction (15-25 percent)--before the next summer if another below average rainfall occurs 4. Voluntary conservation (25 percent)--during the summer if the situation remains critical
21	City of Arcadia, CA	Local	City ordinance	5	1. Prohibition 2. An amount in excess of 90 percent of base use 3. An amount in excess of 85 percent of base use 4. An amount in excess of 80 percent of base use 5. An amount in excess of 75 percent of base use
22	Metropolitan Drought Management Plan, CA	District	MWD	3	1. Moderate: 5 to 10 percent shortage 2. Serious: 10 to 20 percent shortage 3. Critical: 25 to 30 percent or more percent shortage

III. MEASUREMENT OF ECONOMIC IMPACTS OF DROUGHT

INTRODUCTION

Previous Reports on Recent Significant Droughts

In 1976-77 the state of California experienced a major drought that resulted in serious economic losses to the state. Economic estimates were reported by the California Department of Water Resources (California DWR, 1978) and suggest that losses due to the drought amounted to $2,663.5 million. This estimate represented losses reported by producers of livestock, farm produce, energy, recreation activities, and trees. The study also mentioned the expectation that additional indirect losses would occur in some primary industries related to agricultural activities. Table III-1 summarizes the estimated losses to the affected areas.

A preliminary assessment of the 1988 drought impacts was done by Riebsame et al. (1990). Their study attempted to estimate impacts from the drought at the national level and covered a broad range of economic and social sectors. The final tally of their study put the cost to the nation of the 1988-89 drought at $39 billion. This estimate is based only on negative impacts of the drought and does not account for positive impacts in other regions of the nation or sectors of the economy.

Cumulative drought impacts at the national level may be minimal, since losses to one region of the nation are often compensated for by other regions enjoying a marked increase in economic activity. As an example of the relatively small impact that national drought has on the national economy, the President's Interagency Drought Policy Committee, in their final report of December 30, 1988, stated that the "aggregate economic effect of $13 billion lost in farm production on the $4 trillion U.S. economy was minor." In addition to these costs there were substantial environmental costs, however, there has been no economic assessment of the environmental losses.

Riebsame et al. (1990) obtained their data to develop the economic loss estimates from four such sources as (1) briefings, papers and talks presented at meetings and workshops conducted during the fall and winter of 1988-89; (2) newspaper reports collected during and after the drought; (3) interviews with persons in the public and private sectors, especially planners and decision makers, directly affected by the drought; (4) publications, primarily those of the federal government. These sources are not very reliable, thus undermining the credence of the reported losses. However, the authors also state that these dollar values which they developed are only estimates that have not been subjected to any economic analysis. This is pointed out because the estimates are consequently subject to error of an unknown amount, and double counting is a distinct possibility. While the authors are aware that many benefited from the drought event, they do not account for these gains in developing their estimate. The study focuses more on the damages of such an event. Therefore, the estimate of $39 billion does not reflect the true cost of the 1988-89 drought to the nation.

TABLE III-1

ESTIMATES OF ECONOMIC LOSSES FROM THE 1976-1977 CALIFORNIA DROUGHT

Economic Area Affected	Drought Loss (Million $) 1976	1977
(1) Agriculture		
(a) Livestock	467.4	414.5
(b) Grains	22.8	23.0
(c) Irrigated Crops	0.0	89.0
(d) Fruits, Nuts	19.3	40.0
(e) Power Costs	25.0	25.0
(f) Well Costs	40.0	300.0
(2) Energy	144.0	326.0
(3) Recreation	20.0	40.0
(4) Forests		
(a) Loss by fire	0.0	280.0
(b) Loss by insects	150.0	237.5
(5) Industry	(Unknown)	(Unknown)
TOTALS	$888.5	$1,775.0

Source: California DWR, 1978.

Adapted From: Dziegielewski, B. 1990. Designing a Framework for Assessing the Impacts of Drought.

The drought of 1988 was also studied by the President's Interagency Drought Policy Committee and a report was submitted on December 30, 1988, entitled The Drought of 1988 (PIDPC, 1988). This study used an accounting stance at the national level and was quite detailed in its investigation of the various sectors that the drought impacted. The committee that prepared the report was made up of representatives from federal agencies charged with the administration of drought-related programs. The data used in the assessment were obtained from drought status reports by various agencies.

The main finding by the committee was that while some economic sectors were highly affected, timely federal programs and the sale of crop stores moderated the impact to about $13 billion. This figure represents a small part of the U.S. economy as a whole. However, they also point out that if the extreme drought were to continue into another growing season, the impacts would become more significant. They write:

> A return to normal precipitation and temperatures is critical to the recovery of the Nation's forestry, range, and wildlife resources, water supplies, and transportation system. Above normal precipitation is needed to ease the large soil moisture deficits, especially in parts of the Western Cornbelt and Northern Plains.

This suggests that the nation's ability to withstand extreme drought over an extended period and geographic area may be very limited. As such, the need for improved understanding of how drought imposes itself on our social and economic systems is important to establishing adequate drought management policies.

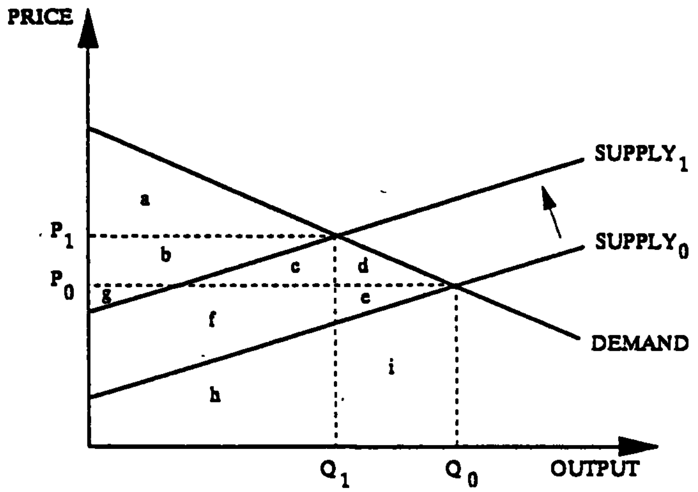
Theoretical Background

The most important element of the development of useful drought contingency plans is an accurate estimation of the economic effects caused by drought. The first step in that process is identifying how drought imposes itself upon the marketplace. As suggested by Russell (1991), at a very general level the drought can be treated as an exogenous force impinging on the economy. By doing so, it creates what we are calling "coping costs" by either raising costs, restricting amounts of available goods and services, or affecting a "quality" of goods and services.

Conceptually, a drought event affects the aggregate economy, as shown in the diagram on Figure III-1. A severe drought affects the price and available supply of water, which is an important input into the production of many goods and services. As water becomes more scarce, production costs rise. This is shown graphically as a leftward shift of the market demand curve. For a given market demand schedule, this results in a higher overall domestic price level and a lower level of output.

One may also explain why the nation's output declines via the production function. Suppose that the nation's production function is denoted by $Q=f(w,X)$, where $\underline{w}$ stands for the country's water resources, and $\underline{X}$ is the vector of other production inputs. Given that factor input combinations are essentially fixed in the short run, a (drought induced) decrease in water resources will, *ceteris paribus*, reduce output.

FIGURE III-1
THE SHORT TERM EFFECTS OF SEVERE DROUGHT ON THE AGGREGATE ECONOMY

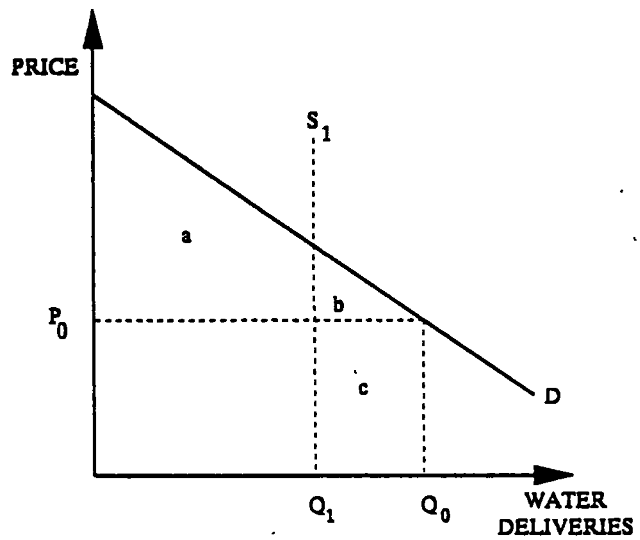


NO DROUGHT: P_0Q_0	DROUGHT: P_1Q_1
consumer surplus a+b+c+d	consumer surplus a
producer surplus g+f+e	producer surplus b+g
producer revenue g+f+e+h+i	producer revenue g+b+c+f+h

Figure III-1 illustrates the effects of drought on consumer and producer surplus, as well as on revenue (i.e., P*Q). In the diagram, consumers are clearly made worse off (losing b+c+d in consumer surplus), while the impact on producer surplus is not as straightforward (compare g+f+e to b+g). Part of the loss in consumer surplus is redistributed to producers in profit (area b) and in revenues (area c). The areas d and e of consumer and producer surplus can no longer be exploited. Obviously, the degree to which producers and consumers are affected depends on the shape of the curves and, therefore, on the price elasticities of supply and demand. Indeed, if the demand curve is sufficiently steep (i.e., inelastic), producer surplus and revenues may rise for a given leftward shift in the supply curve.

Figure III-2 looks directly at the market for water where Q_0 is utility supplied at a price of P_0 per "unit" of water. If coping with drought takes the form of restricting supply, perhaps through regulations banning lawn irrigation, a loss of consumer surplus of area b would result. Theoretically, the value of water measured by this area quantifies the welfare losses that may result from consumer inconvenience, as well as the aesthetic value of green, rather than brown, landscape. A rationing scheme like the one depicted in the diagram would also cause a drop in water utility revenue.

FIGURE III-2
RATIONING IN THE MARKET FOR WATER



b = loss of consumer surplus
c = loss of water utility revenue

Realistically, whether short term "losses" at the microlevel translate into national (or regional, or state) losses depends on what adjustments are possible elsewhere and what the temporal scale of the event is. For example, imagine a barbershop alone on an island in a river, accessible by a bridge that is occasionally flooded. If there were a one- or two-day flood, probably very, very few of the barbershop's customers would go elsewhere. They would postpone their haircuts by a day or two, and the social loss from their shaggier looks would be trivial. If the flood lasted for a month, almost all customers would probably feel they had to get a haircut elsewhere. The island shop might lose nearly a month's revenue, save a month's variable cost, leaving a net loss of the difference. But, if other barbershops in the general neighborhood had excess capacity, they would make an extra profit. Society would only be worse off to the extent that there were no extra costs or that the consumers would have been willing to pay something significant to have access to their original barber (more than the cost of a haircut). Thus, in order to make meaningful statements at the microlevel, one needs to assume that the economy is operating at full employment without idle capacity.

"Economic impact" and the idea of "indirect losses" involve other complexities. Generally, the notion is that if firm X suffers a loss because of a drought, (e.g., has to shut down for a month) so will its suppliers, and their suppliers until the Nth transaction. This is the reverse or obverse of the "stemming from" benefits idea. The reasons for extreme caution also correspond. With stemming benefits, unless there are idle resources, marginal increases in production in one place reflect increases in costs that just balance them. Or, said another way, moving economic activity around is not the same as creating benefits nationally. If suppliers to the affected firm do cut back, the resulting losses must reflect (1) only resources that can't be used in any other way and (2) adjustments for subsequent "making up" of the downtime. If the peach crop in a river valley were destroyed by a frost, it might well be reasonable to calculate the loss at that level as the loss of profit to the peach farmers and to the processors, if any, dependent on that crop. But whether there would be measurable loss of profit at the level of the jam jar or shipping-carton maker is more difficult to predict. In the case of grain elevators storing grains and other surplus and storable crops, avoided storage costs may offset the loss of revenue stemming from crop reductions, but the capital and labor is already in place to perform the elevator's functions.

A comprehensive drought impact assessment system is needed in order to define what the economic consequences of a drought are. While in the past, development of methods for measuring such impacts has proven somewhat difficult, there are some examples of assessments that reflect the cost to society of a drought event. The continued improvement of methods of estimation will allow for better decision-making models and reduce the economic and social costs of precipitation variability at the local, regional, and national levels. To some extent, the difficulty in estimating drought impacts lies in the nature of the hazard. Although a drought creates economic losses, and negative social consequences, often the most urgent concerns are at what point to start counting those costs and to what extent those impacts should be accounted for as a consequence of drought. Communities may choose to respond to a drought situation in a number of ways, as discussed in other parts of this report. Depending on which response is chosen at which time, the impact on the community and the water utility will vary.

There are many estimates in the literature generated by many different methods that give a crude accounting of drought impact. With most, it would appear that they overestimate certain impacts by failing to protect against double counting or by not noting benefits that may accrue to other economic sectors. Other costs are underestimated or not estimated at all due to the difficulty in accounting for them; social impacts such as increases in anxiety to the community members, which may have some cost, are examples of this. While it may be difficult, if not impossible, to estimate all the costs and benefits that a drought may have on a community, the same can be said of many management matters in which "good" decisions must be made using the best available information. The difference being that in other matters there are certain conventions that allow comparison between alternatives, assuring that while all may not be known about the subject, at least comparable estimates are obtained by the same methods.

In general, the cost associated with drought is a function of the severity of drought, the types of uses that are present in a particular region, the timing of the drought event, and the vulnerability that a region may have toward drought. Most researchers would agree that the costs (impacts) of drought have escalated (using constant dollars) and will continue to escalate as more droughts are experienced in the future.

The remainder of this chapter focuses on the measurement of economic impacts on specific economic activities of the society. The activities considered include:

(1) Public water supply
(2) Agriculture
(3) Business and industry
(4) Hydropower production

(5) Navigation
(6) Recreation
(7) Fish and wildlife
(8) Water quality

For each activity (or sector) the types of adverse (and beneficial) impacts are first identified. There then follows a discussion of methods that are or may be used for measuring the economic consequences of these impacts.

PUBLIC WATER SUPPLY

Droughts can have major effects on the supply of adequate, potable water for public use. Water supplies may be reduced due to limited streamflow, lowered reservoir levels, and depletion of groundwater reserves. During drought, water supply agencies are faced with increasing demand for their water while having to maintain adequate reserves to assure public health and safety.

The effect of drought on public water supplies creates the need for increased communication among local, regional, and federal agencies to ensure water availability to meet public needs. The drought creates resource management situations with which many water supply decision makers are unfamiliar. This is often attributed to the relative infrequency of drought in some regions, decreasing the probability of previous drought experience for water resource managers (Changnon and Easterling, 1989).

Water conservation measures which limit nonessential water uses are the first adjustment made to decrease water use during drought periods. The development of new water supplies is another alternative sought during severe drought conditions. The development of drought action plans by water resource providers can ameliorate drought impacts to public water supplies. The plans typically center on voluntary or mandatory measures to reduce water consumption, often with penalties for noncompliance. As the severity of the drought increases, the types of water-use restrictions utilized become more stringent. The water purveyors also have the option of altering the types of water rates charged.

One of the first major studies of drought and its effects on urban areas was conducted by Russell, Arey, and Kates (1970). As part of their study of the drought of the late sixties in the New England, they developed cost estimates for three communities that were affected by the drought. Russell et al. (1970) point out that the first thing which must be done in developing an estimation is to ask how much did the drought cost whom. This is an important consideration in that while a drought represents an economic hardship to some individuals, there are others who will see an increase in revenue as a result of a drought event (e.g., the losses felt by the barge transport industry due to low streamflows result in increased business activity for the overland rail and trucking industry). As a result of this income transfer phenomenon, the costs of drought are lessened as the scale of the drought impact assessment grows. There are some examples of drought events that were very costly at the local level, but at the regional level the impact was lessened, and at the national level the impact was nil (Russell et al., 1970; Warrick et al., 1975; Wilhite et al., 1986; Aakre et al., 1990; Riebsame et al., 1990).

Russell et al. (1970) identified some of the specific problems that are involved with estimating drought impacts. They note that along with selecting an appropriate accounting stance, the analysts must recognize that:

> Some of the costs of the drought take the form of payments to specialized firms (such as well drillers) for services rendered . . . if reasonable resource mobility and full employment may be assumed, the increased activity (employment and production) of these firms can be said to represent a reduction in other forms of activity which society would, in the absence of the drought, have preferred to purchase . . . If, on the other hand, the resources devoted to these activities would otherwise have been idle (e.g., the capital and labor inputs specialized to well-drilling), the extent of the loss will be significantly smaller than the amount of activity called out by the drought.

Another difficulty pointed out in the Russell et al. (1970) study is the selection of an appropriate reference point against which to measure the costs. They note that the estimates of costs are sensitive to the selection of the zero point, but that the criteria for selection have no particular reasoning supporting it. In addressing this situation the authors argue that "choice of reference point is, then, related to the alternatives being considered for improving the situation." Incorporating all of these factors into their study design, the authors ended with the question: How much did the drought cost the people of Massachusetts compared with a situation in which no municipal water system suffered shortage? In this manner they had addressed all of the specific criteria needed to properly isolate the drought impacts from other market forces operating simultaneously along with the drought.

Russell et al. (1970) developed estimates of costs and losses for the various economic sectors identified in the study communities, including:

(1) The industrial sector losses, which were further divided into business losses, investments, and other
(2) The municipal sector losses, which were divided as lost revenue, emergency supply costs, and other
(3) The commercial sector losses, which were subdivided into business losses and investment
(4) The domestic sector losses, where estimates were developed of the total capital costs of drought-related domestic well investment and estimates of sprinkling losses by using the Howe and Linaweaver (1967) demand equation
(5) The miscellaneous sector losses, with three subclasses being farm losses, golf club costs, and tree losses

Table III-2 shows the loss estimates that were developed. The Russell et al. (1970) study is one of the benchmark studies of the economic consequences of drought that continues to serve as a guideline for any following studies on the subject.

Young et al. (1972) performed a study of the economic risk of water supply shortage on York, Pennsylvania. This study was based on estimating the impact of losses in the residential sector through the use of consumer surplus losses.

TABLE III-2

ESTIMATED LOSSES FOR SELECTED CITIES BY SECTOR
(Corrected for Double Counting)[a]

Sector	Braintree Corrected Costs ($)	Braintree Percentage of Town Total	Braintree Percentage of Sector Total	Fitchburg Corrected Costs ($)	Fitchburg Percentage of Town Total	Fitchburg Percentage of Sector Total	Pittsfield Corrected Costs ($)	Pittsfield Percentage of Town Total	Pittsfield Percentage of Sector Total	Sector Totals Corrected Costs ($)	Sector Totals Percentage of Grand Total
Industrial											
Business losses[b]	–			171,400			–			171,400	
Investments	2,500			549,000			70,200			622,500	
Other	2,500			30,000			17,800			50,300	
Subtotal	**5,000**	**2.6**	**0.6**	**751,200**	**64.0**	**89.0**	**88,000**	**20.5**	**10.4**	**844,200**	**47.0**
Municipal											
Lost revenue	–			173,100			54,900			228,000	
Emergency supply	125,000			144,200			12,000			281,200	
Other	12,900			5,200			15,000			33,100	
Subtotal	**137,900**	**72.2**	**25.4**	**322,500**	**27.5**	**59.5**	**81,900**	**19.1**	**15.1**	**542,300**	**30.2**
Commercial[c]											
Business losses nurseries	8,600			–			–			8,600	
Business losses other	–			3,000			3,000			6,000	
Investments	–			6,100			12,000			18,100	
Subtotal	**8,600**	**4.5**	**26.3**	**9,100**	**0.8**	**27.8**	**15,000**	**3.5**	**45.9**	**32,700**	**1.8**
Domestic											
Wells reported	24,000			31,200			50,400			105,600	
Sprinkling loss	14,200			29,400			–			43,600	
Subtotal	**38,200**	**20.0**	**25.6**	**60,600**	**5.2**	**40.5**	**50,400**	**11.7**	**33.8**	**149,200**	**8.3**
Miscellaneous											
Farm losses[d]	–			–			45,000			45,000	
Golf club costs	–			25,000			48,700			73,700	
Tree losses	1,200			6,000			100,000			107,200	
Subtotal	**1,200**	**0.6**	**0.5**	**31,000**	**2.6**	**13.7**	**193,700**	**45.2**	**85.7**	**225,900**	**12.6**

	Braintree	Percentage of GT[e]	Fitchburg	Percentage of GT	Pittsfield	Percentage of GT	Grand Total
Town Totals	190,900	10.6	1,174,400	65.4	429,000	23.9	**1,794,300**

Source: Russell, C. S., Arey, D. G., and Kates, R. K. Drought and Water Suppy: Implications of the Massachusetts Experience for Municipal Planning (Baltimore: John Hopkins Press, Resources for the Future, 1970) Table 22.

[a] In several cases, original calculations (or even original information) included a range of possible values. These ranges depend in most cases on the nature of the assumptions made about the seasonal pattern of demand and the like. In all such cases, the figure in Table III-2 is the simple average of the extremes of the range.

[b] Industrial business losses were estimated differently, depending on the nature of the information contained in the claim. In some cases, value-added per day per man was projected ahead from the 1963 Census of Manufactures. This was used where shutdowns were estimated in days. In other cases, value-added unit prices were estimated and used to value estimated lost production in physical terms. Both sorts of calculations were corrected for savings on water purchases and withdrawals.

[c] Commercial business losses were estimated on the basis of claims of lost sales made in interviews. These figures were corrected to value-added by using an estimate of value-added as a percentage of sales. This, in turn, was derived from figures on wages as a per centage of sales in various affected areas of retailing from the 1958 Survey of Business and from assumptions about the size of profits (36 percent), rent (10 percent), and interest (4 percent) relative to sales.

[d] Farm losses were estimated by the Berkshire County Extension Agent as $1,500 per farm for 30 commercial farms within the city limits.

[e] GT = grand total.

Russell et al. (1970) was completed estimating losses in the same manner. Using the Howe and Linaweaver (1967) demand equation for sprinkling water.

Both Russell et al. (1970) and Young et al. (1972) define the demand curve for sprinkling as a function of irrigable area per dwelling unit, summer evapotranspiration in inches, summer precipitation in inches, and price per 1,000 gallons as states in Howe and Linaweaver (1967). This provided the researchers with an estimate of one-day losses to the residential sector. The cumulative losses as a result of the drought events were assumed to be a linear summation of these one-day losses. Both Russell et al. (1970) and Young et al. (1972) obtained comparable results by using similar methodology, thus providing a further measure of confidence in the study design.

In 1983, Lindsay and Powell completed a study that estimated residential losses in similar fashion, except for that they did not assume that cumulative losses were a simple linear summation of one-day losses. Their study suggested that the total amount of losses were the product of one-day losses and the duration of these losses raised to a power that is representative of increasing, decreasing, or constant costs. This brings a measure of severity into the equation, thus providing a more precise estimation of losses.

Young et al. (1972) and Lindsay and Powell (1983) are two studies that followed Russell et al. (1970). All three studies provide fairly good estimation of losses. The theories and assumptions suggested by these authors deserves further emphasis.

AGRICULTURE

Agriculture is widely thought of as the industry most susceptible to a drought event. If an extended drought occurs, both the crop/livestock production and food-processing industry may be affected. Potential direct losses to the production sector alone may be large, given that the total market value of agricultural products sold in a normal rainfall year can easily exceed $130 billion (U.S. Department of Commerce, 1989, Table 1). Much of the value added in food processing, and at higher levels in the production/marketing chain, could also be lost.

Changnon and Easterling (1989) note the agricultural impacts of the 1980-81 Illinois drought as:

(1) A severe loss in crop production
(2) Soil losses due to dust storms
(3) Cost of water hauling because of the drying up of shallow wells and ponds used to water livestock

The authors indicate that the measurable economic impacts of these factors were sizable. Also, longer term effects from soil loss cannot easily be measured in dollar terms although some measurement methods are available. The U.S. Soil Conservation Service developed a methodology for measuring the long-run losses in land productivity caused by soil erosion.

Impacts from the drought of 1986 were extensive in the southeastern United States. The livestock industry of the area was adversely affected due to poor pasture conditions caused by the drought, which led to the need for supplemental livestock feeding. As a direct result, ranchers marketed more cattle than normal, thereby depressing prices. The drought brought similar need for supplemental livestock feeding to the Midwest. Herd size was once again reduced by producers, thus decreasing returns to ranchers and influencing productivity once the drought conditions slackened.

Farmers often suffer from drought even though the industries supplying farm inputs may experience little impact. This phenomenon occurs because droughts often start after planting, thus farm costs may be nearly identical to the levels in normal rainfall years. For example, the agricultural chemical industry felt little impact from the 1988 drought in the Midwest. The drought did not influence the sale of pesticides or fertilizers, as most farmers had purchased and applied chemicals to fields before the effects of the drought took hold. In fact, the net effect may be in reverse: Worthy (1988) reported the drought as having a potential positive effect for the agricultural chemical industry in 1989, since an increase in acreage planted was expected. The influence of drought on migratory farm labor is an impact of drought that cannot be overlooked. Decreased crop production leaves many without work, thereby reducing their income opportunities.

Within irrigated agriculture, the demand for irrigation water increases with the duration of drought events. Golden and Lins (1988) found that withdrawals from groundwater and surface-water supplies in 1986 exceeded those in the 1980-81 drought. Some depletion of irrigation ponds was reported during 1986 in North Carolina. When needed the most, water sources are often stressed.

The extent to which agricultural economic losses can be controlled during drought through irrigation is limited. Even if water is available in reservoirs and aquifers, only 4.8 percent of the land in farms is currently irrigated and only 13.9 percent of U.S. farmers have irrigated land. Even when considering just cropland, only 14.8 percent of all harvested cropland is irrigated (Table III-3). (Note: Estimates in the table are based on U.S. Dept. of Commerce, 1989, Table 1 and Table 9). Once a drought has started, farmers on 95 percent of the nation's farmland have very few options.

Considerable variability in the extent to which irrigated agriculture can help alleviate drought also exists across the U.S. representative states in the western, central (Great Plains), and eastern U.S. as illustrated in Table III-3. California and Idaho have nearly one-fourth of the irrigated farmland in each state. Idaho irrigates 64.6 percent and California 90.7 percent of all harvested cropland. Clearly, shortfalls in rainfall would have less impact than in dryland farming states, as long as sufficient water is in storage. Florida also irrigates 62.2 percent of harvested cropland; however, this represents only 14.4 percent of all farmland. At the other extreme, North Dakota, Iowa, and New York have only about 1 percent or less of all farmland and harvested cropland irrigated. Any shortage in rainfall during a crop season will generally have a direct adverse impact. Nebraska represents a middle ground, with 12.5 percent of all farmland irrigated and 36.4 percent of the harvested cropland irrigated.

TABLE III-3

FARMS AND IRRIGATED LAND FOR REPRESENTATIVE STATES, 1987

Representative States	Total Number of Farms*	Total Farmland*	Total Irrigated Land*	%	Total Harvested Cropland*	Irrigated & Harvested Cropland*	%	Farms with Irrigated Land: Number*	%	Farmland*	%
California	83.2	30598	7596	24.8	7676	6964	90.7	58.0	70.7	17566	57.4
Idaho	24.1	13931	3219	23.1	4349	2811	64.6	16.6	68.8	905	64.9
North Dakota	35.2	40336	168	0.4	18363	162	0.9	0.8	2.3	1497	3.7
Nebraska	60.5	45305	5681	12.5	15276	5561	36.4	22.0	37.3	22498	49.6
Texas	188.0	130502	42710	32.7	16521	4020	24.3	19.0	10.4	20270	15.5
Iowa	105.0	31638	92	0.3	20484	92	0.4	0.8	0.8	385	1.2
New York	37.7	8416	51	0.6	3900	49	1.2	1.9	5.3	305	3.6
Florida	36.5	11194	1622	14.4	2241	1395	62.2	11.0	32.7	4670	41.7
		Σ311920	Σ61139								
United States	2087.0	964470	46386	4.8	282223	41787	14.8	291.0	13.9	241069	24.9

* Thousands of farms or acres.

Source: U.S. Department of Commerce, 1989 (Tables 1 and 9).

Although it is true that 86 percent of U.S. farmland is not irrigated, and therefore may be more susceptible to drought, the variation in the potential vulnerability is large among states. In California and Idaho, for example, respectively, 70.7 and 68.8 percent of the farms have at least some irrigated land. In fact, 57.4 and 64.9 percent of the farmland on these farms in California and Idaho are irrigated (last column in Table III-3). In contrast, around 5 percent or less of the farms have some irrigated land in North Dakota, Iowa, and New York (Table III-3). In fact, only 0.8 percent of the farms in Iowa have irrigated land, which is typical for the rest of the Corn Belt states as well.

There is a certain degree of interdependence between dryland and irrigated farming, since there are farms that are only partially irrigated (13.9 percent of U.S. farmers) and/or may use irrigated forages as part of dryland-farming practice. Forages may go to feeding cattle on dryland range, for example. Also, crops usually produced only on dryland may be profitable during a drought under irrigation due to higher crop prices. As a result of this interdependence, state and federal offices working with the drought problem may have to deal with both dryland- and irrigated-farming problems simultaneously. Both the water managers having some control over water supplies, and the individuals working with dryland farmers may have to face similar drought problems. It follows that both dryland and irrigated farm impacts need to be assessed during a drought. Even if yield impacts occur only on dryland farming, costs of production can be affected in both types of farming. Water costs on irrigated land may increase due to water shortages at the source(s) (e.g., from having to dig an irrigation well deeper, from managing the irrigation system more intensely to save water, or because of higher valued alternative uses for the water).

The following section identifies and characterizes the analytical approaches and systems available for assessing the positive and negative economic effects and impacts of drought on both dryland and irrigated farms. The literature can be viewed in a hierarchical sense, suggesting the character of a workable analytical system. At each level in the hierarchy, a systems view of drought may be the most appropriate. First the focus is on explaining how to establish the linkage between drought and yield in a soil-water-plant systems model at the field level. Then, a higher level of aggregation is represented by a farm-level systems model. The farmer adjustment to drought can be addressed in this part of the analytical system. The key role that institutions play in farmer adjustment is emphasized. The final level of analysis in the analytical system involves identifying state, regional, national, and international impacts and effects. Again, institutional arrangements can also play a significant role in affecting the ultimate economic impact. (See Appendix C for a detailed discussion concerning more technical aspects of understanding the crop yield to water availability linkage and farmer response to drought as modeled in the farm simulators).

Soil-Water-Plant System

Easterling and Riebsame (1987) emphasize that drought assessment requires the analyst to firmly establish the causal link between drought and its impact. That is, the analyst ideally would have an analytical system for establishing estimates of the water demand-and-supply curves (see Appendix C, Figure C-1) for each crop and livestock operation. Historically, the manner of approaching the estimation of such relationships involved some variant of the production function approach. Generally, yield was viewed as some function of "water," nutrients, and possibly weather or management variables (see Hexem and Heady, 1978). Lynne and Carriker (1972), in a review of that literature, suggest that only a few studies have merged yield response and economic information in such a way that might be directly used for economic assessment. The review herein continues to suggest that little of this literature is directly useful in drought assessment, which depends on understanding both the causal links and the management response.

The limited usefulness of this research for drought assessment arises because in most production function studies, the water variable has been water applied, precipitation plus water applied, or simply precipitation. Such variables make it difficult, at best, to separate yield and management response. Importantly, effective soil moisture really affects yield and cost, and thus the relationship between yield and soil moisture needs to be understood to accomplish economic assessment (Lynne et al., 1987). The yield impacts and the management response really need to be separated. Easterling and Riebsame (1987) support the same view by pointing out that often the management response and weather effects have not been clearly identified in production function studies. As a result, production functions are only useful in a very localized nature. Therefore, it is difficult to generalize and extrapolate results over time and space.

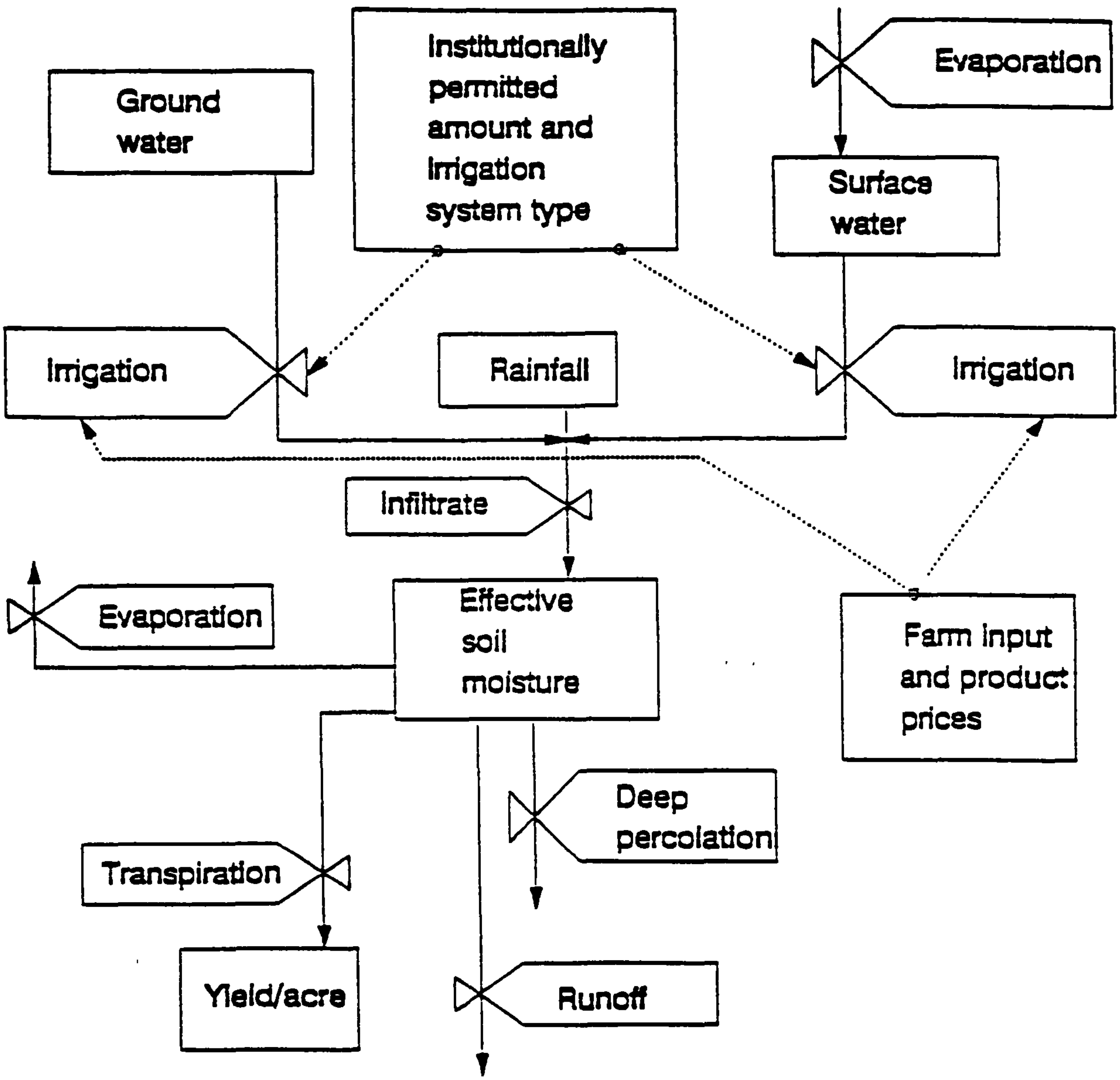
Arthur and Kraft (1988) suggest an improvement over the standard production function approach with a simulation model developed for assessing soil moisture by soil type. The model operates on a daily time step while estimating soil moisture in six layers. Soil moisture deficits were predicted for the entire period 1935-82, with summary statistics of annual soil moisture deficits by growth stage for the crop, crop reporting district, seedbed, and soil type in Manitoba, Canada (Arthur and Kraft, 1988). The moisture deficits were estimated for all major crops in all the crop districts for all of the years. A problem with the approach is that traditional production function estimates were still used to relate per acre yield to drought. The econometrically based models relate yield to such variables as a varietal index, dummy variables for extreme weather events, and fertilization rate.

Crop modeling represents an improved approach to the problem of isolating the causal links between drought and yield, and for separating out weather and management effects. In addition to a soil water model such as that of Arthur and Kraft (1988), crop models are also a part of the simulator. Effective soil moisture is the variable of focus in most of these soil-water-plant simulation models. Such models can be more generic in form and structure than production functions and thus can be used in a wider variety of settings. When combined with farm-level simulators (discussed later), the management influence can also be examined.

A simple, yet illustrative, soil-water-plant systems model is outlined in Figure III-3. The central focus is effective soil moisture in the root zone. Water (rain, irrigation water) enters the root zone as affected by the infiltration rate and water (evaporation, runoff, deep percolation, transpiration) levels. (Note: The "valves" on the lines connecting "boxes" in the figure represent the way to control "flows," which affect "levels"). Yield is influenced by transpiration, which is a direct function of the effective soil moisture, among other forces.

FIGURE III-3

SOIL-WATER-PLANT SYSTEM



The model also suggests that under irrigation, institutions (laws, rules, regulations, customs, habits) may only permit a certain amount of withdrawal by the irrigator from ground and surface sources. If the government agency representing that institution sees low-opportunity costs for the water (i.e., low economic value in alternative uses), the permitted withdrawal will be higher. Alternatively, the permitted withdrawal may be reduced due to perceived high-opportunity costs. It is important to note how both farm production and input prices will also likely influence the grower-selected target level of effective soil moisture.

Institutional factors may also influence the kind of irrigation system used and thus the irrigation water-flow rate (Figure III-3). Water-saving irrigation technologies may be required, especially if drought becomes a regularly occurring event. Agricultural drought may become a more frequent event due to pressures on water supply from rapid growth in population, suggesting again the social aspect of drought. It may also be reasonable to expect that investment levels may change. A drought could spur irrigation investment, although it could also reduce investment if farmers become discouraged.

Jones and Ritchie (forthcoming) reviewed the crop water modeling literature. Over 40 different simulation models have been developed in the U.S. and other parts of the world for studying crop response to various inputs and stresses. Most of these models can be helpful in examining the effects of water stress and thus can be useful in drought assessment.

A representative example of the literature is the soybean model described in Wilkerson et al. (1983). The simulator predicts crop response to variations in daily weather inputs (temperature, rainfall, radiation) and to drought, insect, and disease stresses. Soil water availability and timing affect photosynthesis, leaf expansion, and leaf senescence (Wilkerson, 1983).

Another representative example, with possibly broader application, is the Erosion Productivity Impact Calculator (EPIC), which was initially developed to predict crop inputs, costs, and erosion rates, among other dimensions of the crop-growing process throughout the U.S. (Williams et al., 1984). An earlier version of EPIC was used to generate input variables (mainly yield estimates for different management regimes) for the national agricultural linear programming model (Meister and Nicol, 1975). The programming model was used, in turn, to help establish the status of soil and water resources in the U.S. in 1985 as required by the Resource Conservation Act (Williams et al., 1984). With its recent modifications, EPIC can now be used to assess drought impacts for a wide variety of crops throughout the entire U.S. (Dyke, 1990).

A major advantage of a systems approach such as that used in EPIC is that time becomes an explicit variable in the analysis. Such models usually operate on a daily time step, driven by daily rainfall and other weather variables. This feature can be very useful in drought assessment. As Matthai (1979, p. 13) notes, the onset of a drought is usually subtle and may get progressively worse through time. A systems model, then, can be used in assessing the impact of the progression by facilitating regularly updated projections as the drought unfolds.

Linvill (1990) comments on the evolution of crop systems models, "models of crop development, animal reaction to the environment, and the development of insects and diseases are now available," and that with further development, "assessment of drought impact will be possible" (p. 38). He correctly perceives that the models may not, in all cases, be quite ready for general application. Such physiological models remain experimental in most states (Easterling and Riebsame, 1987).

Linvill (1990) also notes how Geographical Information Systems (GIS) could likely play a role in drought impact analysis. Such data bases, including soil characteristics and parameters as well as acreage devoted to agriculture, could serve as input to soil-water-plant simulators and to farm-level models and help in predicting economic impact. Few soil moisture or yield models and the associated GIS data bases, however, are currently in widespread use. Such data bases could eventually be integrated with crop systems models, e.g., parameters such as soil water-holding capacity could be stored in the GIS data base and used as input to the crop simulators.

Improvements in the crop models and the associated data bases will occur as they are operationalized. The assessment of drought impacts will then be much more easily and accurately accomplished (Linvill, 1990). For now, rather simple models for predicting soil moisture are being used in assessing drought, and yield impacts are estimated more or less independently of the drought indexes.

Two indexes called the Palmer Drought Severity Index (PDSI) and the Crop Moisture Index (CMI) have been developed for indicating the severity of long-term and weekly drought, respectively (Wilhite, 1982). The PDSI is the main tool used for monitoring drought in the U.S. (Wilhite, 1982). The PDSI summarizes prolonged periods of abnormally dry or wet weather by integrating antecedent weather conditions over several months. Problems with the index include:

(1) The plant response is not considered.
(2) The Thornthwaite method for calculating evapotranspiration (ET) is used, which may not be appropriate in subhumid and arid regions of the U.S.
(3) The index is only calculated on the basis of climatic divisions, a scale at which drought assessment may be difficult.
(4) The index is often incorrectly applied (Wilhite, 1982, p. 334).

As Wilhite (1982) notes, the PDSI does not allow predicting the impact of soil moisture stress on any particular crop because each crop responds differently to moisture and heat stress. Linvill (1990) points out the broad-brush character of the Palmer Drought Index but also notes how several states trigger emergency response actions based on the index.

In contrast, with soil-water-plant systems models:

(1) The plant response can be modeled.
(2) The ET calculation method can vary with the region for which the model is calibrated.
(3) The aggregation for analysis purposes can be at the field level, the farm level, and beyond.

It would seem then that systems models could and should play a key role in economic assessment. Encouragingly, the EPIC model was used as a supplementary yield-estimating tool in the 1988 national assessment of drought by the U.S. Department of Agriculture, Economic Research Service (Osborn, 1990), as discussed in detail later in this report.

Farm System

Easterling and Riebsame (1987) also emphasize the need to understand and explain how farmers actually respond to drought. The human adjustment process, i.e., how farmers (as well as others) behave during drought, is just as crucial a link as the yield-to-drought relations discussed in the previous section.

The concern with understanding and explaining farmer behavior has a long history (Jensen, 1977). Recently, simulation modeling has been recognized as the main approach to clarifying the behavioral adjustment process on a farm. For example, financial analysis of farm-level response in the face of farm program changes has been accomplished using whole-farm simulators (Duffy et al., 1986). The impact of drought caused yield reductions and the effect of government drought relief programs on such farm financial attributes as the net worth, debt-to-equity ratio, and the probability of long-term survival can be assessed with the model.

A simple farm-level system dynamics model is depicted in Figure III-4 and shows effective soil moisture and other (also effective) farm inputs being transformed into yield. Drought predictions influence the number of acres planted and the rate of input applied, suggesting adjustments by the farmer as the drought proceeds. The farmer can make only limited changes once the drought starts. Government payments (e.g., crop price subsidies, drought assistance) and crop insurance affect farm income. The general social willingness to share in the burden of the drought likely affects the rate of drought relief payments.

One example of using farm-level models to assess drought is provided by Kulshreshtha and Klein (1989). Five models were used, including

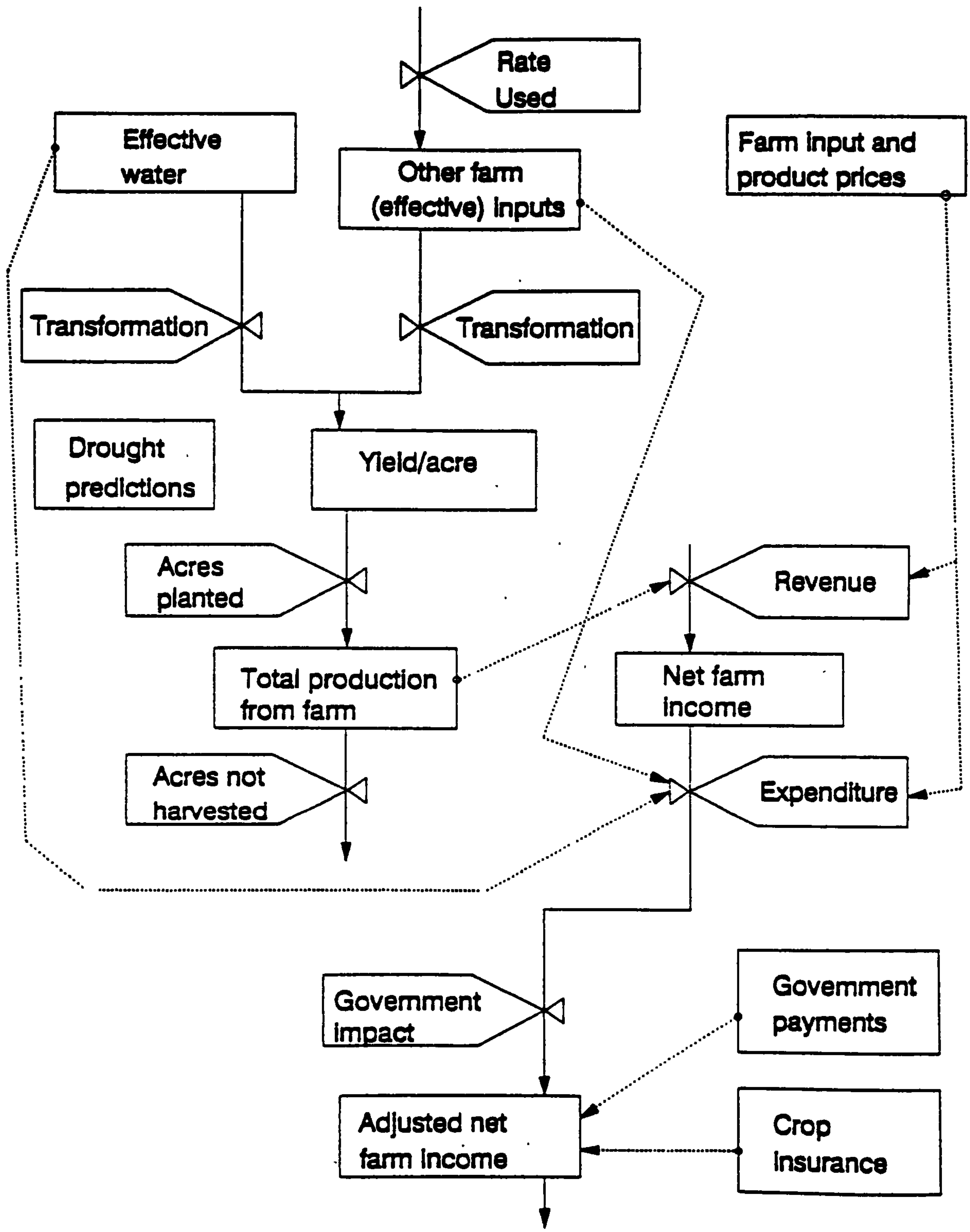
(1) Dryland and irrigated crops model
(2) Beef cattle-forage-grain model
(3) Hog-grain model
(4) Dairy cattle-forage-grain model
(5) Poultry model

Such simulators emulate alternative decision strategies taken by an actual farmer (Kulshreshtha and Klein, 1989). These models allow examination of the impacts of different methods of production, e.g., different planting dates, rotations, tillage operations, machines, fertilizer amounts, and ingredients in feeds and animal diets. Outputs of the model include income, net worth, income variability, cash flow, family consumption expenditures, and income taxes paid. Thus, such models could be used in simulating possible farmer adjustment and the economic impacts. Klein et al. (1989b) provide an in-depth discussion of these farm systems models.

As Riefler (1978) notes, the farm-level impacts can take on many dimensions, including a decline in production, reduced income, price increases, drawing down of previously accumulated wealth, increased indebtedness, bankruptcy, and possibly out-migration. Economic impact assessment should account for all of these aspects.

FIGURE III-4

FARM SYSTEM



Riefler (1978) argues that the biggest challenge for economic impact assessment is to understand the farmer response to a drought situation. Farm simulators could help with this task. Seemingly, there would also have to be considerable effort put into documenting actual farmer response.

Taylor et al. (1988) also suggest the need to study actual farmer behavior during and after droughts. For example, they found that perception of a drought varied substantially among farmers, with the result there was also considerable variability in the response and adjustment. An example of the kind of research that is needed is a careful documentation of the underlying water-law institution and the impact of the institution on how actual farmers and agencies interacted during the drought.

State, Regional, National, and International System

While considerable effort has gone into systems dynamics modeling of larger systems (e.g., the Club of Rome model, which examines world natural resource flows, Meadows et al., 1972), no such models focusing on agricultural drought impact assessment apparently exist. Warrick (1975) outlines such a conceptual, aggregate model but provides no empirical counterpart. Rather, agricultural economic impact assessment has generally relied on well-established techniques of regional econometric modeling, mathematical (e.g., linear) programming, multiplier analysis, and input-output analysis, or some mixture.

The appropriate approach depends in part on the degree of aggregation necessary, which is dictated by the extent of the interdependence arising as a result of the drought. As Riefler (1978) points out, with only a few affected farms in a localized area, the assessment can be primarily a supply-side analysis focused on isolating the impact on yield, input purchases, and acreage changes. Essentially, the problem becomes one of aggregating the results from several farm-level simulations. As the drought expands in scope, the interdependence increases, which requires that both demand and policy analyses be accomplished (Riefler, 1978). That is to say, supply-and-demand effects need to be isolated along with the impacts of current (and changed) institutions and policy.

Arthur and Kraft (1988) used a crop-reporting district (regional) linear programming (LP) model to assess drought impact in Manitoba, Canada. Livestock enterprises and nonfeed operating costs are simulated outside the LP model, but the livestock-feeding enterprises are represented in the model. The model assumes each farmer maximizes profit, and the model simulates the regional net agricultural revenues. Arthur and Kraft (1988) note the potential aggregation bias from assuming the region acts as a single decision maker. Both local and world prices were entered into the model, suggesting the capability of examining the impact of changing foreign prices on local economic returns. These prices are entered into the model and treated as an exogenous variable.

Lee et al. (1987) provide another example of an application of linear programming for a regional assessment. While not specifically addressing drought, the approach does allow an impact assessment of moving water away from agriculture toward an urban use, which could easily become a policy decision in irrigation areas during droughts. The analytical system includes a biophysical simulator for estimating the linear programming coefficients for crop yield as related to irrigation water, the countywide linear programming model for simulating farmer adjustment and estimating output/income, and a regional input-output model that uses data from the linear programming model as input to estimate secondary economic effects. The tie between the urban and agricultural area is the common aquifer under a county (Lee et al., 1987). This analytical system allowed obtaining estimates of the economic impact of changing application efficiency (direct and secondary economic impacts), the percentage of economic activity in the county and in the larger regional area attributable to irrigation, and the general regional economic impact from moving water into urban use.

Riefler (1978) argues that assessment should focus mainly on the farm and regional levels because of the resiliency at the national and, by implication, international levels. When there are more aggregate effects, however, he favors input-output models. He suggests modifying such models to disaggregate agricultural producing and purchasing sectors and to add a water production/consumption row to assist in measuring water dependency (Riefler, 1978).

Kulshreshtha and Klein (1989) also used an input-output model for estimating secondary impacts in the economy. As discussed earlier, direct farmlevel output for entry into the input-output model was estimated using farm level simulators, which in turn depended on a yield-hydrology simulator. An employment model was also developed using the idea of an employment production function. The level of output from an industry as predicted by the input-output model was used to estimate the employment impacts. One problem encountered was that aggregation of farm-level results did not give the aggregate values used by the input-output models, due in part to the farm-level simulators not being specific enough to estimate nonenterprise-related expenditures. They used the entire analytical system (yield-hydrology model, farm-level simulators, input-output model) to examine the effectiveness of various farm management strategies and policy measures. The model has the capability of estimating income and employment effects at the local and regional levels. National and international effects were not explicitly addressed because of their assumption of no product price impacts (i.e., perfectly elastic crop and livestock demand functions).

An earlier example of an input-output approach to evaluating the role of water is provided by Gray and McKean (1976). They warn of the static nature of input-output models and call for more research relating economic activity to water use. Seemingly, a systems dynamics approach to drought assessment would help in alleviating their concerns.

Most aggregate economic impact assessments have been accomplished using rather straightforward techniques. Aakre et al. (1990), for example, used data collected in a field survey by a team from the University Extension Service. Estimates were made as to the percent reduction in small grain production and rangeland capacity. Given projections of the percent reduction from average yield, Aakre et al. (1990) then projected the expected increase in product prices, as well as decreases in deficiency payments (i.e., as prices increase, deficiency payments per bushel of small grains decrease). Five-year averages and planning prices were used to estimate normal returns. The reduced yields and higher prices were used to determine the value of commodities after the drought. The difference was the drought impact (Aakre et al., 1990). For livestock, changes in price expectations and feed costs were factored into the calculus. Aakre et al. (1990) also accounted for the institutional setting: the impact of deficiency payment loss (due to rising prices) was partially offset by forgiven advance deficiency payments and disaster aid payments.

In many respects, the recent extensive agricultural economic drought analysis conducted by the U.S. Department of Agriculture, Economic Research Service (USDA, 1989), in cooperation with a number of other federal agencies was as pragmatic and straightforward as that of Aakre et al. (1990). The effort relied on field surveys. The approach involved a lot of counting and measuring (e.g., number of jobs lost). Practical approaches to predicting impact were used.

Federal Assessment of the Agricultural Economic Impacts of the 1988 Drought

The approach used by the U.S. Department of Agriculture, which is the main federal agency involved in drought assessment, had many facets. The National Weather Service (NWS) gave predictions through the Agricultural Weather Service Centers (Offices), which provided both service and research responsibilities (Linvill, 1990). Daily weather advisories were prepared and disseminated. Data relevant to following weather events that effect agriculture were collected from various sources, including NOAA, FAA airport data, satellite information, and state agricultural experiment stations. Crop and soil data were also collected and shared with the Office. Both the Crop Reporting Service and County Extension Offices (U.S. Department of Agriculture and Cooperative Extension Service) in each state also provided data to the Office (Linvill, 1990).

The USDA is also involved in water supply prediction, and other drought-related programs, through the Soil Conservation Service (SCS). The SCS collects information on snowpack, precipitation, temperature, and other hydrometeorological data (Shafer and Fecke, 1990). Data and predictions are made available on a regular basis.

The SCS makes water supply outlook reports available to the public through the agency's "field office communication and automation system" (FOCAS) (Shafer and Fecke, 1990, p. 41). Water supply forecasts are generated in cooperation with the National Weather Service (Shafer and Fecke, 1990). All of these predictions and forecasts became a part of the ongoing drought assessment process that operated during the 1988 drought (Osborn, 1990).

As already noted, during the 1988 drought EPIC was used as one source of yield estimates along with predictions from econometric models (Osborn, 1990), which were made drought sensitive (see Ash and Lin, 1987). Information from the field surveys coming through the National Agricultural Statistics Service was also used in formulating yield estimates (Leath, 1990). The yield estimates were then entered into econometric models for estimating price impacts (Leath, 1990). The econometric models are systems of equations used in predicting planted acres, harvested acres, corn yield, and production as a function of prices and government programs (Westcott and Hull, 1985). Farm-level prices are estimated. The results can then be used to estimate retail food prices, based largely on changes in farm-level prices and food-marketing costs (Westcott, 1986).

Generally, the USDA effort recognized the "closed" (Riefler, 1978) feature of the national/international economy, in that supply, demand, and policy (institutional) elements were all considered. The assessment generally focused on particular attributes within each dimension, for example, number of farmers facing severe drought, number of banks becoming vulnerable, number of jobs lost in food processing, and changes in farm income. A wide variety of sources of information and data were used to quantify and characterize each attribute. The following illustrates the types of attributes that have actually been considered, shows the immensity of the data collection problem, and briefly shows, when possible, how the data have been used by the federal government in assessing drought. The following is the outline of the drought assessment report (USDA, 1989); only representative sorts of issues are discussed to give the reader a flavor for the character and the immensity of the task of national drought impact assessment.

The first part of the report highlights the role of the Palmer Drought Severity Index, which was provided by the National Oceanic and Atmospheric Administration/USDA Joint Weather Facility. The Index, which was calculated for weather districts, highlighted areas needing particular attention and an assessment. For analysis purposes, the Index was disaggregated and assigned to counties (USDA, 1989). The Index helped identify the areas needing detailed assessment.

The first set of tables in the report suggests the well-established capability of the USDA to monitor crop supplies in the stressed areas. Citing publications from the USDA, Economic Research Service, and Foreign Agricultural Service, the report shows the supply (beginning stocks, production, imports) balanced against the demand (feed and residual; food, seed, and industrial uses; and exports) (USDA, 1989). Drought losses for 1988 were predicted to be about 0.3 percent of the GNP, food price inflation to be 3-5 percent, and the change in the CPI to be 0.16 percent for each percentage point increase in food prices. The exact way in which the estimates were developed is not described.

The report then details food and fiber sector impacts. Financial impacts are discussed first. Data used to describe the impacts include such attributes as gross cash farm income, cash production expenses, and net cash farm income. Based on surveys of farms, it was possible to indicate the extent to which farm households were solvent or not, in addition to the expected impacts of the drought (USDA, 1989). The Farm Costs and Returns Survey for 1985, 1986, and 1987 gave information on returns on assets, percent of farms with positive cash income, and farms that are financially vulnerable (USDA, 1989). Both the substantial data needs and significant data collection capability of the USDA become apparent in the measuring of such attributes.

The likely impact from selling out farm inventories of crops was also established. The effect on prices of reducing federal stocks was also estimated. The analytical system being used is not described.

The report then assesses impacts on farm inputs. Most farmers had already purchased and used seeds, fertilizers, and pesticides before the drought, so there was likely little impact (USDA, 1989). Farm machinery sales dropped, however, as shown by data obtained from the Farm and Industrial Equipment Institute (USDA, 1989). The analytical system being used relies heavily on industry trade groups and associations. Energy use was lower because less harvest energy was used.

Food processor and marketing impacts were found to be minimal. The discussion suggests considerable interaction with the various processing groups, for example, the National Food Processors Association (USDA, 1989). It is not clear how the analysts know, for example, that the industry has significant excess capacity, but clearly the analytical system used suggests industry watchers are involved in the drought assessment process.

Low river flows suggest impacts on barge transport of grain. American Waterways Operators estimated a loss of $200 million for the year. Data are shown from the U.S. Army Corps of Engineers on grain shipments (USDA, 1989) which demonstrate the interaction of the USDA with a number of federal agencies in the drought assessment process. The report mentions the existence of an Interagency Drought Policy Committee (USDA, 1989), which apparently affected the agency cooperation. According to data from the Association of American Railroads, railroads enjoyed more business. Statistics on railroad rate impacts were cited from the U.S. Department of Labor (USDA, 1989).

Credit issues were highlighted. Data were available from the Farm Credit System on loan losses. Data from the Farmers Home Administration showed about a 25 percent delinquency rate. It was possible to locate the percentage of the farm and rural bank areas by counties in the drought areas (USDA, 1989). It was also possible to highlight and quantify, by severity of the drought, a variety of attributes including the number of banks and vulnerable banks, assets, loans as percent of deposits, federal funds as percent of assets, return on equity, and delinquent loans (USDA, 1989). The report also identifies the variability in profitability of Farm Credit Service institutions and suggests an increased demand for rural and farm credit. Again, the analytical system could not be identified from the report.

The report notes how "lenders are reassured by the continued strong Federal support for U.S. agriculture" (USDA, 1989). The report details the federal response through the Farmers Home Administration and the Small Business Administration loan programs.

Effects on various nonfarm industries are highlighted, including the forestry firefighting costs, the likely impacts on mortality rates of plantings, and some general discussion of drought impacts on insect susceptibility (USDA, 1989). Hydropower impacts are highlighted.

An input-output analysis is then accomplished for five multi-county areas as representative regions in the United States. Attributes considered include average county population, percent of counties losing population, per capita income, total employment, farm-related employment (by class, e.g., farm inputs, processing, indirect agribusiness), number of farms, acres, value per farm, percent of sales by crop type, percent of operators reporting off-farm work, and percent of sales from farms in each sales class. Crop-yield loss estimates and income loss estimates for livestock were obtained in each county in each region. Crop loss estimates came from the August Crop Report generated in each state by the USDA, National Agricultural Statistics Service. Livestock budgets came from the USDA, ERS Cost and Returns Surveys. Direct losses were then calculated for the farm sector of each region, with attributes represented in dollar losses in food grains, feed grains, soybeans, beef, dairy, and hogs (USDA, 1989, p. 49). Federal drought payments were subtracted, arriving at net direct effects.

Net direct effects were then used to estimate indirect economic effects in the local businesses by utilizing regionalized input-output models that were based on the U.S. Forest Service input-output model. The user can construct a set of regional income and product accounts for 1982 and the corresponding input-output model for any county or subgroup of counties in the U.S. (USDA, 1989). Total and direct effects in each region were then predicted for the attributes:

(1) Farm production: food grains, feed grains, soybeans, livestock, and other
(2) Processing industries: meat products and dairy products
(3) Nonagriculture industries: manufacturing, transportation, wholesale and retail, services, etc.

The impact of federal drought assistance was estimated and results show substantial variability among regions.

Overall, the report reveals the immensity and the complexity of the problem of assessing agricultural economic impact. Also, while an analytical system clearly does exist at the federal level, the details of the system cannot be determined from available publications.

BUSINESS AND INDUSTRY

Droughts affect the commercial and industrial sectors in similar ways. Russell et al. (1970) developed separate estimates of drought impact for these sectors by using the following categories of losses:

(a) Industrial sector
  (1) Business losses
  (2) Investments
  (3) Other

(b) Commercial sector
  (1) Business losses
  (2) Investments

Business losses were defined as those "resulting from forced slowdowns or shutdowns in production due to drought." Investments entailed "the claimed capital costs of all permanent water-use adjustments" (e.g., developing more efficient water use at the firm, such as a recirculation system for cooling water). The "other" category, which is only present in the industrial sector, includes a variety of costs from miscellaneous expenditures due to drought, such as save-water campaigns or rainmaking schemes.

These categories provide a way to account for drought impacts in the commercial and industrial sectors. The authors are careful to point out the need to be cautious about the possibility of double counting and go to some lengths to show how one may avoid this mistake. An example of the accounting system used by Russell et al. (1970) is shown in Table III-1 of this report.

The specific formulas used to estimate the commercial and industrial drought losses are also presented by Russell et al: (1970, p. 206). Daily losses (DL_f) from the firm's accounting stance are:

$$DL_f = VO_\alpha - AC - W_x \qquad (1)$$

where

VO_α = value of output per day using x units of water and the needed combination of other inputs y used to create output

AC = avoided costs such as wages of workers, raw materials except for the cost of water

W_x = daily water bill not paid

The daily losses to the firm from the societal point of view (accounting stance) (DL_s) are different in that the value of wages per day (E) is subtracted from cost avoided (AC). This then reflects the opportunity cost of society's employment by the firm, which exists whether the firm is operational or not. Then:

$$DL_s = VO_\alpha - (AC - E) - W_x \qquad (2)$$

The authors also note the difference that occurs if the firm is self-supplied with water. Firms which purchase water should also count the city's daily lost revenue if using a societal viewpoint. The formula then becomes:

$$DL_s = VO_\alpha - (AC - E) - H_a$$

where

H_a = avoided cost of water supply

in that

$W_x - H_A$ = the cost of interrupted water production to the city.

Formulas for investment returns are dependent on the type of investment made (e.g., the drilling of a new well or installation of a water recirculation system). A detailed discussion of this appears in Russell et al. (1970, p. 214). The general assumption of the approach is that if, for example, a firm installs a water recirculation system as a consequence of drought events, that investment does not reflect the true cost of the drought event to the firm. The firm enjoys a cost savings from the recirculated water because they either do not need to purchase as much water (if city supplied) or can pump less of their own. This cost savings needs to be subtracted from investment in the recirculation system.

HYDROPOWER

The United States is the world's largest producer of electricity from hydropower. The installed power capacity of the 1,546 generating units exceeds 67 million kilowatts (Federal Energy Regulatory Commission, 1984). In 1987, these generating stations supplied 12 percent of the electricity and 5 percent of all supplemental energy. The total U.S. net production of electric energy (excluding station use) in that year was 2,686 billion kilowatt-hours. Therefore, the market value of hydropower produced at 8 cents/kwh would amount to approximately $26 billion.

Drought Impacts

According to Solley et al. (1988) the hydroelectric power water use in 1985 averaged 3,050,000 million gallons per day (or 3.42 million acre-feet). The hydropower industry is often among the first activities to be affected by drought. Other uses of water, such as public water supply or recreation often compete with the generation of hydroelectric power. For example, the Tennessee Valley Authority Board of Directors gives the lowest priority to hydroelectric power generation during a drought event. The decreases in hydropower production during drought are often coupled with widespread above-average air temperatures during cooling season thus leading to marked increases in the use of air conditioning and high electric power demands.

During the 1988 Drought, the national hydroelectric power generation was 13 percent below the 1987 level, thus implying the value of production loss of $3.4 billion. The President's Interagency Drought Policy Committee (1988) report the reductions in hydropower production on the Missouri River, in the Pacific Northwest, on the Ohio River, and in the Southeast ranging from 20 to 40 percent. However, hydroelectric plants throughout the United States were not as concerned with potential power shortages as they were with budget shortfalls caused by supplementing energy output with costlier coal or petroleum supplies. Electrical production decreases of up to 50 percent were reported in the first six months of 1988 in the southeastern, northeastern, and northwestern regions of the United States (Lagassa, 1988). Independent hydroelectric producers also reported financial concerns due to drought. Lagassa (1988) reported that the drought forced increased energy costs on manufacturers that could not be passed on to product buyers.

The TVA Drought Policy Committee Final Report (1988) included an estimate of the loss of hydroelectric production at $150 million by the end of 1988. Replacing that lost hydroelectric production cost $117 million through June of that year. In terms of the drought that began in June 1984 through mid-1988, the replacement cost of lost hydroelectric power was $350 million. Additionally, the report noted other effects attributable to drought. Steam plants used by the TVA, such as the Allen Steam Plant at Memphis, Tennessee, were affected by the low streamflow in that they lacked adequate supplies of cooling water.

The vulnerability of hydropower industry to drought will likely increase in the near future when additional hydropower potential is developed. The Federal Energy Regulatory Commission (1984) identified additional 4,677 sites that could be developed increasing the installed capacity by 116 percent (or 77 million kw). This new capacity would result in the doubling of the demand for water even with a significant portion of new hydropower production relying on pumped storage (Federal Energy Regulatory Commission, 1984).

Estimation of Drought Losses

The conceptual basis for evaluating the benefits from energy produced by hydroelectric power plants is society's willingness to pay for this energy. The U.S. Army Corps of Engineers suggests that the most practicable measure of the marginal willingness to pay is the resource cost of the most likely alternative source of energy to be used in absence of hydropower. During drought, the most likely alternative sources may include both the existing unused capacity of thermal power generation as well as such alternatives as reducing the level and/or time pattern of demand by time-of-day pricing, utility-sponsored loans for insulation, education programs, interregional power transfers, and others.

The experience of the 1988 drought suggests that the true cost of reduced hydropower production was greater than the theoretical least cost of its replacement through energy conservation. Both lost hydropower and increased demands for electricity were met by increasing production from existing thermal generation sources.

NAVIGATION

Waterborne transportation is dependent upon adequate water supplies to ensure navigability of the inland waterways. Drought creates a variety of problems not only for the transportation industry itself but for related industries which rely on water transport of raw materials, fertilizers, grain, and fuels.

In 1987, the U.S. inland waterways (including rivers, canals, and domestic traffic on Great Lakes) accounted for 15.6 percent of the total domestic freight traffic which measures the total ton-miles moved by railroads, inland waterways, motor trucks, oil pipelines, and air carriers (Eus Foundation, 1989). The total freight in 1987 amounted to 411 billion ton-miles. More than one-half of this freight was accounted for by transportation routes on the Mississippi River system (comprising main channels and all tributaries of the Mississippi, Illinois, Missouri, and Ohio rivers). According to the U.S. Army Corps of Engineers (1985), the principal commodities of domestic commerce carried on inland waterways include petroleum and products, coal and coke, iron ore and sand, and gravel and stone (U.S. Army Corps of Engineers, 1985). Farm products carried on waterways represent approximately 12 percent of total (domestic and foreign) commerce and 7 percent of domestic commerce.

The 1988 drought was noted for severe restrictions on the number of barges traveling the Mississippi and Ohio rivers. Shallow water depths and reduced channel widths caused the U.S. Army Corps of Engineers to limit the weight of barges and number of tows allowed on the rivers (Surviving the Drought, USACE, 1989). Dredging was also utilized to maintain navigation along the White, Missouri, Ohio, Alabama, and Mississippi rivers. The operations to remove sandbars which delayed or prohibited river traffic began in early June 1988 and continued through early December.

The barge industry responded to the restricted waterway transportation by increasing the numbers of tows and barges in service. As a result of the decrease in allowable drafts, materials were shipped by alternate methods, especially by rail (the rail industry benefited from the drought). These shifts caused some short-term increases in the prices of materials normally shipped along the inland waterways (PIDPC, 1988).

Not all waterways were restricted by the drought conditions in 1988. Reports of increased barge traffic were found on the Lower Tennessee River and Tennessee-Tombigbee Waterway. Much of the traffic that may normally have been on the Lower Mississippi was rerouted to these other waterways, at an increased expense for the barge owners.

Changnon (1989) reported that the shipment of bulk commodities (coal, petroleum, and grain on the Mississippi River system was reduced throughout the summer of 1988, resulting in losses of over $200 million or 20 percent of the annual income of the river transport industry. Riebsame et al. (1990) also note the impact that low riverflows had on the navigation industry. The estimated cost to the transportation industry as a whole was placed at $1 billion by Riebsame et al. (1990). This estimate includes both the negative impacts absorbed by the barge industry and the positive benefits enjoyed by the rail, Great Lakes shipping, and aviation industries.

Impact Measurement

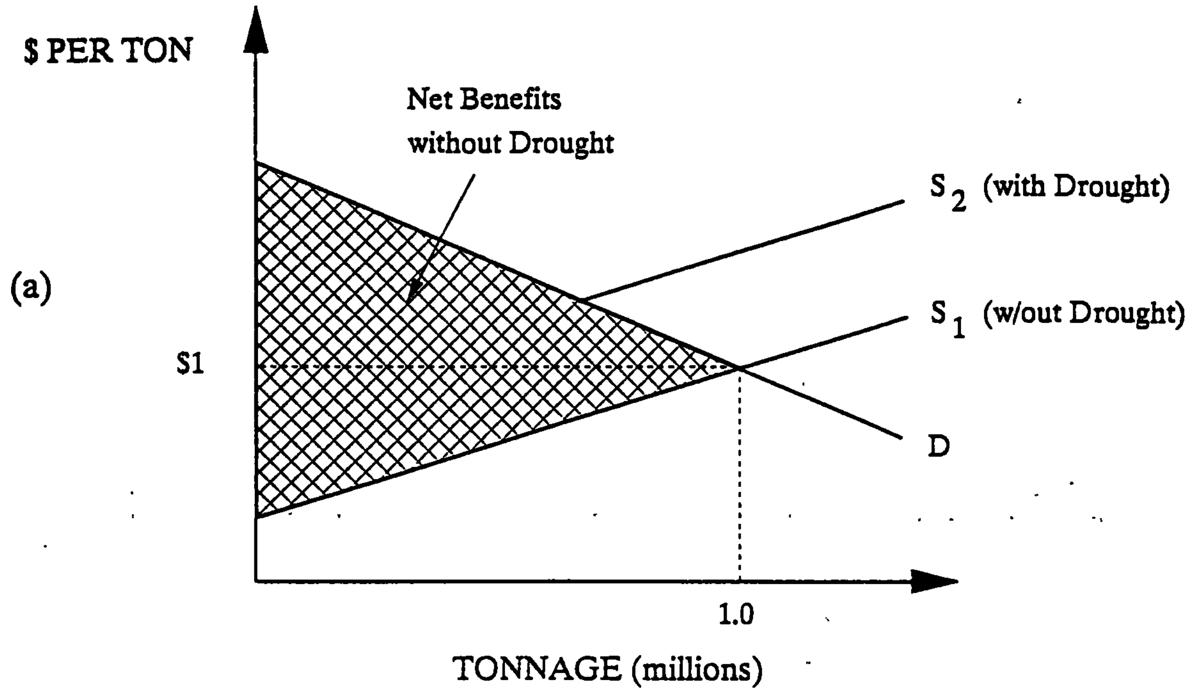
A precise estimation of drought related economic losses in navigation would require an extensive comparative transportation cost analysis. Transportation losses in such an analysis are usually estimated using standard costing techniques, usually engineered cost function that reflect operational parameters and transportation costs for individual commodity flows for each alternative mode of transportation. The comparative transportation costing analysis requires an evaluation of these alternative modes to determine the least costly alternative transportation mode or routing.

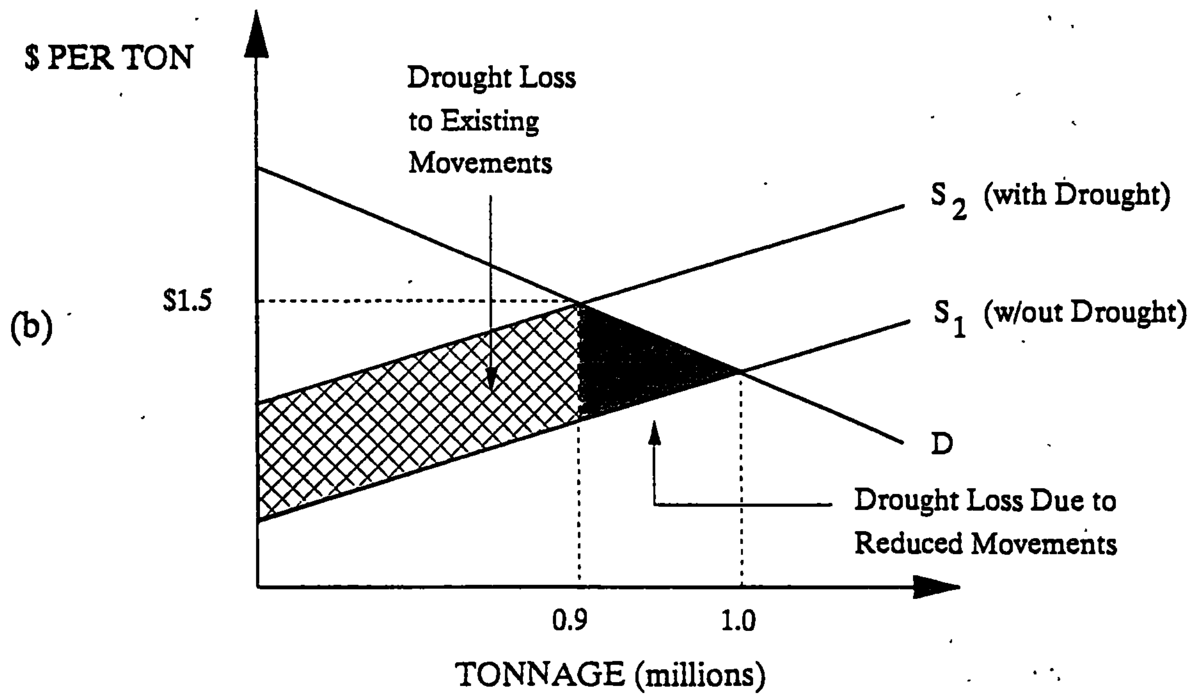
The U.S. Army Corps of Engineers (1990) developed specific procedures for measuring the National Economic Development (NED) benefits of transportation through inland navigation. Some elements of the USACE procedure can be applied to the measurement of economic losses in inland navigation due to drought. The basic economic benefit of navigation is the reduction in the value of resources required to transport commodities. During drought there will be an increase in costs of inland transportation (same origin-destination, same mode) due to: (1) costs incurred from trip delays (i.e., increased congestion), (2) increase in costs because only smaller and shorter tows can use the waterway, (3) increase in costs due to less fully loaded barges. Other cost increases include shifts to costlier modes (rail, motor trucks). Finally, some commodities or marginal quantities of commodities are transported only because of the low cost of water transportation. During drought, when these costs increase the economic loss of the decrease in total movement of commodities can be measured as the decrease in producer and consumer surplus.

The economic impacts of drought on navigation can be explained with the use of Figure III-5. Figure III-5(a) shows the levels of consumer and producer surplus under normal (nondrought) operations. The result of drought could be to increase the costs of producing transportation services, thus shifting the supply curve to

FIGURE III-5

ECONOMIC EFFECTS OF DROUGHT ON NAVIGATION





the left (Figure III-5(b)) A decrease in total consumer and producer surplus will result due to both decreased tonnage moved and increased costs of moving the actual tonnage. If the supply and demand curves for transportation services are not available, the shaded area of Figure III-5(b) can be approximated by estimating the difference in costs for each ton moved and the number of tons moved with and without drought conditions. In the example this is the area of the parallelogram. The surplus loss represented by the triangle results from decreases in tonnage caused by drought.

A major difficulty in measuring drought-induced losses in navigation may arise due to the fact that during drought shippers face not an expected delay but rather a highly uncertain delay value. Shippers' response to uncertainty may be quite different from their response to an expected increase in shipping cost (the latter will be reflected by the intersect of the demand and supply schedules). The uncertainty may force shippers to "overreact" in switching to other modes of transportation or reducing the total volume transported.

WATER-BASED RECREATION

Water-based recreation has become a major part of leisure activity of the U.S. population. Water resources supporting the recreational activities include 2,654 storage reservoirs that can hold more than 5,000 acre-feet of water and perhaps at least 50,000 reservoirs with capacities ranging from 50 to 5,000 acre-feet (U.S. Army Corps of Engineers, 1981). In addition, there are thousands of miles of rivers which can support fishing, swimming, water skiing or water travel.

Water-based recreational use of national forests and public lands in 1985 was estimated at about 400 million visitor hours (U.S. Bureau of Commerce, 1988). Statistical data indicate that in 1985 there were 13.9 million recreational boats and more than 50 million sport fishermen. Annual expenditures for new and used boats, motors, accessories, safety equipment, fuel, insurance, docking, maintenance, storage, repairs, and other expenses exceeded $13.3 billion in 1985. Fishing license sales in that year exceeded $36 million (U.S. Fish and Wildlife Service, 1986).

Drought impacts on recreation are caused by changes in water level and water quality. Low water levels characteristic of drought conditions in reservoirs and lakes can create unpleasant shoreline conditions for swimming and sunbathing. Boat ramps and docks may become unusable, and underwater hazards may be exposed when water level drops. The potential for increased boat accidents also becomes a consideration when the lake or reservoir area decreases but the traffic levels do not. Water quality may decrease to levels where swimming is unsafe because of increased bacterial counts. Degrading water quality due to drought may also lead to foul odor, poor fishing conditions, and increased bacterial activity.

During the 1988 drought, the adverse impacts on recreation reported by the Interagency Drought Policy Committee (1988) included: (1) reductions in the length of hunting seasons and bag limits, and (2) a ban on all outdoor recreation by Montana's governor because of extreme fire danger.

Economic Impacts

Helpa (1988) reported that during the 1988 drought there was a 15 percent decrease in recreational uses of rivers and lakes. The economic value of that decrease was not assessed. Such a value can be obtained using one of three methods for valuing such goods and services as water-based outdoor recreation. These methods include (1) the travel cost method (TCM), (2) contingent valuation method (CVM), and (3) unit-day value (UDV) method.

The travel-cost-based demand function was developed by Clawson and Knetsch (1966). They showed that such a function can be constructed on the basis of data linking rates of visiting a site to the distance from the visitors' homes to the site. Properly done, the analysis can yield a consumer-surplus approximation to aggregate willingness to pay for a site of recreation or the decrease in consumer surplus due to lost recreation opportunities during drought.

An alternative measurement method, recognized in the Principles and Guidelines as approved by President Reagan in 1983, is the contingent valuation (or better, the willingness-to-pay (WIP) survey). In this method, individuals are asked what they would be willing to pay rather than lose the use of a site. The great advantages of the CVM method are its flexibility and relative simplicity. However, the design of the WTP survey questionnaire remains more art or craft than science, making it difficult and expensive for federal and state agencies to use.

The unit-day value method is also accepted by Principles and Guidelines. This method assigns a value to each visit. Ideally, it should assign the per capita surplus associated with the actual or anticipated level of use. Because these values are not known, the unit-day values in use are, at best, approximations to average access fees and much lower than the desired willingness-to-pay estimates. The suggested unit-day values range from $1.60 to $19.00 (1982 constant dollars) depending on activity categories and characteristics of the site (such as recreation experience, availability of opportunity, carrying capacity, accessibility, and environmental amenities).

Although severe droughts may have significant economic impacts on water-based recreation, no attempt to measure such impacts was found in the drought literature.

FISH AND WILDLIFE

Drought effects on fish and wildlife populations are not always readily measurable during the drought period. Oftentimes the impacts are not known until the populations born during a drought reach maturity. This delayed influence on fish and wildlife is the effect that hydrologic conditions may have on the reproductive capacities of many species.

During the 1988 drought, some spawning areas for commercial and sport fish species were dry. Reduced streamflows, lowered water levels, and increased concentration of treated effluent discharges affected water quality. The supply of water to hatcheries was also reduced, creating conditions which favored the spread of disease and reduced reproductive capacity (PIDPC, 1988). Warm water temperatures, reduced dissolved-oxygen levels, and lowered pH readings contributed to minor fishkills and catches reported to be of poor quality at Kentucky Lake. Wastewater discharges were related to nearly 80 fishkills in Alabama (Golden and Lins, 1988).

Waterfowl-breeding areas of the northern prairies experienced significant reduction in water levels in 1988. This type of drought impact may carry over into future years as the breeding population is reduced. Food supplies for ducks and other waterfowl are also reduced as drought impacts native wild grain production.

Drought conditions can have long-term positive impacts which actually improve wetland basins. Dry periods reduce the vegetation which infringe upon the wetland and reduce the tendency for vegetation to "choke" the wetland. This leads to improved waterfowl habitat in the future when normal weather patterns return.

Most drought impacts that fish and wildlife would be subjected to may be considered in terms of nonmarket costs. Diminished numbers of fish in lakes and streams for several years following a drought event may be experienced, but any economic consequence of this is difficult to gauge. Contingent valuation methods may perhaps be applied to determine the economic consequences of degraded habitat for fish and wildlife due to drought.

Also, impacts to fish and wildlife associated with drought may potentially be magnified as a result of human response to drought. Water-use decisions during drought events must be made with an awareness of those potentially increased impacts.

WATER QUALITY

Drought affects water quality in a number of ways. Concentrations of salts can build up as normal flushing is disrupted by low streamflows. Bacterial counts can increase as water temperatures rise. Increased blue-green algae blooms mark significant changes in water conditions, which can be measured in the pH and dissolved oxygen levels of streams, lakes, and reservoirs.

Muchmore and Dziegielewski (1983) performed an analysis of streamflow and several water-quality parameters in six Illinois rivers during the 1976-77 drought. The results of this study showed both deterioration and improvements in water-quality indicators. They found an increase in ammonia and manganese concentrations and, to a lesser degree, increased phenol and specific conductance as negative impacts. On the positive side they found concentrations of nitrites and nitrates, total iron, and the number of coliform bacteria decreased significantly due to drought. These positive factors suggest that streams, generally too high in these constituents, may become usable sources of emergency supply during drought events. All these factors combine to influence the conditions for fish populations, wildlife species, and public water supplies. Sykes (1984) noted the need for increased monitoring of water quality from streams that are used to provide water for municipalities. Drought impacts the quality of water taken in by municipalities and other users, causing the need for increased treatment to meet water-quality standards. Drought-induced water shortage also reduces the flushing capacity for effluent discharges, since there is not enough water to dilute the discharge.

The intrusion of salt water at the mouth of the Mississippi during the drought of 1988 caused the U.S. Army Corps of Engineers to push up the schedule for building a barrier sill in Plaquemines Parish of Louisiana. This underwater levee was designed to reduce the impacts of the annual intrusion of salt water from the Gulf of Mexico during the low streamflow period of September to October. The drought of 1988 caused the volume of water flowing into the Gulf to be reduced to the extent that the intrusion of salt water began earlier than normal (June) that year. Construction of the sill was completed August 1, 1988. Salt water which had migrated upstream from the sill was diluted with freshwater brought down from the Upper Mississippi and carried by flush deck water barges from mid-July to early December of that year (Surviving the Drought, 1989).

SUMMARY

The review of literature on measurement of drought losses shows a large number of studies on quantifying the impacts of drought on agriculture. Methods for measuring economic impacts on other sectors are still under development. At the present time, the available knowledge on the economic effects of drought is insufficient for building a comprehensive impact assessment methodology for all economic activities.

IV. WATER MANAGEMENT DURING DROUGHT

WATER MANAGEMENT ENVIRONMENT

Research and prior drought experience indicate that virtually all of the adverse impacts of drought can be substantially reduced with proper management (Boland, 1986, Dziegielewski, 1986c). Yet, most water supply agencies do not rely on aggressive drought management programs. Few public systems have prepared adequate contingency plans for controlled implementation in the event of a drought. Rather, local and regional water suppliers usually wait until water shortages are imminent and then implement an adhoc drought response program. Typically, such programs consist of measures such as appeals for voluntary conservation, mandatory restrictions on nonessential uses, water rationing, and acquisition of emergency water supplies (Meier, 1977; Dziegielewski, 1986c). Many factors are responsible for the failure to plan for water deficits. These factors are grouped under the term "water management environment." The following sections provide a brief discussion of legal and institutional factors, since the legal aspects of drought management and water management institutions usually play a critical role in the successful implementation of drought management measures.

Legal and Administrative Environment

In a colloquium, "Drought Management and Its Impact on Public Water Systems," sponsored by the Water Science and Technology Board (1986) of the National Research Council, the legal and administrative factors were considered among the most important areas of research for improving drought management. Matters of primary concern included (1) the powers local authorities require to implement effective drought management programs and (2) constraints imposed by state and federal legislation on effective management choices.

According to Ferrell-Dillard (1991), the legal and administrative environment within which the drought management decisions take place can be described by the following characteristics:

(1) State water law regime
(2) Organization and management responsibilities of a water supply system
(3) Degree of financial autonomy
(4) Type of local (or regional) government
(5) Presence of specific water supply and/or water shortage ordinance
(6) Presence of water shortage contingency plans among agencies
(7) Elements of existing contingency plans
(8) Presence of water purchase agreements
(9) Previous experience with water supply-related litigation
(10) Source of authority to reallocate supplies
(11) Source of authority to declare a water resources emergency

(12) Presence of state-level statutory drought management
(13) Presence of state-level administrative body for drought management
(14) State emergency declaration mechanism
(15) Use of non drought-specific statutory support
(16) Other legal and administrative factors

These and other factors can either expedite or constrain effective choices in drought management. One of the primary factors is the state water law regime.

In the broad sense, states are free to develop their own laws regarding their specific water resources holdings. The federal government limits its involvement in water resources issues to managing water quality, regulating navigable waterways, managing federal and Indian reserved water rights, interpreting water resource activities according to the Constitution, and addressing commerce and public access concerns. Although there are slight variations from state to state, consumptive water-use laws can be classified into three systems: riparian, prior appropriation, and groundwater. Water-quality laws, which are mostly statutory in nature, may also have effects on drought management alternatives. This section will consider these different legal frameworks, along with environmental, water-quality, and administrative factors, as they may affect the types of decisions made in response to drought events.

Table IV-1 summarizes the similarities and differences which exist between the prior appropriations doctrine and the riparian doctrine. In most respects, the two systems are the antithesis of one another. For example, co-sharing is the basis for making allocations between rival uses, in riparian states; whereas seniority is the rule in prior appropriation states. The difficulties faced by users under each of the rules are described below. The importance of these two doctrines, with respect to drought management and response, is significant because both doctrines govern surface waters which are more susceptible to drought events. Table IV-2, shows the water allocation systems that are used by various states, as reported by Hrezo et al. (1984). Figures IV-1 through IV-4 show the types of surface-water and groundwater laws in individual states.

Riparian System

Butler (1985) examined the adverse effects that the riparian doctrine has on the ability of a community to obtain and utilize consumptive rights to water. The study identified three problem facets related to the riparian doctrine (1) the area that can benefit from a watercourse, (2) the quantity of water that can be used, and (3) the transferability of water rights. These are directly related to the fundamental principles of riparianism, which prohibit the diversion of water, restrict use to watershed riparian land only, and require "reasonableness" of use. The question of reasonableness has been determined primarily on a case-by-case basis. Thus, not only may the determination of reasonableness rest solely with the particular court involved, but it may also be subject to change over time as conditions surrounding the use change. Even if water supplies are abundant, the contextual nature of riparian rights introduces the element of uncertainty. In areas where water shortages are a concern, the allocating problems can be expected to increase. Municipalities have not traditionally been granted riparian status because their

TABLE IV-1

WATER LAW IN THE UNITED STATES - SUMMARY AND COMPARISON OF THE DOCTRINES OF APPROPRIATION AND RIPARIAN RIGHTS

Appropriation	Riparian
1. Beneficial use, independent of land ownership, is the basis of the water right.	1. Landownership is the basis of the water right. Water may be used for any reasonable purpose.
2. Priority of use is the basis of allocation between rival claimants. Rights of the appropriators are not equal.	2. Co-sharing equality is the basis of allocation between rival claimants.
3. Rights are to definite quantity of water.	3. Rights not fixed to a definite quantity of water.
4. Water may be used on nonriparian land.	4. Use of water may be restricted to riparian land.
5. Right may be lost by nonuse or abandonment.	5. Rights do not depend on use and are not subject to abandonment
6. There is no natural flow requirement.	6. There is qualified right to natural flow in some jurisdictions.

Source: van der Leeden, F., F.L. Troise, D.K. Todd. 1990. Adapted from Driscoll, F.G. 1986.

TABLE IV-2

STATE LEGAL ENVIRONMENTS FOR MANAGING DROUGHT-INDUCED SUPPLY SHORTAGE

Common Approach to Drought Management	State	Allocation System
A. States that rely primarily on general water rights systems to manage drought-induced supply shortages	Alabama	Riparian
	Idaho	Appropriation
	Louisana	Riparian
	Maine	Riparian
	Michigan	Riparian
	Mississippi	Appropriation
	Montana	Riparian
	New Hampshire	Appropriation
	South Carolina	Riparian
	Texas	Riparian
	Vermont	Riparian
	Wisconsin	Riparian
	Wyoming	Appropriation
B. States with a disaster or emergency legislation which represent emergency responses rather than planning efforts	Illinois	Riparian
	Indiana	Riparian
	Massachusetts	Riparian
	New York	Riparian
	Ohio	Riparian
	Rhode Island	Riparian
	Tennessee	Riparian
	Virginia	Riparian
	West Virginia	Riparian
C. States with modified appropriation systems to facilitate emergency responses	Arizona	Appropriation
	Colorado	Appropriation
	Kansas	Appropriation
	Nebraska	Appropriation
	Nevada	Appropriation
	New Mexico	Appropriation
	North Dakota	Appropriation
	Oklahoma**	Appropriation
	Oregon	Appropriation
	South Dakota	Appropriation
	Utah	Appropriation
	Washington	Appropriation

TABLE IV-2 (Continued)

STATE LEGAL ENVIRONMENTS FOR MANAGING DROUGHT-INDUCED SUPPLY SHORTAGE

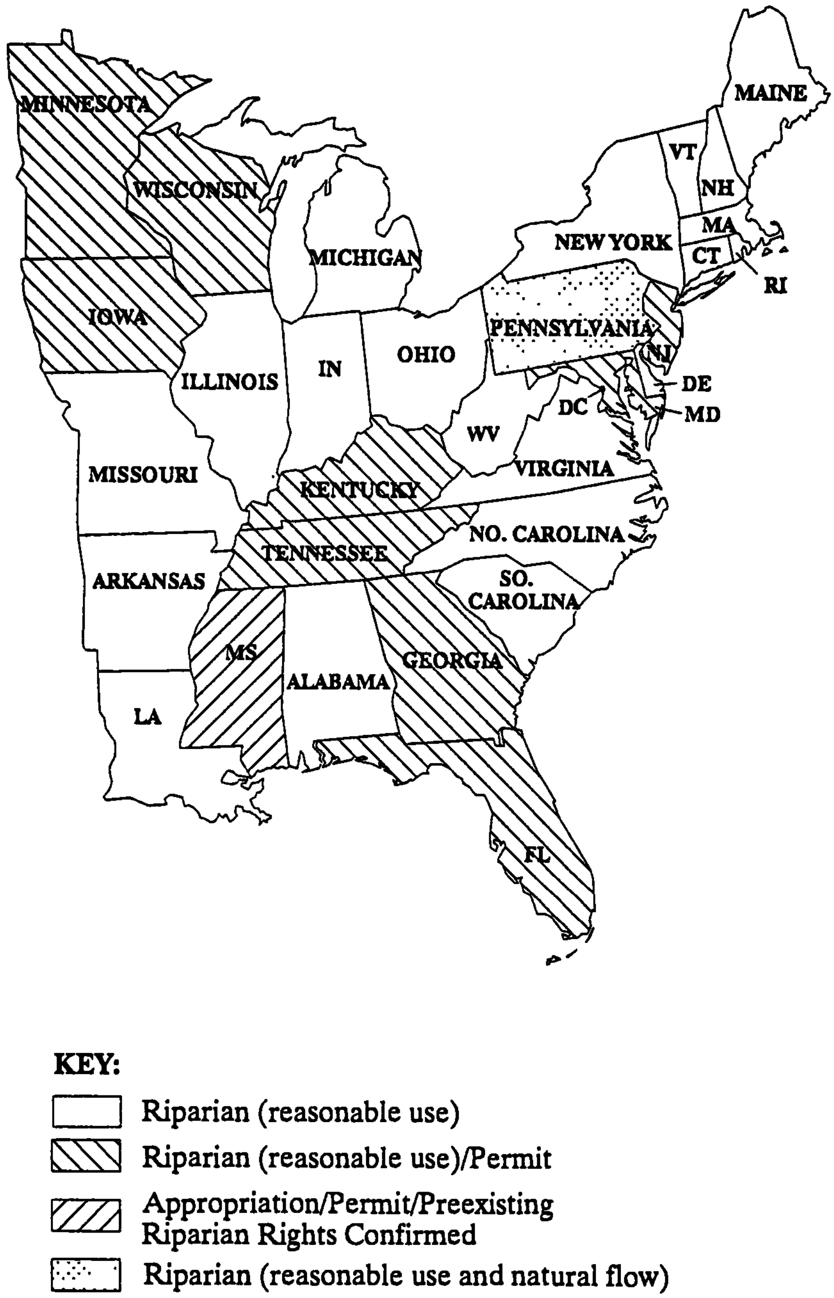
Common Approach to Drought Management	State	Allocation System
D. Eastern states with permit systems that regulate emergency	Georgia	Modified Riparian
	Iowa	Permit
	Kentucky	Modified Riparian
	Maryland	Modified Riparian
	North Carolina	Modified Riparian
	Pennsylvania	Modified Riparian
E. States with comprehensive water shortage management plans	Arkansas	Modified Riparian
	California	Appropriation*
	Connecticut	Modified Riparian
	Delaware	Modified Riparian
	Florida	Modified Riparian
	Minnesota	Modified Riparian
	New Jersey	Modified Riparian

* Indicates appropriation states that tend to follow the "California Doctrine" by utilizing both the riparian and appropriation systems. The trend in these states is toward elimination of riparian elements.

** Oklahoma stream water laws are based primarily on the appropriation doctrine. The state relies on the doctrine of correlative rights combined with personal property ownership, however, to regulate groundwater.

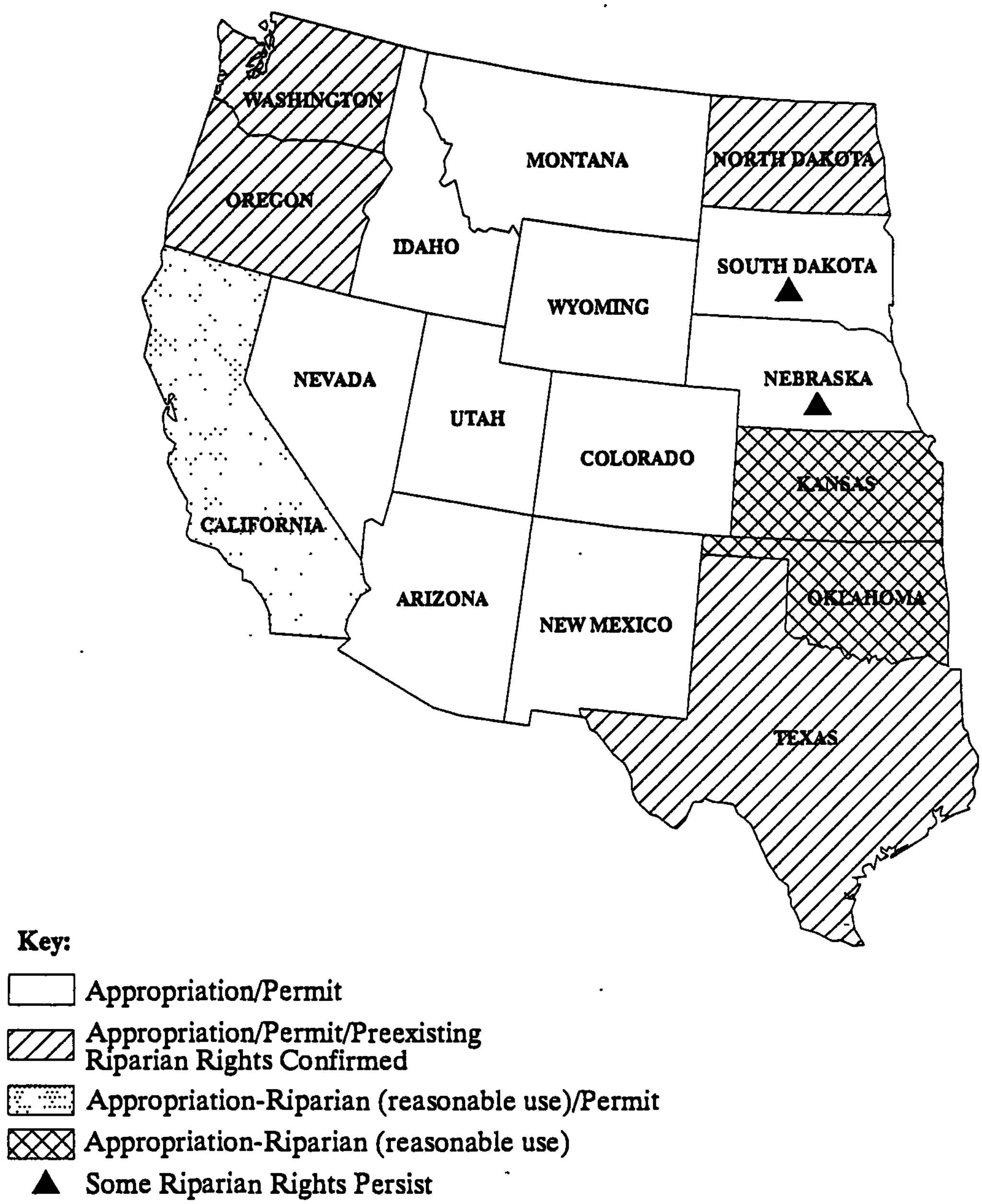
Source: Adapted from Hrezo et al. (1984).

FIGURE IV-1
SURFACE WATER RIGHTS SYSTEMS IN THE EASTERN UNITED STATES



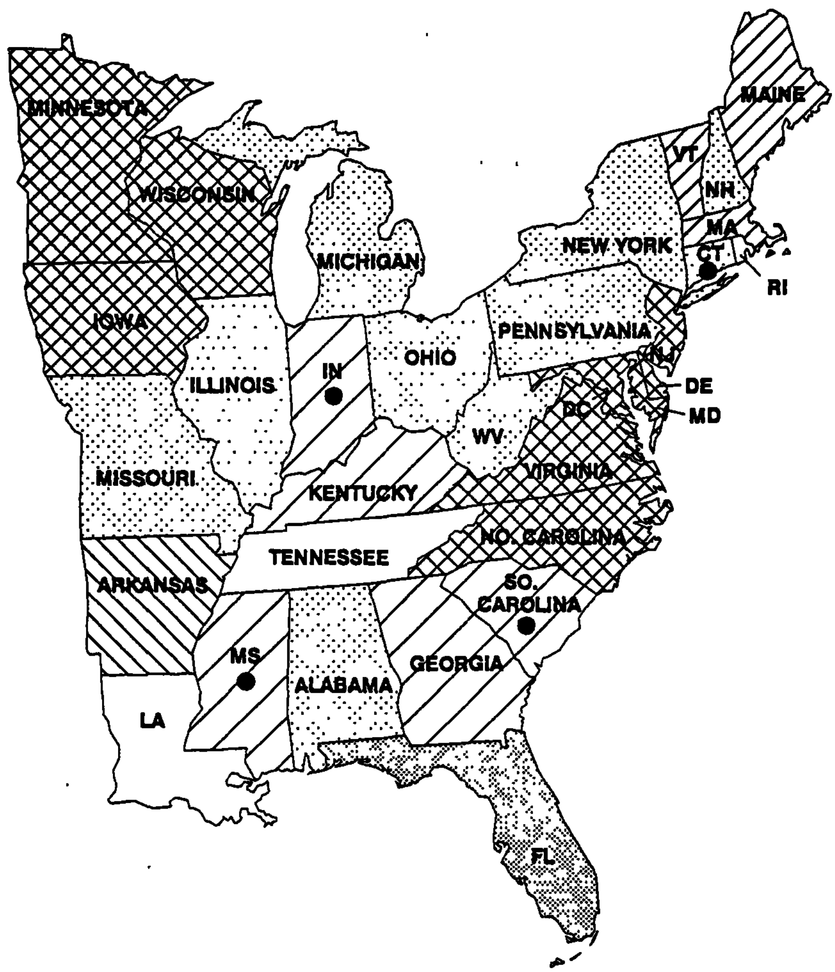
Source: Viesmar & Welty (1985)

FIGURE IV-2
SURFACE WATER RIGHTS SYSTEMS IN THE WESTERN UNITED STATES



Source: Viesmar and Welty (1985)

FIGURE IV-3
GROUNDWATER LEGAL SYSTEMS IN THE EASTERN UNITED STATES

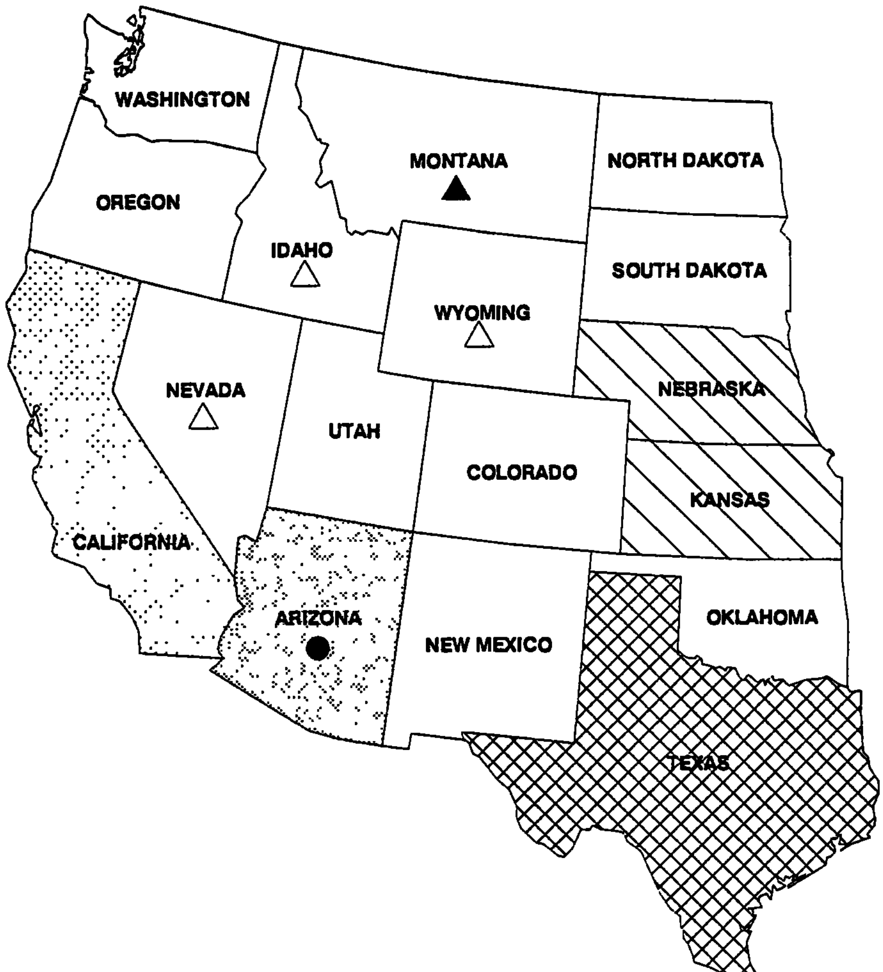


KEY:

- Correlative Rights/Reasonable Use
- Law of Capture
- Absolute Ownership
- Correlative Rights/Permit
- Reasonable Use
- Reasonable Use/Permit
- Absolute Ownership (percolating waters)- Reasonable Use (subterranean streams)
- Absolute Ownership (percolating waters)- Reasonable Use/Permit (subterranean streams)
- ● Permit Required Only in Critical of Capacity Areas

Source: Viesmar & Welty, 1985

FIGURE IV-4
GROUNDWATER LEGAL SYSTEMS IN THE WESTERN UNITED STATES



Key:

- ☐ Appropriation/Permit
- Reasonable Use/Permit
- Absolute Ownership
- Correlative Rights/Appropriation/ Conjunctive Management
- Reasonable Use (percolating waters)- Appropration/Permit (subterranean streams)
- ● Permit Required only for Large Consumptive Users
- ▲ Permit Required for both Critical and Noncritical Areas; but only for Large Consumptive Uses in Noncritical Areas
- △ Permit Required for both Critical and Noncritical Areas; but less Scrutiny Given to Projects in Noncritical Areas

Source: Viesmar & Welty, 1985

function as providers of water to various residents has been considered off-tract usage, and the quantities needed for use have been considered too large for reasonableness. For example, municipalities which attempt to initiate or increase withdrawals during a drought without prior condemnation or negotiation proceedings may find themselves involved in an adverse condemnation suit in which injured riparians seek damages and/or injunctive relief (Trelease, 1977).

In another study, Hrezo et al. (1984) evaluated the riparian doctrine in terms of its performance during periods of water shortage and found three shortcomings:

(1) The requirement that water be shared during a drought with no established criteria for reductions in use

(2) The absence of a right to some specific amount of water during a shortage

(3) The reliance on the courts as the implementing institution, which means that water-allocating decisions are made only after a water shortage exists

In the past, courts which have had to make allocating determinations when existing supplies were not sufficient have attempted pro rata reductions (Trelease, 1977; Sax and Abrams, 1986). When existing uses have not been quantified these types of proportionate reductions have proven difficult to implement. Also, in cases where the competing uses are mutually exclusive or somehow incompatible, the courts have consistently sided with the existing user and against the newcomer. This introduces the element of priority into a system based on correlative rights (Trelease, 1977; Butler, 1985).

As a result of the inability of the riparian doctrine to promote effective water management in the modern era, some states have replaced the common-law riparian system with administrative permit systems or enacted legislation modifying the common law, e.g., statutes defining a water-use preference system that reflects state policies (Hrezo et al., 1984; Sax and Abrams, 1986).

Prior Appropriation System

In this system the appropriative right depends entirely on a user's priority in time, so that in the event of shortage all senior appropriators' rights are fully guaranteed, even if that means a junior appropriator must cease all use in order to allow the full realization of a senior's rights. Regardless of this time priority factor, many states have increased the protection provided to certain uses through the adoption of preference-based systems (Hrezo et al., 1984; Sax and Abrams, 1986). Under these scenarios, domestic uses typically have the highest preference, although there are instances in which municipal uses have been granted greater or equal preference to domestic uses. In most cases, preferences may only be exercised if compensations are made to the injured user. True preference can exist if the preferred use may be initiated regardless of whether the supply is fully appropriated or the preferred user is not required to compensate any injured users (Trelease, 1955; Peel, 1986). An evaluation of the performance of the prior appropriation system during drought was performed by Howe et al. (1982), which resulted in recommended reforms to increase allocating flexibility during periods of shortage, emphasizing the importance of local initiative in drought mitigation.

Not only can the appropriation doctrine affect a community's ability to acquire additional water rights during a shortage, but it may also affect its ability to implement water conservation measures (Brown and Weinstock, 1981). In many appropriation states, return flows are subject to further appropriation, and wastewater recycling may be prohibited to protect downstream users. As a result, in states where the nature and quantity of use and the transferability of rights are highly restricted, a community may have difficulty in seeking augmentation of its water supply during drought.

Groundwater System

Traditionally, there has been a separation in water law between surface and groundwater supplies. Several common-law rules have been applied to the consideration of groundwater rights. Table IV-3 presents the basic legal theories that allocate rights to groundwater within the U.S. A quick review of these will suggest that some, if not all (note theory no. 6, combination), have shortcomings when used to address modern competing interests for groundwater allocation.

Table IV-4 lists those states that are governed by the four basic theories used in the U.S. There would not appear to be any regional bias for preference of one legal theory over another. However, most states have developed some version of the American, or "reasonable," use rule. These rules examine the totality of the resource use, including reasonable and beneficial use, as well as the nature and extent of harm done to other users. There are also examples in several western states of protecting senior users by prioritizing time of usage and establishing permit and recordkeeping systems for groundwater rights (Trelease, 1977; Sax and Abrams, 1986). Conflicts between senior and junior users in those states have generally centered around the depth of the water table and resultant pumping costs, not on suspension of junior water rights to supply a senior during times of shortage.

California's rule of correlative rights is similar to riparian law in that all share groundwater rights co-equally in an individual aquifer. During shortages, available supply is apportioned among all landowners, generally using a pro rata basis. Off-tract uses are only permissible in times of surplus, and those who pump groundwater for export do not enjoy the correlative laws' benefits (Sax and Abrams, 1986).

Hrezo et al. (1984) suggested that reasonable use rules do not contain any specific provisions for accommodating the various needs of users during water shortage. Thus, if there are several large groundwater users relying on the same aquifer, the provision of supply during drought becomes highly uncertain. Although this is not the case with the correlative rights doctrine, it suffers from the suspension of water export during shortage on which many municipalities rely. Also, municipalities who hold junior groundwater rights under this doctrine can face difficulties if not protected by legislative preference.

TABLE IV-3

BASIC LEGAL THEORIES USED TO ALLOCATE RIGHTS TO WITHDRAW PERCOLATING GROUNDWATER IN THE UNITED STATES[a]

(1) The English Rule of Capture, or Absolute Ownership rule. Originating in English common-law doctrine, the owners of land overlying a groundwater resource are allowed to withdraw from their wells all the water they wish for whatever purpose they desire. The water withdrawn can be used for any purpose on or off the owner's land. Under this rule, the landowner could even waste the water, thereby injuring a neighbor, but still have no liability under the law.

(2) The American, or Reasonable Use, Doctrine. Under this doctrine, landowners can withdraw groundwater to the extent that they must exercise their rights reasonably in relation to the similar rights of others. Futhermore, the owner's use of groundwater for off-lying land may be unreasonable and, therefore, unlawful if the withdraws for the off-lying land injured a neighbor.

(3) The restatement of the Law of Torts. This is a version of the reasonable use doctrine that establishes a process to balance competing uses, whether they are on or off the overlying land. In this interpretation, the landowner who withdraws groundwater from the land and uses it for a beneficial purpose is not subject to liability for interference with the use of water by another, unless:

- (a) The withdrawal of groundwater causes unreasonable harm through lowering of the water or reduction of confined pressures.
- (b) The groundwater occurs in a distinct underground stream.
- (c) The withdrawal of water has a substantial effect upon a stream, river, or lake.

(4) Correlative Rights. This interpretation derives from the concept that water users will share the resource during droughts, based on the relative areal extent of the land owned by the competing landowners. If no competition for water exists, then correlative rights are the same as reasonable use.

(5) Appropriation. In this system, all water is declared to be public and subject to appropriation on the basis of the "first in time, first in right" principal. Control of well use is usually accomplished by permits.

(6) Combination. Increased groundwater use among competing interests is leading many states to adopt more than one way of handling the legal aspects of resource allocation and protection.

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[a] Groundwater is treated under two classifications - underground "stream" water and percolating water. Groundwater occurring in streams (a rare occurrence except in karstic terrains or lava flows) is treated under the same general rules as those applying to surface streams, i.e., the Riparian Doctrine, the Appropriation Doctrine, and a combination of these two.

Source: van der Leeden, F., F.L. Troise, and D.K. Todd. 1990. Adapted from Driscoll, F.G., 1986.

TABLE IV-4

GENERAL THEORY OF STATE GROUNDWATER LAW IN THE UNITED STATES

Reasonable Use	Correlative Rights	Absolute Ownership	Appropriation
Alabama	California	Connecticut	Alaska
Arizona		Hawaii	Colorado
Arkansas		Indiana	Florida
Delaware		Louisiana	Idaho
Georgia		Maine	Montana
Illinois		Massachusetts	Nevada
Iowa		Mississippi	New Mexico
Kansas		Ohio	North Dakota
Kentucky		Pennsylvania	Oklahoma
Maryland		Rhode Island	Oregon
Michigan		South Carolina	South Dakota
Minnesota		Texas	Utah
Missouri		Vermont	Washington
Nebraska			Wyoming
New Hampshire			
New Jersey			
New York			
North Carolina			
Tennessee			
Virginia			
West Virginia			
Wisconsin			

The allocation of states in this table is subject to change through permit legislation and exemptions.

Source: van der Leeden, F., F.L. Troise, D.K. Todd. 1990. Adapted from Driscoll, F.G. 1986.

Environmental and Water-Quality Laws

Environmental and water-quality regulation has an effect on drought management in two ways. First, the Safe Drinking Water Act of 1974 maintains that drinking-water standards must be met in both primary and any emergency sources of supply. If quality were to decline as a result of drought, municipalities might be denied the right to supply sources. Second, minimum streamflow requirements may compel reservoir operators to release water for instream flows, thus reducing the supply base. There are cases where streamflow has been insufficient to meet both withdrawals and instream uses, and the Public Trust Doctrine was used as a force for the preservation of instream requirements over the withdrawal needs of a community (see National Audubon Society vs. Superior Court, 1983).

Administrative Law

Common-law riparianism has been administered by the courts traditionally. However, the trend toward greater state stewardship of natural resources and the desire to alleviate uncertainties inherent in riparianism have resulted in modifications by some states to adopt statutory management systems (Sax and Abrams, 1986). Also, most prior appropriation states now use an administrative permit system similar to that described above in this chapter. The use of a permit system allows prior determination of the availability of appropriated water, beneficiality of use, and determination of any potential conflict with other users that may occur and provide public records of actual uses and priorities (Trelease, 1977; Sax and Abrams, 1986).

Administrative difficulties in dealing with water shortage are often temporal. Waiting periods, public notices, hearings, and administrative processing often impede timely implementation of some measures such as modify rate schedules or obtaining additional water rights. Lastly, the discretionary factor of many administrative decisions allows for the possibility of challenges.

WATER MANAGEMENT INSTITUTIONS

The existing laws and statutes that govern allocation of water resources are applied within the institutional environment. Water institutions make day-to-day decisions about the use of water resources and perform planning activities which determine drought management strategies. These institutions can operate at state/interstate, regional (substate), or local levels.

River Basin Commissions

There are several interstate agencies that manage some water resources regions. Examples of such agencies include hydrologic basin commissions such as:

(1) Great Lakes Commission
(2) Interstate Commission on the Potomac River Basin
(3) Susquehanna River Basin Commission
(4) Upper Colorado River Commission

These commissions usually have the authority to allocate water from the river (or lakes) they manage; however, they may not have the authority to manage other sources of water in the region (see Chapter II for more information on River Basin Commisions).

State Departments of Natural (Water) Resources

Some states exercise a large degree of control over water resources found within their state boundaries. Such states usually rely on statutory laws and permit systems to allocate water resources and modify water use if necessary. Other states limit their management of water resources to data acquisition, monitoring, and research. Currently, only a few states have a well-defined drought response plan (see Table II-4).

Water Management Districts

Typically, water management districts have significant authority over water resources in the region they manage. Often the management districts' primary function is that of a wholesale agency supplying water to its member agencies. As such, they are involved in the development of new supply sources, storage facilites, and distribution systems.

Many water management districts have also received permission to develop hydroelectric potential as another way of utilizing their resources. Recreational activities may be another way in which water management agencies may be empowered to use the resource.

These agencies are generally very sophisticated in terms of "water management." They are often involved in water conservation/education campaigns, retrofitting programs, and many other activities designed to reduce water demand on themselves and their member agencies.

Local Water Supply Agencies

The local water supply agencies exhibit the greatest variability in terms of the level of water management employed. Some local utilities are very involved in development of techniques that affect the water use by their constituents. Other agencies are primarily concerned with their ability to supply water "on demand."

There is some evidence that the level of water management present is, to some extent, dependent on the size and type of supply base used by the agency. For example, local agencies with an unlimited supply are not very concerned with demand reduction except as it may be required by their pumping capacity. Conversely, those agencies that are in situations when their safe-yield/water-use ratios are approaching 1 are more actively involved in "water management."

The level of management activity, however, does not necessarily reflect the actual need for employing water management techniques. Many agencies that could benefit from some type of water management have yet to develop active demand and/or supply management programs.

DROUGHT RESPONSE DECISIONS

In order to effectively manage a drought event, water management agencies have to make several decisions. These decisions typically relate to the following questions:

(1) Are we in a drought?
(2) How long and severe will the drought be?
(3) What can we do to avoid water shortages?
(4) When should we impose water-use restriction?
(5) How should the adverse impacts of the drought be shared?
(6) When should we call off the emergency?

These and other questions must be answered before specific drought management actions are taken. Unfortunately, the information and data needed to provide answers to these questions are usually not available, and the decisions are made with a great deal of uncertainty. Previous experience and research provide some guidance for decision making in drought management. Such guidance is summarized below.

Drought Indicators and Triggering Mechanisms

The onset of drought can only be precisely identified ex post because of our inability to make reliable long-term forecasts of weather. However, there are several drought indicators that characterize the severity of accumulated precipitation or soil moisture deficits at any point in time. The most widely used regional index of drought is the Palmer Drought Severity Index (PDSI). This index is designed to characterize both the intensity of drought as well as its onset and outset. Other indices include Palmer Hydrologic Drought Index (PHDI), Palmer Z-index, and Basin Climatic Index (BCI). The primary purpose of these indices is to recognize the existence of persistent cycles of dry weather. Unfortunately, the achievement of this objective by PDSI or other drought indicators have had mixed successes (Alley, 1984, Karl, 1986). The second purpose of these indices is to characterize antecedent weather conditions at a given point in time. However, this information can also be provided by simple comparisons of precipitation, streamflow, or reservoir storage records to their respective normal or average values.

Drought indicators can be used to construct triggering mechanisms for implementation of drought response measures. Drought researchers seldom make a clear distinction between drought indicators and triggering mechanisms. In reality, the triggering mechanisms may be defined using little or no information about actual drought conditions. A review of drought contingency plans conducted by Dziegielewski et al. (1988) indicated that in practice the triggers were often defined in terms of:

(1) Reservoir levels
(2) Probability of water shortage
(3) Water demand levels
(4) Groundwater levels in wells
(5) Water conservation goals used to define triggers
(6) Combination of drought indicators
(7) Drought declarations by public officials

Two of these triggers (i.e., water demand levels and conservation goals) are not directly related to the severity of an ongoing drought.

Models for Optimizing Drought Response

Moreau and Little (1989) developed a method for improving the management of water supplies under drought conditions. Their model uses the sequentially implemented, increasingly stringent stages of water conservation. The model forces the decision maker to assume the acceptable risks of undesirable events to derive the reservoir trigger levels. Palmer and Holmes (1988) developed a linear programming model as part of an expert system for drought management in Seattle which uses a formal economic loss function for water shortages. Both models attempt to incorporate the optimization criteria discussed in Chapter I.

DROUGHT MANAGEMENT MEASURES

The drought literature documents a large number of actions that were taken by water agencies in order to avert some serious consequences of impending water shortages caused by droughts. These actions can be grouped into measures that reduce demand and measures that enhance existing supplies. Tables IV-5 and IV-6 give examples of such measures in each group as applied to urban water systems. Examples of specific applications of selected measures are described below.

The importance of a thorough investigation of drought management alternatives can be illustrated with the following example. The traditional method of planning for capacity expansion is to look at alternatives singly rather than in combination. For example, the city of Virginia Beach, Virginia, rejected reverse osmosis because then-current cost estimates indicated that it would be significantly more expensive than conventional treatment of water imported from the Roanoke River, some 100 miles away ($4-$6/1,000 gallons vs. $1.50-$2.00/1,000 gallons). This estimate, however, assumed that all the water necessary would have to come from one source or the other. A more thorough investigation would have examined a package of options and based the decision on the total cost. For example, a local surface-flow option was rejected because the yield was inadequate to meet the total demand-even though it was significantly cheaper than importing water from the Roanoke River. The option of having a small desalination facility to supplement the local source during years of low flow was not investigated. A package consisting of the local surface-water resource used conjunctively with a desalination plant might well have been economical.

Demand Reduction Measures

Public Information and Education Campaigns

Public information campaigns continue to be the most popular means of encouraging urban water users to perform water conservation behaviors during drought. Primary objectives of such campaigns include (1) persuading the consumers that they should conserve water and (2) providing them with information on how to do

TABLE IV-5

EXAMPLES OF TACTICAL AND EMERGENCY DEMAND REDUCTION MEASURES

Public Information and Education Campaigns
- Mass-media campaigns
- School education programs
- Community relations: tours, speakers bureau, exhibits

Emergency Conservation Programs
- Residential plumbing retrofit programs
- Home water audits (High Users)
- Government buildings retrofit
- Commercial/Industrial water audits

Restrictions on Nonessential Uses
- Filling of swimming pools
- Car washing
- Lawn sprinkling
- Pavement hosing
- Water-cooled air conditioning
- Street flushing
- Public fountains
- Park irrigation

Prohibition of Selected Commercial Uses
- Car washes
- Laundromats
- Golf courses

Drought Emergency Pricing
- Drought surcharge
- Excess use charge
- Emergency rate
- Conservation credits

Rationing Programs
- Per capita allocation
- Per household allocation
- Allocation based on prior use
- Rationing through inconvenience (carrying water from street taps)

TABLE IV-6

EXAMPLES OF TACTICAL AND EMERGENCY SUPPLY MANAGEMENT MEASURES

A. Water System Improvements

Raw Water Sources
- Reservoir evaporation suppression
- Reduction of dam leaks
- Transfers of surplus water
- Pumped reservoir storage
- Lining of transmission canals

Water Treatment Plants
- Recirculation of washwater
- Blending impaired quality water

Distribution System
- Reduction of system pressures
- Leak detection and repair
- Discontinuing hydrant and main flushing
- Meter replacement program

B. Emergency Supply Sources

Interdistrict Transfers
- Emergency interconnections
- Importation of water by trucks
- Importation by railroads cars

Cross-Purpose Diversions
- Reduction of reservoir releases for hydropower production
- Reduction of reservoir releases for flood control
- Diversion from recreational water bodies
- Relaxation of minimum streamflow

Auxiliary Emergency Sources
- Utilization of creeks, ponds and quarries
- Construciton of a temporary pipeline
- Temporary channel storage
- Reactivation of abandoned wells
- Drilling of new wells
- Desalinization of seawater
- Utilization of dead reservoir storage

Table IV-6 (Continued)

EXAMPLES OF TACTICAL AND EMERGENCY SUPPLY MANAGEMENT MEASURES

C. Resources Management Alternatives

Nonperpetual water transfers from agriculture
- Land-fallowing programs
- Individual exchange agreements

Water banking

Conjunctive use

Precipitation management (cloud seeding) so. Changing behaviors associated with high water use and encouraging the use of water-saving devices are often seen as the most effective means for achieving reduction in water use (Dziegielewski et al., 1988). For example, an evaluation of consumer response to drought conducted by the Metropolitan Water District (MWD) of Southern California indicated that urban water users will take actions to conserve water if they:

(1) Believe that there is a drought.
(2) Believe that their conservation efforts will help mitigate the adverse consequences of the drought.
(3) Believe that all members of the community are asked to conserve and make sincere conservation efforts.
(4) Believe that choices furthering group welfare, rather than self-interest, will have desirable long-term consequences.
(5) Believe that their efforts will involve only minimal personal cost and inconvenience.

The research conducted by MWD also showed that the use of persuasive communication and modeling of desired behaviors are required if the campaign is to be successful. This was demonstrated by statistically significant increases of 5 to 10 percent in proconservation attitudes and conservation behaviors before and after the campaign. Using an econometric model of total water demand in Southern California, the actual water savings were estimated at 90,000 acre-feet (Chestnut and McSpadden, 1989).

Plumbing Retrofit Campaigns

Although technological devices usually are readily accepted by consumers, the savings in water resulting from their use are small compared to those that can be achieved by behavioral changes, especially under drought emergency conditions. Yet, retrofit campaigns can also increase public awareness of drought and thus enhance the overall conservation effects. Examples of retrofit campaigns include (1) the City of Phoenix Emergency Retrofit Program of 1985 and (2) mass mailings of conservation kits during the 1976-77 drought in California. These campaigns were successful in reducing indoor residential water use by 5 to 10 percent (California Department of Water Resources, 1978).

Water-Use Restrictions

Restrictions on selected urban uses of water and water rationing plans were reported to reduce water use by up to 65 percent (Hoffman et al., 1979). Undoubtedly, a substantial portion of these savings can be attributed to changes in the habitual water use of individuals.

SUPPLY MANAGEMENT MEASURES

There are many options for increasing supplies during drought, but they are rarely well implemented. There seem to be five major reasons:

(1) Most require fairly sophisticated preplanning.

(2) Many require action when forecasts indicate that drought threatens and such forecasts are not available.

(3) Some require construction of facilities which will be used only on an intermittent basis.

(4) Some require cooperation among independent operating agencies.

(5) All require that the implementing agency understand the concepts of risk management.

Almost all of these are directly related to the uncertainty associated with the recurrence of droughts. Dealing with uncertainty is difficult in the public arena, where the responsibility for water supply most often lies, and standards for dealing with uncertainty in water supply do not currently exist. Certainly nothing approaching "generally accepted engineering practice" has developed in this area. Our problem has been in categorizing methods and determining the extent of their applicability.

Supply enhancement often seems to boil down to a question of engineering feasibility and, depending upon the perceived severity of the situation, cost. The following sections provide selected "real world" examples of innovative drought management techniques.

Nonperpetual Water Transfers from Agriculture

Metropolitan Water District of Southern California (MWD)

MWD attempted to negotiate "dry year option" contracts with the Palo Verde Irrigation District in 1987-88. The negotiations appeared to be going well but at the last minute fell through over price. Not much has been written about this effort, possibly to keep it out of the press. Conversations with MWD staff indicate that they believed that the price offered represented twice the value of the water if used for agriculture. The farmers rejected the offer and also appeared to want an arrangement whereby they could sell water to MWD in all years.

City of Boulder, Colorado

Boulder is in the rather unique position of being water rich. A conscious decision to limit growth coupled with extensive hydrologic modeling conducted over the last five years has convinced the city that they have rights to an abundance of water. As a result, the city is now investigating the sale of its share of the U.S. Bureau of Reclamation Windy Gap Project. If any or all of its entitlement to 8,000 acre-feet (AF) is sold, the city may replace it with "interruptible supply contracts" for agricultural water. Negotiations are still very preliminary, but at this stage it appears that such arrangements are very possible. Unlike MWD, which was trying to conclude one deal with an irrigation district, Boulder will be negotiating with individual owners for smaller quantities of water for which there is an established market. The general form of contract being discussed is the purchase of either an agricultural easement or development rights. These are being considered in lieu of the outright purchase of water rights for two reasons: to keep the property on the tax roles and to ensure that the water is used in order that the entitlement to it not be lost.

Water Banking

Metropolitan Water District of Southern California (MWD)

MWD has two ongoing efforts that can be described as water banking. Negotiations have been concluded with the Arvin-Edison Water Storage District for a program whereby MWD would store State Water Project (SWP) water during wet periods and receive in exchange a portion of Arvin-Edison's entitlement to water from the federal Central Valley Project (CVP) during dry periods. Approximately 125,000 acre-feet will be involved in the transfers. MWD will pay for approximately $18 million of improvements to Arvin-Edison's facilities in order to make the program work. The needed facilities are primarily spreading grounds and a distribution system to better utilize the water received from MWD. Environmental documentation is now being prepared, and construction may begin as early as next year.

MWD also has a local banking program known as the Seasonal Storage Program. To encourage those customers who have the facilities to store water to do so, water rates during high-flow months rates reduced from the normal $220/AF to $115/AF. This rebate program is essentially the flip side of the fairly common practice of increasing rates to promote conservation. For several reasons, a rebate program was politically more palatable to the MWD Board. Principal among these was a concern for the potential inequities and hardships that might result from increasing rates. This program achieves the same result. The California Department of Water Resources also operates water-banking schemes in California in conjunction with the State Water Project.

State of Colorado

Banking schemes involving groundwater are common in Colorado to the extent that they may no longer be considered innovative. For example, the South Adams County Water and Sanitation District uses surface water to recharge alluvial wells. Since they receive credit for return flows to the South Platte River, the District is guaranteed both additional surface and groundwater during dry periods.

Conjunctive Use

Conjunctive use differs from water banking in that water need not be recharged to the ground. In a conjunctive-use scheme, surface water is used whenever it is available. Groundwater is pumped more heavily during droughts and less heavily during normal periods. This reduces the average annual pumping from groundwater sources and thus reduces groundwater drawdown. Conjunctive use is practiced by farmers in the Sacramento Valley but not on an organized basis. Farmers who receive water from the Central Valley Project have their deliveries reduced during critically dry years. In those years, they increase their groundwater pumping to make up the deficit. This practice occurs because it is more economical to accept the CVP water, when available at low cost, rather than to pay for pumping. The Salt River Project in Arizona has been employing conjunctive use for many years.

Importation by Barges

U.S. Army Corps of Engineers (1989) reported the use of barges for the transportation of water during droughts. Between July 14 and December 2, 1988, approximately 131 million gallons were barged from Mississippi River Mile 104 downstream to treatment plants in Plaquemines Parish, Louisiana, at Miles 49 and 18.6. The water was used to reduce the concentration of chlorides prior to treatment. Although conditions were exacerbated by the drought, this action had already been planned as a part of the mitigation plan associated with the Mississippi River Ship Channel Project. To arrest the normal progress of the saltwater wedge upstream during low-flow periods, an underwater barrier was constructed. The supplemental water was originally planned for the period between the construction of the channel and completion of the underwater barrier.

Except in the most extreme emergencies, it seems unlikely that barges could play a significant role in drought amelioration. Obviously their application is limited to population centers located on navigable waterways. As evidenced by the 1988 drought, navigability even on the Mississippi River is not always guaranteed. Apart from water for the most basic needs, it is unlikely that sufficient quantities of water could be transported to make a real difference in communities of any size. A more feasible alternative, discussed in more detail below, is to construct barge-mounted treatment plants capable of treating brackish, or salt, water. These units could serve both coastlines as well as communities located on waterways that are navigable. In practical terms, such assistance would be limited to smaller communities. It is difficult to imagine, for example, enough barge-mounted treatment capacity to provide even a minor fraction of the demand of any major coastal city.

Desalination

There is tremendous body of literature dealing with desalination. Distillation and membrane techniques are most commonly mentioned. Of the membrane techniques, reverse osmosis appears to be the most successful, and a number of such plants are now in operation in the Middle East. The cost of energy is the determining factor as to whether reverse osmosis or distillation is the cheaper alternative. If, however, desalting is used only when drought threatens, the cost of energy would not be as important because the plant would be operated only infrequently. Where brackish water is available, reverse osmosis is considered to be a cost-effective treatment technique. Capital costs of $2-$5 million per MGD (million gallons per day) and operation and maintenance costs of $2-$4 per thousand gallons have been reported depending, in part, on the quality of the water to be treated.

For municipalities situated along the coasts or on navigable waterways, the idea of barge-mounted reverse osmosis plants is intriguing. Modular units could be loaned or leased to local utilities that perceive the risk of a shortage is greater than they wish to bear. A detailed examination of the economics of this concept are beyond the scope of this study. This setup might be particularly attractive in the East, where reservoirs usually refill during the winter months and carry-over storage, therefore, is not provided. (In the West, multi-year storage is the norm, and the time frames for reacting to drought are much longer.) If a decision is made early enough in the year, usually a supplementation of only a very small fraction of demand is sufficient to "weather" a drought. There is a barge-mounted reverse osmosis plant in operation in Abu Dhabi. The unit produces about 0.33 MGD on a barge 18.5 by 60 meters. The decision to mount the unit on a barge was made because it was cheaper than in situ construction, but it demonstrates clearly that large-scale plants can be constructed in this manner. Since reverse osmosis is already cost competitive where there is a source of brackish water, this concept may be worthy of future investigation, but detailed examination of the economics of this concept are beyond the scope of this study.

Other Techniques

Metropolitan Water District of Southern California (MWD) Drought Pricing Program

Use of increased rates to decrease demand during periods of drought has been widely discussed. As noted above, such a practice was politically unacceptable for MWD. Instead, a rebate program of $100/AF was instituted for those who actually conserve (as opposed to simply shifting demand from MWD to another source). These positive incentives were felt to be much more appropriate than penalties for high use or water rate surcharges.

Kansas Assurance Districts

The U.S. Army Corps of Engineers operates three major reservoirs on the Kansas River, for which there are established releases to maintain downstream water quality. The Kansas Water Office contracted for water supply storage in the reservoirs and for a number of years has operated a water-marketing program to provide water for municipal uses. Prior to the establishment of the Assurance District program, municipal users were exercising their water rights by withdrawing water that the Corps had released for water quality. As a consequence, there was little participation in the water-marketing program, and water quality suffered. This program assures that water will be available for both purposes. The assurance is possible because by operating the three reservoirs as a system, more water can be made available for downstream purposes than would be available if the reservoirs were operated individually. A series of drought exercises convinced municipal users on the Kansas River that their current method of operation made them quite vulnerable to periods of drought when releases for water quality might be curtailed. Through the Assurance District, then, municipal customers are basically participating in the marketing program but with the added assurance that water will also be available for water quality. It is important to note that salinity is one of the major water-quality problems in the Kansas River, and that by participating in the Assurance District program, the water users are ensuring that the supply of water will be both adequate and potable.

Savannah River

During the drought of 1988-89, there was considerable controversy over the manner in which the Savannah District of the Corps operated its three major reservoirs on the river. In short, lack of a dependable weather forecast led the Corps to operate normally in the fall of 1987, which led to near-record low lake levels for the next two years. The District Commander responded to the outcry with a pledge that releases from Lake Thurmond, the largest and downstream-most lake, would not exceed 3,600 cubic feet per second (cfs) until all the lakes returned to rule curve elevations (the method used to balance the three lakes is not of concern here). The South Carolina Water Resources Commission suggested to the Corps in January 1989 that the conditional probability of inflows (given the most recent record of low inflows) be used as a basis for adjusting the releases from Lake Thurmond. The basic concept was that flows could be decreased below 3,600 cfs during the cool months, and the water saved could be used to improve water quality in the summer (although not widely reported, water quality violations occurred in the river during the summer and fall of 1988). Likewise, in August 1989, after extremely high summer runoff, it was suggested that the release be increased even though the lakes were not full. The expected revenues from the sale of additional power were significant, and the probability of refill before the next recreation season was extremely high. Although these arguments were presented to the Corps, they were rejected. One possible reason for the rejection was the novelty of the forecasting techniques used to assess the probability of future inflows.

Conditional Instream-Flow Requirements

In several places, including California, instream-flow requirements for maintaining fisheries are increased during wetter periods and reduced during drier periods. This allows a balancing of impacts of fisheries and reduction of available supplies for agricultural, municipal, and industrial use.

Conditional Reservoir Operations

Reservoirs which supply water for the Washington Metropolitan Area are operated jointly whenever drought threatens. The reservoirs are owned individually (and some jointly) by local water supply utilities. Whenever forecasts indicate a threat of water shortage exists over the next 6 to 12 months, operations of the reservoirs are integrated to ensure maximum yield. The integration occurs when the threat of drought appears, rather than in the midst of the drought, in order to allow whatever unregulated flow may be available during the onset of drought to be used in lieu of stored water. This leaves the stored water available for use during the periods of lowest flow while preserving the ability of the independent utilities to operate their individual reservoirs to best meet their own needs (including minimizing costs) during normal periods.

V. DROUGHT PREPAREDNESS AND RESPONSE PLANS

PURPOSE

Over the past 20 years a general consensus has developed that an effective drought response plan should include the following components:

(1) Forecasting (supply and demand)

(2) Demand reduction (through pricing, appeal, or regulation)

(3) Supply enhancement (through water transfers and system improvements)

(4) Implementation by means of an ordinance calling for increasingly severe water-use restrictions imposed sequentially until the drought resolves

(5) Drought management policy structure and criteria

While there is agreement with the concept, to date no consensus has developed on acceptable methods of carrying out the individual steps.

The purpose of this chapter is to identify the requirements for designing studies to develop Drought Preparedness and Response Plans (DPRPs) for selected regions of the country. Such studies will be undertaken under the National Water Management During Drought Study conducted by the U.S. Army Corps of Engineers. The DPRP studies will analyze regional drought problems in selected regions of the country and will then be utilized to develop a planning guide which water management agencies in various regions of the country could use to prepare for drought.

The requirements for designing and conducting DPRP studies are discussed under several headings in the following sections of this chapter.

SELECTION OF STUDY AREAS

An important element of the DPRP study design is the selection of study areas. The study areas should be selected to assure the general applicability of each case study (or representativeness of each study area for application to similar areas or regions of the country).

Because droughts usually affect large regions of the country, it is necessary to conduct the DPRP studies at the regional level. The selection of regions to be studied must consider the existing definitions of water resources management regions. Such regions are defined differently at different levels of government and they include:

(1) Physical drought regions
(2) Water resources regions
(3) River basin regions
(4) State water resources
(5) Regional water management districts
(6) Service areas of local water supply agencies

Droughts affect various regions of the United States in different ways because of different climatic zones. Drought researchers usually subdivide the country into two or more climatic zones with different characteristics of droughts in each zone. One example of such a regional definition, proposed by Warrick et al. (1975), is discussed in Chapter II. It subdivides the country into four physical drought regions:

(1) East (humid)
(2) Midcontinent (semiarid or subhumid)
(3) Southwest (arid or semiarid)
(4) Northwest (humid or semiarid)

This regionalization scheme relies on the comparison of annual precipitation with potential evapotranspiration. DPRP studies should represent each of these regions.

Another regionalization scheme subdivides the continental United States into 18 hydrologic basins. It was established by the U.S. Water Resources Council in 1970. The purpose of this definition of regions was to collect and analyze water resources data (water supply and water use) by federal agencies. Although this regional scheme may be useful for analyzing drought conditions, it has an important shortcoming in that water resources are not directly managed at this regional level. That is, decisions about resource use are made by entities whose water management areas may not coincide with the regional boundaries. Therefore, the use of water resources regions as study areas may not be the best choice. However, these regions were subject to many investigations to develop data on water use and water supply. Such data can be helpful in drought assessments.

In addition to regional differences, the specific drought management problems will depend on the type of organization that is responsible for managing water resources. Such agencies may include river basin commissions, state departments of natural resources, regional water management districts (wholesale and retail), and local water supply agencies. A useful study to develop DPRP must include some regional and local agencies.

EXAMPLE OF A DPRP STUDY DESIGN

This section describes an example of an outline of work for conducting a regional (river basin or regional agency) drought management study. The purpose of such a study would be to formulate a detailed drought preparedness and response plan for a region (or a study area). The study plan would look into two major activities: (1) normal water management and (2) water management during drought.

Assessment of Water Supply-and-Demand Conditions

Before a drought preparedness and response plan can be prepared for a region, it is necessary to perform a detailed assessment of the current and future water resources and their use. Figure V-1 shows a conceptual diagram for conducting a regional "sources and needs" study. Table V-1 identifies 27 specific tasks for the initial assessment of "supply sources and water demands." For each task there is a brief description of (1) the purpose, (2) the sources of data and data requirements, and (3) the required or expected product.

Assessment of Drought Management

Once the present and future status of the water supply-and-demand balance during average-weather years is known, it is possible to conduct a comprehensive analysis of drought management alternatives.

Figure V-2 outlines the specific tasks of the drought assessment study. Table V-2 contains a description of each task. Figure V-3 and Table V-3 provide the organizational characteristics of the complete study (i.e., Sources and Needs Assessment and Drought Preparedness and Response).

FIGURE V-1
REGIONAL WATER SOURCES AND NEEDS STUDY: EXAMPLE DESIGN OF ACTIVITIES

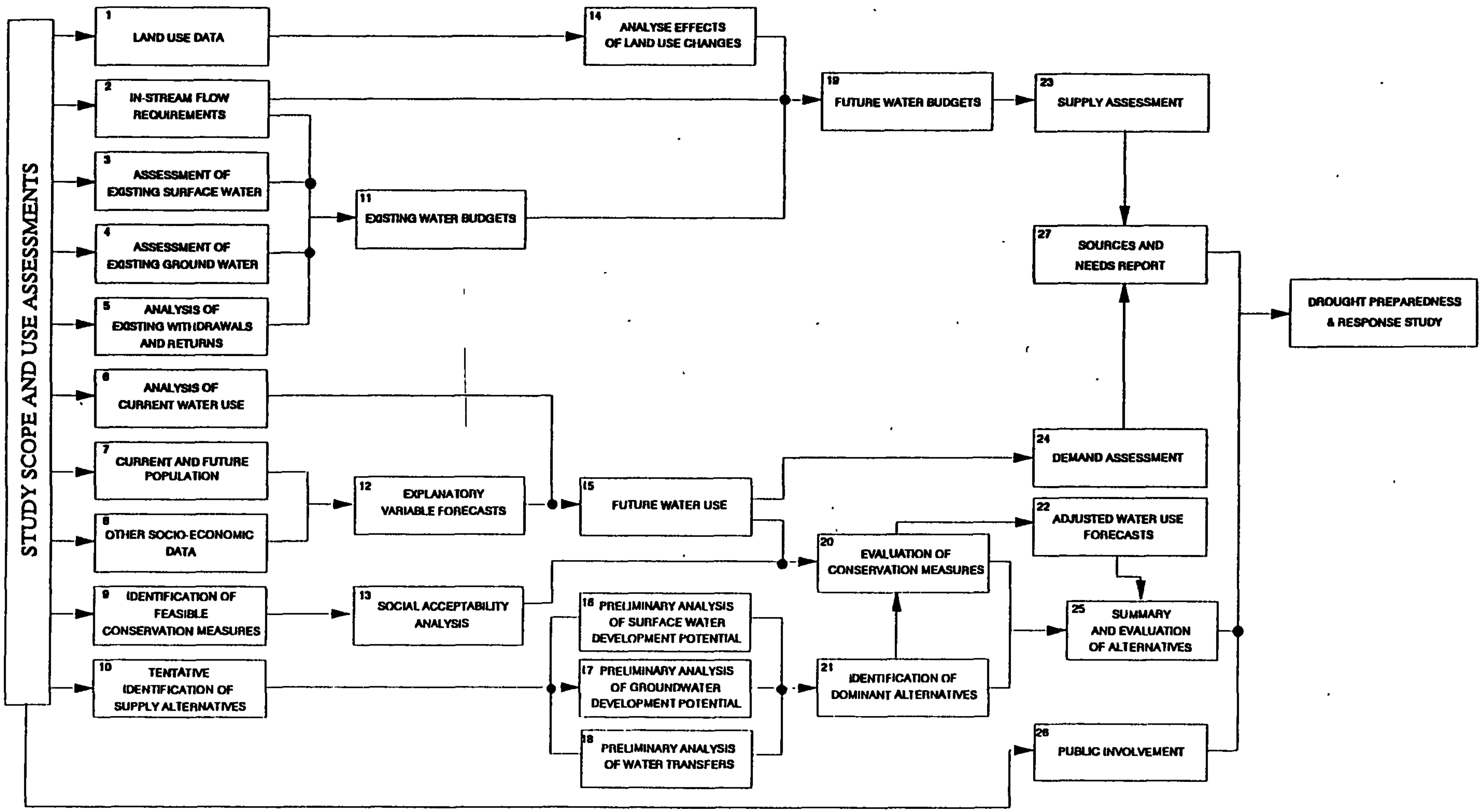

TABLE V-1

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 1-Assess Current and Future Land Use	This task will provide forecasts of major expected changes in land use within each of the defined subareas of the region. The land use plans should be analyzed to develop current and water budgets. Changes in land use are of interest to the extent that they imply changes in surface runoff or in groundwater infiltration.	Data on present land uses can be obtained from the U.S. Geological Survey Land Use and Cover Maps and from local and regional planning agencies. Forecasts may draw on related population and economic forecasts prepared by other agencies. Other data, aerial photography, etc., may be obtained from the U.S. Forecast Service, the State Department of Conservation, and the U.S. Army Corps of Engineers.	Land uses may be grouped into six categories: (1) urban land, (2) cultivated land, (3) pasture land, (4) forested land, (5) surface mining area, and (6) water surface. The number of acres in each use should be estimated for each subarea, and for the years 1990, 2000, 2010. All watershed land will be allocated to one of the six categories. The forecasts must be consistent with population forecasts of other socioeconomic variables. A technical memorandum should be prepared which outlines sources of data and assumptions, detail methods used, and presents and explains results. Where significant uncertainties exist, and with agreement of the Study Integrator, alternative land use plans may be consulted.
TASK 2-Determine Instream-Flow Requirements	This task will determine the minimum streamflows required in each stream of the study area. These minimum flows act as a constraint on surface water availability, and are required for the preparation of existing and future water budgets and for the preliminary analysis of potential surface-water developments.	The primary sources of data, assumptions, and methods for determining minimum instream flows are the State Department of Conservation and the U.S. Fish and Wildlife Service.	Minimum acceptable streamflows should be defined for a specified critical period of drought at the outlet of each hydrological basin or subbasin. Exceptions from these minimum flows (if any) should be defined. Possible exceptions include low flow events of very short duration, and periods when natural streamflow approaches or falls below the required minimum flow. Where minimum flows are determined by water-quality considerations (as opposed to biological habitat requirements), the sensitivity of required flows to possible future changes in water quality should be explored. In addition to the basin or subbasin outlets, minimum streamflows may also be specified at other points in the basin where local conditions demand. The task report should outline sources of data, major assumptions, methods used, and should present and explain results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 3-Assess Existing Surface Water Resource	This task will characterize the existing surface-water resource in the study areas, and in each of the defined subareas. The surface-water information is required for later combination with groundwater information, and with data on water withdrawals and returns to develop water budgets.	Streamflow data for the ten upstream stations are available from the Water Resources Division, U.S. Geological Survey. Surface-water-quality data are available from the U.S. Geological Survey, the State Geological Survey, and from prior and ongoing studies. Precipitation and land use data may be needed to estimate runoff in the reach of the subbasins. These data are available from National Weather Service reports.	Surface-water characteristics will be determined and presented for each subarea. The required information includes annual runoff in a "normal" (median) year, annual runoff in a drought (10-, 20-, 40-, 100-year recurrence interval) year, and minimum expected ten-day low flow in a drought year. For the river reaches potentially affected by backflow, required information may include annual runoff in normal and drought years. If lakes or reservoirs of significant size are found in the area, minimum safe yield should be estimated. In the case of instream reservoirs with controllable releases, the relationship of minimum safe yield to the release rule must be determined. All stream reaches, lakes, and reservoirs should be classified according to reported water quality as: A. Suitable for public water supply; B. Conditionally suitable for public water supply. C. Unsuitable for public water supply. The definition of the water-quality categories may be proposed by the contractor and approved by the Study Integrator and the Study Steering Committee prior to completion. The task report should outline sources of data, major assumptions, methods used, present and explain results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 4-Assess Existing Groundwater Resource	This task will characterize the existing groundwater resource in the study area, and in each of subarea. The groundwater information is required for later combination with surface-water information and with data on water withdrawals and returns to develop water budgets.	Precipitation, temperature, and the climatologic data can be obtained from the periodic publications of the National Weather Service. Vegetative cover information will be collected as a part of Task 1. Other information is available from the State Department of Geology and Land Survey (DGLS) and from prior groundwater studies.	Groundwater characteristics will be determined and presented for each of the subareas. Required information includes a general description of the area's geology; typical hydraulic conductivity; inferred underflow into and out of the basin; annual recharge for "normal" (median) year; annual recharge for drought (with various recurrence intervals) year; static water levels; etc. The existing groundwater resource should be classified according to reported water quality as: A. Suitable for public water supply B. Conditionally suitable for public water C. Unsuitable for public water supply The definition of the water quality categories may be proposed by the contractor and approved by the Study Integrator and by the Study Steering Committee. A task report should outline sources of data, major assumptions, methods used, and present and explain results.
TASK 5-Analyze Existing Water Withdrawals and Returns	This task will identify and estimate the quantity of all significant withdrawals from and returns to the water resources of the basin, and of each of the subareas. This information, together with the results of Tasks 2, 3, and 4 is required to develop water budgets.	Withdrawals and returns associated with public water supplies can be estimated from data contained in the Census of Public Water Supplies published by the State Department of Natural Resources. Various demographic and economic data available from State and Federal agencies will be required to estimate mining, industrial, agricultural, rural, and other nonpublic water use. Some of these data will be collected in Task 6.	The results of this task will include estimates of aggregate water withdrawals and returns, detailed by location (subbasin) and by source (surface vs. groundwater). Estimates will be prepared for "normal" (median) year quantities, and for drought year quantities, based on 1990 population and economic activity. A task report should outline sources of data, major assumptions, methods used, and present and explain results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 6-Analyze Base Year Water Use	This task will identify all significant classes of water users in the study areas, and in each of the subareas. Base year (1980) water use, disaggregated by user class and by subbasin, is required for the preparation of water-use forecasts (Task 15).	Public water supply systems are cataloged, together with total water production for each, in the Census of Public Water Supplies of the Missouri Department of Natural Resources. Demographic and economic data are available from various State and Federal agencies. Water-use data may also be available from individual manufacturing and mining firms, and from NPDES permits.	A classification of water users will be provided, incorporating major types of residential, commercial, industrial, and agricultural users. Base-year water uses should be estimated for each classification and for areas located within or deriving supply from each subbasin. Seasonal water use should be estimated separately, and normalized for median weather conditions. The results of this task, together with supporting documentation, will be made available to the investigators responsible for Task 5 and 15.
TASK 7-Current and Future Population	Population estimates and forecasts are required for each of the defined subareas of the study areas. These forecasts will be the basis of water-use forecasts prepared in Task 15, and of forecasts of other explanatory variables prepared in Task 12.	Population data are available for the base year from the 1980 Census of Population, from the State Office of Administration, and from the State University Department of Public Affairs. Methods and asumptions for preparing forecasts may also be obtained from the Department of Public Affairs. Areas obtaining water supply from each source will be identified in Task 6.	Population forecasts are required for years 2000 and 2010. For each year, forecasts will be prepared for the area lying within and/or obtaining its water supply from each subarea. The results of this task will be made available to the Task 12 and Task 15 investigators.
TASK 8-Other Socioeconomic Variables	Estimates and forecasts of socioeconomic variables (other than population) are required for each of the defined subareas of the study area, and for any areas served by water sources of the region. These forecasts will be used to project explanatory variables in Task 12, and water use in Task 15.	Base-year values are available for such variables as household income, employment, housing characteristics, etc., from the 1990 Census of Population and from state agencies. Areas obtaining water supply from each of the subbasins are identified in Task 6.	Socioeconomic variables to be forecast include household income, household size, number of farm households, total employment, and employment by industrial classification (e.g., 2-digit SIC codes). Additions, deletions, or changes to this list may be made following consultation with the Study Integrator, and subject to approval of the Study Coordinator. Each variable will be forecast for the years 2000 and 2010 and for each of the subareas, including any areas which are served by water obtained from the study area. The results of this task will be made available to the Task 12 and Task 15 investigators.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 9-Identify Feasible Conservation Measures	This task will identify permanent water conservation measures which appear to be technically feasible and applicable to the study area. Any measures identified will be reviewed for social acceptability in Task 13, and those found acceptable will be evaluated in Task 20.	Information on the range of possible water conservation measures and on technical feasibility can be obtained from various publications of the Institute for Water Resources, U.S. Army Corps of Engineers. Data related to applicability of specific measures to the study area can be obtained from the State Department of Natural Resources and from local water supply districts.	A list of broadly defined water conservation measures to be considered will be generated from various sources. For each subarea and/or water supply district, those measures which are not applicable will be deleted, giving a list of applicable measures for each subarea and/or water supply district. Further deletions will be made from each list for technical infeasibility. Measures which cannot be clearly classified as feasible or infeasible (on technical grounds) will be noted as potentially feasible, pending further investigation. The results of this task will be made available to the Task 13 investigators.
TASK 10-Identify Tentative List of Supply Alternatives	A broad range of supply augmentation alternatives must be identified so that preliminary analysis can be conducted (Tasks 16, 17, 18) prior to identification of water supply needs (Task 26).	Supply augmentation alternatives may have been proposed in previous studies, and by the U.S. Army Corps of Engineers. Other alternatives may be suggested by the State Department of Natural Resources and other agencies.	The tentative list of supply augmentation alternatives must identify each alternative in sufficient detail to support a preliminary analysis of technical and environmental feasibility. So as to be inclusive of all plausible supply alternatives, the list will reflect both those alternatives which have been previously proposed in the study areas studies and additional alternatives which may be suggested in the course of a workshop convened for this purpose. The workshop will include study participants and representatives of interested state and federal agencies. The Study Steering Committee will also be consulted in the course of this task. The list of alternatives will be provided, together with supporting detail, to investigators responsible for Tasks 16, 17, and 18.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 11-Define Existing Water Budgets	Water budgets for the base year (1990) are required to serve as the basis of estimated future water budgets (prepared in Task 19), which permit assessment of water supply availability during drought (Task 23).	The characteristics of existing surface-water and groundwater resources are available from the results of Tasks 3 and 4, respectively. Base-year withdrawals and returns, adjusted for both normal and drought weather conditions, are available from Task 5. Minimum instream flows are determined in Task 2.	Complete water budgets are required for each of the subareas showing surface-water runoff, groundwater recharge, groundwater underflow, water withdrawals and returns, and streamflow. Surface water and groundwater are further categorized by quality according to suitability for public water supply. Water budgets will be prepared for both normal-(median)year and drought-year conditions. At the discretion of the Study Integrator, additional water budgets may be required for other critical periods, depending upon the results of Task 3.
TASK 12-Forecast Explanatory Variables	This task utilizes forecasts of population and various socio-economic variables (Tasks 7 and 8) to develop projections of variables which explain municipal, industrial, and agricultural water use. These projected values are used to forecast water use in Task 15.	Population forecasts are prepared in Task 7; forecasts of other socioeconomic variables are prepared in Task 8. Additional information needed to prepare explanatory variable forecasts is obtained from sources utilized in Tasks 7 and 8.	A list of explanatory variables required by Task 15 will be prepared in consultation with the Study Integrator. Using the results of Tasks 7 and 8 as a basis, each explanatory variable will be forecast for years 2000 and 2010. A task report, in the form of a draft section of a technical memorandum, will be prepared which details data sources, assumptions, methods used, and which presents and explains all forecasts.
TASK 13-Determine Social Acceptability of Water Conservation Measures	In order to determine which water conservation measures are likely to be implemented in various communities within the study area, and to predict the effectiveness of these measures, a preliminary analysis for social acceptability is required. The results of this analysis will support the evaluation of individual measures to be conducted in Task 20.	The applicable and technically feasible water conservation measures to be considered will be available from the results of Task 9. General information defining and measuring social acceptability is available in various publications of the Institute for Water Resources, U.S. Army Corps of Engineers. Data will also be available from the public involvement effort, Task 27.	The study area must be divided into a number of reasonably homogeneous population centers so that social acceptability studies can be carried out in each of them. Within each population center, community advisors should be identified and consulted, so that major water resource-related issues, individuals and organizations can be delineated. Basic community ideologies will be determined, along with specific responses to major types of conservation measures. Each broadly defined water conservation measure listed in Task 9 will be classified, for each population center, as acceptable, potentially acceptable, or not acceptable. A task report should be prepared showing data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 14-Analyze Effects of Land Use Changes	This task will determine the impact of expected land use changes (forecast in Task 1) on future runoff and groundwater recharge rates. This information is necessary to prepare water budgets for future normal weather and drought periods.	Land use forecasts are available from Task 1. Base-year water budgets are available from Task 11.	To the extent that total acreage in any of the land use categories can be expected to change during the planning period, runoff rates and groundwater recharge rates may be changed as well. Modified estimates of these rates are required for each subarea and for normal as well as drought years. These modified estimates must be prepared for land use patterns expected in the years 2000 and 2010. A task report, in the form of a draft section of a technical memorandum, will be prepared which details the data and assumptions used, the methods employed, and the results obtained.
TASK 15-Forecast Unrestricted Water Use	This task will develop a forecast of future water demands without conservation. Unmitigated demand in water use in the absence of rationing or water conservation, except to the extent that conservation measures may already be in effect. The results of this task form the basis of the assessment of water demand (Task 24) as well as the preliminary assessment of water conservation as a means of meeting, in whole or in part, water supply needs during drought.	Current water use patterns are analyzed, including both sectoral and spatial disaggregation, in Task 6. Possible explanatory variables are forecast for the planning period in Task 12.	Detailed forecasts are required of future water use for the years 2000 and 2010. Each forecast will be disaggregated by subarea (each subarea to include any areas served by public supplies which utilize a source in that subarea), and by user category (as defined in Task 6). Uses associated with public water supply systems should be stated separately from self-supplied uses; public systems should be identified by location of source. Water use in each user category (sector) should be forecast as a function of all likely explanatory variables including, where practicable, price and income variables. Seasonal water use should be forecast separately from nonseasonal use. Expected future water use should be forecast for both normal (median) and drought years. The task report should incorporate the results of Tasks 6, 7, 8, and 12.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 16-Analyze Surface-Water Impoundments	This task will develop preliminary designs, cost estimates, and environmental assessments for all potential surface-water impoundments identified in Task 10. The results will be used in Task 21 to identify dominant supply augmentation alternatives.	Data are available in the form of existing water budgets, including water-quality information, for each subbasin (Task 11). Various geographic, topographic, and hydrologic information will also be available from Tasks 1, 3, and 4. Required instream flows are developed in Task 2. Other data sources include prior basin studies and preliminary designs, the State Department of Natural Resources and the U.S. Army Corps of Engineers.	For each potential project, results will include development of the functional relationship between the cost of impoundment and increasing levels of sustained supply from each project. A preliminary assessment of expected environmental impacts should also be presented for each project. Cost estimates will include investigation of water treatment and transmission costs associated with each impoundment and the most likely location of demand. Because Tasks 1, 2, and 3 will overlap Task 16 in their performance periods, some results may be tentative, to be modified as improved data are available. A task report should be prepared showing data sources, assumptions, methods used, and results.
TASK 17-Analyze Groundwater Development	This task will develop preliminary designs, cost estimates, and environmental assessments for all potential groundwater development projects identified in Task 10. The results will be used in Task 21 to identify dominant supply augmentation alternatives.	Data are available in the form of existing water budgets, including water quality information, for each subbasin (Task 11). Various geographic, topographic, and hydrologic information will also be available from Tasks 1, 3, and 4. Other data sources include prior basin studies and groundwater studies, State Department of Natural Resources and the U.S. Army Corps of Engineers.	For each potential project, results will include development of the functional relationship between project cost and the level of withdrawal from each aquifer. A preliminary assessment of expected environmental impacts will also be presented for each project. Cost estimates will include investigation of water treatment and tranmission costs associated with each project and the most likely location of demand. Possible interactions of groundwater projects with potential surface-water impoundments will also be determined. Because Tasks 1 and 4 will overlap Task 17 in their performance periods, some results may be tentative, to be modified as improved data are available. A task report, should be prepared showing data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 18-Analyze Water Transfer Projects	This task will develop preliminary designs, cost estimates, and environmental assessments for all potential water transfer projects identified in Task 10. Water transfer projects will transport water from the major rivers to supplement the yield of the local hydrologic system. The results of this task will be used in Task 21 to identify dominant supply augmentation alternatives.	Data on the quantity and quality of major river(s) water are available from the U.S. Geological Survey, the State Department of Natural Resources, and from past and ongoing studies. Data on the nature of the hydrologic systems of the study area are available from Tasks 2, 3, 4, and 11.	For each potential project, results will include development of the functional relationship between the cost of the project and the capacity of the transfer facility. A preliminary assessment of expected environmental impacts will also be presented for each project. Cost estimates will include investigation of any required pretreatment costs, plus treatment and transmission costs associated with moving water to likely locations of demand. Because Tasks 1, 2, and 3 will overlap Task 18 in their performance periods, some results may be tentative, to be modified as improved data are available. A task report should be prepared showing data sources, assumptions, methods used, and results.
TASK 19-Forecast Future Water Budgets	Future water budgets will reflect any impact of changing land use patterns on the water resources of the study area. Knowledge of such changes is required to permit a full assessment of future supply conditions (Task 23) and to verify the feasibility of potential supply augmentation projects (Task 25).	Base-year water budgets are available from Task 11. Changing land use patterns are evaluated in Task 1, and their impact on surface-water runoff and groundwater recharge is determined in Task 14. Future self-supplied water use is available from Task 15.	Complete water budgets are required for the years 2010 and 2020 and for each of the subareas. The water budgets will show surface-water runoff, groundwater recharge, groundwater underflow, water withdrawals and returns (based on base-year public system use and future self-supplied use), and streamflow. Surface water and groundwater are further categorized by quality according to suitability for public water supply. Water budgets will be prepared, at each future time period, for both normal (median) and drought weather conditions. At the discretion of the Study Integrator, additional water budgets may be required for other critical periods, depending upon the results of Task 3. The task report will be prepared in the form of a technical memorandum, showing data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 20-Evaluate Water Conservation Measures	This task will provide a preliminary evaluation of all applicable, technically feasible, and socially acceptable water conservation measures in each of the study area population centers. This evaluation is used to determine which measures may be considered, in Task 25, as alternatives to the construction of supply augmentation in meeting the water supply needs of the study area. Calculations of effectiveness, performed within this task, are used to modify water use forecasts to account for the expected effectiveness of water conservation.	Candidate water conservation measures are those identified in Task 9 and found applicable, technically feasible, and socially acceptable in Tasks 9 and 13. Foregone supply costs will be obtained from Tasks 16, 17, and 18, as summarized in Task 21. Data on implementation costs and conditions are available from local water districts in the study area.	A list of specific water conservation measures will be prepared, based on the broadly defined measures considered in Tasks 9 and 13, and utilizing the results of Task 13 to eliminate unacceptable or inferior versions. A preliminary evaluation of these measures will be carried out, using the results of Tasks 16, 17, and 18 as sources of foregone supply costs. For each population center, the set of water conservation measures which maximizes the contribution to the economic efficiency (NED) objective, and the set which maximizes the net contribution to environmental quality (EQ) will be reported. Documentation of each set of measures will include combined effectiveness, implementation cost, implementation conditions, foregone supply cost, and environmental impacts. A task report, in the form of a technical memorandum, will be prepared which incorporates the results of Task 9 and 13, and which presents data sources, assumptions, methods used, and results.
TASK 21-Identify Dominant Alternatives	This task will identify the dominant supply augmentation alternatives, permitting development of the optimum mix of supply projects designed to furnish the water supply needs of the area. The results of this task are utilized in Task 25, where possible water conservation strategies are incorporated.	Data are obtained from the results of Tasks 16, 17, and 18.	For each subbasin, or combination of subbasins (in the case of water transfers or regulating impoundments), potential supply augmentation projects should be listed (if possible) in order of relative dominance. Project A is said to dominate project B when A provides a safe yield equal to or greater than that of B, at costs which are not higher, and with environmental impacts which are not, in overall effect, worse. All potential projects will be listed with summaries of expected environmental impacts. Attention will be given to possible statutory, regulatory, or institutional constraints on implementation, and to possible future changes in those constraints. A task report, in the form of a technical memorandum incorporating the results of Tasks 10, 16, 27, and 18, will be prepared showing data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 22-Adjust Water-Use Forecasts	Where demand management strategies, such as water conservation measures, are to be considered, forecasts of unrestricted water use, such as those prepared in Task 15, are no longer appropriate. This task adjusts forecasts to incorporate the effect of the water conservation plans developed in Task 20. The results are included in the summary of alternatives prepared in Task 25.	Unrestricted water-use forecasts are available from Task 15. The effectiveness of water conservation measures, and of sets of measures, is analyzed in Task 20.	For each forecast associated with a public water supply, as prepared in Task 15, two additional water-use forecasts will be prepared: one will incorporate the effect of the set of water conservation measures which maximizes the net contribution to the NED objective, the second will incorporate the effect of the set of measures which maximizes the contribution to the EQ objective. These two adjusted forecasts will be presented in the same detail as the original unrestricted forecasts. The results of this task will be provided to the Task 25 contractor.
TASK 23-Assess Water Supply	This task will provide a summary description of the water resources of the study areas and a detailed description of expected future water budgets. This information will be used in Task 26 to determine needs for additional water supply capacity in the study area.	Future water budgets are available from Task 19. Other information on the geographic, topographic, cultural, and hydrologic characteristics of the study area is available from Tasks 1, 3, 4, and 5. Capacity of existing public water supply facilities is available from State Department of Natural Resources.	A complete description of the water resource of each subbasin will be prepared, incorporating expected future hydrologic conditions and self-supplied withdrawals and returns. The capacities of all existing public water supply facilities will be presented, along with an assessment of the ability of surface-water and groundwater resources to support these capacities. The quantity, quality, and location of all unexploited water, in excess of environmental flow-by requirements, will be determined for each subbasin. A task report will be prepared showing data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 24-Assess Water Demand	This task will provide a summary description of the public system water demands existing within the study area and within areas served by sources located in the area. This information will be used in Task 26 to determine needs for additional water supply capacity in the study area.	Future unrestricted water-use forecasts are available from Task 15 and are reported in Technical Memorandum No. 3. Other information on water users, water system capacity, and population center characteristics is available from Tasks 5, 6, 7, and 8.	A complete description of the requirement for public water supply in each subbasin will be prepared. The forecast water use levels of Task 15 will be converted into requirements for water supply capacity. Normal- and drought-year withdrawals and returns will be calculated for each forecast year. A task report will be prepared showing data sources, assumptions, methods used, and results.
TASK 25-Summarize and Evaluate Alternatives	This task merges the results of the evaluation of water conservation measures (Task 20) with the supply augmentation alternatives (Task 21) to obtain an array of least-cost supply/conservation strategies which can be used to satisfy needs during normal and drought periods identified in Task 26.	Data describing water conservation approaches are available from Task 20. Adjusted forecasts of water use from public supplies are available from Task 22. Supply augmentation alternatives are summarized and ranked in Task 21.	For each subarea, this task will provide the least cost and/or least environmental impact strategy for coping with any specified supply need. Each of the supply augmentation measures rank ordered (according to dominance) in Task 21 will be merged with water conservation strategies developed in Task 20. Two sets of alternatives will be developed for each subbasin: one which maximizes the net contribution to the NED objective; and another which maximizes the net contribution to the EQ objective. A task report, in the form of a draft section of the overall project report, will be prepared which shows data sources, assumptions, methods used, and results.

TABLE V-1 (Continued)

EXEMPLARY OUTLINE OF A RESOURCES AND NEEDS ASSESSMENT STUDY

Research Task	Purpose	Data Source	Results
TASK 26-Facilitate Public Participation	Public involvement throughout the course of the study is necessary to (1) disseminate information relevant to the study and (2) identify and measure public concerns and preferences. Knowledge of public concerns, attitudes, and preferences will assist in the performance of various study tasks, notably Tasks 13, 15, and 21. The public involvement activity will also assist in the preparation of conclusions and recommendations.	Information describing study goals, methods and results will be available from all tasks as the study progresses.	This task will include the development and dissemination of an information booklet and three fact sheets. The booklet will describe the study area and the study and will be designed so that brief summaries of study results can be added as they become available. The fact sheets, issued periodically during the course of the study, will summarize interim progress and findings. The task will also include the organization and conduct of a series of three public meetings, to be held just before completion of the study. These meetings will be the principal source of public comment on the study findings prior to circulation of the draft report. The task report should describe methods used and present results.
TASK 27-Assess Water Resources Needs Report	This task contrasts the requirements for future water supply (Task 24) with the possibilities afforded by area's water resources (Task 23). The result, a description of future water resources needs, is contrasted to various alternative solutions (developed in Task 25) to yield conclusions and recommendations.	Future water supply possibilities are described in Task 23, net of forecast self-supplied water use. The requirement for future public system water supply is described in Task 24.	For each subbasin, the requirement for future water supply will be contrasted with the expected future capability of existing supply facilities. Where the location of expected needs differs from existing population centers, those needs may be assigned to a closer supply source in a different subbasin. Areas lying outside the Mainstem River Basin, but served by water supply sources within the basin, are included in the appropriate subbasin. The location and magnitude of any supply shortfalls will be determined for each forecast year. An overall project report, will be prepared which shows data sources, assumptions, methods used, and results.

FIGURE V-2

REGIONAL DROUGHT ASSESSMENT STUDY DESIGN

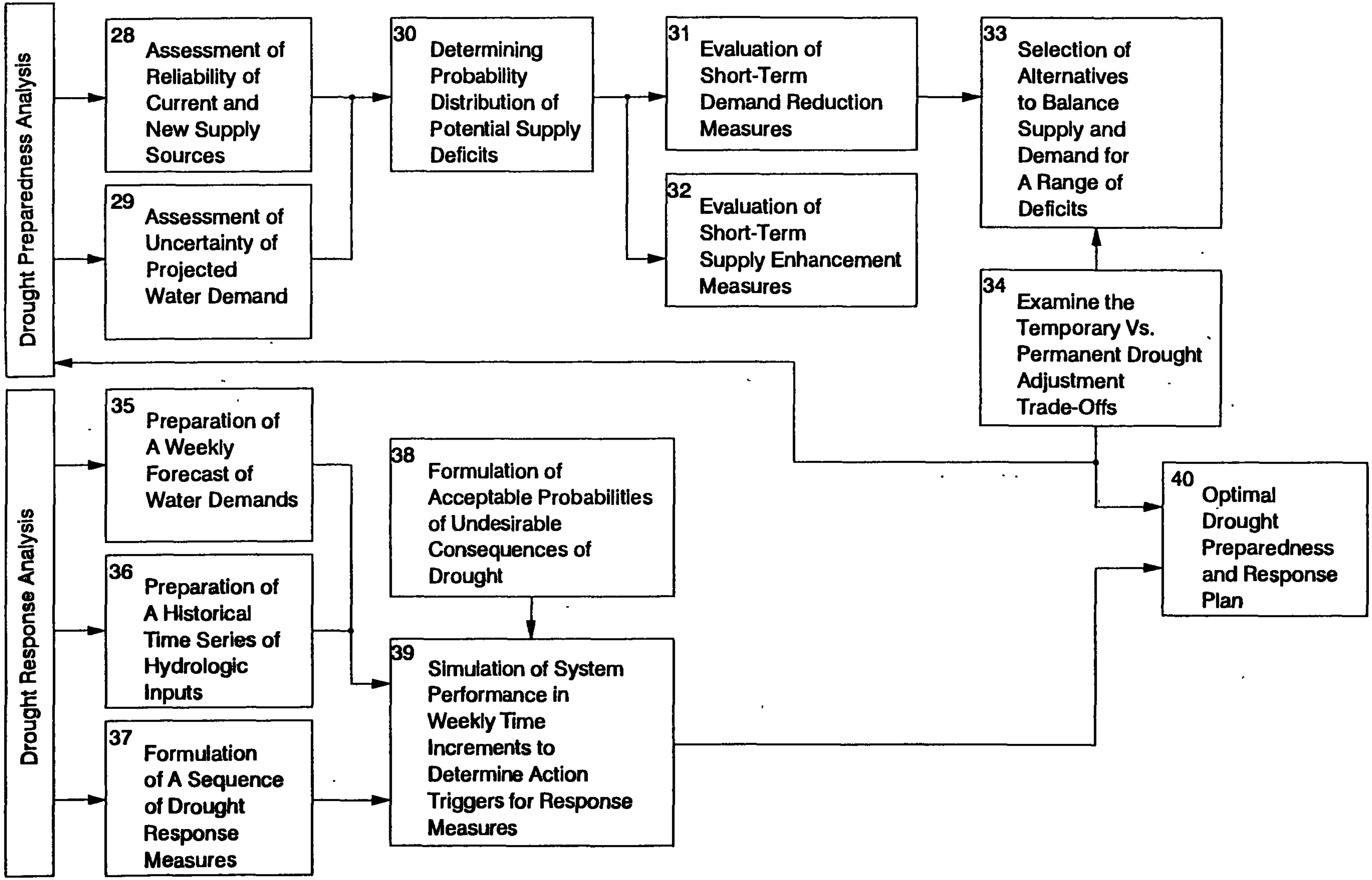

TABLE V-2

EXEMPLARY OUTLINE OF A DROUGHT PREPAREDNESS AND RESPONSE STUDY

Research Task	Purpose	Data Sources	Results
TASK 28 - Assessment of Reliability of Current and New Sources	This task will determine the levels of supply under different drought scenarios.	Data on hydrology of sources can be obtained from U.S.G.S. or state resources agencies.	Water supply levels in the long run must be determined in order to carry out a complete evaluation of drought management alternatives. The magnitude and probability of potential water supply deficits are determined from the probability distribution of system yields in each future year. A method for analyzing the system yields used in this study was developed by Stall and Neill (30) of the Illinois State Water Survey.
TASK 29 - Assessment of Uncertainty of Projected Water Demand	This task examines the probability distribution of water demands during drought.	Data on future water demands and their influencing factors are included in the Sources and Needs Report.	A computerized water-use forecasting system known as IWR-MAIN (Dziegielewski and Boland, 1989) can be used to predict average summer and winter water use in the area. This system estimates water use at a highly disaggregate level based on demographic and socioeconomic characteristics of the area for the base year and key variables describing local historical data and furture forecasts. However, a variety of methods may be used.
TASK 30 - Determining Probability Distribution of Potential Shortages	This task will combine information from Tasks 28 and 29 to produce the range of probable shortages.	Data will be obtained from Tasks 28 and 29.	A good example of a probabilistic forecast of water supply deficits is presented in Boland et al. 1980. The results should be presented as the probability distribution of deficits/surpluses for each forecast year.
TASK 31 - Evaluation of Short-Term Demand Reduction Measures	To determine costs and effectiveness of demand reduction measures.	Information can be obtained from Tasks 9, 13, 20, and 25 of the Sources and Needs Report.	Each alternative demand reduction measure (see Table IV-5, for examples) should be evaluated in terms of its economic effects, water savings, and social effects. Also legal and administrative aspects should be considered.
TASK 32 - Evaluation of Short-Term Supply Enhancement Measures	To determine costs and available yields of feasible supply enhancement measures.	Information can be obtained from Tasks 2, 3, 4, 5, and 23 of the Sources and Needs Report.	Each alternative supply enhancement measure (see Table IV-6, for examples) should be evaluated in terms of the availability and quality of water, the construction and O&M costs and the necessary implementation lead time, and the potential legal and administrative considerations involving permits, rights to the source, or easements for transferral systems.

TABLE V-2 (Continued)

EXEMPLARY OUTLINE OF A DROUGHT PREPAREDNESS AND RESPONSE STUDY

Research Task	Purpose	Data Sources	Results
TASK 33 - Selection of Alternative to Balance Supply and Demand for a Range of Deficits	To find a least cost combination of sequential drought management measures.	Data will be obtained from Tasks 30, 31, and 32.	The descriptive data on individual shortage mitigation measures must be integrated so that best plans can be identified. A mixed integer programming model can be used to select the mixes of shortage mitigation measures for each volume of deficit. This procedure solves for both integer and continuous variables, or "activity levels," in the objective function so that the total expenditures for a hypothetical emergency program are minimized while meeting constraints on water availability and satisfying the reduced demands.
TASK 34 - Examining the Trade-off between Long-term and Short-term Adjustments	To determine whether the reliance on short-term drought management is the best solution.	Data will be obtained from Tasks 31 and 32 as well as the Sources and Needs Report.	The need for expanding the supply capacity of an existing system is assessed based on explicit consideration of the potential for recurrent water shortages during a prescribed period. The critical element in selecting the optimal capacity is the determination of the benefits of increased system reliability. For an existing capacity of a water supply system, the range of possible supply deficits in each future year can be determined by comparing system yields with anticipated levels of water use, with and without extra drought protection. A set of various volumes of deficit, each corresponding to a stated probability, is defined for each year. A minimum-cost emergency plan for coping with each deficit is determined by solving the mixed integer problem, thus producing a set of corresponding cost estimates. Each estimate is assigned a probability of occurrence, so that higher costs associated with large volumes of deficit have lower probability. The critical step in the analysis is the accumulation of the costs of various deficits to determine the expected total cost of coping with drought for the given year. Having estimated the expected cost of coping with droughts over the entire planning period, the next step is to examine the effectiveness of long-term projects in reducing this cost. By comparing the aggregated present worth estimates it is possible to examine the trade-off between the cost of the long-term water supply/conservation projects and the expected value of the cost of coping with water supply deficits during the planning period.

TABLE V-2 (Continued)

EXEMPLARY OUTLINE OF A DROUGHT PREPAREDNESS AND RESPONSE STUDY

Research Task	Purpose	Data Sources	Results
TASK 35 - Preparation of Weekly Forecasts of Water Demands	To develop a time series projection with weekly water demands under drought conditions.	Data can be obtained from Tasks 6, 7, 15, and 24 of the Sources and Needs Report.	This task will provide a partial result for the simulation of system performance under alternative operating policies during drought emergency.
TASK 36 - Preparation of a Historical Time Series of Hydrologic Inputs	To facilitate the risk analysis for adverse consequence of drought.	Data can be obtained from Tasks 11, 19, and 23 of the Sources and Needs Report.	This task will provide necessary information for determining the probabilites of reaching critical reservoir or groundwater levels under alternative operating policies.
TASK 37 - Formulation of a Sequence of Drought Response Measures	To develop alternative operating policies for drought management.	Information on least-cost sequencing will be generated in Tasks 31, 32, and 33.	Depending on the level of deficit the number and type of management measures will vary. However, a progressive sequence of alternatives from least costly to most costly can be determined.
TASK 38 - Formulation of Acceptable Probabilities of Undesirable Consequences of a Drought Event	To identify the operating regime of a water supply system.	This information can be obtained from surveys of agency strategies for drought management, e.g., DalMonte, 1990 Garbharran, 1989.	The results of this analysis will be presented in the form of probabilities that are acceptable to water managers.
TASK 39 - Simulation of System Performance in Weekly Time Increments	To test the effects of alternative implementation schedules on the risk of undesirable consequences.	Data for this analysis will be obtained from Tasks 35, 36, 37, and 38.	The result of this analysis is a set of action triggers (i.e., reservoir or groundwater levels) that can be used to put the sequential drought management measures into effect.

TABLE V-2 (Continued)

EXEMPLARY OUTLINE OF A DROUGHT PREPAREDNESS AND RESPONSE STUDY

Research Task	Purpose	Data Sources	Results
TASK 40 - Optimal Drought Preparedness Response Plan	To present the analysis and results of drought preparedness and response.	All tasks of the Drought Assessment Analysis.	The summary of the drought assessment study will be presented in a final technical report.

FIGURE V-3
ORGANIZATIONAL CHART: REGIONAL DROUGHT PREPAREDNESS STUDY

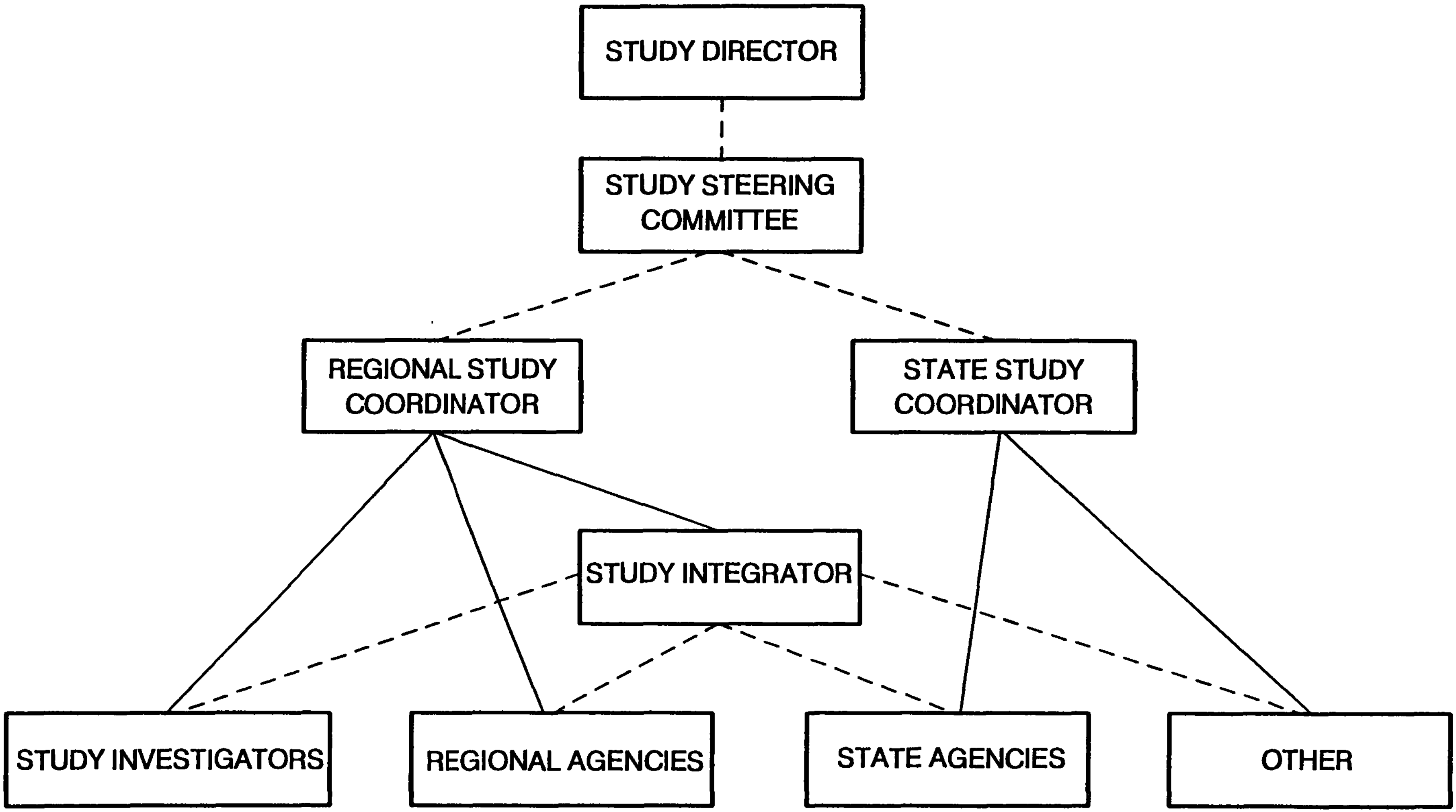

TABLE V-3

REGIONAL DROUGHT PREPAREDNESS STUDY
PROPOSED STUDY ORGANIZATION

STUDY STEERING COMMITTEE

Comprised of Director, State Department of Natural Resources; District Engineer, U.S. Army Corps of Engineers; representatives of other federal and state agencies as needed; and alternate members for above.

Monitors progress of study through monthly (approximate) meetings with Study Coordinators, Study Integrator, and representatives of consultants and agencies as required.

Provides technical advice and direction through Study Coordinators.

Coordinates participation of federal and state agencies.

Coordinates comments and critiques on completed study elements through Study Coordinators.

STATE STUDY COORDINATOR

Assigns tasks to state agencies and/or consultants.

Monitors progress of state-assigned tasks.

Facilitates flow of information among agencies and consultants, providing assumptions, data, etc., as needed.

Issues notice to proceed for individual state-assigned tasks.

Ensures timely submission of draft and final task reports to Study Integrator.

Coordinates task presentations to Study Steering Committee as required.

Authorizes, subject to concurrence of Study Integrator, changes in tasks.

TABLE V-3 (Continued)

REGIONAL DROUGHT PREPAREDNESS STUDY
PROPOSED STUDY ORGANIZATION

CORPS STUDY COORDINATOR

Assigns tasks to Corps personnel, federal agencies, and/or consultants.

Monitors progress of Corps-assigned tasks.

Monitors performance of Study Integrator.

Facilitates flow of information among agencies and consultants, providing assumptions, data, etc., as needed.

Issues notice to proceed for individual Corps-assigned tasks.

Ensures timely submission of draft and final task reports to Study Integrator.

Coordinates task presentations to Study Steering Committee as required.

Sets agenda for meetings of Study Steering Committee.

Schedules, organizes, and facilitates meetings of Study Steering Committee.

Authorizes changes in Corps-assigned tasks.

Solicits and collects comments on draft final report.

Transmit comments to Study Integrator and to other agencies and consultants.

STUDY INTEGRATOR

Monitors technical progress on all tasks ensuring, through Study Coordinators, desired end product.

Periodically briefs Study Steering Committee on overall technical progress.

Reviews task draft reports.

Solicits and collects comments on task draft reports.

Transmits comments on task draft reports.

Reviews task final reports, where required.

Performs Tasks 28 and 29.

VI. RESEARCH RECOMMENDATIONS

The purpose of this chapter is to summarize the most pressing inadequacies in our present knowledge before we can modify national policies or regional practices for managing water during drought. These include the inadequacies which must be addressed in the ongoing National Water Management During Drought Study.

Future droughts will likely increase the pressures on existing water resources nationwide. A national policy for drought response cannot be developed without a basis (or a set of guiding principles) for regional and national water management decision making in drought situations. Although the current laws provide for allocation of scarce water resources, they may not assure that dwindling supplies are shared among various purposes in a way that would minimize the adverse effects of drought on the affected region or the nation as a whole. Therefore, there is a need to prioritize alternative uses of water resources in terms of their economic, social, and environmental values to the nation.

Two general research recommendations that pertain to the development of an analytical framework for prioritizing all major uses of water resources are:

(1) Development of practical guidelines for measuring the economic value of water in alternative uses including:

   (a) Municipal and industrial water supply
   (b) Agricultural irrigation
   (c) Hydropower generation
   (d) Navigation
   (e) Water-based recreation
   (f) Protection of wildlife
   (g) Water quality

(2) Development of objective methods for quantifying nonmarket impacts of drought on these activities in order to determine the social and environmental effects of restricting or temporarily eliminating these water uses during drought

Although, most likely, these values of water will depend on location, the availability of a standard methodology would be of assistance to decision makers. It would be invaluable in developing a consensus ranking of uses for management of available water resources, especially the supply sources that are controlled by the Corps of Engineers and other federal agencies.

The specific critical gaps in our knowledge are presented below under three broad categories of drought impacts: agricultural drought, urban drought, and other water resources activity impacts.

URBAN DROUGHT RESEARCH

The experience with recent droughts helped develop a consensus among water managers and researchers that the key to adequate drought management in urban areas lies in predrought preparation, especially as it relates to conservation and planning for future water needs. Several areas of inquiry can be expected to be most productive in facilitating the development of optimal drought management or drought response plans for urban water systems. The areas are presented below.

(1) Voluntary water conservation programs hold the greatest promise for achieving major temporary reductions in urban water use at the minimum economic, social, and environmental costs. Basic research in social psychology and communications is needed in order to identify ways of influencing individuals and social groups to change their water-using behaviors during drought.

(2) Practical guidelines for measuring economic losses from restricting specific urban uses of water need to be developed. Because the range of possible restrictions is very wide, the economic impact studies would have to deal with a great variety of activities and economic sectors. The most pressing needs include measurement of restriction-loss relationships for the following types of restrictions:

(a) Urban irrigation including watering of residential lawns, golf courses, public parks, roadside and medians, and other areas
(b) Restrictions on sprinkling through inconvenience (i.e., limiting of watering to even/odd day and/or specific hours of the day)
(c) Restrictions on commercial car washing and car washing in general (by individuals)
(d) Mandatory rationing plans limiting monthly or bimonthly use of water by households to a predetermined amount
(e) Mandatory reductions in water use for various commercial and manufacturing activities

(3) Adequate conceptual frameworks are needed to distinguish between short-term and long-term economic, social, and environmental impacts of water supply shortages created by alternative water management methods. The most pressing research need is to develop adequate optimization techniques for drought management that would determine the optimal selections of long-term and short-term drought mitigation measures.

(4) There is a need to identify proper legal and institutional arrangements for successful implementation of drought management plans. These relate to questions of authority to implement voluntary or mandatory conservation, i.e., increase the price of water or impose severe penalties for high use of water. Also, there is a need to evaluate the influence (positive or negative) of the decision-making process in drought response.

(5) A promising demand management technique for drought response is the use of pricing mechanisms to allocate (or ration) dwindling supplies among urban uses. Developing practical methods for determining the necessary prices and devising structures of water rates that would achieve the desired reductions in water use are the most critical needs for establishing effective drought pricing policies.

AGRICULTURAL DROUGHT RESEARCH

Research on agricultural drought needs to distinguish, when necessary, between the irrigated and nonirrigated (dry-farming) agricultural sectors. This distinction will often be important because the arrays of drought management and response measures usually are different for each type of activity. Irrigated agriculture faces problems closely akin to municipal water supply systems because both rely on water storage. Therefore, the important problems of drought management for irrigated agriculture concern the questions of how, when, and where to allocate scarce water and to impose water-use restrictions in order to conserve remaining supplies. These questions must consider efficacy, cost, and acceptability of alternative conservation techniques as well as alternative institutional arrangements for water allocation (e.g., reservoir operating rules, water-marketing laws).

For dryland agriculture, the drought management options during a drought are limited to selection of crops and acreage based on soil moisture, and to a lesser degree on modifying cultural practices, and on precipitation management (i.e., cloud seeding). The most-needed research to alleviate impacts during a drought involves the assessment of alternative farm management methods as a drought evolves, development of improved insurance programs for income protection, and consideration of better institutional arrangements (e.g., drought relief programs, debt restructuring, improved relationships with neighboring farmers not impacted by the drought) for reducing the costs associated with drought. In anticipation of droughts, or in cases where a tendency toward more drought events for an area has been identified, longer-term research needs include the development of new crop varieties, cultural practices, and technologies that enable farming with less water. Many of the research efforts started during the 1930s, e.g., on optimal windbreak spacing in the Great Plains, continue to have long-term implications for best farming practices in drought-ridden areas.

During a drought, both the water manager charged with allocating limited water supplies among agriculturalists, and between agriculture and other users, and the individuals addressing dryland drought problems need accurate impact assessment tools and procedures. Recommendations pertaining to improving analytical systems for assessing the agricultural economic impact of drought are listed below:

(1) A federal economic impact analytical system is functioning reasonably well; however a detailed assessment of the system by outside reviewers should be considered.

(2) Federal agencies involved in assessing the impact of drought need to establish an "agency memory." That is, analysts actually making projections need to document number estimates and qualitative statements made in drought assessment reports.

(3) Federal agencies should work toward systematically identifying a minimal set of attributes for representing the effects and impacts of a drought. The choice of attributes seems somewhat ad hoc at the moment. A common set of attributes agreed upon by analysts would serve to focus efforts in drought assessment.

(4) States should also develop analytical systems for agricultural drought evaluation. The systems should be consistent and complementary to the federal effort.

(5) State and federal research funding should be expanded for:

(a) Further development of soil-water-plant simulators for the major crops in each state should be undertaken. Such systems should focus on effective soil moisture and associated-yield response and facilitate forecasting drought impacts in real time as the drought unfolds.

(b) Further development of farm-level simulators for assessing farmer adjustments that might be made while enhancing data and information collection about what human adjustments have actually been made by individuals in drought areas. Very little literature describes actual farmer response, and farm simulators have seen only sporadic use in drought assessment.

(c) Further examination of the linkages between dryland and irrigated agriculture to consider (1) the extent to which irrigated agriculture does and can help alleviate impacts on dryland agriculture during droughts (e.g., in providing livestock forage) and (2) the degree to which irrigated agriculture does help offset the economic effects of drought.

(d) Further refinement of methods and models for assessing drought at more aggregate levels, and documenting the performance of models that have been used in the past (e.g., input-output models or systems dynamics models).

(e) Intensification of the efforts at identifying, understanding, and evaluating alternative institutional arrangements for handling drought. The paucity of social science research on drought institutions and human behavior as affected by those institutions needs attention. Impact analysis needs to be expanded to include social (as well as economic) impacts.

One general problem also has become apparent in this review: current economic assessment as practiced by state and federal agencies is more akin to economic impact analysis (e.g., counting job losses, measuring income) as opposed to social benefit/cost economic analysis. Consumer and producer surpluses are not usually estimated. Areas under derived demand and above water supply curves (see Appendix C, Figure C-1) are only approximated. Drought economic impact assessment should be moved ever closer to true economic benefits and costs assessment and supplemented by sound institutional and behavioral analysis.

Miewald (1978, p 79) in citing Borchert (1971) also makes the point that scholarly interest in drought "is as cyclical as rainfall patterns. . ." The same can be said for most state and federal agency interest and certainly that of the general public. Concern for drought tends to dissipate with each drop of rain. It is hoped that this report will help reinforce the point being made by many that improving agricultural drought assessment should be an ongoing process because of the inevitability of more drought events.

DROUGHT VS. OTHER WATER RESOURCE USES

Measurement of economic impacts of drought and development of innovative drought response measures would also benefit other water resources activities. Research needs pertaining to each activity are summarized below.

Hydropower

Because the production of hydropower is in a direct conflict with water uses that require keeping water in storage, there is a need to identify economic trade-off between hydropower production and other beneficial uses of reservoir water. There is a need for conducting more studies similar to the just-completed TVA study of reservoir drawdowns (TVA, 1990). The TVA methodology could be applied to measure the costs of protecting reservoir levels at Corps of Engineers' reservoirs.

Navigation

Drought losses in inland waterway navigation result from tow delays, light loading, and lock delays. The barge-shipping industry also incurs the cost of traffic diversions. Large-scale transportation models should be developed to optimize the inland navigation system and to assess the cost of reduced flows in existing navigation channels. Such models could incorporate the existing computer models designed for optimizing transportation of a single commodity such as coal.

Recreation

A precise measurement of benefits of water-based (instream and reservoir) recreation is necessary for development of reservoir operating rules that would maximize total net benefits of all project purposes. An increasing number of studies are devoted to the economic measurement of instream uses of water and protection against low lake levels. A critical review of such studies should be undertaken in order to select a suitable analytical framework that would become a standard procedure to be used by the Corps of Engineers and other federal agencies.

Fish and Wildlife

The effects of droughts and water management during drought on fish and wildlife populations are poorly understood, and additional research is required before the short-term and long-term effects of reduced availability of water can be predicted.

Water Quality

Streamflow quality is significantly changed during periods of low flow. However, only some quality characteristics are considered in protecting water quality during drought. These characteristics include salinity in coastal areas and estuaries and dissolved oxygen in inland waters. There is a need to determine the effects of drought on other water-quality parameters (e.g., nitrates, phosphates, coliforms) that are important to municipalities using streams and rivers for public water supply.

ACRONYMS

Acre-Feet	AF
Agricultural Stabilization Conservation	ASC
Agricultural Stabilization and Conservation Service	ASCS
Army Civil Works	ASACW
Basin Climatic Index	BCI
Central Valley Project	CVP
Consumer Price Index	CPI
Crop Moisture Index	CMI
Cubic Feet per Second	CFS
Delaware River Basin Commission	DRBC
Department of Water Resources (California)	DWR
Deputy Administrator, State County Operations	DASCO
Drought Impact Assessment	DIA
Drought Preparedness and Response Plan	DPRP
Drought Preparedness Studies	DPS's
Economic Research Service	ERS
Emergency Conservation Program	ECP
Environmental Protection Agency	EPA
Erosion Productivity Impact Calculator	EPIC
Evapotranspiration	ET
Extension Service	ES
Farmers Home Administration	FmHA
Federal Aviation Administration	FAA
Federal Crop Insurance Corporation	FCIC
Federal Emergency Management Agency	FEMA
Field Communications and Automation System	FOCAS
Forestry Service	FS
Geographical Information Systems	GIS
Gross National Product	GNP
Institute for Water Resources	IWR
Linear Programming	LP
Metropolitan Water District of Southern California	MWD
Million Gallons per Day	MGD
National Oceanic and Atmospheric Administration	NOAA
National Weather Service	NWS
Palmer Drought Severity Index	PDSI
President's Interagency Drought Policy Committee	PIDC
Soil Conservation Service	SCS
Storage Water Project	SWP
Susquehanna River Basin Commission	SRBC
Tennessee Valley Authority	TVA
United States Army Corps of Engineers	USACE
United States Department of Agriculture	USDA
United States Geological Survey	USGS
Water Resources Council	WRC
Willingness to Pay	WTP

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APPENDIX A

SUMMARY OF FIVE STATE DROUGHT PLANS

COLORADO

(1) Primary impacts addressed: Water intensive activities such as agriculture, wildfire protection, municipal usage, commerce, tourism, and wildlife preservation.

(2) Structure of plan: The purpose of the plan is to provide an effective and systematic means for the state to deal with emergency drought problems, short- and long-term. The plan consists of an assessment system and a response system. The assessment system, which is composed of ten task forces, uses a wide range of information sources, gathers and evaluates data, and helps delineate problem areas that cannot be resolved locally. The response system deals with current needs that fall within the state's capabilities. If needs exceed the state's capabilities to resolve them, the response system can make recommendations to the governor for state legislative or federal assistance. The Inter-Agency Coordinating Group (IACG) deals with unusually complex emergency problems; this group is composed of representatives of lead response agencies. IACG resolves issues internally when possible and provides recommendations for further action to the governor. The drought plan lists a number of drought severity indicators that serve as triggers for the drought plan. The assessment system is activated by a governor's memorandum when the Water Availability Task Force notes the development of drought (-2.0 on Palmer or Water Availability indexes) on any of Colorado's main river basins. The response system functions through various existing departments of state government until the IACG is activated by the governor's proclamation of a drought emergency; this proclamation is issued when the Review and Reporting Task Force indicates the existence of emergency conditions (unmet needs that cannot be resolved through normal channels).

(3) Components (elements) of the plan:

(a) Monitoring and Assessment--The Water Availability Task Force of the assessment system collects data and makes assessments and projections on snowpack, soil moisture, reservoir levels, ground water levels, precipitation, temperatures, and stream flows, and makes water availability/shortage estimates for each river basin. This information is used to determine the existence of drought; it is reported to the governor's office, which then issues a memorandum. Other task forces monitor and assess municipal water supply sources and municipal fire fighting capacities related to low-system pressures or supplies; wildfire hazard and protection capabilities; soil erosion, crop and livestock loss, and insect and pest problems; loss of sales tax revenues, increase in unemployment, and decreases in tourism; impacts on wildlife; economic losses; and energy loss.

(b) Response--The response system consists of various existing departments of state government. They address drought-related problems through normally established program activities and cooperate with those agencies that are designated as lead response agencies. The lead response agencies provide direction and integrate the efforts of all agencies concerned with drought response. They include Local Affairs, which covers commerce and tourism, municipal water systems, and promotion of conservation practices; Natural Resources, covering wildlife, water shortages, and promotion of conservation practices; Agriculture, covering agriculture and promotion of conservation practices; State Forester, covering wildfire protection; Office of Planning and Budgeting, covering economic problems; Health, covering public health; Public Utilities Commission, covering energy shortages and interruptions and promotion of conservation practices; and Division of Disaster Emergency Services/State Forester, covering life-threatening or other high priority emergency situations, including federally declared disasters. The IACG is responsible for developing, coordinating, and recommending solutions to impact problems involving executive branch actions (may include interdepartmental or federal support); state legislative actions (may include requests for funding); and program implementation, monitoring, and approval. The IACG also determines when drought has receded enough to allow termination of IACG activities.

(4) A few state drought relief programs exist they include: the Emergency Water and Sewer Fund of the Division of Local Government; Construction Project Trust Fund of the Water Conservation Board, Department of Natural Resources; Emergency Fire Fighting Fund, Emergency Fire Suppression Resources and Assistance, and technical assistance for forest-related drought problems, provided by the State Forest Service; Agriculture Emergency Fund of the Department of Agriculture; Wildlife Cash Fund of the Division of Wildlife, Department of Natural Resources; and Emergency Contingency Fund of the Governor's Office. Federal programs provide the majority of drought assistance. Federal agencies providing assistance are USDA (programs include a variety of conservation programs, feed programs, crop insurance, loan programs, and so forth); Department of Commerce (including various grants and loan programs for various public works, and weather and river forecasts and warnings); SBA (Disaster Loans, Economic Injury Disaster Loans, and Economic Dislocation Loans); FEMA (fire suppression assistance, water supply equipment, and emergency and major disaster assistance for areas covered by presidential declarations); and Department of Labor (Unemployment Insurance Assistance Program, Comprehensive Employment and Training Program, and Employment Service Program). Other agencies providing assistance include Army Corps of Engineers (Emergency Drought Assistance, emergency supply of drinking water for communities with contaminated water supplies); General Services Administrator (donation of federal surplus personal property), and Department of Interior (Irrigation Distribution System Loan Program, Small Reclamation Projects Program, Drought-related Technical Assistance Program).

(5) Triggers: The various phases of the Colorado Drought Plan are activated on the basis of Palmer or Water Availability Index (developed by the Water Availability Task Force, using various drought assessment means, including the PDSI and measures developed by the Colorado Department of Natural Resources) numbers. An index number of -1.0 to -2.0 in any river basin causes the Division of Disaster Emergency Services (DODES) to activate the Water Availability Task Force (WATF). When the index reaches -2.0 in any river basin, WATF prepares the Governor's Memorandum of potential drought emergency, which activates the assessment system's task forces. Lead

agencies under the response system take actions within their normal programs and available resources, and the Review and Reporting Task Force of the assessment system delineates needs that cannot be resolved through normal channels. This task force is responsible for declaring the next phase of the drought plan, which involves issuing the Governor's Proclamation of drought emergency, the activation of the IACG, and, when necessary, a request for a presidential declaration. When IACG determines that all requirements for assistance are being met within normal channels, the group prepares a governor's proclamation to end the drought emergency. When the index number reaches -1.6, the task forces of the assessment system cease activity and issue a final report. At -0.6, normal conditions are considered to have returned. WATF is deactivated, and DODES continues to monitor the Palmer and Water Availability Index Maps.

(6) Primary authority: DODES has primary authority and responsibilities in the plan. The governor is responsible for issuing proclamations declaring and ending drought emergencies, and also makes requests for presidential declarations and federal aid.

(7) Level of federal interaction/involvement in the function of the plan: The various task forces of the assessment system include representatives from federal agencies. The Water Availability Task Force, for example, includes persons from NWS, SCS, USGS, and BLM. The Colorado Drought plan does not call for federal assistance until it has been determined that the state's needs cannot be met through existing state agencies and channels. The governor may then request a presidential declaration; if this is given, the director of DODES then becomes the state coordinating officer for drought, which interacts with FEMA to secure the necessary federal assistance.

SOUTH DAKOTA

(1) Primary impacts addressed: Agricultural. Also fire danger; water supply and distribution; fish, wildlife, parks, and recreational areas; social (health and safety); business (especially tourism and industrial development); revenue (local government, school districts, state government); unemployment.

(2) Structure of plan: Department of Water and Natural Resources monitors precipitation during the pre-growing season and notifies the governor of current and anticipated precipitation conditions (by March 1). They may also make recommendations on assembling a drought task force. The governor then determines the need for the task force. The task force is composed of representatives of various agencies, which are divided into two categories--primary and secondary. The plan lists task assignments for each of these agencies. Many of the agencies continue to monitor and assess impacts of drought as part of their assignments under the drought plan. If the task force is assembled but is unable to resolve drought problems, the governor may activate the Drought Assistance Office, which works with federal agencies to alleviate problems. It also helps the governor's office prepare and distribute public information material and news statements. The Office is terminated when drought conditions subside. The coordinator of the Office then prepares a post-drought report on its activities and makes recommendations for improvement. "Reports and assessment data will be catalogued and a central file established. This information will be retained for guidance in future drought operations."

(3) Components (elements) of the plan:

(a) Monitoring--Plan calls for pre-growing season assessment (Dept. of Water & Natural Resources maintains liaison with State Climatologist & NWS to monitor pre-growing season precipitation during periods of noticeable shortfall) and a growing season precipitation assessment (monitored by Department of Water and Natural Resources).

(b) Assessment--Task force, once called together, establishes a mechanism for monitoring drought and a drought damage assessment system, and assembles and analyzes data and recommends actions to alleviate drought conditions. The Drought Assistance Office, if activated, also continues to collect and analyze drought information data.

(c) Response--Both the task force and the Drought Assistance Office have response functions. The task force is responsible for recommending actions to help alleviate drought conditions; the Drought Assistance Office works with federal agencies to alleviate problems and acts as a clearing house for drought-related calls. The state agencies represented on the task force and in the Assistance Office "perform drought related response actions" defined in the state drought plan. In addition to making drought impact assessments, the primary agencies can take certain actions to mitigate drought. The Department of Water and Natural Resources coordinates federal, state, and local efforts to develop new water supply and distribution systems; the Department of

Agriculture coordinates with USDA in providing emergency drought assistance as available and augments fire fighting capability for the duration of the drought, in conjunction with the Departments of Commerce and Regulation and Military and Veterans Affairs. The Department of Game, Fish and Parks takes measures for the protection of fish, wildlife, parks, and recreational areas during drought and for restocking or restoration at the end of the drought. The Department of Military and Veterans Affairs coordinates with FEMA on disaster assistance programs. Support agencies generally provide drought impact assessments and assist many of the primary agencies.

(4) The plan does not mention many specific assistance programs (local, state, or federal). Most of the specific programs relate to agriculture. These include the following: haying or grazing of conservation reserve acreage in 10-year retirement, one-year set-aside program. Hay Assistance Program; emergency food assistance (all USDA); certain kinds of livestock feed and/or help in restoring damaged farmland (Emergency Conservation Program, Emergency Feed Program, Indian Acute Distress Donation Program), and Migratory Wildfowl Feeding and Resident Wildlife Feeding programs through ASCS and SCS; low-interest loans to farmers, through FmHA; indemnity payments to farmers for crop losses covered by insurance, through FCIC; technical info. and assistance to farmers & others in developing plans to reduce disaster effects, and in returning to normal after drought, in coop. with State Cooperative Extension Services & State land-grant universities; assistance in controlling fires (Forest Service). Other types of assistance (other than agriculture) are covered in the procedures of the South Dakota's Emergency and Disaster Service Law; the Federal Emergency Management Agency (FEMA) and the Small Business Administration (SBA) are mentioned in conjunction with the responsibilities of some of the agencies represented on the Task Force and the Drought Assistance Office.

(5) Triggers: The Drought Task Force is activated when at least 30 days of below 50% precipitation have occurred during the growing season. The Drought Assistance Office is activated when the Task Force Coordinator notifies the governor that it can no longer resolve drought problems.

(6) Primary authority: Governor initiates both the task force and the Drought Assistance Office. Department of Water & Natural Resources is responsible for monitoring conditions and notifying governor of conditions that will trigger initiation of the Task Force, and the Department of Agriculture serves as lead agency in providing drought information and sources of assistance to the agricultural sector.

(7) Level of federal interaction/involvement in the function of the plan: The Drought Assistance Office works with federal agencies to remedy or alleviate drought problems. The Department of Water and Natural Resources, one of the primary agencies, coordinates federal, state, and local efforts to develop new water supply and distribution systems. The Department of Agriculture provides supportive data and coordinates with the USDA in providing emergency drought assistance. The Department of Military and Veterans Affairs provides supportive data and coordinates with FEMA on disaster assistance programs, as well as prepares applications to FEMA for drought assistance. The Department of State Development prepares

assistance requests and supportive data directed toward the Small Business Administration and other federal entities offering assistance to nonfarm business and community economic development.

OHIO

(1) Primary impacts addressed by plan: Industrial and public water supply needs; also public safety and health, fires, and agriculture.

(2) Structure of the plan: Ohio places greater emphasis on regional planning for industrial and public water supply needs. The state generally evaluates and plans water supplies to meet present and projected needs during a theoretical 50-year drought. Specific projects tend to be designed to meet needs during a 20-year drought. Regional water supply plans exist for the five planning regions of the state. These plans discuss alternative sources for each major public water supplier and make recommendations for projects to provide recommended water supply and treatment improvements based on the most cost-effective solution. Resources available (surface runoff, ground water aquifers, etc.) and water supply needs of each region are reviewed; this information is used to make recommendations to fill estimated supply deficiencies. In terms of a drought plan, the Department of Natural Resources has a drought preparedness and response matrix that consists of four levels--normal, alert, conservation, and emergency. Under normal conditions, some of the Department's responsibilities include continuing to gather, monitor, and evaluate water data (concerning supply, use, and trends); reviewing and updating water supply plans; and providing assistance to communities, industries, and others developing water supply systems or conservation plans. Under an alert, the Department coordinates with local water supply officials to review water conservation plans. The Department increases monitoring of hydrological and water supply conditions; and reviews, correlates, and maps data from weather information services and water-level monitoring systems. They analyze precipitation deficiencies with communities that have inadequate storage capacity; the Department also compares hydrologic information with past drought conditions and determines stressed areas. The Department prepares and disseminates a weekly drought report for decision makers and the press, and they inform Emergency Operations Center (EOS) if conditions warrant declaring conservation or emergency status; they are also responsible for coordinating activities within the Department and other local, state, and federal agencies. For the conservation stage, the Department continues to increase monitoring of hydrologic and water supply conditions; they provide daily or weekly reports on water levels, hydrologic information, and developing shortages. They also review the status and availability of water storage in state and federal reservoirs. The Department makes calculations of drawdown under various release rates for state-owned reservoirs, and they make field checks to verify need and availability of water from those reservoirs. During emergency conditions, the Department monitors uses and releases from state-owned reservoirs; they make recommendations for rationing withdrawals from those reservoirs and also work closely with the Corps of Engineers and appropriate conservancy districts concerning emergency water releases from reservoirs. They monitor hydrologic conditions as needed and provide updates, and they make recommendations to USDA concerning requests for harvesting hay or pasture on set-aside acreage. During public water supply drought emergencies, communities work with the Department, the Ohio Environmental Protection Agency (EPA), and the Federal Emergency Management Agency (FEMA).

(3) Components (elements) of the plan:

(a) Monitoring--The Ohio Department of Natural Resources' interagency water team maintains a statewide network of gages for precipitation, stream flow, ground-water levels, reservoir levels, and soil moisture. Most of the measurements from these gages are published annually as Water Supply Papers by the U.S. Geological Survey.

(b) Assessments--The state's Drought Preparedness and Response Matrix calls for continuous monitoring of hydrologic and water supply conditions, with periodic evaluations of these conditions (timing and frequency of the evaluations varies according to level [normal, alert, conservation, or emergency]). Department of Natural Resources also reviews, correlates, and maps data from weather information services and water level monitoring systems, analyzes precipitation deficiencies for communities with known storage capacity inadequacies, makes calculations of drawdown under various release rates for state-owned reservoirs, makes field checks to verify need and availability of water from state-owned reservoirs, and identifies large withdrawals and consumptive uses. Under Level 2, Alert, the Department is responsible for informing EOC and the governor's staff when conditions warrant conservation and emergency status.

(c) Response--Ohio Department of Natural Resources coordinates with local water supply officials to review water supply plans. They also prepare weekly drought reports for the media and decision makers. The Department coordinates requests for water from state-owned reservoirs with appropriate agencies, evaluates requests for downstream discharges from state-owned reservoirs for community water systems on emergency status, and considers approval of water hauling from state-owned reservoirs for authorized purposes. They work with the Corps of Engineers and appropriate conservancy districts concerning possible emergency water releases from reservoirs, make recommendations to USDA about harvesting hay or pasture on agricultural set-aside land, make recommendations for rationing withdrawals from state-owned reservoirs, restrict managed wetland pumping at selected locations as needed, restrict recreational uses as needed, and ban open burning throughout the state as needed.

(4) The Department of Natural Resources has contact with the Corps of Engineers concerning releases from reservoirs. They also make recommendations to USDA concerning harvesting of hay and pasture on agricultural set-aside. No other federal agencies are specifically mentioned in the Matrix. Federal aid for specific projects recommended in the regional water plans may include grants from FmHA, Economic Development Administration, SCS, Army Corps of Engineers, and Urban Development Action Grant Program (UDAG). State assistance may come from the Ohio Environmental Protection Agency (Emergency Village Capital Improvement Rotary Fund), Ohio Water Development Authority (OWDA), and Ohio Community Development Block Grant--Small Cities Program. Various bonds may also be used.

(5) Triggers: No specific triggers mentioned in Matrix, but decisions to activate certain levels of the Matrix apparently are motivated by analysis of hydrologic and water supply conditions, data from weather information services, and water level monitoring systems.

(6) Primary authority: Department of Natural Resources, which is responsible for informing EOC and governor's office when conditions warrant conservation and emergency status, and which coordinates activities within ODNR and other local, state, and federal agencies "as appropriate."

(7) Level of federal interaction/involvement in the function of the plan: Department of Natural Resources coordinates its activities with various federal agencies when appropriate. In later stages of Matrix, they work with the Corps of Engineers concerning emergency water releases from reservoirs, and they make recommendations to USDA for hay or pasture harvesting on set-aside acreage. Local communities may receive financial support from various federal agencies (Corps of Engineers, UDAG, SCS, FmHA, EDA, and UDAG).

NEW YORK

(1) Primary impacts addressed: Public water supplies.

(2) Structure of plan: The Drought Management Task Force, which created the plan, is on standby for normal conditions and meets as needed to ensure adequate response during various drought stages (drought alert, drought warning, and drought emergency). (The Task Force includes the Departments of Environmental Conservation; Health; Transportation; Commerce; Agriculture and Markets; Office of Parks, Recreation and Historic Preservation; Public Service Commission; Division of Military and Naval Affairs; and Division of the Budget.) The drought management section of the plan lists actions to be taken by state and local agencies to mitigate, respond to, and recover from drought. It lists specific drought-related actions for the State Disaster Preparedness Commission, the Task Force, state agencies, and local governments under normal conditions of water availability as well as during drought stages. The Task Force coordinates the drought activities of member agencies, and it also assists localities and water suppliers in mitigation, response, and recovery activities. The Task Force also considered options for programs and projects to meet the needs of any drought condition, including short range (up to 3 years) and long range (3 to 10 years or more). The plan calls for the replenishment of the Disaster Preparedness Emergency Stockpile as the most critical need for immediate action, and it lists, in order of priority, specific actions to be taken to update various programs and water systems.

(3) Components (elements) of the plan:

(a) Monitoring and Assessment--The lead state agency, the Department of Environmental Conservation, cooperates with the State Department of Health and federal agencies such as the USGS and NWS to monitor drought conditions using various criteria, including two drought indices that were modified for the six regions of the state: the Palmer Drought Severity Index and the State Index, based on four hydrologic indicators (precipitation, stream flow, ground water levels, and reservoir/lake storage). These monitoring efforts continue and intensify throughout the various drought stages.

(b) Response--Both long- and short-term response actions are specified by the plan. During a drought alert, state agencies are responsible for reviewing and updating local, regional, and state drought contingency plans and providing technical assistance to localities. During a drought warning, the Office of Disaster Preparedness leads coordination with appropriate federal agencies in order to provide federal assistance to state and local governments. Other state agencies promote public information and technical assistance programs during this phase. During a drought emergency, the Task Force can recommend special state legislation and funding as needed; they also support NWS surveys for estimating potential run-off from snow, and they continue to promote water conservation measures and provide technical assistance. Among the responses of state agencies during this phase are provision of equipment and technical assistance to localities. The Disaster Preparedness Commission requests emergency assistance from FEMA during this phase and the drought disaster phase. During the drought disaster phase, the governor may direct state agencies to implement rationing plans, activate water supply interconnections, activate the Chelsea Pump Station in New York City, conduct emergency reservoir operations, oversee operation of emergency wells, and use milk trucks for water supply. Local responses throughout the various drought phases generally deal with promotion of water conservation and enforcement of water use restrictions.

(4) State and local governments are responsible for providing most drought assistance. Federal assistance is requested only during advanced stages of drought. One of the long-term solutions specified by the plan, the replenishment of the state emergency equipment pile, calls for state funds. For short-term actions, the plan gives specific instructions for responses by the State Disaster Preparedness Commission, the Task Force, state agencies, and local governments for the various stages of drought. These responses include technical assistance, provision of equipment (e.g., pumps and pipes) and some resources, and provision of emergency sources of water. If federal assistance is requested and granted, it may include grants, contributions, and specialized services to state and local governments for (1) suppression of forest and grassland fires that have the potential to become major disasters; (2) essential protective work on public and private lands; (3) relief to local governments affected by substantial loss of tax and other revenue. Families and individual citizens may receive federal relief in the form of emergency shelter and temporary housing, unemployment assistance, crisis counseling, and legal services. A number of federal agencies may provide disaster assistance without a presidential declaration of disaster. FEMA, for example, can provide fire suppression assistance; FmHA can provide emergency loans for agriculture; and SBA can provide disaster loans for homeowners and businesses. The plan notes that other drought-related disaster assistance programs are necessary--particularly programs for urban areas, where public health and safety are major concerns.

(5) Triggers: Palmer Index, precipitation, reservoir/lake storage, stream flow, and ground water levels are the major drought indicators in New York's plan. The primary indicators for specific water uses include reservoir storage and ground water levels for public water supply; ground water levels for individual domestic and some industrial uses; precipitation and the Palmer Index for crop production; stream flow for water quality management, fish and wildlife, power generation, and navigation; and lake water levels for recreation. The drought plan established criteria for defining normal conditions and the four drought stages. The Palmer Index is used as one basis for determining drought stage. Another index, the state drought index, is based on hydrologic factors weighted on a regional basis; this indicates drought stage. The weighting in the state drought index gives priority to public water supply. These two indexes reflect different aspects of drought; the Palmer Index is useful for agricultural droughts and for identifying early stages of drought as well as short-term droughts. The state index is oriented toward reservoir/lake storage for

public water supply and is a better indicator of long-term and severe droughts. Drought stages determined from the two indices do not automatically trigger specific drought actions, but they are used along with other factors in making drought decisions.

(6) Primary authority: The Department of Environmental Conservation is the lead agency for the plan.

(7) Level of federal interaction/involvement in the function of the plan: Federal involvement in the early stages of the plan generally consists of working with and providing information to the Task Force in its attempts to monitor and assess drought and plan for "worst case" scenarios. Federal assistance (loans, contributions, services) may be requested as conditions worsen.

SOUTH CAROLINA

(1) Primary impacts addressed: Agriculture, industry, municipalities and public water supplies.

(2) Structure of plan: The South Carolina Water Resources Commission has authority to monitor and record climatic and other data to determine drought conditions; determine levels of drought based on that data; establish drought management areas in the state for drought response; and establish drought alert phases and coordinate and implement responses to those phases. The phases are incipient drought, which initiates "inhouse mobilization by Commission personnel and the drought committee"; moderate drought, during which "appropriate agencies accelerate monitoring activities"; severe drought, which prompts an official declaration by the Commission and water-use restrictions; and extreme drought, during which appropriate water-use restrictions may be imposed. When a drought alert phase is declared, the Commission is responsible for disseminating public information about all aspects of the drought; public education about potential conditions and necessary water conservation measures is considered essential. The Commission coordinates drought response after consultation with the drought response committee, which is composed of two parts: a statewide committee composed of various state agencies, and a local committee within each drought management area. The local committees are composed of members appointed by the governor on the recommendation of legislative delegations from each of the drought management areas. The statewide committee coordinates planning and response within each drought management area after consultation with the appropriate local committee. In carrying out response actions, the drought response committee consults and works with representatives of municipalities, counties, and commissions of the public works in affected drought management areas. If the drought response committee determines that drought conditions in any drought management area have become severe enough to threaten the health and safety of the area's citizens, they will report those conditions to the governor, along with a priority list of recommended actions to alleviate drought impacts. The governor may then declare a drought emergency.

(3) Components (elements) of the plan:

(a) Monitoring and Assessment--The South Carolina Water Resources Commission monitors and records "climatic and other data necessary to determine drought conditions." This data includes climatic variables monitored routinely by the State Climatology Office. Based on this data, the Commission determines levels of drought. Specific monitoring and assessment activities are not given in the plan.

(b) Response--The drought response committee, consisting of a statewide committee and local committees, consists of members from a wide range of disciplines and concerns: counties, municipalities, public service districts, private water suppliers, agriculture, industry, domestic users, regional councils government, and commissions of public works. In addition, the committee consults and works with representatives of municipalities, counties, and commissions of the public works in affected drought management areas. If the drought response committee determines that drought conditions are severe enough to threaten the health and safety of any drought management area, they report to the governor, who may declare a drought emergency. Specific response actions are not given in the plan.

(4) The plan does not mention any specific state or federal assistance programs. Drought response actions are considered the responsibility of the drought response committee, based on drought conditions in the particular area involved.

(5) Triggers: The various drought phases are triggered by Palmer Index values. The incipient drought phase is initiated by a value of -0.50 to -1.49, as verified by climatic variables monitored by the State Climatology Office. The moderate drought phase occurs when the Palmer Index reaches -1.50 to -2.99. The severe drought phase occurs when the Palmer Index reaches -3.00 to -3.99, verified from data from various agencies in conjunction with National Weather Service forecasts and routinely monitored data. The extreme drought phase is initiated when the value reaches or falls below -4.00.

(6) Primary authority: The lead agency is the South Carolina Water Resources Commission.

(7) Level of federal interaction/involvement in the function of the plan: The Water Resources Commission "may consult and cooperate with federal agencies and agencies of the states of Georgia and North Carolina in carrying out its responsibilities." No other references to federal involvement.

APPENDIX B

STATE ACTIONS TAKEN IN 1988 AND PENDING
(RESPONSE TO A SURVEY CONDUCTED IN DECEMBER 1989)

ALABAMA

Agency responding: Planning and Economic Development
Date of response: January 18, 1989

(1) Primary impacts: Corn production was down 60 percent. Cotton production was down only 2 percent, but only because of an increase in the number of acres in production. Hay production was short in some areas. Twelve to fifteen communities needed to have water hauled, which was done by the National Guard at a cost of $192,500. Commercial navigation along the Apalachicola-Chattahoochee-Flint and Alabama Rivers was affected, but no figures are available. An increase in forest fires occurred; the state expended $27,500 on fire-fighting. Hydroelectric production was down, but no figures are available.

(2) Geographic areas affected: Statewide. Stressed ground water areas included most of the southern third of the state and the extreme western edge of the state.

(3) Types of interaction with other states, federal government: The Governor's Drought Task Force consists of state and federal agencies. Alabama is also a part of the Tennessee Valley Regional Drought Task Force (a multistate committee to address drought concerns and issues in the Tennessee Basin). The state also sends representatives to the Apalachicola-Chattahoochee-Flint (ACF) Drought Management Committee (which is composed of representatives from other states and the Corps of Engineers).

(4) Mitigative actions: Before the 1988 drought, the ACF Drought Management Committee created a drought plan for the ACF basin; the state of Alabama has no drought plan. The state manages drought through the Task Force. The Department of Environmental Management regulates water quality for the state. The Department of Conservation and Natural Resources monitored fish kills.

(5) Current water availability outlook for 1989: Many areas showed year-end deficits in ground water and surface water levels. If low rainfall continues in 1989, impacts of the 1988 drought could worsen. Particularly in the north, some areas could take years to replenish ground water. Low reservoir water levels will affect hydropower industries and may increase power costs. The state believes that agricultural drought is over, but the hydrological drought continues.

(6) Actions state will take if drought continues in 1989: Alabama is continuing to cooperate and communicate with neighboring states and involved federal agencies.

CALIFORNIA

Agency responding: Department of Water Resources
Date of response: December 6, 1989

(1) Primary impacts: Water shortages occurred in 45 counties. Drought adversely affected 45 percent of the state's irrigated agriculture and 26 percent of the population. By mid-September, 14 counties and two cities declared drought emergencies. Drought also degraded water quality. Sacramento-San Joaquin Delta water supplies contained higher concentrations of salt. Drinking water in the Delta is becoming more contaminated and is harder to treat. Serious fishery losses were recorded throughout the state, and waterfowl were also stressed.

(2) Geographic areas affected: Northern and central California.

(3) Types of interaction with other states, federal government: The Department of Water Resources' Drought Center has contact with Nevada drought groups, and the Nevada state climatologist/drought response coordinator attended some of California's Interagency Drought Task Force meetings. Some members of California's Interagency Drought Task Force are representatives of federal agencies.

(4) Mitigative actions: In response to the 1988 drought, the Department of Water Resources opened the Drought Center, which serves as an informational clearinghouse for the state on drought conditions. They prepared drought publications, held drought conferences around the state, surveyed water districts on the status of their water supply, and assisted water districts with shortage emergencies. The California legislature also passed drought preparedness legislation.

(5) Current water availability outlook for 1989: Major reservoir storage, as of early December 1988, was 63 percent of normal. The long-range outlook for 1989 was for a normal winter.

(6) Actions state will take if drought continues in 1989: The Department of Water Resources was preparing a report to the Legislature with recommendations for actions to be taken if water supply conditions are below normal.

DELAWARE

Agency responding: Office of Secretary of Agriculture
Date of response: January 5, 1989

(1) Primary impacts: The agricultural sector had the greatest losses; as of mid-July 1988, total damage to crops was estimated at $37,638,388 (not including soybeans).

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: No reply.

(4) Mitigative actions: After the 1987 drought, the state passed legislation providing a state subsidy for farmers to purchase crop insurance.

(5) Current water availability outlook for 1989: Water shortage is "not a problem." The state considers distribution of water its greatest problem.

(6) Actions state will take if drought continues in 1989: The Select Panel on the Future of Delaware was recently appointed to study the current state of agriculture (their report was not finished as of January 5, 1989).

HAWAII

Agency responding: Department of Land and Natural Resources
Date of response: February 1989

(1) Primary impacts: The state was not affected by the 1988 drought; they experienced good rainfall and were able to replenish much of their ground and surface water reserves.

(2) Geographic areas affected: Not applicable.

(3) Type of interactions with other states, federal government: Not applicable.

(4) Mitigative actions: The state has a separate water shortage plan for each county. In 1987, Hawaii established a state water code, giving the state broad powers in controlling water usage in designated (water shortage) areas. They do not have plans to develop a statewide drought plan right now.

(5) Current water availability outlook for 1989: Good.

(6) Actions state will take if drought continued in 1989: Not applicable

IDAHO

Agency responding: Department of Water Resources
Date of response: March 21, 1989

(1) Primary impacts: Some municipal areas implemented watering systems (mostly odd-even lawn watering) during 1988; Boise was among these. The severity of the 1988 drought showed that municipal and domestic systems in Idaho were adequate. Most (90 percent) of the municipal and domestic supply comes from ground water sources; major ground water aquifers are not as susceptible to rapid fluctuation in available surface water. Most of the problems occurred in shallower ground water systems. Livestock water was a "significant" problem in 1988, mostly in the southern part of state. Springs dried up, or intermittent streams dried up earlier than usual. Some irrigated land was idled because of the drought.

(2) Geographic areas affected: No reply; scattered across state?

(3) Types of interaction with other states, federal government: No formal interaction among Pacific Northwest states. Direct communication and brief summaries of drought conditions were exchanged among affected states. Federal assistance was a major component of drought relief in Idaho; the state has no drought emergency funding. Federal agencies are also involved in Idaho's Water supply Committee, especially the Data Subcommittee, which compiles and reports water supply statistics.

(4) Mitigative actions: Few mitigation actions were implemented. Some potential actions were proposed by the IDWR: create or restore water districts as needed to distribute water to right-holders; provide staff training workshops on watermaster supervision for regional personnel; hold training seminars at each region or provide one-on-one training for watermasters; increase water right enforcement for nonadjudicated sources; develop procedures to expedite processing of applications for replacement water supplies.

(5) Current water availability outlook for 1989: Water supply appears to be "much better than last year." The February report of the Data Subcommittee shows normal to above-normal snow and precipitation for the state.

(6) Actions state will take if drought continues in 1989: No specific actions are planned for 1989. The Water Supply Committee will reconvene if necessary. As of March 1989, it appeared that the water supply would be adequate, unless a major change occurred in April-June. Most reservoir systems were expected to nearly fill. Stream flows were normal or near normal, and no additional action appeared to be necessary.

ILLINOIS

Agency responding: Illinois State Water Survey
Date of response: January 31, 1989

(1) Primary impacts: The agricultural sector was most affected. About 20 public water supply systems faced shortages. No final assessment was available because the state did not feel that the drought had ended.

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: The governor of Indiana asked Illinois to decrease irrigation from a common aquifer to reduce the impact on nearby domestic wells; Indiana can limit ground water withdrawals, but Illinois cannot. This request was granted. Illinois also requested that water be released from Lake Michigan to increase the depth of the Mississippi River; this request was denied. The Corps of Engineers provided emergency water to two communities.

(4) Mitigative actions: The state provided advice and limited direct assistance to persons and local units of government.

(5) Current water availability outlook for 1989: Water availability continued to improve, although drought was not yet over. The Drought Contingency Task Force was continuing water resource monitoring and availability problem detection. All Illinois communities had lifted water restrictions.

(6) Actions state will take if drought continues in 1989: Public meetings will be scheduled and held in coming months to provide information on mitigation of existing or possible impacts.

KANSAS

Agency responding: Kansas Water Office
Date of response: February 2, 1989

(1) Primary impacts: No reply.

(2) Geographic areas affected: Most of state.

(3) Types of interaction with other states, federal government: Kansas has a memorandum of understanding with the federal government regarding access to federal reservoir storage during a drought emergency. This memorandum was used once during summer 1988 with the cooperation of the Corps of Engineers.

(4) Mitigative actions: Kansas State University Extension Service set up a drought task force of specialists for an information campaign; they also set up a hay and forage hotline with the Kansas Farm Bureau and the Kansas Board of Agriculture. The Board of Agriculture also set up other information hotlines. ASCS approved 77 counties for emergency haying and grazing. The governor formed a drought response team, and the state provided informational programs on a variety of subjects to various sectors of the economy and areas of the state.

(5) Current water availability outlook for 1989: Subsurface moisture as of January 9, 1989, was rated 76 percent short, 24 percent adequate. Rivers were maintaining seasonal flow. Reservoirs were below the "top of conservation pool." The 30-day outlook called for near-normal precipitation; the 90-day outlook predicted below-normal precipitation. The governor's Drought Response Team was continuing to monitor drought conditions.

(6) Actions state will take if drought continues in 1989: Agencies represented on the Drought Response Team were preparing action plans in case drought continued into spring and summer 1989.

MAINE

Agency responding: Governor's office
Date of response: December 20, 1989

(1) Primary impacts: Lower yields of hay (approximately 10 percent below normal).

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: Maine participated in USDA's weekly drought assessments by computer. The state also helped organize a hay lift to Ohio.

(4) Mitigative actions: No reply.

(5) Current water availability outlook for 1989: No reply.

(6) Actions state will take if drought continues in 1989: No reply.

MARYLAND

Agency responding: Coordinator of Maryland Agricultural Task Force
Date of response: February 3, 1989

(1) Primary impacts: The state ASCS office prepared a damage assessment report that initially estimated losses to crops at $200 million, but wheat and barley crops were "excellent" despite the drought, and dry conditions elsewhere helped drive up the price of these crops. The state did not plan to do an economic and environmental assessment.

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: Maryland participated in the National "Haynet" program (listing of forage supplies). The state kept in close touch with Delaware officials. The Maryland Department of Agriculture helped expedite shipments of hay, donated by Maryland farmers, to farmers in Ohio and Indiana. Contacts with the federal government were "frustrating"; USDA responded slowly to requests for disaster assistance.

(4) Mitigative actions: The state has no drought plan, but in mid-June 1988, the governor of Maryland ordered the state Department of Agriculture to activate its drought plan, which involved convening the Maryland Agricultural Emergency Task Force. The task force met periodically to gather information and prepare joint action plans.

(5) Current water availability outlook for 1989: In late January 1989, key agricultural regions were averaging 6 inches short of the normal precipitation for 1988.

(6) Actions state will take if drought continues in 1989: Maryland has no active plans for dealing with drought. Maryland officials will monitor precipitation patterns and work with the University of Maryland to assess drought potential.

MASSACHUSETTS

Agency responding: Executive Office of Environmental Affairs
Date of response: January 20, 1989

(1) Primary impacts: No reply.

(2) Geographic areas affected: A few areas of the state received less-than-normal amounts of rain.

(3) Types of interaction with other states, federal government: No reply.

(4) Mitigative actions: No reply.

(5) Current water availability outlook for 1989: The state's largest water source, Quabbin Reservoir, which serves 2.5 million people in 44 cities and towns, was at 69.4 percent of capacity (compared to a 40-year average of 81 percent).

(6) Actions state will take if drought continues in 1989: A drought management task force is monitoring the situation and preparing action plans.

MINNESOTA

Agency responding: Department of Agriculture
Date of response: January 23, 1989

(1) Primary impacts: Crop losses totaled $1.3-$2 billion. Small businesses were adversely affected because of these crop losses.

(2) Geographic areas affected: Substantial portion of the state.

(3) Types of interaction with other states, federal government: The Drought Task Force sent letters to the Department of Agriculture in each of following states and provinces--Iowa, North Dakota, South Dakota, Indiana, Michigan, Manitoba, Ontario, and Saskatchewan, asking for information about response programs they had or were anticipating.

(4) Mitigative actions: In a preliminary report to the governor of Minnesota, the Drought Task Force identified and analyzed 25 problems and gave proposed solutions. (Problems included interest rates, agricultural and rural business trust fund, property taxes, crop insurance, and so forth.) The Task Force urged passage of their recommendations as legislation during the legislative session of January 1989.

(5) Current water availability outlook for 1989: No reply.

(6) Actions state will take if drought continues in 1989: The Drought Task Force planned to continue to seek additional solutions to problems that had been identified. The Task Force recommended to the governor and legislative leaders that legislative action be taken on their recommendations in January 1989.

MISSOURI

Agency responding: Director of Agriculture
Date of response: December 20, 1988

(1) Primary impacts: No reply.

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: The Missouri Department of Agriculture worked closely with state offices of ASCS, FmHA, and National Agricultural Statistics Office. They also maintain frequent contact with USDA's Intergovernmental Affairs staff.

(4) Mitigative actions: The state established a hay hotline. The Missouri Highway and Transportation Department helped farmers by allowing haying on highway rights-of-way; they also eased hay hauling restrictions.

(5) Current water availability outlook for 1989: No reply.

(6) Actions state will take if drought continues in 1989: No reply.

NEW JERSEY

Agency responding: Department of Environmental Protection, Division of Water Resources
Date of response: January 9, 1989

(1) Primary impacts: Drought damaged vegetable and grain crops and stressed the capability of water suppliers to meet demand. No quantitative report of total losses was available.

(2) Geographic areas affected: South Jersey most affected.

(3) Types of interaction with other states, federal government: Water suppliers who rely on the Delaware River interact with state agencies in New York, Pennsylvania, and Delaware through the Delaware River Basin Commission. The State Agricultural Department shares information with neighboring states on the availability of hay; they also lobbied for federal financial support for farmers with crop losses.

(4) Mitigative actions: The state encountered difficulties in applying water supply emergency plans and regulations for protecting drinking water. Water supply drought response plans will probably be updated in 1989 to correct the problem.

(5) Current water availability outlook for 1989: No reply.

(6) Actions state will take if drought continues in 1989: Water supply drought response plans will probably be updated in 1989 to solve the problem of difficulties with implementation.

NORTH CAROLINA

Agency responding: Department of Natural Resources and Community Development
Date of response: December 20, 1988

(1) Primary impacts: Twenty-one water systems had to implement various levels of water use restrictions.

(2) Geographic areas affected: Western part of state.

(3) Types of interaction with other states, federal government: The state has an ongoing program with the Corps of Engineers to manage federally built reservoirs as related to water supply storage. The state also cooperates with USGS to monitor ground water levels and streamflows. North Carolina was also a part of TVA's Drought Management Task Force (which was established to monitor drought conditions on streams and reservoirs in their jurisdiction).

(4) Mitigative actions: The state created an in-house plan for responding to drought conditions and facilitating better coordination among state agencies. The Division of Water Resources also held a drought management conference in western North Carolina to discuss steps local water managers can take during drought, stressing the importance of local-state-federal cooperation. The Division of Water Resources also published and distributed Water Supply Drought Advisory Bulletin in drought areas. Water Shortage Response Handbook for N.C. Water Supply Systems describes how a multilevel water shortage response plan can be developed and implemented.

(5) Current water availability outlook for 1989: Cumulative rainfall for 1988 in western North Carolina was about 45 percent less than normal. Streamflow there was about 50 percent to 60 percent of the long-term median for November. If the trend continues, the state could experience another drought in 1989.

(6) Actions state will take if drought continues in 1989: The state is monitoring water resources on a continuous basis in cooperation with USGS and Weather Services. The state will also work with local government and water systems in 1989 to monitor water supply conditions, assist in developing drought management plans, and conduct workshops on the use of the Water Shortage Handbook. Drought management conferences will be held as needed in areas of potential droughts.

RHODE ISLAND

Agency responding: Division of Planning
Date of response: January 4, 1989

(1) Primary impacts: Five public water systems experienced some problems, in part because of the drought.

(2) Geographic areas affected: Blackstone Valley, East Bay Aquidneck Island.

(3) Types of interaction with state, federal government: Two water systems have "interstate characteristics."

(4) Mitigative actions: Mitigative actions are taken at the local level only. One district instituted a leak detection program. One town built a second connection for water delivery, and one system banned outdoor water use for one month.

(5) Current water availability outlook for 1989: Under "normal" conditions, no particular problems are anticipated. But problems of inadequate infrastructure continue--pumping capacity, transmission systems. Lack of snow may also cause problems.

(6) Actions state will take if drought continues in 1989: The Division of Planning will prepare a plan for response to emergencies, including drought. Limited staff and funds have restricted progress; the plan was not completed by summer 1989.

SOUTH DAKOTA

Agency responding: South Dakota Department of Agriculture
Date of response: January 30, 1989

(1) Primary impact: The state experienced crop loss; reduction in cattle herds; and water supply shortages in streams and rivers, wells, and impoundments. Rural communities were also adversely affected, which may mean the end of some small towns or the combining of some counties. Fire danger was also high.

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: The governor's office regularly makes contacts with other states. Most federal agencies were cooperative once the proper information was provided to them.

(4) Mitigative actions: A well program provided 50 percent of the funding for wells deep enough to reach potable water. The state allowed early mowing of roadsides and medians and some state lands for livestock feed. South Dakota also has a drought plan, although for political reasons it wasn't always followed in 1988.

(5) Current water availability outlook for 1989: Subsoil moisture is short. Surface water is expected to be short if rain or snow does not occur.

(6) Actions state will take if drought continues in 1989: No special actions had been taken as of the end of January; the state was continuing to monitor the situation.

TENNESSEE

Agency responding: Tennessee Emergency Management Agency
Date of response: January 20, 1989

(1) Primary impacts: Some communities had to implement water cutbacks, both voluntary and mandatory. Springs and shallow wells dried up, streamflows stopped, and large reservoirs dropped to new lows (mostly in east and mid-state regions). Commercial navigation also was adversely affected. Agriculture was affected statewide, and wildfires were also a problem.

(2) Geographic areas affected: Statewide. Hydrologic problems were worst in the east and mid-state regions.

(4) Types of interaction with other states, federal government: All state agencies concerned with drought issues and response worked closely to exchange information and assist each other. The governor's office and the Tennessee Emergency Management Agency headed the effort through a drought monitoring/response task force. Other agencies represented included the Department of Agriculture and Health and Environment; Division of Forestry; Tennessee Wildlife Resources Agency; and State Fire Marshal's Office. Federal agencies included the Corps of Engineers, Tennessee Valley Authority (TVA), U.S. Geological Survey, and National Weather Service. The state also served on the TVA Regional (7-state) Drought Task Force, thereby exchanging information with other states.

(4) Mitigative actions: The state monitored drought and kept all coordinating agencies informed of developing conditions. The Tennessee Department of Agriculture worked closely with USDA in agriculture-related matters. The respondent expressed the opinion that not much, outside of emergency response, could be done to counter the effects of drought.

(5) Current water availability outlook for 1989: January rainfall was good, but the state is still a year behind in precipitation for the past 5 years.

(6) Actions state will take if drought continues in 1989: The state drought plan and implementing procedures document will be revised in response to lessons learned over the past few years. Tennessee will continue to monitor drought conditions. The state is encouraging communities and citizens to develop drought contingency plans and alternate water sources for drought years.

VIRGINIA

Agency responding: Virginia Department of Agriculture and Consumer Services
Date of response: January 13, 1989

(1) Primary impacts: [This response covered only agriculture. The State Water Control Board was in the process of preparing a final report that covered more impact areas.] The secretary of agriculture gave 31 counties federal disaster declarations. The total loss in value for crops was more than $88.1 million (42 percent of their potential value). Tobacco, corn, pasture, hay, corn silage, wheat, barley, vegetables, and soybeans were affected.

(2) Geographic areas affected: Western and northeastern counties.

(3) Types of interaction with other states, federal government: The Virginia Department of Agriculture and Consumer Services worked with USDA and departments of agriculture in other states to gather and share information about sources of hay. The Department of Agriculture coordinated a hay lift program that donated hay from Virginia farmers (in the central part of the state) to Virginia farmers without hay; farmers in five other states also received hay.

(4) Mitigative actions: Virginia established a hay hotline and a hay lift program. The State Drought Task Force monitored the impact of prolonged dry weather on agriculture, water supply, and so forth. The Task Force also issued periodic reports to state and local officials.

(5) Current water availability outlook for 1989: The State Drought Task Force was preparing a report that was to include information on water supplies. Information on the outlook for 1989 was not provided.

(6) Actions state will take if drought continues in 1989: The Department of Agriculture will continue to monitor the agricultural situation and will keep the secretary of economic development and the governor advised of any problems relating to prolonged drought. The Department will also make recommendations for state actions. The Task Force will probably be reactivated if drought continues.

WASHINGTON

Agency responding: Department of Ecology
Date of response: March 8, 1989

(1) Primary impacts: Washington was not significantly affected by water shortages in 1988. No impact assessment was available.

(2) Geographic areas affected: Water shortages that did occur affected the entire state. The area that may have suffered the greatest damage was the dryland farming area of southeastern Washington, which relies entirely on precipitation for its water supply.

(3) Types of interaction with other states, federal government: Dealings with adjacent states and the federal government were limited to exchanges of information (mostly drought conditions) and approaches to dealing with drought.

(4) Mitigative actions: Washington did not have a drought response plan in place in 1987 (when the possibility of drought in 1988 first arose). The state adopted a plan based on one used in 1976-77. The new process consisted of two committees to encompass all drought forecasting and response activities. The 1988 Washington State legislature mandated that the Department of Ecology develop a drought contingency plan for dealing with future drought; the Department is preparing the plan for incorporation into the State Comprehensive Emergency Management Plan. The general outline of the plan will follow the state's past practices, with a water supply availability committee and executive water emergency committee as the focal points for forecasting and policy-making activities.

(5) Current water availability outlook for 1989: Snowpack is good but overall precipitation is somewhat below normal. The water supply availability committee will continue to monitor water supplies throughout the state.

(6) Actions state will take if drought continues in 1989: Current plans for dealing with future drought center on the Department's drought contingency plan. This plan will involve a water supply availability committee, executive water emergency committee task forces, and development and implementation of a drought action program (if necessary).

WISCONSIN

Agency responding: Department of Natural Resources
Date of response: February 1989

(1) Primary impacts: Agricultural losses ranged from 30 percent to 60 percent statewide. In industry, low surface water levels caused concern for companies dependent on higher water levels for waste discharge. Record low flows also concerned industries dependent on flows for production, but although plans were made for this possibility, no industries had to cut back on production. Hydropower generation was reduced to 70 percent to 85 percent of normal, and the barge industry was affected. Fish kills occurred, and the fish population may be affected in the long run. Waterfowl and wildlife numbers were also reduced.

(2) Geographic areas affected: Statewide.

(3) Types of interaction with other states, federal government: Federal programs were available to farmers. The governor proposed diversion of Great Lakes water to raise the level of the Mississippi River, but federal, international (Canadian), and other states' representatives opposed the action.

(4) Mitigative actions: The governor signed the Proclamation of State of Emergency Relating to Drought Conditions (June 6, 1988), which allowed the governor to take immediate action on drought problems for 30 days. The main intent of the Proclamation was to allow permits to be issued for emergency surface water irrigation from state waters. (However, only about half of the permits issued were used because irrigation equipment was not always available.) The federal government allowed haying and grazing, and the state created some low-term loans and aid programs for agriculture. A drought property tax credit was also instated.

(5) Current water outlook for 1989: Although levels and flows of many surface water bodies increased last fall, and although soil moisture seems to be "substantially replenished," the state has below-normal snow cover, and officials are cautious about the water outlook for 1989.

(6) Actions state will take if drought continues in 1989: The Department of Natural Resources is developing a drought management plan. It will propose actions and policy directions for the Department (as well as for the consideration of other state agencies and the Wisconsin legislature).

WYOMING

Agency responding: Department of Agriculture
Date of response: January 30, 1989

(1) Primary impacts: Most livestock had been removed from northeast quarter of state because of the drought. Producers who kept livestock had to supplement their feed with hay the entire summer. Hay prices increased, but an open winter with little snow has decreased demand and kept prices from increasing further.

(2) Geographic areas affected: Northeast quarter of state.

(3) Types of interaction with other states, federal government: Wyoming obtained hay and pasture in Nebraska and Colorado, with little help from the federal government. The federal drought program was difficult to understand and came at least three months too late to help most of the state's farmers. In addition, program qualifications were confusing and differed between counties.

(4) Mitigative actions: The state's original drought plan called for state cost-sharing to individual producers for drought-related expenses, but it became apparent that the state did not have adequate funds. The state instead relied on the federal government. Wyoming made an effort to keep the public informed of drought assistance; they also set up a drought information hotline.

(5) Current water availability outlook for 1989: Snowpack in most river basins was below normal as of January 30, 1989. If precipitation does not occur, the state expected to have serious problems with irrigation water.

(6) Actions state will take if drought continues in 1989: "Other than providing drought information, it is unlikely that Wyoming can do very much to help in drought situations."

APPENDIX C

SOIL - WATER - PLANT SYSTEM

SOIL-WATER-PLANT SYSTEM

The most crucial part of a drought assessment involves understanding and explaining what a farmer actually faces in field management during a drought. First, predictions of drought impact rely on knowing how yield responds to water deficit. Importantly, the literature review on soil-water-plant research suggests a paucity of such knowledge, although the crop modeling, simulation efforts are encouraging. Significant progress is being made toward eventually having the ability to more accurately predict yield response to drought. Second, how the farmer manages water in the field in light of the current institutional setting which affects behavior needs to be understood. The farmer response must be understood as well as the yield response.

The general problem faced by a farmer during drought can be assessed with the help of the framework in Lynne et al. (1987) and Lynne et al. (1984), which is summarized in Appendix Figure C-1 (a similar figure, and further discussion of the framework, is also presented in Apogee Research, Inc., et al., 1990). Both the economic demand (marginal value) and supply (marginal cost) curves are illustrated for effective soil moisture, which represents the water in the root zone available for plant growth. Specifically, the effective soil moisture means the amount of water available for transpiration and evaporation. Yield is a function of transpiration, and, in fact it usually is directly proportional to transpiration. Plotting yield against transpiration would show a positively sloped, linear relationship.

Even so, plotting yield against effective soil moisture will generally give a nonlinear, decreasing at a diminishing rate relationship due to how effective soil moisture relates to transpiration (and evaporation). Yield plotted against effective soil moisture gives the traditionally shaped "production function" shape that is usually assumed in economic analysis. As a result, the demand curve for effective soil moisture, which is the slope of the yield to effective water relationship multiplied by the product price, will have a negative slope, as shown by AT in Appendix Figure C-1.

The demand curve reaches zero at point T, at maximum (potential) evapotranspiration. At this point, the maximum yield is obtained. A steeper evapotranspiration (ET) to effective soil moisture relation, or a higher product price, will give a steeper demand function. With very high product prices, the demand curve becomes ever more vertical at point T. For high valued vegetable crops, for example, a farmer may well supply the maximum ET level of effective water: the water demand would be very inelastic. For lower valued forage crops, however, the demand curve may be very flat, and thus something much less than maximum ET will likely be economically best; the demand would also be considered very elastic.

Generally, the water supply curve at the field level depends on the character of the water supply system and the setting. Three cases can be outlined. First, under dryland farming, the water supply function is the horizontal axis; all water (OT)

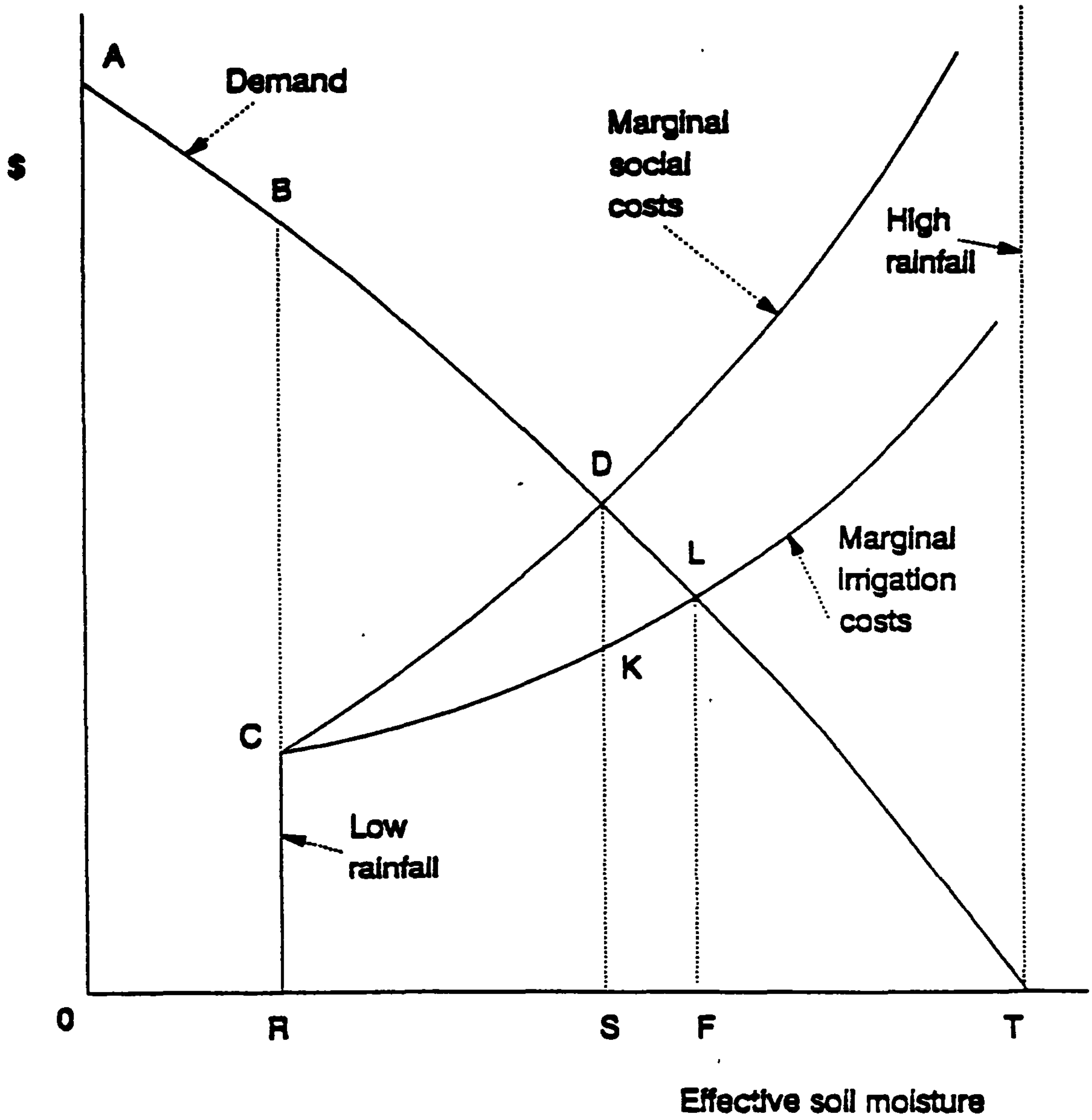

Figure 1. Yield and cost response to effective soil moisture.

comes without cost from rainfall. Second, under near desert conditions with only a small amount of water coming from rainfall (OM), the supply curve becomes OMNQ (with NQ from irrigation). Third, under supplemental irrigation conditions, where somewhat more rain (OR) falls during the irrigation season, the supply curve becomes ORCL.

The positive slope to the supply curve occurs because of water lost to deep percolation and runoff from keeping the profile more completely filled (Lynne et al., 1987). That is, in moving from R toward F, the irrigation farmer is keeping ever more water in the soil profile, so more of the irrigation water is lost due to unexpected rain after an irrigation. Costs thus increase at an increasing rate as effective water moves to the level consistent with maximum ET at point T.

The economically optimum level of effective soil moisture, and the drought impact from less than normal rainfall, then, varies with the type of farming situation. Under dryland conditions, the optimum amount of water is at point T, with the profit given by the area OAT. A drought reduces the size of the triangular area. For example, if rain gives only OR in effective water, the drought impact is the triangle RBT.

Under near desert conditions, with effective water from rainfall only OM, the maximum profit water level is defined at point Q. The profit is the area OAQNM. If it didn't rain at all, for example, the drought impact would be the area OWNM, and the irrigator would have higher irrigation costs as shown by the area OWNM.

Given effective water from rainfall of OR under supplemental irrigation, profit is maximized at point L, with profit of OALCR. If rain is something less, the CL portion of the function will shift to the left. That is, drought shifts the vertical line segment CR to the left, and moves CL to the left, which reduces the size of the area OALCR.

If the farmer is able to (or has to, because of water laws) purchase water for irrigation purposes, the supply curve becomes ORCD for the supplemental irrigation case. The triangular area CDK represents payment to the owners of the water supply. During droughts (which, as noted, shift supply curves to the left), some of the potential losses can be overcome by purchasing more water, but with a negative economic impact as compared to a plentiful water situation. If water prices increase due to the drought, areas like CDK will increase in size. The profit, as represented in areas like OADCR, would be decreased to the farmer. Clearly the meaning of "economic impact" and, indeed of a drought, varies with the situation. Under dryland conditions, point T cannot be reached. The task facing the analyst is to measure the triangular areas RBT. Under irrigated conditions, but with water given as a right rather than purchased, a drought occurs whenever point Q (desert) or L (supplemental irrigation) cannot be reached. Assume, for example, only RS irrigation water is available due to low snow pack or rainfall in the mountains supplying water to an irrigator in a western state. Even if the farmer receives normal rainfall R on the land, there will be an economic loss given by areas like DLK, in addition to any losses measured in areas like 0ADCR becoming smaller due to higher water costs. When water can be purchased, areas like CDK increase in size, which transfers money from farmers buying water to entities (who may be farmers) selling the water.

Additionally, product prices may increase during droughts, which as noted pivots the demand curve out and to the right around point T. Thus, decreases in the various profit areas due to drought would tend to be offset by increases in those same areas due to product price increases. Also, the possibility exists for lower input costs during droughts, such as for diesel fuel to operate irrigation pumps, which can shift curves like CL down, again offsetting some of the drought loss.

The economic impact on the farm depends on many factors, and can be complex to calculate. Understanding, explaining, and measuring the impacts requires quantitative knowledge of the supply and demand curves in the figure, and how farmers act during droughts. At this time, the best way to obtain such knowledge is with soil-water-plant simulation models, farm simulation, and studies of farmer behavior.

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The report summarizes research on water management during drought and makes recommendations for additional research areas that offer the most promise for improving the drought management response at Federal, regional, state and local levels of government. This report is part of a comprehensive study that has been undertaken in response to recommendations of the U.S. Amry Corps of Engineers made after the drought of 1988-89.

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