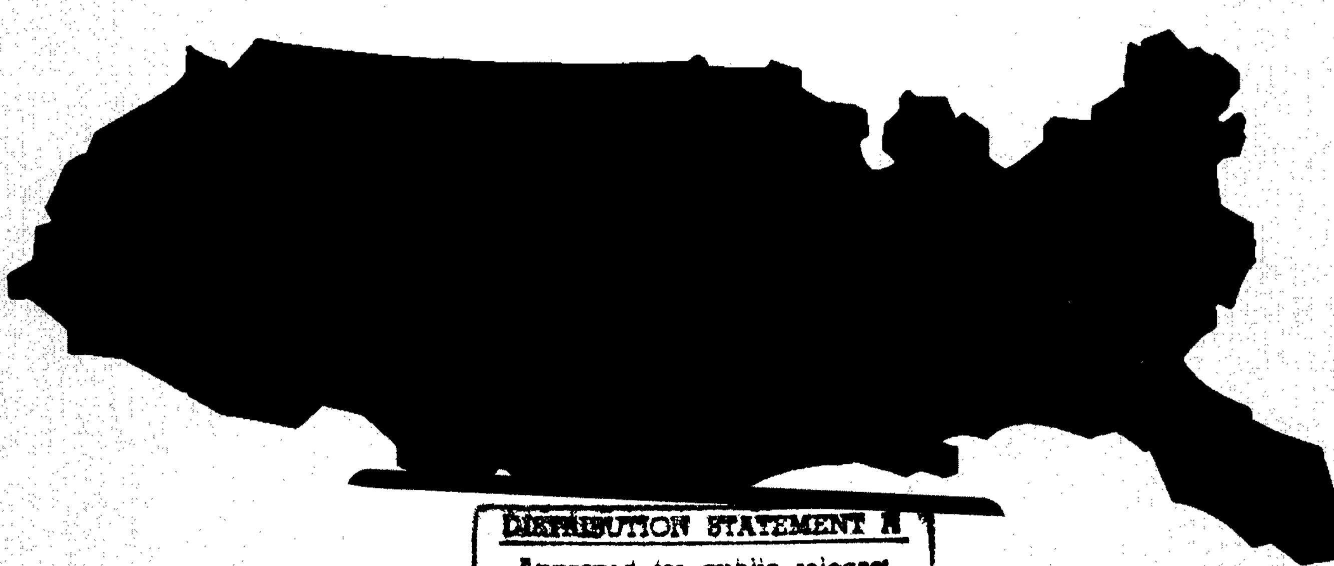
US Army Corps of Engineers®

National Study of Water Management During Drought

The Report to the U.S. Congress



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IWR Report 94-NDS-12

NATIONAL STUDY OF WATER MANAGEMENT DURING DROUGHT

THE REPORT TO THE U.S. CONGRESS

PREPARED BY

U.S. ARMY CORPS OF ENGINEERS
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Executive Summary

The droughts of the late 1980s and early 1990s caused persistent and widespread conflicts among water users despite the federal, state and local planning efforts in place before the droughts began. Although details differ from place to place, these plans can be broadly characterized. Federal plans were meant to assure that the authorized purposes of federal reservoirs were met. State plans defined the stages of drought, the emergency response powers of the governor, and (sometimes) a general way of prioritizing water allocation by the type of use. Local (city or water utility) plans identified stages of drought, drought response measures for each, and named drought committees and task forces.

With all this planning, why was there still conflict and confusion in our responses to drought? The Corps concluded after the first year of the Drought Study, as did many other reviewers, that the problems in water management during drought are manifestations of problems in water management in general (IWR, 91-NDS-1). Just as recessions may reveal weaknesses in the management practices of a company that made money when business was good, these droughts revealed weaknesses in water management systems which were hidden in the years when water was plentiful.

In the United States, water management problems come not from limited overall supply, but from problems in regional availability, management and usage (Foster, 1988). Water is not always where people want to use it, and the ways we allocate and use water have not been entirely successful in achieving economic efficiency, equity, and environmental quality. Taken as a whole, the U.S. always has more water than it needs. About 1,400 billion gallons of water per day is available in the conterminous 48 states. Less than a third of that (380 billion gallons) is withdrawn for all human uses, and most of that is returned to streams. In all but a few places in the U.S., a year long drought so severe that it can be expected only twice a century will still produce from one half (50%) to two-thirds (67%) the average precipitation for the year (IWR, 94-NDS-4).

There is broad agreement, if not consensus, among water scholars about what the primary flaws in American water management are: inefficiency and lack of holistic management (rooted in the division of water management responsibilities according to political boundaries and agency missions); the practice of pricing water below its real value; and the failure to involve stakeholders in water management. Ignorance is a problem, too. Multiyear droughts in California (IWR, 93-NDS-5) and the Columbia River Basin (Lee, 1992) show we have much to learn about long term environmental management of river basin ecosystems.

Water managers face the challenge of increasingly complex and conflicting water uses, as well as increased demands (in some areas) from rapid population growth. In some cases, we have had to choose between two or more competing environmental needs (Monberg, 1994). Budgets have been restricted at both federal and state levels, and water supply issues compete for funding not only with crime and education, but with other water issues: water quality, wastewater treatment, and infrastructure maintenance and replacement. As the era of dam building draws to a close, performance once secured through sheer abundance of water supply storage must now be assured by more skillful management.

Recognizing that the key to better water management during drought is to improve current water resources planning and management practices, the principles and practice of water management were revisited as part of the National Drought Study to develop an innovative, integrated, and collaborative approach to drought management. The DPS planning approach is based on the principles of multiobjective water management derived from the Harvard Water Program of the late 1950's and early 1960's, modified and implemented in Federal water studies, and codified in "Principles and Guidelines" (P&G) for federal water planning. Like the P&G, the DPS method requires the explicit establishment of problems and the goals and objectives for water management and the articulation of what the study area would be like if the study produced no change in water management. Like the P&G, the DPS method compares alternatives to that status quo; and the use of commensurable measures, such as economic efficiency, to help identify society's best interests when one water use must suffer if another is to prosper. The DPS Method differs from the P&G, though, in that it is designed to be used when non-structural and non-Federal solutions are the norm. The DPS method was also inspired by the process that led to a multi-government agreement on water supply for the Washington, D.C. metropolitan area in the early 1980's. Those agreements were facilitated by easily understood computer simulations of a water supply system that convinced decision makers that the safe yield of the system could be increased more, and at a lower economic and environmental cost, by interconnecting existing reservoirs rather than building additional reservoirs (Eastman, 1987). This approach has been tested and refined in four regional case studies (called Drought Preparedness Studies*, or DPS's) that collectively represent much of the diversity found in American water management.

Many water utilities, states, and river basin organizations already had prepared drought plans (see page 17). The features that distinguish a DPS from these traditional drought preparedness efforts are that the DPS:

- uses collaboratively built *shared vision* computer models to bridge the gap between the information specialized water models can provide and the way people negotiate water decisions.

- involves stakeholders in a way that balances the benefits of broad participation with the problems of managing a large study group.

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* The case studies were conducted on the Kanawha River Basin (West Virginia, Virginia, and North Carolina), the Marais des Cygnes-Osage River Basin (Kansas and Missouri), the Cedar and Green River Basins (Washington), and the James River (Virginia).

- is designed to reduce impacts, not just allocate water shortages

- integrates drought response with long term water resources management

- lets regional managers benefit from expertise and experience from around the country

- assembles planning teams from existing organizations, linking them in a way that addresses the fragmentation of responsibilities among agencies without creating new bureaucracies

In addition to the four major case studies, the Corps is currently applying the DPS method in drought preparedness efforts at two Corps projects (the Rogue River in Oregon and the Youghiogheny River in Pennsylvania) to determine how effective these methods can be even when the time and budget allotted for the studies are minimal. The Corps is concurrently reviewing its regulations and policies for operating its projects during drought to see how they could be improved based on these and other National Drought Study case studies.

The DPS method can be applied to water issues beyond drought because it is based on sound principles for multipurpose, multiobjective water resources management. The DPS method has already influenced the way water is managed outside the drought case study areas. State water departments in Washington and Virginia, the Interstate Conference on the Potomac River Basin, and the Susquehanna River Basin Commission are already incorporating elements of the DPS method in drought management and long term water resources management. The DPS method will be used in the Comprehensive Study of the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint River Basins, and elements of the method are being used in the Central and Southern Florida Study (the "Everglades Study"). These techniques were shared with water managers from Corps districts, the Bureau of Reclamation, the U.S. State Department, the Bonneville Power Administration, the Interstate Conference on the Potomac River Basin and other groups in a technology transfer session held in September 1994 in Alexandria, Virginia. It appears from the favorable reaction of the case studies and others who are using the methods in studies unrelated to the Drought Study that use of the DPS method will become more common in the future. This was the ultimate goal of the National Drought Study: not just to prescribe a better way to manage water, but to implement it and reap the benefits.

Acknowledgements

This report was produced as part of the National Study of Water Management During Drought, which was managed by the Institute for Water Resources (IWR) of the U.S. Army Corps of Engineers. It is one of 17 reports which will be produced, including "Managing Water For Drought", the main technical summary of the innovative approaches that were developed and used during the National Drought Study.

The study benefitted from the experiences, research, critical analysis, and writing of the over one hundred professionals who worked directly on the National Drought Study, but the contributions of three people were most influential in the preparation of this report.

The central theme of the Drought Study, the use of the methods and tools of multiobjective water resources planning to prepare a drought response, is based on the work of Dr. Eugene Z. Stakhiv, Chief of IWR's Policy and Special Studies Division. Dr. Stakhiv had made the case in previous papers that the multiobjective federal planning methods were unique in that they constituted a *comprehensive and uniform* set of principles for water resources planning and management that had been established and tested by an unprecedented coalition of researchers and practioners. Moreover, he had demonstrated that these principles and methods, which have traditionally been applied to the development of federally financed water projects, could be used to address regional objectives. Under his direction, the National Drought Study developed these concepts one step further, applying these principles to what were primarily *regional* and *operational* water resources matters.

Mr. Zoltan L. Montvai, of the Corps' Headquarters Planning Division, oversaw the National Drought Study from its inception to its final products. He tirelessly reviewed and criticized drafts of this report and offered advice to assure that it answered the questions raised during the design of the National Drought Study. The Planning Division is headed by Dr. G. Edward Dickey.

Brigadier General (Ret.) William Whipple, Jr. co-wrote "Managing Water for Drought" and rewrote an early draft of this report and criticized subsequent revisions. As he had in other parts of the study and other reports, he provided the rest of the team with the insights he has garnered during his half century of experience in water resources planning, construction, and management.

Additional material for this summary report was also provided by Dr. Hanna Cortner (University of Arizona), Mr. Charles Lancaster, Dr. William Lord (University of Arizona), Dr. Richard Palmer (University of Washington), and Dr. Gene Willeke (Miami (Ohio) University).

The report, of course, is a synthesis of the National Drought Study. The report on the first year of the study (IWR, 91-NDS-1) acknowledges the many professionals who set the course and collaborative tone for the study. Of those, however, three people deserve to be acknowledged again since they shaped the study in its infancy. Harry Kitch (Corps Headquarters), Randy Hanchey and Kyle Schilling (past and current directors of IWR) shaped the basic study direction, making sure the scope and subject matter of the study would include non-Corps and non-federal problems and viewpoints.

William J. Werick
Principal Author and Study Manager

Findings of the National Drought Study

The nature of drought

1. **Definition.** Droughts are periods of time when natural or managed water systems do not provide enough water to meet established human and environmental uses because of natural shortfalls in precipitation or streamflow.

2. **Drought management is a subset of water supply planning.** The distinction between a "drought" problem and a "water supply" problem is essentially defined by the nature of the best *solution*. Urban areas that persistently use more than the safe yield of their water supply systems may have frequent or even standing drought declarations that could only be eliminated through strategic water supply measures. Those measures can be structural, such as the construction of new reservoirs, or non-structural, such as conservation.

3. **Drought response problems are water management problems.** Participants at a National Science Foundation Drought Workshop concluded that attempts to understand and address the failings of water management during drought would be unsuccessful unless shortcomings in the larger context of water management are also understood and addressed. This was also one of the conclusions drawn by the Corps of Engineers in the first year of the National Drought Study (IWR, 91-NDS-1), and the premise upon which the DPS method was built.

The seriousness of the problem

4. **Concern is widespread.** Fifty percent of all **water supply** utilities asked their customers to reduce consumption during the 1988 drought (Moreau, 1989). In a 1990 poll, forty-one percent of U.S. mayors anticipated water shortages in the next several years, caused by drought, growing population, water pollution, and leaks from distribution lines (Conserv90).

5. **Water use is stable nationally**. Several reports in the 1970s forecast rapid increases in American water use. There has been no national assessment of water use since then, and an impression lingers to this day that water use *is* increasing. In fact, total American water use is less now than it was in 1980, although there is growth and more intense competition for water in some regions. Water use forecasts are different from water *demand* forecasts because demand is a function of price. This stabilization in the quantity of water used is largely due to the impact of new legislation, technological advances, and the opportunity costs, economic and environmental, for developing new supplies.

6. Several states reported that **water quality** suffered during drought because low flows affected their ability to dilute effluents from wastewater treatment plants and sustain the aquatic ecosystem.

7. **Drought impacts are difficult to measure.** This is because:

- They are often reported as reductions from the benefits a water system can support when water is plentiful; this approach often overstates the problem because these drought "costs" are usually based on sizing the water system so as to maximize return on the economic and environmental investments in the water system and is not necessarily based on efficient use of the water resource.

- Impacts caused by drought are difficult to separate from impacts that occur coincidentally during a drought. Because droughts continue for much longer than floods, earthquakes, or wind storms, external factors (such as recessions, market changes, land management, and fishing practices) may also contribute to the impacts associated with drought, as was the case recently in California.

- Regional drought impacts are often more than offset at the national level by gains in production somewhere else in the country.

8. **Drought impacts understate our aversion to droughts.** Despite the overestimation of impacts induced by the above factors, the level of conflict and anxiety droughts stimulate is still apt to be far greater than the magnitude of impacts would suggest. On a national and even a state level, the impacts to agriculture and urban areas from the California drought were relatively small, but the drought was newsworthy for years and played a significant role in the passage of new state and new federal laws. Observations of droughts in the 1980's suggest that turmoil will be greater when the losses are felt more personally and when long term entitlements to water use are threatened.

Shortcomings in the way we have dealt with droughts

9. **Learning from the past**. Lessons learned during ongoing droughts are too rarely documented, critically analyzed, and shared with other regions;

10. **Price and efficient use.** Water is almost always priced below its economic value to users or full cost to produce. This tends to impede efficient use of water and misrepresent the demand for water. National Drought Study reviews of water use in Boston and California suggest that shortages of water are sometimes just shortages of *low priced* water.

11. **Assessing risk.** Information about expected drought severity and duration is not readily available, so risk assessments cannot be quantified as well.

12. **The problems are integrated, solutions are not**. Management responsibilities for problems that are physically integrated in a river basin are fragmented by agency missions and political boundaries. The many disciplines required to analyze drought problems and develop and institute solutions are poorly coordinated.

13. **Typical problems with traditional drought plans** include (IWR, 91-NDS-1):

- they may not recognize newer uses of water

- they are usually designed for the drought of record, without consideration of the rarity of that drought

- they often are not understood or endorsed by those who will suffer the impacts of the drought

- they may not sufficiently address equity issues or economic differences in the use of water

- they are often triggered by indicators not related in a known way to impacts.

- they are better characterized as documents rather than ways of behaving, and so their effectiveness diminishes as staff changes occur and time passes between plan preparation and drought.

14. **There are three time frames for response planning.** Drought responses can be classified as strategic, tactical, and emergency measures. *Strategic* measures are long term physical and institutional responses such as water supply structures, water law, and plumbing codes. *Tactical* measures, like water rationing, are developed in advance to respond to expected short term water deficits. *Emergency* measures are implemented as an *ad hoc* response to conditions that are too specific or rare to warrant the development of standing plans.

15. **Technology transfer.** Methods for managing water for multiple objectives have been developed and tested over decades, but that tradition resides in the agencies that built the extensive complex of federal dams, not in the organizations responsible for preparing tactical drought plans. This expertise must be transferred before that institutional memory is retired.

16. **Law and drought**. Law sometimes drives and sometimes constrains water management during drought. Basic appropriations doctrine discourages water conservation, because water not put to beneficial use may be lost, but many western states have modified the basic doctrine to accommodate conservation. In addition, sixteen eastern states have legislation recognizing the need to conserve water supplies.

17. **Basin transfers and drought**. Diversions are strategic measures designed to increase water supply reliability. During a severe drought, if the necessary facilities exist and the state law allows, temporary interbasin diversions may be authorized to meet the needs of the most severely affected areas.

Lessons from the Case Studies

18. **Domestic water users are willing and able to curtail water use during a drought.** During the first two years of the drought, a mixture of voluntary and mandatory conservation in California's cities reduced water use from 10 to 25%. In the last three years of the drought, urban conservation efforts were generally more intense. Similar savings were recorded in Seattle and Tacoma, Washington in their 1992 drought.

19. **Investments in infrastructure can increase the options for adaptive behavior.** Water banking, storage for instream flow maintenance, conjunctive use of groundwater and surface water, regional interdependence, and economies of scale require a water storage, allocation and distribution system. California's storage and distribution system provided the flexibility and resiliency to withstand severe droughts, even in the face of rapidly growing population and increasing urban and environmental demands on a fixed supply of water.

20. **Droughts act as catalysts for change.** Complex sociopolitical systems, which reflect a multitude of competing and conflicting needs, are not particularly well suited for crisis management. Yet despite these well understood and accepted deficiencies in the democratic decision making process, the overall conclusion is that communities not only weathered the drought in a reasonably organized manner, but also introduced a series of useful water management reforms and innovations that will influence future water uses in a positive manner.

21. **Conservation may or may not reduce drought vulnerability**. To the extent that methods of reducing water use during droughts, such as discouragement of outdoor use and physical modifications to toilets and faucets to reduce water use, are used as long term water conservation measures that allow the addition of new customers to a water supply system, drought vulnerability is increased. When normal use becomes more efficient, efficiency gains are harder to realize during a drought. But it is not always that simple. In the Boston Metropolitan area, for example, long term conservation will reduce drought vulnerability because some of the water saved will also be stored for use during droughts and because some of the most effective long term conservation savings (such as the detection and repair of leaks) cannot be implemented quickly enough to be as effective as a drought response.

The DPS Method

22. **The lineage of the DPS method.** The DPS method is derived from the traditional strategic water resources planning framework, but addresses two common shortcomings in water management: the separation between stakeholders and the problem solving process, and the subdivision of natural resources management by political boundaries and limited agency missions.

23. **Drought responses are primarily behavioral.** The DPS method reflects the fact that, like responses to earthquakes and fires, drought responses are largely behavioral, and their success depends on people understanding their role, and knowing how their actions fit into a larger response.

24. **Collaboration between agencies and stakeholders can make planning much more effective.** This collaborative approach:

- harnesses the knowledge and creativity of stakeholders near the beginning of problem solving efforts;

- makes it more likely that stakeholders can take actions unilaterally to reduce their drought vulnerability;

- builds broader, deeper stakeholder support for water management plans.

25. **Lessons learned from past efforts at collaborative planning are abundant and must be heeded.** The benefits of participatory planning are not guaranteed by simply making the planning process accessible. There is a substantial body of research and practical experience with participatory planning, especially in water resources, that is often overlooked. The temptation is to believe that honesty and common sense will suffice. The participatory methods used and developed during the Drought Study recognized and managed these potential liabilities:

- public involvement can involve considerable expense.

- the "public" that gets involved in planning may be self-selected and unrepresentative of the public that will be affected by drought.

- if the public is actually involved in the study process (as opposed to just expressing problems and goals in workshops or surveys), then additional efforts may be required to provide technical training and to coordinate the work of public task forces.

- the misapplication of the techniques of group process can result in the use of stakeholder opinions on issues that should be addressed by experts.

- broader citizen participation increases the risk that the planning process will be slowed or stopped.

26. **The problem solving team should be appropriate to the problem set.** Rarely will there be one agency or political entity whose responsibilities include all the problems a region will face during future droughts. The creation of the DPS team, then, is the creation of a new entity whose collective interests and responsibilities are pertinent to the set of problems addressed. Thus, the DPS team constitutes a new, integrated community that more closely reflects the integrated nature of the problemshed.

27. **The objectives for the drought response must be articulated early and clearly.** The DPS method uses 5 management parameters including the ***criteria*** decision makers will use in approving or rejecting new plans, ***planning objectives***, ***constraints***, ***measures of performance***, and environmental, economic, and social ***effects***. Developing good planning objectives early is paradoxically the most important and most often ignored step in the drought planning process.

28. **Innovations**. The DPS method takes advantage of several innovations developed in parallel during the National Drought Study:

- The shared vision model (see Finding 29)
- Circles of influence and decision maker interviews
- Water Conservation Management
- Trigger Planning
- The National Drought Atlas
- Virtual Drought Exercises

29. **Shared vision models** are computer simulation models of water systems built, reviewed, and tested collaboratively with all stakeholders. The models represent not only the water infrastructure and operation, but the most important effects of that system on society and the environment. Shared vision models take advantage of new, user-friendly, graphical simulation software to bridge the gap between specialized water models and the human decision making processes. Shared vision models helped DPS team members overcome differences in backgrounds, values, and agency traditions.

30. **A Virtual Drought Exercise** is a realistic simulation of a drought using the shared vision model to simulate that experience without the risk associated with real droughts. Virtual Drought Exercises can be used to exercise, refine and test plans, train new staff, and update plans to reflect new information.

31. The **National Drought Atlas** (IWR, 94-NDS-4) is a compendium of statistical information designed to help water managers and planners answer questions about the expected frequency, duration and severity of droughts. The Atlas provides a national reference for precipitation and streamflow statistics that will help planners and manage assess the risks involved in alternative management strategies.

32. **Water conservation management** is the prioritization and selection of water conservation measures based on their estimated benefits and costs. A new version of a widely used water use forecasting model, IWR-MAIN, provides a powerful new tool for linking water savings with specific combinations of water savings measures.

33. **Trigger Planning** is a collaborative and continuous process for updating water supply needs assessments and responding in time, but just in time, with the necessary economic and environmental investments necessary to address those needs. Trigger planning uses a shared vision model and the DPS method to minimize those investments while reducing the frequency of drought declarations caused by inadequate water supply. Trigger planning was tested and refined in the Boston metropolitan area.

34. **There are simple ways to improve agency collaboration with elected officials and stakeholders.** The DPS method used "circles of influence" to effectively and efficiently involve stakeholders in the development of plans. The circles created new ways for people to interrelate and interact, without destroying the old institutions, their responsibilities or advantages. In addition, during the DPS's, political scientists conducted interviews with elected officials and other influential political agents. The interviews were included in reports available to the entire study team, and were used to assure the planning process addressed issues critical to the public and elected officials.

National Study of Water Management During Drought

I. Introduction

In response to the droughts of 1988, Congress funded a four year **National Study of Water Management During Drought** led by the U.S. Army Corps of Engineers. The primary objective of the study was to find a better way to manage water during drought in the United States. (The study was not intended to address drought problems that do not involve water management, such as drought related forestry problems and crop losses on non-irrigated farms). This report describes the results the study team acheived in each of the major components of the study.

A. Study Authority

This study was conducted under the authority of Sections 707 and 729 of the Water Resources Development Act of 1986 (WRDA 86).

Section 729, "Study of Water Resources Needs of River Basins and Regions", directs the Secretary of the Army, in coordination with the Secretary of the Interior and in consultation with other governmental agencies, to study "water resources needs of river basins and regions of the United States." This section specifically requires consultation with "State, interstate, and local government entities.

Section 707, "Capital Investment Needs for Water Resources", authorizes the Secretary to estimate long term capital investment needs for, among other things, municipal and industrial water supply.

These authorities allowed the Corps to:

- investigate water resources needs for all purposes, including those purposes such as municipal water supply for which users bear the financial burden in new federal reservoirs.

- investigate these issues at the national level, in collaboration with the states and other federal water agencies.

The National Drought Study was not intended to be a complete response to Sections 707 and 729. A plan of study was developed by a task force composed of leading Corps of Engineers, university, and state water managers. The plan of study was based on directives contained in Office of Management and Budget (OMB) budget justifications.

The study process was designed to encourage participation across the spectrum of stakeholders and management agencies.

The primary objective of the study was to find a better way of managing water during drought in the United States.

The study plan was to:

- determine the concerns related to water management during drought throughout the country;
- describe the ways water is managed during drought and identify the linkage between management methods and concerns;
- identify impediments to improving those methods;
- design a method that would address the identified concerns;
- test and refine the new method in case studies across the country;
- share the findings with the water management community and look for ways to implement the new method.

The OMB language divided the study into two parts. In the first part (FY90), the Corps was directed to complete an overview of the problem, make preliminary suggestions for change, and recommend whether further study was justified.

The "National Study of Water Management During Drought; Report on the First Year of the Study" found that the problems with water management during drought were symptomatic of the problems of water management in general. The report recommended that the remainder of the study be devoted to the testing of an alternative approach to water management during drought and the conduct of supportive technical studies.

In the second part of the study:

- the new drought preparedness method was tested and refined in 4 case studies;
- the National Drought Atlas was developed;
- drought and water supply planning were integrated in a project called "Trigger Planning" in Boston;
- a series of conceptual and field studies were conducted in collaboration with the U.S. Advisory Commission on Intergovernmental Relations (ACIR) to improve the effectiveness of the working relationship between water agencies and elected officials and water agencies and the public.

This report is organized around these steps.

II. Problem Identification

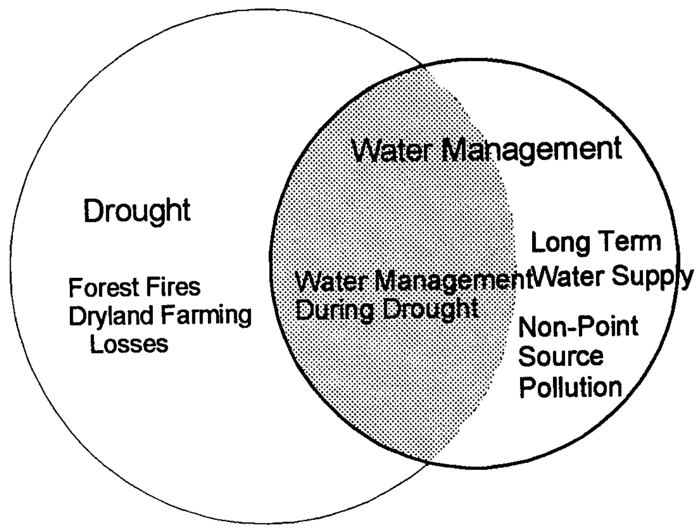
A. The subject area of this study.

The subject of the National Study of Water Management During Drought is the intersection of drought and water management. As **Figure 1** illustrates, there are water management and drought issues which fall outside the subject of this report.

For example, drought related forestry problems and crop losses on non-irrigated farms are not affected by the storage, conveyance, allocation and pricing of water; they are the direct result of reduced precipitation. One of the products of the Drought Study, however, the National Drought Atlas, provides state of the art statistical information that should be useful in managing these sorts of problems.

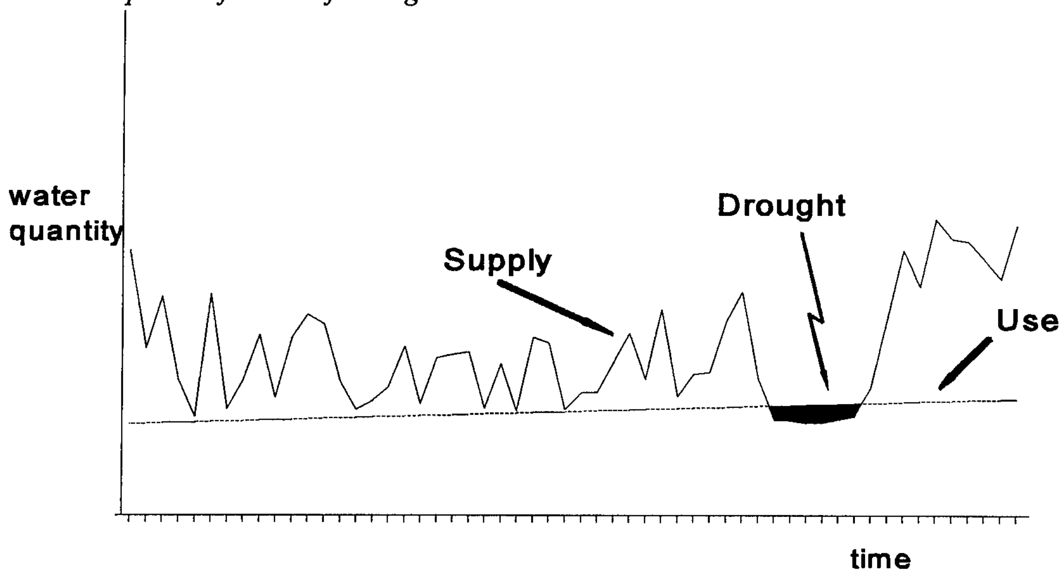
Similarly, water managers deal with many issues besides drought. However, a direct connection can be made to *long term water supply*, and the Drought Study did examine this connection. The phrase "water supply" is used here in a broad sense, meaning the provision of water for hydropower, navigation, recreation, and instream flow needs, as well as for municipal, industrial and agricultural consumption. The "drought" that was subject of the National Drought Study is best defined in the context of water supply planning.

Figure 1. *The Subject of This Study*



B. The definition of drought. There are at least 10 meteorological, 4 agricultural, 3 hydrologic, and 3 socioeconomic definitions of drought used in water management literature (IWR, 91-NDS-3). Some authors restrict its use to what others call meteorological drought (less precipitation than usual, with "less" sometimes quantified). Others use "drought" to refer to *agricultural* drought (not enough precipitation for crops), or *hydrologic* drought (less water available than usual, typically defined statistically in terms of less than normal streamflow). But in water systems that use distant sources of water or large reservoirs, declarations of drought may be unrelated to the amount of local rainfall, so this definition was too

Figure 2. A Graphic Definition of Drought



broad to fit the subject of the National

Drought Study. For the purposes of the National Drought Study, a socioeconomic definition was used:

Droughts are periods of time when natural or managed water systems do not provide enough water to meet established human and environmental uses because of natural shortfalls in precipitation or streamflow.

This definition is represented graphically in **Figure 2**. Over a period of time, supply will vary based on precipitation and streamflow. These variations can be reduced and smoothed by the use of natural and man-made storage facilities, both on the surface and in the ground.

Although this definition is useful and appropriate for a national study of the problem, it is still too broad to be used in determining whether a recent shortfall in precipitation should be treated as a drought. This is because a determination that the water system cannot provide enough water is often dependent on future inflows that cannot be forecasted accurately.

In most areas of the country, there are risks involved in setting the threshold at which reduced precipitation and streamflow are officially declared to be droughts. If the droughts are declared too early, droughts will be declared more frequently and sometimes unnecessarily. If managers wait longer to declare a drought, water supplies that could reduce the impacts of a prolonged drought will be depleted if water use is not reduced early in the drought.

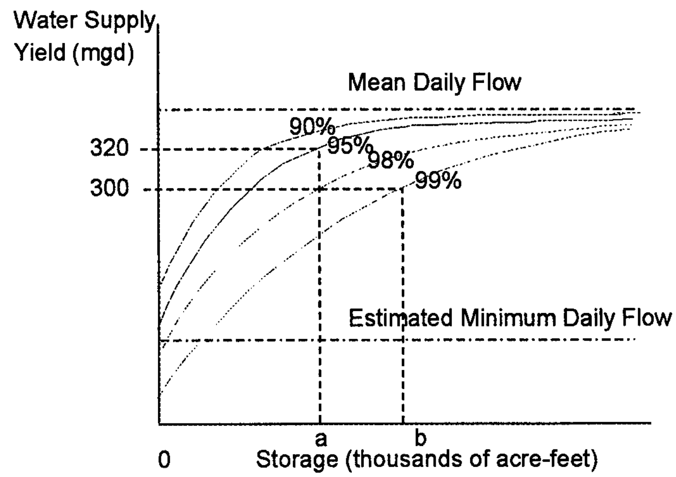
C. Water Supply Planning and Drought

Figure 2 helps illustrate the difference and the connectedness between drought and water supply.

Water supply planning is a strategic endeavor that attempts to balance water supply and use, mindful of economic and environmental costs. Water supply planners forecast future water use and calculate how often the existing or alternative water supply systems would fail to deliver that amount of water. They generally accept less than 100% reliability - that is, they accept the fact that droughts will occasionally be declared - because the environmental, social, or economic costs required to completely eliminate droughts is too great. These residual problems (shown in **Figure 2** as drought) can be addressed more efficiently through *tactical responses* - such as lawn watering bans or special rules governing the release of water from reservoirs during such episodes.

The tradeoffs between the number of drought declarations, water use, and storage capacity are shown in Figure 3. Of the many ways that the adequacy of water supply is measured, the most basic and universal is "safe yield". If a system is said to have a safe yield of 300 million gallons of water a day at 98% reliability, it means that it can support water use of 300 million gallons per day (mgd) 98% of the time. This is usually based on records of streamflow gages, which are from 40 to 100 years long in many places in the country. For a fixed capacity of storage (*a* in Figure 3) this system could be described as having a safe

Figure 3. An illustration of safe yield curves. Adding storage trades present days costs for increases in reliability (shown as 90%, 95%, etc.) or yield.



yield of 300 mgd at 98% reliability or 320 mgd at 95% reliability. Figure 3 also shows that increasing storage from *a* to *b* can increase the reliability of 300 mgd water service from 98% to 99%. This is a strategic measure that uses present day investments to reduce the number or severity of future droughts.

Many of the drought concerns across the country come from areas where municipal water needs or recreational needs have outstripped the growth of water supply systems. In the case of municipal needs, the imbalance can be caused simply by the rate of population growth, the costs of new supply, or the length of time required to obtain approval for new supply structures. Recreational water use is almost always incidental to other uses; people simply take advantage of water storage reservoirs built for other purposes. Yet recreation has a significant economic and political dimension, and water managers everywhere are learning that recreation can raise the "use" line in **Figure 2**, either increasing the frequency of drought declarations or adding to the opportunity costs of reducing drought impacts to traditional water uses.

The distinction between a "drought" problem and a "water supply" problem is essentially defined by the nature of the best *solution*. Urban areas that consistently use more than the safe yield of their water supply systems may have frequent or even standing drought declarations that could only be eliminated through strategic water supply measures. Those measures can be structural, such as the construction of new reservoirs, or non-structural, such as conservation.

D. Concerns Across the Country

The National Drought Study began with an assessment to determine what the impacts of drought were and what problems there were with drought response mechanisms.

In 1990, then Assistant Secretary of the Army for Civil Works Robert Page wrote to each of the 50 Governors, asking for their help with this study, and they responded, expressing their main concerns and naming a state study coordinator. Those concerns are summarized in **Table I**. Corps division offices were asked to report what they felt were the principal drought problems (**Figure 4**) and major impediments (page 18) to reducing those problems.

The information from these surveys was refined, checked and supplemented during three workshops, co-sponsored with the Western States Water Council and the International Drought Information Center. Water managers, environmentalists, and researchers participated in these workshops.

Throughout the first year of the study, existing drought plans and notable case studies with drought management implications were reviewed. Finally, the Drought Study team participated in other reviews of the subject (such as the National Science Foundation workshop on drought) and reviewed papers written on the impacts of drought and shortcomings of the water management system. All of these efforts were summarized in the Report on the First Year of Study (91-NDS-1). Lessons Learned from the California Drought (1987-1992) (93-NDS-5), further contributed to the understanding of the problems.

The results of these assessments shaped the remainder of the National Drought Study in two fundamental ways:

- The study team focused on ways to address the subject areas of greatest concern: the inadequacies of water resources planning, the division of responsibility by agency missions and political boundaries, and lack of communication between agencies, elected officials, and stakeholders.

- Case studies were chosen to represent a cross section of the issues the assessments had revealed.

TABLE I. GOVERNORS CONCERNS

NEW ENGLAND REGION: Not a problem over much of area, but there is an increasing susceptibility to drought of public sector water supply and lack of redundancy of water supplies.	
Maine	Not a major problem, but there are some concerns about agricultural damage, forest fires, and river pollution.
New Hampshire	Public water supply and river water quality because of importance to tourism.
Vermont	Livestock frequently affected.
Massachusetts	Conflict between irrigation and municipal and industrial use.
Connecticut	Domestic water supply biggest concern.
Rhode Island	Lack of redundancy in community water supplies and inability to develop new supplies
MID-ATLANTIC REGION: Salt water intrusion and water supply along coast and Delaware River.	
New York	New York City's water supply system which is overburdened and currently operating above safe yield. There are lesser water supply problems in Rochester and Syracuse areas.
New Jersey	Domestic water supply is the biggest concern; saltwater intrusion in Delaware River is on-going concern.
Pennsylvania	Public water supplies are a major concern, especially the numerous small supply systems. Agriculture and crop losses.
Delaware	Declines in ground water levels in confined aquifers, salt water intrusion, increasing municipal and industrial usage
Maryland	Drought is not a major concern because of state effort to deal with water supply. Salt water intrusion is concern in coastal areas; some areas have sufficient water but need better retrieval capability (e.g., new wells) to access it.
Virginia	Southeastern coastal areas have water supply problems

TABLE I (CONTINUED) GOVERNORS CONCERNS

SOUTH-ATLANTIC REGION: Increasing municipal and industrial use, management of major river systems	
North Carolina	Impacts to agriculture and domestic uses.
South Carolina	Need for management and coordination of surface and ground water resources; Management of Savannah River reservoirs.
Georgia	Many northern communities have insufficient water supply and access to recreation lakes.
Florida	Competition between agricultural uses and others; Municipal and industrial use; Everglades water; fish and wildlife; Recreation
Alabama	Droughts affect agriculture first, and then hydropower, navigation, and recreation
LOWER MISSISSIPPI BASIN: Impacts to agriculture, Mississippi River low flows, drought impacts in Mississippi-Missouri-Ohio River Basin, which drains 41% of contiguous U.S., impacts Mississippi River delta	
Mississippi	The 1988 drought was devastating to farming community; Northeastern low flows and catfish farm pumping.
Arkansas	M&I supplies, especially those with marginal storage; damage to row crops and pasture crops; damage to livestock and poultry; instream flow needs. Agriculture is the major problem - irrigation is extensive (86% from ground water).
Louisiana	Not a major concern, but Mississippi River and Sabine River flows may drop below water intakes during severe droughts.
OHIO RIVER BASIN: Ohio River low flows. Municipal water supplies of medium- to small-sized communities	
West Virginia	Drought is not a major concern for communities, but there are instream needs (recreation and environment) that may be impacted.
Tennessee	Water quality and recreation impacts; domestic supply of towns in eastern Tennessee.
Kentucky	Competition between municipal water supply and irrigated agriculture.
Ohio	Municipal supplies (medium-sized communities);instream flow needs.
Indiana	Ohio River navigation, water supply distribution systems.

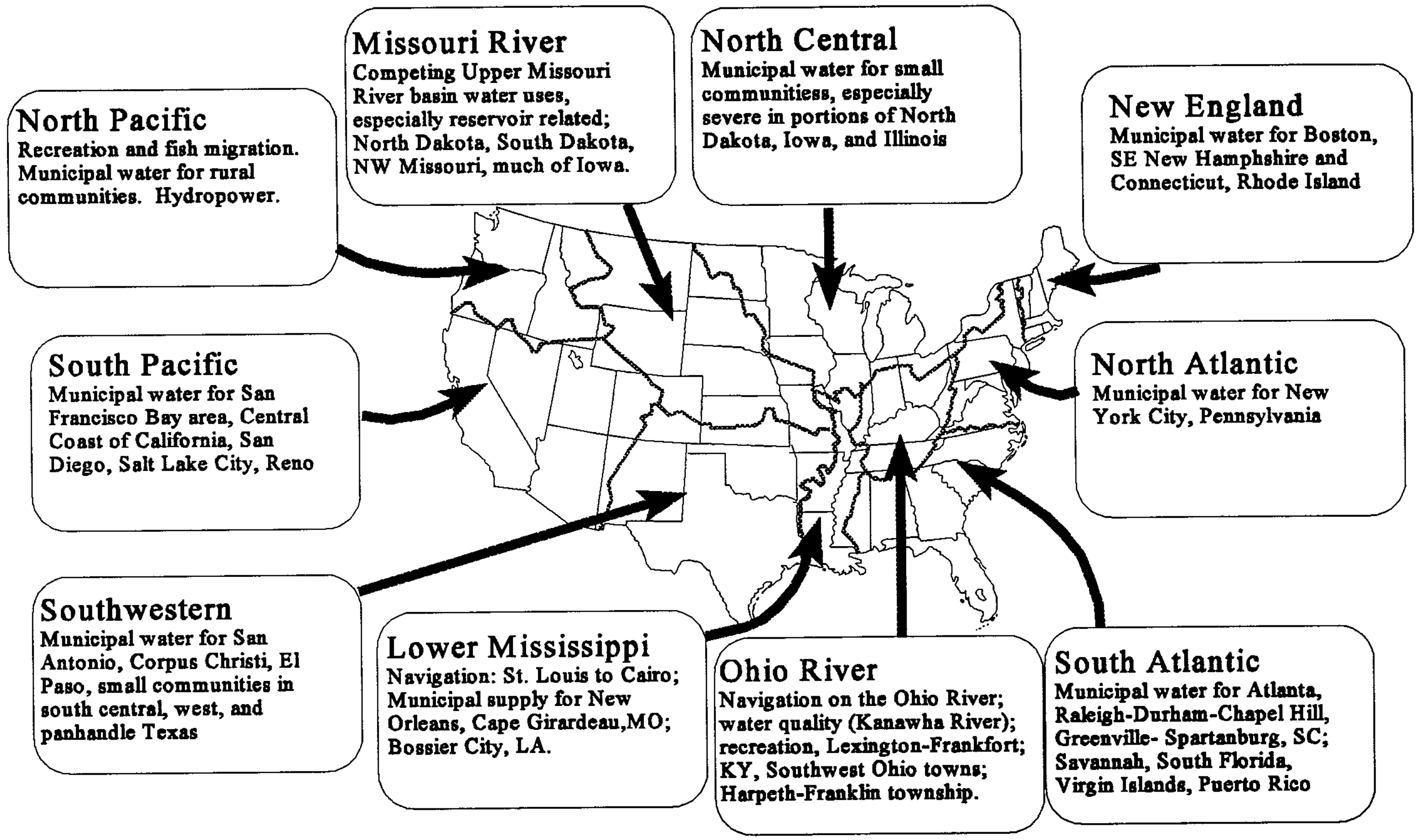
TABLE I (CONTINUED) GOVERNORS CONCERNS

LOWER COLORADO RIVER BASIN/SOUTH PACIFIC COAST REGION: Increasing municipal water supply needs versus irrigation needs	
Arizona	Groundwater overdraft; drought impacts on rangelands, stock watering; conflict between cattle and wildlife (stock ponds); shortages on Colorado River system; Federal water/regulation claims; instream flows and fish and wildlife.
Nevada	Priorities have changed dramatically: water switched from agriculture to municipal and other competing uses, such as fisheries, wildlife habitat.
California	People expect more water than there is. Aesthetics - recreation, streams and reservoirs; agriculture, primarily in foothills (valleys have switched to groundwater); fires; municipal supplies, especially for poor planners; salt water intrusion; hydropower; tourism/recreation.
NORTHWEST & PACIFIC COAST REGION Municipal water supply needs of smaller communities, competition between power and fish/recreation in northwest	
Idaho	Anadromous fisheries; use of Idaho streamflow for augmentation of flows downstream; smaller communities have water supply problems; competition between M&I and irrigation; hydropower; tourism/recreation.
Oregon	Coastal communities affected by one dry summer because of lack of storage; power and fish/recreation; forest fires - resource and environmental loss; Federal water/regulation claims; agriculture.
Washington	Municipal and industrial water supply in western part of state. The state is concerned about wetlands; agriculture; hydropower; tourism/recreation; navigation
Alaska	Drought is not a major concern.
Hawaii	Small communities have only short-term water supply. Most droughts are short-term events; agriculture.

TABLE I (CONTINUED) GOVERNORS CONCERNS

PLAINS STATES: Agricultural impacts, management of the Missouri River Mainstem reservoirs, competition between lake recreation and downstream uses, small community water supplies	
North Dakota	Missouri River management and planning on a basin basis; Lack of contingency water supply plans for many cities in the state; Agriculture; Tourism/recreation.
South Dakota	Primary concern is the use of Missouri River reservoirs to supply water for downstream users. Problems in 1988 were forest fires and crop failures.
Nebraska	1989 drought affected farmers and ranchers all across state; FERC relicensing and downstream irrigation needs; Small community M&I and an aging well system; Instream flows/fish & wildlife.
Kansas	Agriculture and M&I. Western Kansas depends on Ogallala Aquifer which faces potential depletion; the east uses more surface water.
SOUTHWEST REGION: Agricultural impacts	
Oklahoma	Agriculture; Federal water/regulation claims; Tourism/recreation; Instream flows/fish and wildlife; Hydropower.
Texas	Mostly agricultural impacts; Curtailments of all other uses for domestic and livestock uses; Irrigation and urban uses compete with recreation; Wildlife; Tourism impacts; Drought impacts differently across the state, but is most common in southwest central portion; Salt water intrusion.
New Mexico	Only 2 towns with chronic water supply problems (most of state relies on ground water); Major problem hampering water development is endangered species (e.g, Animas-La Plata); Agriculture.
ROCKY MOUNTAIN WEST REGION: Agricultural impacts; competition for water between agriculture and instream use, increasing municipal water supply needs	
Montana	Water shortage is persistent; Irrigators versus full stream users (especially trout fishing); Hydropower; Effluent dilution; Federal water/regulation claims.
Wyoming	Agriculture; Fires.
Colorado	Agriculture; Effluent dilution; Tourism/recreation.
Utah	Environmental health (drinking water) especially for small spring-dependent communities; agriculture, especially grazing; Instream flow/fish and wildlife.

Figure 4. *Corps divisions reported what they considered to be the worst potential drought problems.*



E. Drought Impacts That Could be Addressed by Better Water Management

There are conceptual problems which make it very difficult to provide useful estimates of the damage droughts cause, but there are some broad conclusions which can be drawn from the research and case study experience of the National Drought Study.

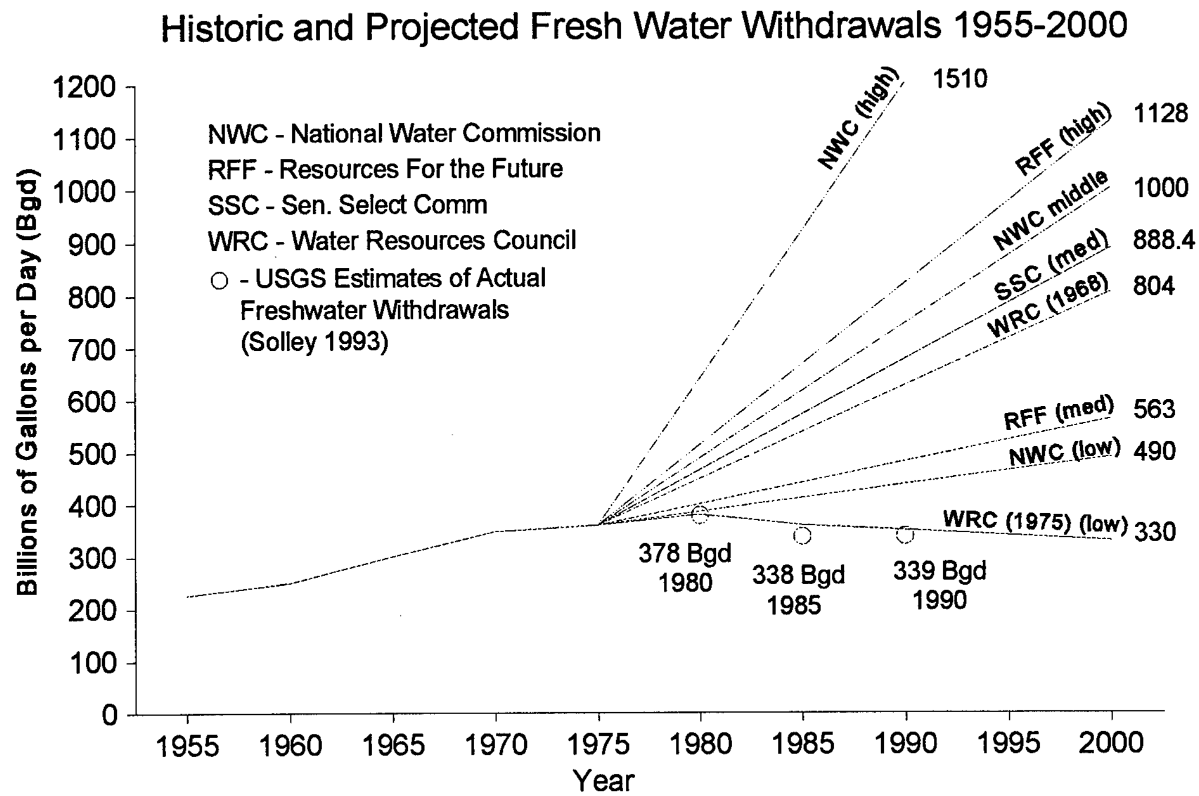
Fifty percent of all **water supply** utilities asked their customers to reduce consumption during the 1988 drought (Moreau, 1989). In a 1990 poll, forty-one percent of U.S. mayors anticipated water shortages in the next several years, caused by drought, growing population, water pollution, and leaks from distribution lines. (Conserv90, 1990).

Other national studies have warned of potential water shortages by comparing the safe yield of water systems to *per capita* projections of water use. (U.S. WRC, 1978). **Figure 5** shows that the national commissions have, in the past, forecasted sharply increasing water use. These forecasts were based on fairly simple assumptions.

The reality is that nationally, the quantity of freshwater withdrawn is less than it was in 1975, although municipal and industrial water use has increased somewhat. The national studies did not take into account very important factors such as the impact of water pollution control regulation on industrial and thermoelectric power cooling uses, nor of technological developments which made water use more efficient in a number of industrial processes (Stakhiv, 1989). In fact, it can be argued that with the enactment or revision of several impending environmental protection laws (the Safe Drinking Water Act, Energy Efficiency Act, and Clean Water Act), the trend towards more effective use of water will continue and that overall water use in the U.S. will stay about the same or decline, even as population grows.

Nearly half the governors asked by the National Drought Study said they expected **agricultural** impacts from drought, but this was primarily in the area of dryland farming. Agriculture thrived despite the drought in California until 1991; the net loss that year in agricultural benefits across the U.S. because of the California drought is estimated to be about $80 million (IWR, 94-NDS-10). Navigation losses in 1988 were estimated to be about $1 billion (Riebsame, 1990). Lost **hydropower** can often be replaced with power from other sources, but it is generally more expensive and causes more air pollution. The 1988 drought caused an estimated $200 million increase in the cost of energy production (President's Interagency Committee, 1988), but that cost continued to climb in California. During the six year California drought, electric power customers paid an additional $3.8 billion (IWR, 94-NDS-6) to replace electricity generated at hydropower plants with power generated by thermal plants. The increased use of fossil fuels

Figure 5. Past national assessments of future water use did not account for the effects of recent environmental legislation. Figures at right show projections for 2000 (Stakhiv, 1989).



also worsened air pollution, and the discharge of cooling water from the thermal plants caused increased stream temperatures, a hazard to some species of fish.

Many reaches of large rivers that routinely produce walleye, northern pike, and yellow perch were dry in 1988 (IWR, 93-NDS-5) and the drought affected public use of beaches, boat ramps, and boat docks. Many observers felt that the most severe drought impacts were **environmental** (Riebsame, 1990; IWR, 93-NDS-5) but the cumulative stress on an ecosystem is difficult to judge (Riebsame, 1990).

Several states reported that **water quality** was impaired because low flows affected their ability to dilute effluents from wastewater treatment plants (IWR, 91-NDS-1).

Several cautions apply in interpreting the seriousness of these impacts:

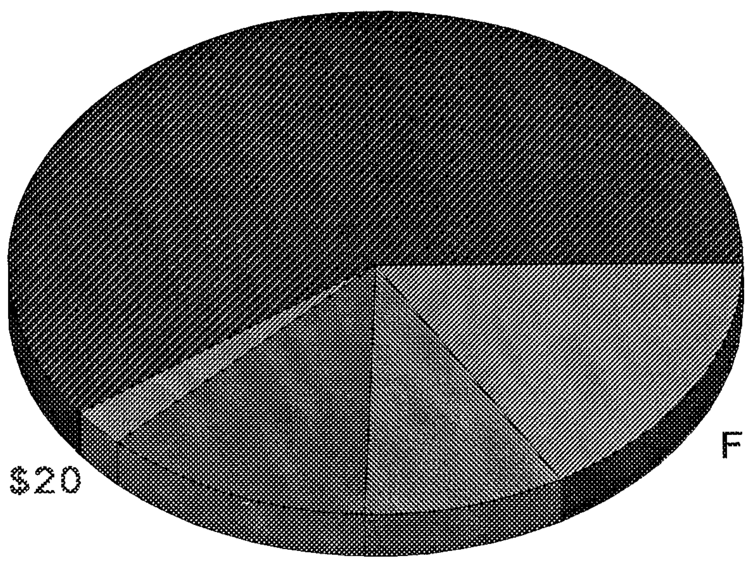
- Drought impacts are generally reported as reductions from the benefits a water system can support when water is plentiful. Comparing system outputs during droughts and normal conditions can overstate the problem, however, because at least some of these temporary reductions could be eliminated only by much larger long term economic and environmental investments in the water system. Just as the impacts of a Thanksgiving weekend traffic jam do not necessarily justify a wider highway, drought impacts do not necessarily justify increases in the safe yield of water supply systems. **Figure 6** shows the "normal" distribution of economic benefits that the Missouri River Main Stem reservoir system can generate during times of normal precipitation. If long term investments are not made, in some cases the impacts in one category of water use (such as recreation or domestic consumption) could be reduced only by imposing greater impacts in another area of water use. The third step in the Drought Preparedness Study Method (Describe the Status Quo, page 34) is borrowed from traditional strategic water resources planning. It is designed to reduce confusion surrounding the estimates of drought impacts by forcing a comparison between current and proposed *drought* management alternatives, rather than allowing comparison of drought to non-drought conditions.

Impacts caused by drought are difficult to separate from impacts that occur coincidentally during a drought. Because droughts continue for much longer than floods, earthquakes, or wind storms, external factors (such as recessions, market changes, land management, and fishing practices) may also contribute to the impacts associated with drought.

• Regional drought impacts can be offset at the national level, by gains in production somewhere else in the country. The economic impacts (the reduction consumer and producer surplus) of the drought to agriculture in California was estimated to be about $276 million, but the effect nationally was only $80 million because of the offsetting increases in other parts of the country (IWR, 94-NDS-10). Industrial losses may also be largely offset by production gains elsewhere. The benefits provided by navigation, recreation, and power facilities may be offset somewhat, but there is generally an economic penalty in using alternative sources (IWR, 94-NDS-9).

Despite the overestimation of impacts induced by these factors, the level of conflict and anxiety droughts stimulate is still apt to be far greater than the magnitude of impacts would suggest. Economic damages from the California drought (**Table II**) were small except for those related to the reduction in hydropower production, and the power industry saw the reduction as an inevitable and acceptable cost of harnessing the energy in the hydrologic cycle. Most observers believed that environmental damages were more important, but they were difficult to measure and ascribe to just the drought. Despite all this, the drought was newsworthy for years and played a significant role in the passage of new state and new federal laws, including new federal legislation concerning the allocation of water from the Central Valley Project (IWR, 93-NDS-5). The California experience is not dissimilar from the experience on the east coast as a result of the drought of the

Figure 6. Average annual economic benefits from the Missouri River Main Stem Reservoirs, in millions of dollars (Corps of Engineers, MRD, 1990).



1960's. Then President Lyndon B. Johnson intervened to help avoid a threatened reduction of streamflow from New York to Pennsylvania that could have caused saltwater to enter Philadelphia's drinking water supply during that drought. The crisis spurred changes in Federal water resources planning procedures (Holmes,1979), introducing the multi-objective approach associated with the Harvard Water Program (Maass, 1962). Nonetheless, the actual economic impacts of that drought were also relatively small (Russell, 1970).

Observations of droughts in the 1980's suggest that turmoil will be greater when the losses are felt more personally and when long term entitlements to water use are threatened.

III. The Current State of Water Management During Drought

A. Existing Drought Response Plans and Measures

There were many drought plans in place before the 1988 droughts. The plans were prepared by different levels of government and by private utilities. Plans sometimes overlapped each other geographically, each plan with its own assumptions, objectives, and decision rules. Coordination, collaboration, and communication among the various entities responsible for water management during drought was not as effective as it could have been (Grigg, 1988; GAO, 1993). The most common types of plans were these:

- *Utility Responses.* A utility may be small or large, a public or private corporation or part of a city government. Power utilities, especially those that produce or market hydropower, also have to adjust their operations during drought. About half of all urban water supplies in the county were adversely affected by the 1988 drought. About half of all utilities had drought contingency plans in place before 1988 (Wilhite, 1990). Although they vary considerably in detail from one utility to another, drought contingency plans generally follow similar forms throughout the country, namely a sequence of increasingly stringent steps to augment supplies or reduce demands. Within this format there is a wide variation in the number of steps in the sequence, the kinds of triggering indexes (if any), and expected responses to each step.

- *State Level Responses.* State drought responses take several forms. State water law, especially in the west, helps establish priority of use for water (along with Federal laws and legal concepts such as the public trust). States may also have water quality regulatory responsibilities that affect drought operations.

State drought plans are a relatively new concept. In 1982, only New York, Colorado, and South Dakota had plans (Wilhite, 1990). By the beginning of the National Drought Study, more than half the states had drought management plans (IWR, 91-NDS-1). Some of these plans are more concerned with impacts to dryland farming than water management. In general, state plans are designed to monitor and distribute information and make recommendations concerning responses to the governor. In the west, that response can include the condemnation of water rights, but this power has never been used (WSWC, 1986).

- *Basin and subbasin plans.* The Corps of Engineers, the Bureau of Reclamation, the Tennessee Valley Authority, and the California Department of Water Resources, as well as basin authorities such as the

Delaware River Basin Commission and the Susquehanna River Basin Commission each have plans for drought response. Stimulated by recent drought experience, all Corps of Engineers reservoirs now have written drought contingency plans. The recent drought in California led to the repeal of the Warren Act, allowing the Bureau of Reclamation to use its storage and conveyance facilities more effectively to reduce drought impacts (IWR, 93-NDS-5). In the 1988 drought, TVA acted quickly to establish temporary water use priorities, monitor water quality, organize state task forces; and coordinate releases to supplement flows in the lower Ohio and Mississippi Rivers (IWR, 91- NDS-1). The TVA Management Task Force facilitates information flow among agencies (IWR, 91-NDS-3).

B. Shortcomings of Existing Plans

Overall management inadequacies identified during the first year of study include:

- management responsibilities for problems that are physically integrated in a river basin are fragmented by agency missions and political boundaries;

- the many disciplines required to analyze drought problems and develop and institute solutions do not work together as well as they should;

- lessons learned during ongoing droughts are too rarely documented, critically reviewed, and shared with other regions;

- water is almost always priced below its economic value to users or full cost to produce;

- information about expected drought severity and duration is not readily available, so risks cannot be quantified;

In a survey of Corps offices at the beginning of the National Drought Study, the impediments to successful drought management that were rated "serious" most often were the lack of techniques for evaluating social, institutional, and political impacts of water shortages, and difficulties of using those impacts as criteria in defensible management decisions.

Typical problems with traditional drought plans include (IWR, 91-NDS-1):

- they may not recognize newer uses of water

- they are usually designed for the drought of record, without consideration of the rarity of that drought

- they often are not understood or endorsed by those who will suffer the impacts of the drought

- they may not sufficiently address equity issues or economic differences in the use of water

- they are often triggered by indicators not related in a known way to impacts.

• they are better characterized as documents rather than ways of behaving, and so their effectiveness diminishes as staff changes occur and time passes between plan preparation and drought.

C. Long term water allocation and drought

Managing Water During Drought (IWR, 94-NDS-8) divides the ways of dealing with drought into strategic, tactical, and emergency measures.

Strategic measures are long term physical and institutional responses such as water supply structures, water law, and plumbing codes. *Tactical* measures, like water rationing, are developed in advance to respond to expected short term water deficits. *Emergency* measures are implemented as an *ad hoc* response to conditions that are too specific or rare to warrant the development of standing plans.

Estimates of the physical capacity of systems to respond to droughts (and the value of improving that capacity) should be based on an evaluation of both strategic and tactical measures.

D. Allocating water among competing activities during drought.

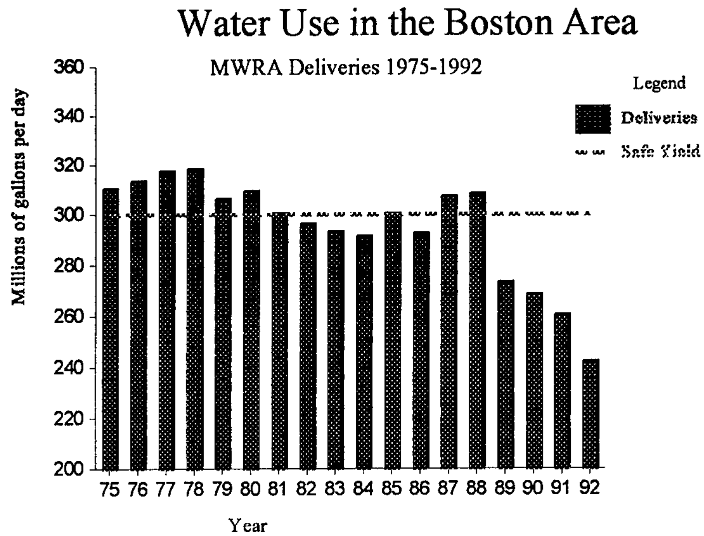
The Report on the First Year of Study (IWR, 91-NDS-1) described the hierarchy of rules for making these allocations: the U.S. Constitution, treaty, law, policy, and practice. Laws include state laws governing the right to use water, and federal and state regulations concerning its use. Policy and practice include drought contingency plans, and reservoir allocations and operating policies.

In some **strategic** water resources planning efforts, such as federal feasibility studies, a conscious effort is made to allocate water according to the overall goals of water management such as environmental quality, economic efficiency, and equity. Methods for managing water for multiple objectives have been developed and tested over decades, but that tradition resides in the agencies that build federal dams, not in the organizations responsible for preparing **tactical** plans.

Other approaches to long term allocation were not designed to effect the broadest benefits or limit impacts, making it difficult to institute drought response measures that do. Allocation of surface water in western states is based on the level and starting date of rights holders use. Basic riparian law limits allocations that inflict harm on other riparian users, but it has no inherent mechanism that encourages the highest economic or environmental use of the water. The right to pump groundwater in most of the United States has been based on the rights of land ownership. However, there are trends in all of these systems to reflect concerns about the impacts of water use.

In states in which the right to use water is based on prior use, junior water users may receive no water during a drought, while senior users receive full deliveries, no matter the economic, social, or environmental consequences of that allocation. New laws, regulations, and innovative drought response programs have changed this to some extent (see page 21 for a discussion of trends in water law and allocation). Water markets are increasingly being used to buy, sell, and lease water rights (MacDonnell, 1989). In a pure market, water would be allocated according to users willingness to pay, a reflection of the relative worth of the impacts of shortfalls in water deliveries to users. But unless represented by governmental or private buyers, broad public values in water use may be under-represented in an unregulated market allocation.

Figure 7. *The* ***Greater Boston Metropolitan Area*** *dramatically increased the reliability of water system through conservation. Safe yield is at about 98% reliability.*



E. The need for additional structural capacity.

The determination that more water storage or distribution infrastructure is needed can be realistically be made only through regional water supply studies, but some of the work done as part of the National Drought Study provides general insights on how communities address the question.

Santa Barbara, California, tried, but was unable, to expand its water supplies as its population grew. Many feared that abundant water would draw too many people to the area. In fact, growth continued despite the limits on water, and when a drought hit Santa Barbara in 1987, the city had to use water police to enforce up to 45% reductions in water use. Water from the state and a new desalting plant built at the end of the drought eventually provided additional capacity, but at great expense and too late to mitigate most of the drought impacts (IWR, 93-NDS-5).

Long term demand management will not necessarily reduce drought vulnerability. It will help in the Boston area, which had been delivering more water than the safe yield of its water system for many years. ("Safe yield" is defined in traditional probabilistic terms (page 5). MWRA defines safe yield as the minimum amount of water that could be delivered based on the rate that water flowed into the system from October 1949 to September 1980. This period includes the 1960's drought, the most severe drought in Boston's record (IWR, 94-NDS-9). During a more severe drought, the water system could not deliver 300 mgd.) The vigorous water conservation campaign Boston has pursued reduced water use well below the safe yield, which means that drought responses will be necessary much less often, if at all (**Figure** 7) (IWR, 94-NDS-9). Moreover, because of the size of Boston's Quabbin Reservoir relative to average annual inflows, water savings can be carried over from wet to dry years. Thus, the amount of water in storage at the beginning of a drought will now likely be greater than it would have been without conservation.

Ironically, some of the most common long term water conservation measures will likely increase drought vulnerability. If the amount of water used per person in toilets, showers, and outdoor use is permanently reduced to allow more people to share a fixed supply of water, increases in efficiency will not yield as great a savings during drought.

F. Legal and institutional issues

Law sometimes drives and sometimes constrains water management during drought. The National Drought Study identified the areas where the law was changing or needed to change to allow better water management during drought (94-NDS-14). Because state water laws and regulations are so important in water allocation decisions, conditions vary from state to state. Nationwide, though, eight issues were identified as most significant.

1. Site Specific Programs

The trend of water law both in the east and the west is to apply new, improved approaches to specific geographic areas where problems are sufficiently obvious to warrant political action. In Virginia, recent statutes allow the State Water Control Board to designate management areas within which restrictions may be imposed to meet emergency conditions. Indiana, North Carolina, South Carolina and New Jersey allow restrictions on groundwater use in specific areas. In the west, the Arizona Groundwater Management Act establishes special use restrictions in certain areas.

2. Quantification of Water Allocations

Many senior tribal and federal water rights are recognized in principle, but no amount has been set in an adjudication process. Some western states are taking steps to adjudicate existing water rights in order to determine how much water is really needed. The threat of adjudication - an expensive establishment of a fixed, quantified right to use water - often spurs negotiated accommodation during drought.

3. Public Trust Doctrine and Instream Flows

The full extent of the public interest in water is not always recognized by water allocation decisions. The public trust doctrine holds that the sovereign government retains ultimate control of the water resource to serve public trust purposes, which may include recreation and ecological values associated with instream flows. The public trust doctrine has been explicitly recognized in some form in nine eastern and western states. In California, a court decision requires California water managers to take the public trust into account in the planning and management of water resources.

In most states, instream flows are, to some extent, explicitly protected (IWR, Installation Water, 1994). A 1989 survey lists eight western states with instream flow laws, and four which protect instream flows by means other than allocation. In the east, many states have authorized agencies to establish minimum stream flows or water levels.

4. Water Conservation

Basic appropriations doctrine discourages water conservation, because water not put to beneficial use may be lost. But California and Oregon have enacted salvage laws which allow conserved water to be used for other purposes or conveyed to a third party. Utah courts have come to the same conclusion. Water marketing or water banking may also have the effect of encouraging conservation by allowing users to transfer their conserved supplies to others. Some western states, such as California, have passed new laws protecting the rights of users who use less water during drought and transfer the water saved to others. Sixteen eastern states have legislation recognizing the need to conserve water supplies.

5. Transbasin Diversions

Diversions are strategic measures designed to increase water supply reliability. During a severe drought, if the necessary facilities exist and the state law allows, temporary interbasin diversions may be authorized to meet the needs of the most severely affected areas.

A number of eastern states have altered the riparian law prohibition against such diversions, allowing transfers in certain limited situations, consistent with the public interest.

Basic appropriation law does not limit transbasin diversion of water, but several western states do limit such diversions due to the adverse impacts to the exporting area. The trend in the law is toward allowing some transbasin diversions, but applying specific restrictions on them.

6. Groundwater Law and Conjunctive Use Management

In most states, allocation of ground water is handled differently from surface water (Blomquist, 1991). In some states there is no provision at all for state allocation of ground water. This may prevent the most effective conjunctive use of ground and surface water for droughts. Only two states in the east have expressly provided for conjunctive surface and groundwater management. The main development of conjunctive use management in the west has been on

■

New laws and recent court rulings have accelerated a trend in the West to accommodate efficiency and environmental quality within the framework of the appropriation doctrine.

■

■

In most states, allocation of ground water is handled differently from that of surface water. This complicates the preparation of drought plans which should provide for most effective use of ground and surface water combined.

■

an incremental, site-specific basis, rather than a statewide program.

G. Lessons Learned from the California Drought (1987-1992).

The full value of the experiences of those who have survived a severe drought can be realized only if the lessons are recorded, critically analyzed, and communicated to others who can use the information. The National Drought Study's investigation of the California drought (IWR, 93-NDS-5 and 94-NDS-6) was designed to achieve those ends.

The lessons learned study captured the views of some 100 key members of the California water community representing 57 organizations. The participating organizations represented federal, state, regional, and local water supply agencies as well as environmental, private, and governmental entities that influence water management in the state.

The approach to identifying the important lessons of the drought consisted of three research activities:

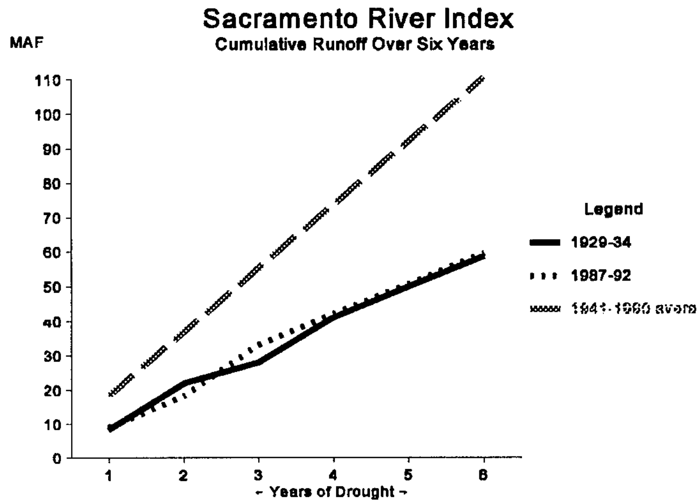
- literature review of published and unpublished documents

- field interviews, and

- critical review of the draft findings by survey participants and other water professionals.

The study team identified nine lessons learned (**Table IV**).

Figure 8*. Two Six Year California Droughts of the 20th* Century



1. Magnitude of this drought

The 1987-1992 drought was not "the big one". In terms of streamflow, it was very similar to the 1929-1934 California drought (**Figure 8**), and it was never as intense as the 1976-1977 drought. Nonetheless, it held the attention of the media and politicians for years.

2. Impacts

According to many observers, including the California Department of Water Resources (1991), it was likely that the most severe impacts of the drought were suffered by the environment. Environmental problems, such as high stream temperatures recorded in the Upper Sacramento River, began during the first year of drought. The impacts of the drought on the environment consisted of a pronounced effect on

TABLE II. ESTIMATES OF REVENUE LOSSES IN THE HARDEST HIT INDUSTRIES

Sector	Duration	Loss ($)	Percent Decline in Sector Activity	Study
Agriculture	1991	250 million	1.4%	CDWR, 1992
Green Industry	1991	460 million	7%	NDS-10
Hydroelectric Power	1987-1992	11 billion	39%*	CDWR, 1991 U.S.E.I.A., 1993

* - the percent decline in hydroelectric power production compared to a "typical" year. Consumers spent $14.8 billion to replace this loss in hydropower with electricity produced by other sources, a net replacement cost to consumers of $3.8 billion.

fisheries and aquatic resources, particularly species such as salmon.

The economic losses of the six-year drought are difficult to quantify because only limited data are available, and it is difficult to separate drought impacts from other occurrences such as the simultaneous recession in California. **Table II** shows losses in *revenues* to agriculture, landscaping and hydropower. Estimates of lost economic *benefits* (i.e., the reduction of consumer and producer surplus) were $276.3 million in agriculture in California ($80 million nationally due to increases in production elsewhere in the country) and $3.8 billion in energy because lost hydropower was replaced by more costly sources.

The impacts on individual households were primarily behavioral, and to a lesser extent economic. A small study of residential economic impacts in the Los Angeles and San Francisco Bay area (IWR, 94-NDS-10) estimated drought impacts to be about $500 million in 1991 for each of the two areas, less than five dollars per week per household in the San Francisco Bay area and less than two-and-a-half dollars per week in the Los Angeles region. About 90% of estimated costs result from replacing dead landscaping, purchasing water conserving irrigation fixtures, and xeriscaping (IWR, 94-NDS-10).

3. Responses

During the first two years of the drought, a mixture of voluntary and mandatory conservation in California's cities reduced water use from 10 to 25%. In the last three years of the drought, urban conservation efforts were generally more intense.

Urban water use adjustments included rate increases for the industrial and commercial sectors, and water-conserving life-style adjustments for the residential sector.

On February 1, 1991, Governor Pete Wilson signed Executive Order No. W-3-91 establishing a State Drought

Emergency Water Bank to meet critical water needs, a major innovation. It created a voluntary market for the transfer of water on an economic basis.

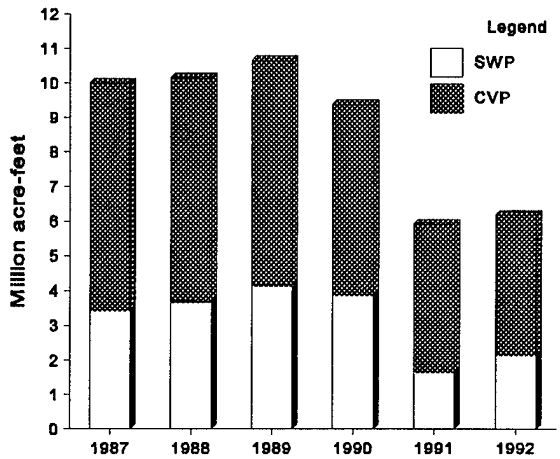
Because of the extensive water storage and distribution investments in California, the State Water Project (SWP) and Central Valley Project (CVP) did not reduce water deliveries significantly until 1990 (**Figure 9**).

New federal and state legislation reduced institutional impediments to drought response. In 1991, the U.S. Congress repealed the Warren Act, which had prohibited the transport of non-CVP water in Federal aqueducts, and the California legislature passed Water Transfers (called AB 10x), which declared that temporary transfers of water for drought relief would not affect any water rights. These change made the Water Bank much more successful.

The most important legal change came as the drought was ending: the CVP Improvement Act of 1992 (U.S Public Law 102-575), reallocates an estimated 800,000 acre-feet of California's developed water from off-stream to in-stream uses. It is unlikely the bill would have passed if the long drought did not engage the media and public in a debate on the equity of California water allocation since it was vigorously opposed by the agricultural community.

Many of the lessons learned are valuable, but intangible in nature, and can be assigned to the rubric of wisdom and experience; that is, mistakes that should not be repeated. Others reaffirmed conventional

Figure 9 *Deliveries, SWP - CVP, 1987-1992*



wisdom associated with decisions and practices in previous droughts. Most important are the many tangible, long-lasting changes that were made in California's water management institutions as well as those of the Federal government. **Table III** lists the major federal and California laws that were changed as a result of the drought.

There was also an overarching realization that California's vast water storage and distribution network made many of the long-term structural and institutional changes possible. Water banking, storage for instream flow maintenance, conjunctive use of ground and surface water, regional interdependence, and economies of scale require a water storage, allocation and distribution system. The existing system provided the flexibility and resiliency to withstand severe droughts, even in the face of rapidly growing populace and increasing urban and environmental demands on a fixed supply of water. **Table IV** summarizes the lessons learned.

TABLE III. MAJOR STATE AND FEDERAL LEGISLATION PASSED DURING THE DROUGHT

Year	Month	Legislation or Agreement	Government
1988	Apr	**Drought Emergency:** Declared by CDWR	California
	Aug	**Federal Disaster Assistance Act of 1988:** Enables Secretary of the Interior to assist temporary water transfers.	Federal
1989	Jan	**Assembly Bill 982 (AB 982):** Expedites procedures for temporary water transfers.	California
1991	Feb	**Executive Order W-3-91:** Established a Drought Action Team, the Water Bank, community rationing plans, urban water conservation, and alliances with environmental groups.	California
	Apr	**H.R. 1281 Dire Emergency Supplemental Appropriations (Pub Law 102-27):** Appropriates $25 million in drought relief funds for Western States.	Federal
	Jun	**1902 Reclamation Act Revisions (H.R. 355):** Repeals **Warren Act**, which prohibited conveyance of nonproject water. Bars delivery of subsidized water to farms over 960 acres. Farmers receiving Federally subsidized water will pay delivery costs.	Federal
	Dec	**Memorandum of Understanding:** Agreement between Urban and Environmental interests groups. Developed "Best Management Practices" for Urban Water Conservation.	California
		Water Transfers (AB 10x): Declares temporary transfers of water for drought relief will not affect any water rights	California
		Urban Water Management Plan (AB 11x): Requires Urban water suppliers to prepare and submit an urban water shortage contingency plan. Non compliance disqualifies suppliers from State drought assistance.	California
		Water Resources (AB 16x): Authorizes the State Water Resources Control Board to adopt drought response emergency regulations for 270 days without Office of Administrative Law approval.	California
1992	Dec	**CVP improvement Act of 1992 (U.S. Pub Law 102-575):** Reallocates 800,000 acre-feet annually from off-stream to in-stream uses (fish and wildlife), develops water transfer provisions.	Federal

TABLE IV. LESSONS FROM THE 1987-1992 CALIFORNIA DROUGHT

- The complexity of impacts of a sustained drought demands more sophisticated planning. For example, reduced hydropower production means more thermal power must be used. That creates higher fuel costs, but it also increases air pollution and thermal pollution of streams.

- Severe drought can change longstanding relationships and balances of power in the competition for water. The CVP Improvement Act of 1992 (U.S Public Law 102-575), which has been called one of the most important pieces of environmental legislation ever passed, was vigorously opposed by the agricultural community. The drought created the political support for the radical change by prompting a shift in urban support from agriculture to the environment.

- Irrigation can provide complementary environmental benefits. For example, flooded California rice paddies were used to provide habitat for migrating wildfowl.

- Drought can convince communities to accept water management options that are not seriously considered during normal years. Santa Barbara built a desalting plant and voted to use State Water Project supplies; neither had been accepted before the drought.

- The success of drought response plans should be measured in terms of the minimization and equitable redistribution of the impacts (as opposed to simply alleviating shortages), but there is much to be learned about the best ways of accomplishing this goal. Most drought response rules satisfy the rights of different users or try to reduce water deliveries equally to all users, no matter the value of water to each user. The water bank, on the other hand, created a market that allocated water according to its value to users.

- Severe droughts can expose inadequacies in state and federal water institutions, causing significant institutional and legal changes. The repeal of the Warren Act (federal) and the safeguarding of water rights in water banking (state) are two significant examples of this.

- Increases in water rates should precede or accompany rationing plans. California utilities reported that water users reacted more favorably to concurrent increases and drought declarations than to price increases announced after months of conservation. Also, since almost all utility costs are fixed, starting price increases and curtailment at the same time reduces revenue shortfalls.

- Mass media can play a positive role in drought response, but water managers should be involved in designing the message. The media will try to answer the public's simple questions ("when will the drought be over?"). Water managers must accommodate that need for bottom line information, but must assure that the media does not mislead through oversimplification.

- Market forces are an effective way of reallocating water supplies. The Water Bank was generally considered a success by agriculture, the cities, and environmental groups.

IV. A Framework for Drought Planning and Management

The first year of the drought study was devoted to an analysis of problems and a collaborative search for measures that could be implemented to improve the nation's readiness for drought. The Report on the First Year of Study (IWR, 91-NDS-1) made three recommendations:

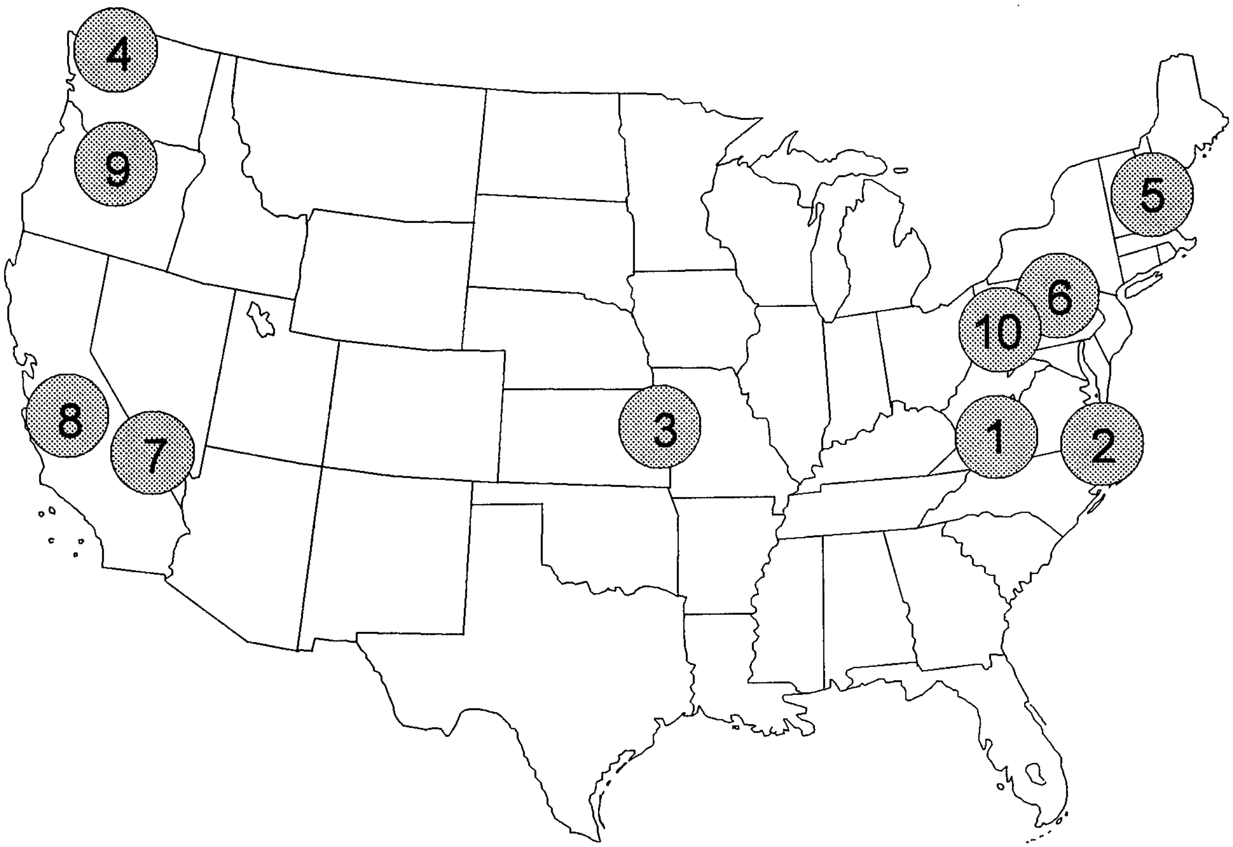
• **Test and refine a model approach to drought preparedness in case studies across the country**. The model approach was developed during the first year after water agencies, stakeholders, and water experts reported on the strengths and shortcomings of drought plans and responses by utilities, states, and reservoir operators.

• **Produce a National Drought Atlas.** Drought plans are typically designed in response to the drought of record. But the eastern United States was in crisis in the 1960's because when a drought larger than the drought of record occurred. The expected frequencies of droughts that large had been, at best, very difficult to estimate statistically. And in practice, the data, skills, and methods were often insufficient to develop the estimates. The National Drought Atlas was proposed to provide a national reference for precipitation and streamflow statistics. The Atlas takes advantage of recently refined national databases and a new statistical method that reduces the probable error in estimating the expected frequency of long duration droughts.

• **Conduct topical studies on issues such as water law, institutions, and negotiation**. A review of case histories, scholarly papers and the studies and workshops of the National Science Foundation, the Western States Water Council, the International Drought Information Center, and the Interstate Council on Water Policy all indicated that water law, the cooperation and communication among government agencies, and the successes and failures of alternative dispute resolution should be studied to see how these areas could contribute to better drought responses.

The primary contribution of the National Drought Study is the **DPS method**, described on the next few pages. The **Atlas** (page 40) is a tool that will help water managers answer questions about the probable location, duration and severity of future droughts. Results of the **topical and special studies** (page 43) informed the development of the DPS method and can be used in future drought preparedness studies.

Figure 10. *Case Studies Conducted During the National Drought Study*



Four river basins were chosen to test and refine the "DPS Method" of managing water during drought. In addition, smaller studies were conducted in the Boston and Harrisburg areas. The National Drought Study collaborated with a team of western universities on a gaming exercise in which the Colorado River States experienced a severe (computer simulated) drought. The DPS method is now being tested on low budget preparedness efforts at two Corps lakes (9 and 10).

1. Kanawha River DPS (WV, NC, VA
2. James River DPS (VA)
3. Marais des Cygnes-Osage Rivers DPS (KA-MO)
4. Cedar-Green Rivers DPS (WA)
5. The Boston Area (MA)
6. Susquehanna River Basin (PA)
7. Colorado River (7 states)
8. California (Lessons Learned, Impacts from the Drought)
9. Rogue River, Lost Creek Lake (OR)
10. Youghiogheny River Lake (PA)

A. The DPS Method

Bad water management often occurs when facts are confused with values, when means are confused with ends, and when technical judgments are made by citizens and politicians while value judgments are made by scientists and professionals.

- William B. Lord (Water Resources Bulletin, 1984)

The real need is to institutionalize drought management into improved overall water management systems.

- Conclusions from a National Science Foundation Drought Water Management Workshop, February 1990 (Grigg, 1990)

Efforts to deal with water geographically typically encounter strong resistance from bureaucracies that are functionally organized for different purposes.

- Peter Rogers (America's Water; 1993)

The NSF workshop participants concluded that attempts to understand and address drought problems will be unsuccessful unless shortcomings in the larger context of water management are also understood and addressed. This was also one of the conclusions drawn by the Corps of Engineers in the first year of the National Drought Study (IWR, 91-NDS-1), and the premise upon which the DPS method was built.

The DPS method is derived from techniques of multiobjective, multipurpose water resources planning first established during the Harvard Water Project and refined by experience in federal water project planning. These well founded techniques were adapted for use in situations which the federal government plays a smaller role and the solutions are much more likely to be non-structural. The strength of the DPS Method is not that it includes so much that is new, but that it makes practical and whole what is well regarded in theory. Undergirding the well established planning, evaluation, and implementation steps is the innovation of the shared vision model, a method of visualizing future droughts that would have been impossible before recent advances in personal computers. Hence, as conceived in this study, Drought Preparedness Studies:

- are joint efforts requiring intergovernmental cooperation with those who have a stake in how water is allocated and used.

- constitute a more general version of the planning methods and evaluation principles of federal water resources planning principles (U.S.WRC, 1983).

The first year study recommended testing a drought preparedness method based on principles for multi-objective water resources management.

TABLE V. THE SEVEN STEPS OF THE DROUGHT PREPAREDNESS METHOD

1. Build a team and identify problems.
2. Develop objectives and metrics for evaluation.
3. Describe the status quo; that is, what will happen in future droughts if the community does nothing more to prepare itself?
4. Formulate alternatives to the status quo.
5. Evaluate alternatives and develop study team recommendations.
6. Institutionalize the plan.
7. Exercise and update the plan and use it during droughts.

- accommodate the extensive responsibilities of state, regional, and local entities in drought situations.

- are results oriented. Reports and written plans are by-products of behavioral changes that reduce environmental, economic, and social impacts from drought.

- take advantage of experience, research, and expertise from across the country.

- integrate long and short term responses.

- are dynamic, because plans are exercised in regularly conducted virtual droughts

Although a DPS is a joint cooperative effort between interested parties, it needs a sponsor to provide funding, and a leader to initiate it. The leader must assure that appropriate state officials, regional agencies, and important municipalities are adequately represented on the working group, as well as important industrial, commercial, and public interest groups. The DPS approach to drought management is distinguished by being a joint collaborative approach by Federal and non-Federal agencies, designed to recognize the inherent responsibility of different levels of government in solving the complex problems of drought management. A DPS is conducted through seven steps (**Table V**), applied in an iterative fashion.

Step 1: Build a team and identify problems.

There is a natural, physical integration of water problems in a river basin; the challenge is to assemble a problem solving team that can work with a corresponding wholeness. The first step in the DPS method was designed to overcome two common shortcomings in water management: the separation between stakeholders and the problem solving process, and the subdivision of natural resources management by political boundaries and limited agency missions.

In a DPS, water managers and stakeholders work together to specify problems and develop solutions. Compared to the more common approach in which water managers develop plans and then present them to stakeholders in public meetings, this collaborative approach:

- harnesses the knowledge and creativity of stakeholders near the beginning of problem solving efforts;

- makes it more likely that stakeholders can take actions unilaterally to reduce their drought vulnerability;

- builds broader, deeper stakeholder support for water management plans.

Water managers do not surrender their responsibility or authority because of this collaboration. In fact, water management decisions are less likely to be challenged (and overridden) if managers develop public understanding, input, and support prior to the drought.

Broadening study participation may also pose some problems:

- money spent on public involvement is not available for technical studies.

- the "public" that gets involved in planning may be self-selected and unrepresentative of the public that will be affected by drought.

- the more the public is actually involved in the study process, the more effort may be required to provide technical training and to coordinate the work of public task forces.

- the misapplication of the techniques of group process can result in the use of stakeholder opinions on issues that should be addressed by experts.

- broader citizen participation increases the risk that planning will be slowed or stopped.

- there may be insufficient interest in these problems between droughts to attract stakeholders to a planning effort.

In the DPS, a simple approach called "circles of influence" (see page 47) was used to balance effectiveness and representativeness, and it worked well. This approach is built on the common themes in three very different examples of organizational effectiveness (none water related) and is consistent with research on how people work together well.

Rarely will there be one agency or political entity whose responsibilities include all the problems a region will face during future droughts. The DPS team constitutes a new, integrated community that more closely mirrors the integrated nature of the problems.

Step 2: Develop planning objectives and metrics for evaluation of alternatives

A successful DPS team will reduce drought impacts through the implementation of their recommended measures. But what makes one plan better than another? And what criteria will those who must approve the plan demand that it meet? Until the DPS team identifies the criteria that define a successful study, they cannot manage to succeed.

Developing good planning objectives early is paradoxically the most important and most often ignored step in the planning process. How can a team manage to achieve objectives if they have not agreed on what those objectives are? The DPS method uses five management parameters including the ***criteria*** decision makers will use in approving or rejecting new plans, ***planning objectives***, ***constraints***, ***measures of performance***, and environmental, economic, and social ***effects***. ***Planning objectives*** are concise, formally structured statements which explain how and when a study will try to affect a specific water use in a specific place (for example, "*increase the reliability of recreation on Lake Lanier during drought*"). ***Constraints*** are natural system or legal boundaries that limit operational alternatives, such as required minimum flows. ***Performance measures*** and ***effects*** are quantified indications of how well an alternative drought response plan addresses the decision criteria, planning objectives and constraints.

Performance measures are statistics concerning how often the system will achieve a designated state: for example; the percentage of time that navigation depths can be maintained at 8 feet, or the percentage of time that surface storage can supply water at the rate of 300 million gallons per day (see page 5 for an explanation of "safe yield" at a stated reliability). Performance measures track success in meeting individual planning objectives, but are less helpful in discriminating between alternatives that help one objective but hurt another. When changes in water management improve one performance measure at the expense of another, alternatives can be compared using the commensurable ***effects*** of plans. In water resources management, the most common commensurate outputs are economic efficiency and income, measured in dollars. Environmental and sociological effects are also commonly grouped, although there is no metric for either group that is equivalent to dollars.

Step 3: Describe the status quo

The status quo is simply a collective best estimate of what future droughts will be like without changes brought about by the DPS. In other words, it postulates a "business as usual" approach to problem solving and decision making. But the status quo does not mean that *nothing* is being done. In fact it must include all change expected outside the DPS, such as the effects of national legislation or recent water price increases. **Figure 16** shows, for

The success of drought response plans should be measured in terms of the minimization and equitable redistribution of the impacts of shortages, as opposed to the shortages themselves

Lessons Learned from the California Drought (1987-1992) (NDS-5) example, that new plumbing codes will substantially reduce water use, but an additional rebate program will have little additional effect. The costs of the rebate program should be compared to the improvement over the status quo, which includes water reductions caused by the change in plumbing codes.

The status quo serves as the baseline from which to measure the strengths and weaknesses of alternative drought responses (using the parameters agreed to in the previous step), and a consensus view of the problems stakeholders will face if they fail to agree on an alternative. This collective agreement on what the future holds unless the DPS team can find a better alternative is captured in a *shared vision model.*

Step 4: Formulate Alternatives

The DPS method assures that the formulation of alternatives is thorough, efficient, and directly related to the planning objectives.

The procedures for this step are designed to reduce the risk that a DPS team will overlook good alternatives, to assure that alternatives are formulated in an appropriate level of detail, and to recognize the influence of group dynamics on the formulation of alternatives.

Step 5: Evaluate alternatives and develop study team recommendations

In this step, the team compares proposed alternatives against the status quo, measuring how well they meet the objectives developed in step 2. Alternatives that do not measure up are eliminated or redesigned in an interactive process, until the team is ready to recommend a plan to decision makers.

This step is designed to produce a study team recommendation in a cost effective, defensible fashion. It begins with a quick screening of many alternatives using decision criteria, planning objectives, and constraints, and concludes with more detailed evaluation and tradeoff according to performance measures and economic, environmental, and social effects using the shared vision model.

Step 6: Institutionalize the plan

The DPS team constitutes a new, integrated community that more closely mirrors the integrated nature of the problemshed. But as the team's planning work nears completion, it must find a way to institutionalize that integrated problem solving approach so that it can outlive the DPS for use in the next drought. To do that, decision makers must approve the recommendations of the DPS team and agree to change water management institutions.

The attention early in the study process to the criteria that decision makers would use before accepting a recommendation from the study team is designed to minimize reformulation delays at this step.

The DPS will not be sufficient in itself to effect some recommendations, such as changes in the authorized purposes of existing Corps projects. The parties present can agree to support such a move; but the official action must follow the appropriate process.

In many cases either a formal or informal agreement between state and Federal agencies will be required.

Step 7: Exercise, update and use the plan

It is common wisdom that responses to emergencies such as fires, earthquakes, even floods will not work well unless they are exercised before the emergency. Perhaps because the onset of droughts is so much slower, "exercises" for drought responses are very unusual. But like other emergencies, drought plans are largely behavioral, and their success depends on people understanding their role, and knowing how their actions fit into a larger response.

Because drought response plans become outdated as water uses change in nature and quantity, exercises can also stimulate useful updates.

During the conduct of the four demonstration studies, Dr. Richard Palmer, a University of Washington researcher and the developer of the simulation model used in the first Potomac River drought exercise, suggested that the shared vision models and close collaboration among stakeholders in a DPS would make it possible to simulate a drought much more realistically than ever before. He suggested that the resultant ***Virtual Drought Exercise*** could be used in the years after a tactical drought plan had been designed to exercise a regional drought preparedness strategy. This would let agencies address new water uses and train new staff and stakeholders.

B. New Tools for the DPS Method

The DPS method takes advantage of several innovations developed in parallel during the National Drought Study: the shared vision model; Virtual Drought Exercises; the National Drought Atlas; water conservation management; Trigger Planning; and decision maker interviews and circles of influence. These are described on the following pages.

1. Shared Vision Models and Traditional Models

The phrase "shared vision" was applied to the computer simulation models used in the National Drought Study DPS's because the models were built, reviewed, and tested collaboratively with all stakeholders. The models represent not only the water system, but the effects of that system on society and the environment. Shared vision models do not necessarily take the place of existing, specialized models; they take advantage of new, user-friendly, graphical simulation software to bridge the gap between those specialized water models and the human decision making processes.

***Figure 11**. <u>Traditional models</u> are built from words assembled in a special computer language, so they can be understood (and hence reviewed and trusted) only by those who know the language.*

```
READ (5,1000) SUPPROCW
1000 FORMAT (180F5.3)
DO I=1,180
  IF SUPPROCW<20000 GO TO 20
  IF SUPPROCW<40000 GO TO 30
PRODUCT(I)=80000
```

***Figure 12** <u>Shared vision models</u> represent complex systems using a combination of diagrams and mathematical relationships. This diagram shows that production is a function of water supply.*

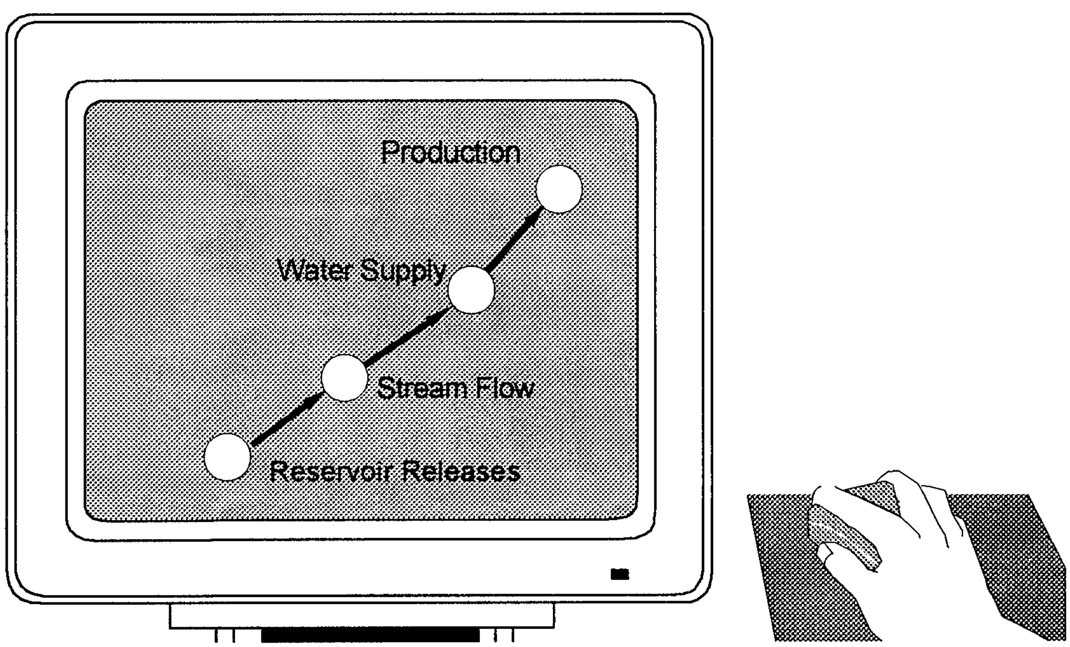
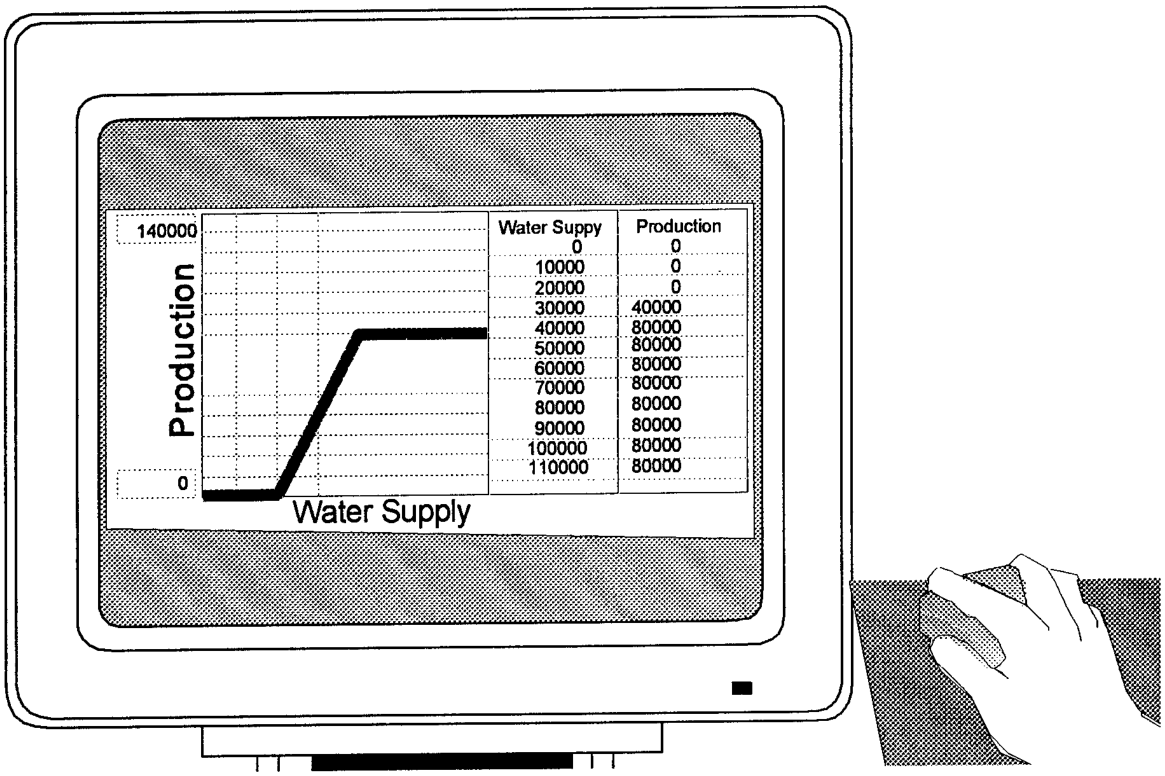


Figure 13. *Mathematical relationships can be defined using graphs and equations in another "level" of the shared vision model accessed by pointing and "clicking" on an object with the computer mouse.*



Because software is available now that is much more user friendly, simulation models of water systems can be built so that stakeholders and decision makers can use, understand, and trust them. This means that models can:

- be built much more quickly and inexpensively.

- be reviewed and tested for errors by more people.

- more easily be designed to suit the people who will use the models, rather than computer experts.

- be modified easily and quickly, and so are well suited to use in negotiating operating decisions after a broad group of people have examined a range of possible forecasts and plans.

- simulate both the hydrology and the important needs of water users.

In the language of diplomats and negotiators, the shared vision model becomes a *single text negotiating* reference, representing a set of assumptions that stakeholders agree on.

2. Virtual Drought Exercises

A Virtual Drought Exercise is a realistic simulation of a drought using the shared vision model. Anyone who has been close to the management of water during a drought knows that it is an extraordinary learning experience. The only problem is that the learning comes at the time of the disaster. Virtual Drought Exercises allow water managers and user representatives to simulate that experience without the risk associated with real droughts.

Virtual Drought Exercises can be used to exercise, refine and test plans, train new staff, and update plans to reflect new information. A Virtual Drought Exercise (VDE) is composed of:

- a facilitator, to explain the rules of the VDE and manage the time spent on negotiations.

- participants, namely the people who would represent water agencies and stakeholder groups during a drought

- a member of the press or a public affairs specialist to represent the needs and influence of the media

- the virtual drought; that is, data synthesized for the exercise, including forecasts, initial storage amounts, inflows, and demand variables. These data are not shared with the participants except as they are revealed during the unfolding of the virtual events.

- two versions of the shared vision model, modified for this specific application. The first is used by the facilitator to track the performance of the system as decisions are made. The second is used by the participants to estimate the impacts from alternative management decisions.

The first virtual drought was held in Tacoma, Washington on August 4, 1993. The exercise was configured as a one day workshop in which decision makers and stakeholders played their assigned roles in developing decisions on reservoir releases, minimum flow requirements, and the initiation of conservation efforts. It was well received by the participants and can be used as a model for other regions interested in exercising water plans.

3. The National Drought Atlas

One of the problems identified during the first year of the National Drought Study was the difficulty regional planners had in estimating the probable severity and duration of ongoing or future droughts.

This is a problem during an ongoing drought, because the best response to a short drought is usually not a good response for a long drought. For example, a rapid release of stored water might completely eliminate the shortfalls of a short drought, while depleting storage and leaving the region more vulnerable to the effects of a long drought.

There are similar problems when planners do not know the probable severity or duration of future droughts. Planners often measure the performance of tactical and strategic plans by simulating their operation using precipitation and runoff recorded during historic droughts, either the worst on record, or the worst in recent memory.

The primary disadvantage to this approach has been the inability to estimate the probability of a similar drought occurring in the future. If the most severe droughts on record are very unlikely to reoccur during the period planned for, then planners may expend too many natural and economic resources by designing systems or plans to eliminate impacts that are unlikely to happen. If the worst historic drought is fairly likely to reoccur, then planners may endorse systems and plans that are inadequate for droughts that have a reasonable probability of occurring (Maass, 1962).

For example. record low precipitation in the early and middle 1960's created a drought emergency in New England and the mid-Atlantic states. Planners had designed water systems on the drought of record, but the 1960's drought was more severe (Holmes, 1979).

There is no inherently correct level of long term protection or tactical response. Communities must assume risks in making tradeoffs between the frequency and severity of economic and environmental impacts. The Atlas provides probabalistic information to inform those risk assessments. The information includes the expected frequency, duration and severity of droughts in terms of precipitation and streamflow. An analysis of recorded Palmer Drought Index levels is also included.
Analysts can use the Atlas to help estimate the:

- rarity of historic droughts, providing an objective measure of confidence in the use of the historic drought to test drought plans.

- expected probability of various levels of precipitation over a 1 to 60 month period, which can help provide a probabilistic answer to the inevitable question, "When will the drought be over?"

The Atlas was a collaborative effort headed by the Corps of Engineers in cooperation with Miami University (Ohio), the National Climate Data Center (NCDC), and International Business Machines (IBM). The Atlas was based on recently refined national precipitation and streamflow data sets. The statistics were generated using a method (referred to as *l-moment analysis*) developed at IBM by J.R. Hosking and J.R. Wallis that permits greater confidence in estimating drought frequencies from the relatively small number of droughts for which there are precipitation and streamflow records.

The Atlas includes statistics in three categories:

• **Precipitation**. The percentage of normal precipitation that can be expected for a variety of durations and starting months at various frequencies for 111 "clusters" covering the contiguous 48 states. Clusters are groups of gages that share the same statistical properties. Population statistics properly developed for clusters of similar stations have been shown to be more reliable than population statistics developed independently for each individual station.

The Atlas provides the percent of normal precipitation that can be expected in each cluster for frequencies of from once every 5 to once every 50 years. The durations are 1, 2, 3, 6, 12, 24, 36, and 60 months. For durations of 1, 2, 3 and 6 months, percentage of normal precipitation is provided for each starting month from January through December. The values are provided in tables and graphs. These statistics are based on a regional frequency analysis of the 1,119 stations in the Historical Climatology Network (HCN). The HCN is composed of verified data from stations with long historic records; it was developed by the National Oceanographic and Atmospheric Administration (NOAA) for climate change studies.

• **Streamflow**. The percentage of normal streamflow that can be expected at various frequencies for durations of up to 12 months at individual gaging stations in the 48 contiguous states. The frequencies are the same as for precipitation. These statistics represent the estimated population based on an at-site (rather than regional) frequency analysis for a subset of the Historical Climatological Data Network (HCDN), developed by the U.S. Geological Survey.

• **Palmer Index**. The Palmer Drought Severity Index, is used by some States as an indicator of drought severity, and is often the signal to begin or discontinue elements of a drought contingency plan. The Palmer Index was first calculated on a regular basis in 1965, as a means of providing a single index of drought severity. The index is essentially an index of soil moisture. The Atlas tabulates the percentage of the historic record during which the Palmer Drought Severity Index (PDSI) fell below -3, -4, and -5. The PDSI was calculated at 1,135 precipitation stations, including all of the HCN stations. These are at-site, sample statistics.

To aid the user in applying these statistics, the Atlas includes:

- a map of the U.S. showing average annual precipitation. The map is the first national precipitation map since 1962, and is based on the HCN.

- A United States map showing the precipitation clusters

- A United States map showing the precipitation stations.

4. Managing Water Conservation

The populations of many cities in the western United States are growing very rapidly at a time when the economic and environmental costs of developing new sources of water supply have never been more difficult to justify. Because water use forecasts drive the size and timing of new water supply projects, urban water planners have turned to disaggregated forecasting systems to improve the accuracy of their forecasts. Studies have long shown that the amount of water a city will use depends not just on the population, but the types of industry and housing, its climate, regulations, and the personal wealth of its citizens (Linaweaver, 1966). A disaggregated water use forecast is based on independent forecasts of these explanatory variables. The Metropolitan Water District of Southern California, Phoenix, and Las Vegas have used IWR-MAIN, a computerized water use forecasting system (IWR, 94-NDS-11), and other cities, such as Seattle, have used similar disaggregated water use forecasting models to more reliably estimate the need for additional supplies.

But many cities are attempting to reduce per capita consumption of water use to avoid or delay the development of new supplies.

The population of the city of Boston is expected to grow only 4%, from 541,434 to 563,345 during the period 1990-2020. Like many western cities, the Massachusetts Water Resources Authority will use IWR-

Figure 15. Disaggregated water use forecast algorithms rely on forecasts of explanatory variables, such as the types of housing people will occupy.

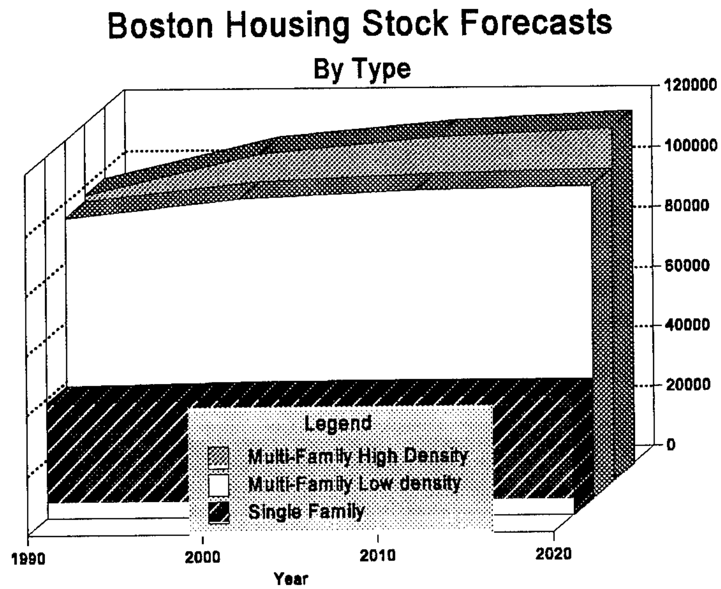
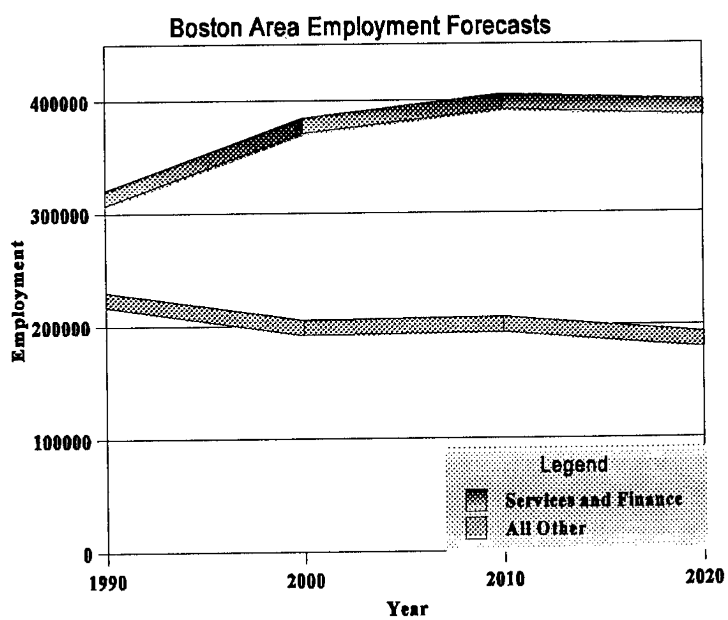


Figure 14. Forecasts of employment by industry are combined with information on water use per employee in each industrial category to forecast industrial water use.



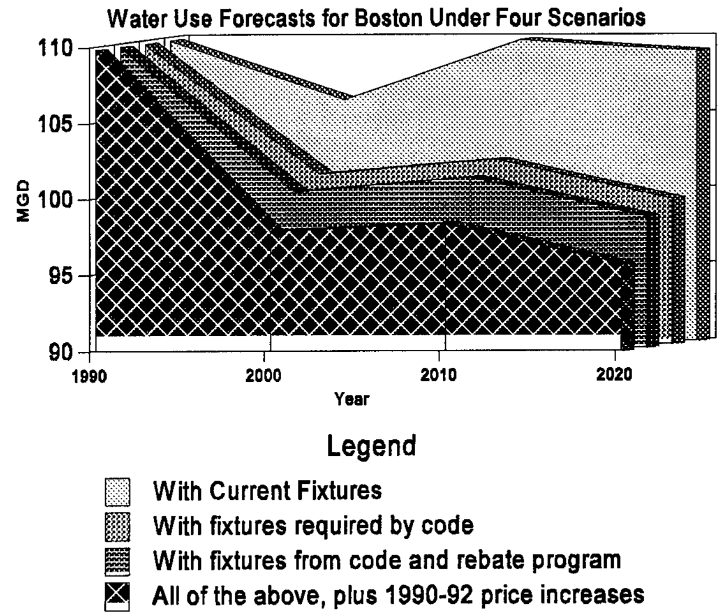
MAIN based forecasts to assure that the Boston area has adequate future water supplies. But MWRA and the National Drought Study used a new version (6.0) of IWR-MAIN for a new purpose: to begin to manage the investments MWRA makes in water conservation (IWR, 94-NDS-11).

The feature of IWR-MAIN 6.0 that makes it a valuable aid in managing conservation programs is a supplemental forecasting algorithm based on the number and types of water fixtures that will be in use over time under different scenarios.

In this study, modelers estimated the current mix of *non-conserving, standard* and *conserving* toilets, showerheads and faucet aerators in Boston. For toilets, for example, these categories correspond to 5.5, 3.5, and 1.6 gallons per flush fixtures. Water use was then forecast under 4 assumptions. In the *baseline*, the savings expected from leak detection and repair was the only mitigating factor. *Passive* conservation shows the reduction of water use because fixtures that meet the requirements of the Energy Policy Act of 1992 will be used in remodeling and new construction. That law specifies the maximum water use for fixtures manufactured after January 1994: 1.6 gallon per flush toilets, 2.5 gallon per minute showerheads, and 2.75 gallons per minute faucets.

Active conservation includes passive savings, plus the amount saved by offering rebates to encourage people to replace inefficient water fixtures before they fail. Finally, the water use reduction expected *with price*

Figure 16*. City of Boston water use will decline mainly because of national plumbing code changes and higher water rates. (Note: Figure 5 shows water use for the Greater Boston Metropolitan Area).*



increases Boston levied from 1990 to 1992 is shown. During that period, water and wastewater prices were raised 33.9 percent in real terms.

With a complete set of these incremental forecasts, an agency can determine the combination of measures that will produce a desired reduction in water use at the lowest cost. The joint use of IWR-MAIN and the Trigger Planning STELLA II® model (see page 46) provides a rigorous and systematic framework which can be used to evaluate the necessity and cost-effectiveness of demand and supply measures.

5. Trigger Planning

The Massachusetts Water Supply Authority, the Water Supply Citizens Advisory Committee (WSCAC) and the Corps of Engineers collaborated on a National Drought Study project called "Trigger Planning".

Trigger Planning uses the DPS method and a shared vision model to quantitatively link strategic and tactical plans. This is done through the use of an explicit set of performance criteria or targets which "trigger" the nature and timing of decisions to implement *strategic* plans.

Trigger Planning promises greater flexibility than traditional planning. Commitments to invest economic and environmental resources in water supply solutions can be made incrementally, in time, but "just in time". When a long term forecast shows the need for new supplies, promising alternatives may progress through the design, environmental impact assessment, and implementation phases while leading indicators continue to be monitored.

The leading indicators include the conditions of local sources, proposed projects, laws, regulations and agreements, watershed conditions and operational procedures, precipitation and streamflow, public views, and building permits. These leading indicators are used to forecast scenarios describing future system supply and demand conditions, which are in turn used to estimate when the system is likely to reach a *critical point* of unacceptable performance.

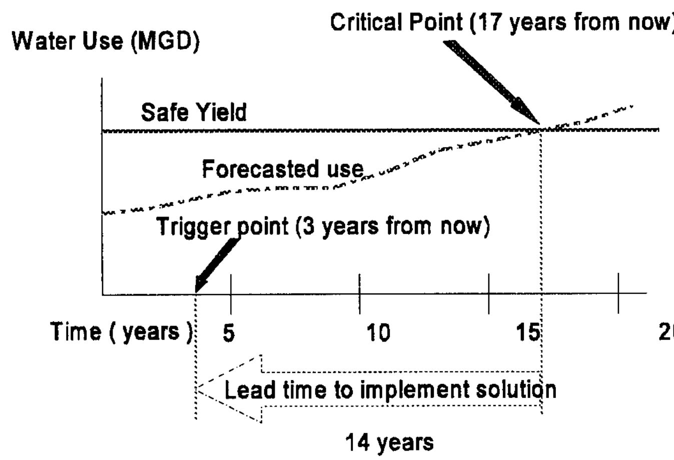


***Figure** 17. Trigger planning keeps economic and environmental investments in water supply low while avoiding catastrophic water supply failures.*

MWRA now defines this as the time when forecasted use reaches a specified percentage of the system's safe yield (*the supply of water that could be sustained by the system throughout the historic record, including the drought of record*). The *trigger* points are fixed in time by backtracking from the time the system will reach a critical state. These trigger points indicate when activities to investigate, design and implement each alternative must be initiated in order to prevent the system from reaching the critical state.

Estimates of critical points and trigger points will be readjusted to reflect this updated information. These estimates, in turn, may impact the decision to proceed with the implementation of an alternative. In this way, implementation will be postponed as late into the time horizon as possible.

6. Involving the Public and Decision Makers

Decision making should include all affected interest groups.

- Long's Peak Working Group (America's Waters: A New Era of Sustainability, 1992)

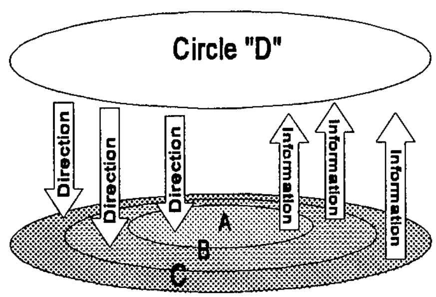
The goals for water management are set by the public through its elected officials. These goals are translated into practical guidance by policy makers in water management agencies. But because droughts may not reoccur for years, or even decades, a gap may develop between the practical effects of those policies and the original intent of lawmakers and the public. Stakeholders in particular may not be aware of how system operating policies will affect the uses of water important to them. The National Drought Study sponsored research and case study demonstrations of methods that would allow the parties to drought conflicts to work better together.

a. Circles of Influence

"Circles of influence" were used to balance effectiveness and the representativeness of participation. This approach was built on the common themes in three very different examples of organizational effectiveness (none water related) and is consistent with research on how people work together well.

DPS team members can belong to one of three circles, A through C. Each successive circle from A through C has broader representation but less personal involvement.

Figure 18*. Circles of Influence*



Circle A encompasses the traditional experts concerned with study management and technical analysis. The makeup of this circle is more likely to be multi-agency than some traditional technical study teams, where one agency *performed* the study and other agencies reviewed its results.

Circle B includes Circle A as well as one representative from each major stakeholder class (such as industrial users). Team members in Circle B may review and revise draft papers from Circle A, and act as the points of contact between the study and their industries and interest groups.

Circle C is much larger than B because it includes a representative from each major stakeholder, management agency, and each advocacy group, rather than one from each class. Circle C may meet twice a year in fairly formal workshop settings.

■

When existing organizations are too restrictive to deal with water issues in a holistic way, circles of influence can create new ways for people to interact, without destroying the old organizations or their responsibilities and advantages.

■

Regional decision makers (agency heads and elected officials) constitute a fourth circle, "D". They were involved formally at the beginning and end of the DPS's, and were kept informed during the study through their study representatives.

For the most part, stakeholders and decision makers outside Circle A communicated with the members of "A" in forums that existed before the DPS, thus lowering the administrative burden on the study. These connections were usually through common workplaces, related work groups, or professional organizations. The connections were based on a combination of trust and communication. Individuals who were able to work on the study, or who had not yet come to trust the process were free to move into the central circles, and vice versa. While existing institutions may be too restrictive to deal with water issues in a holistic way, the circles created a new ways for people to interrelate and interact, without destroying the old institutions, their responsibilities or advantages.

b. Decision Maker Interviews

Unless decision makers, including politicians are involved from the beginning, water managers have no assurance that their recommendations will be implemented. These are social choices and they involve politics (Dickey, 1993).

The U.S. Advisory Commission on Intergovernmental Relations (ACIR) helped two DPS's bridge the gap between political and agency perspectives on water management (94-NDS-14). In two DPS's, ACIR asked political experts to determine what elected officials expected from drought preparedness efforts. For the James River DPS, the focus was on the development of a state water policy for Virginia. For the Seattle area, the focus was on Seattle's perspective on regional water management. In both cases, the result was valuable to the DPS staff and also provided new insights to officials concerned.

c. Shared Vision Models and Collaboration

Differences in backgrounds, values, and agency traditions can reduce the effectiveness of drought preparedness. In the National Drought Study, the team collaboration on the development of the shared vision models gave team members a chance to appreciate and understand each others perspectives.

d. ADR

Alternative dispute resolution (ADR) is the name given to non-litigious interventions in the decision making process which use a variety of methods developed in legal, labor relations, and other fields.The Corps has led efforts to use ADR in water resources management. Managing Water for Drought (IWR, 94-NDS-8) includes an annex describing the range of dispute resolution processes and how they can be used in conjunction with a shared vision model.

C. Summary results of the major field studies (DPS's)

The DPS method has been tested and refined in four major case studies across the country. Each case study was selected to represent different physical conditions and water management concerns. Each study provided different insights and lessons, forcing the study team to confront realistic planning situations and constraints. The results, as a consequence, were mixed. In each case, however, the DPS approach contributed to a substantial improvement in the methods and mechanisms available to the participants before the study.

The Kanawha River DPS (in West Virginia, Virginia, and North Carolina) produced agreement on new water management procedures that will increase water quality and recreation during future droughts without hurting other water management purposes. The new method is expected to save millions of dollars in tourism revenue during the next severe drought.

The Cedar and Green River DPS (Seattle-Tacoma, Washington) involved two neighboring river basins, each with different primary management agencies, but many of the same stakeholders. Participants on the Green River portion of the study have integrated the DPS methods into the general practice of water management, reducing the amount of time required to negotiate water management decisions, and the confidence and trust in the decisions and the process. The participants in this study used their shared vision model in August 1994 to negotiate Corps reservoir releases, Tacoma withdrawals for municipal water and increased flows to facilitate salmon migration and spawning (Corps of Engineers, 1994). Acceptance of the method on the Cedar River has come more slowly, but there is demonstrable evidence that the DPS method will strongly influence future water management processes there, too. The James River DPS (Virginia) team considered two alternatives to the status quo: a new drought response plan for a five city area including Norfolk, and a state water policy for Virginia. The DPS team helped clarify the advantages of a state water policy, which was being actively considered by the Virginia Assembly towards the conclusion of that study, but did little to reduce the near term vulnerability of the five city region. Nonetheless, the Virginia Department of Environmental Quality has adopted many of the features of the DPS method for state water resources planning.

The Marais des Cygnes-Osage DPS had a promising beginning, but the completion of the study was delayed when staff was reassigned to Missouri flooding problems, so results are not available at this time. The DPS method helped Kansas and Missouri understand how their two dissimilar water management systems would work together in a severe drought. Kansas is an appropriation state with prioritized water rights and highly managed "assurance districts", and Missouri is the downstream state, subject to riparian water law. This study should be completed late in 1994.

The numerous large and small successes in all the case studies offer convincing proof that the method can reduce the conflicts and impacts that would otherwise have occurred in a drought. The case studies were chosen because they represented difficult challenges, so the limited success on the James and the Cedar still represents an improvement on what otherwise would have occurred. The shortcomings in those experiments were used to refine the study method.

Bibliography

Blomquist, W., 1991. Coordinating Water Resources in the Federal System: The Groundwater-Surface Water Connection. U.S. Advisory Commission on Intergovernmental Relations. Report A-118.

California Department of Water Resources, 1992. Economic Impact of Drought on California Agriculture in 1991. Division of Planning, Internal note. Sacramento, CA. July 1992.

Conserv90 poll, June 1990. Conserv90 was a conference on water conservation co-sponsored by the American Society of Civil Engineering, American Water Works Association, American Water Resources Association, and the National Water Well Association. The cities polled were Los Angeles, Pittsburgh, Chicago, San Francisco, Phoenix, Boston, Seattle, Little Rock, Sand Diego, Salt Lake City, Reno, Trenton, Santa Barbara, Virginia Beach, Macon, Columbus, Albuquerque, El Paso, Tampa, Des Moines, Louisville, and Charleston, WV.

Eastman, P., 1987. "Metropolitan Washington Area Water Supply," in Social and Environmental Objectives in Water Resources Planning and Management. W. Viessman and K. Schilling, (eds.) pp. 55-71; Proceedings of the Engineering Foundation Conference, Santa Barbara, CA, May 1986; American Society of Civil Engineers, New York, New York.

Foster, H. and P. Rogers, 1988. Federal Water Policy: Towards an Agenda for Action. Discussion Paper. John F. Kennedy School of Government. Harvard University, Cambridge, MA.

Grigg, N. and E. Vlachos, November, 1988. Drought Water Management, Proceedings of a National Workshop, Washington, D.C.; A Report for the Natural and Man-Made Hazards Mitigation Program of the National Science Foundation.

Holmes, B., 1979. History of Federal Water Resources Programs and Policies, 1961-1970. U.S. Department of Agriculture. Miscellaneous Publication No. 1379.

Lee, Kai, 1992. Compass and Gyroscope. Island Press. Washington, D.C.

Linaweaver, F.P. Jr., J. Beebe, F. Skrivan, 1966. Data Report of the Residential Water Use Research Project, Johns Hopkins University, Department of Environmental Engineering Science, Baltimore, MD.

Long's Peak Working Group; America's Waters: A New Area of Sustainability; Report of the Long's Peak Working Group on National Water Policy; The Natural Resources Law Center; University of Colorado, Boulder; December, 1992.

Maass, A., 1962. Design of Water Systems; Harvard University Press; Cambridge, MA.

Lord, William B., 1984. "Institutions and Technology: Keys to Better Water Management." Water Resources Bulletin, 20(5): 653, October.

MacDonnell, L., 1989. "Recent Developments in Water Marketing and Water Transfers," Water Resources Update. vol. 79; pp. 19-21. The Universities Council on Water Resources.

Monberg, H., 1994. Western Resources Wrap-Up Series XXXII, No. 3 Date: 1-20-94. A recent example of conflicting environmental objectives. The U.S. Fish and Wildlife Service (USFWS) may not be able to preserve an endangered species such as the Colorado River humpback chub, generally regarded as a trash fish, if it and/or its habitat are in conflict with another endangered species, such as the bald eagle. The conflict between types of endangered species is found in the draft environmental impact statement (EIS) released on January 6, 1994 on the operation of the Glen Canyon Dam on the Colorado River in Northern Arizona.

Moreau, David and Keith Little, 1989; Managing Public Water Supplies During Droughts: Experiences in the United States in 1986 and 1988; Water Resources Research Institute Report No. 250; University of North Carolina.

President's Interagency Drought Policy Committee, 1988. The Drought of 1988: Final Report on the President's Interagency Drought Policy Committee; U.S. Government Printing Office, Washington, D.C.

Riebsame, W., S. Chagnon, and T. Karl, 1990. Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987-1990 Drought. Natural Hazards Research and Applications Information Center, University of Colorado, Boulder. p. 54.

Rogers, Peter, 1993. America's Water: Federal Roles and Responsibilities. The Twentieth Century Fund. MIT Press. Cambridge, MA.

Russell, C.S., D.G. Arey, and R.W. Kates, 1970. Drought and Water Supply: Implications of the Massachusetts Experience for Municipal Planning. Baltimore: Johns Hopkins University Press.

Stakhiv, Eugene Z.; *Achieving Social and Environmental Objectives in Water Resources Planning: Theory and Practice*; Social and Environmental Objectives in Water Resources Planning and Management; 1986; Proceedings of and Engineering Foundation Conference sponsored by ASCE; Edited by Warren Viessman, Jr. and Kyle E. Schilling; p. 107-125.

Stakhiv, Eugene Z., James R. Hanchey, 1989. *Policy Implications of Climate Change*. Report on the First U.S.- Canada Symposium on Impacts of Climate Change on the Great Lakes Basin; Joint Report No. 1 of the U.S. National Climate Program and the Canadian Climate Centre. National Climate Program Office/NOAA, Rockville, MD.

U.S. Army Corps of Engineers, 1990. Draft Phase I Report for the Review and Update of the Missouri River Mainstem Water Control Manual, Missouri River Division; Omaha, Nebraska.

U.S. Army Corps of Engineers, 1994. "Weekly Summary for the Period 8/26/94 - 9/2/94". Engineering Division, Hydrology & Hydraulics Branch, Seattle District; Seattle, Washington.

U.S. Army Corps of Engineers, 1991. National Study of Water Management During Drought; Report on the First Year of Study. IWR 91-NDS-1. The analysis of existing drought response mechanisms was based on Corps reviews of state, urban, and Corps reservoir drought contingency plans, and independent reviews of drought plans, especially Moreau and Little (1989) (above); the U.S. General Accounting Office, June 1989, "Corps of Engineers' Drought Management of Savannah River Projects", Report to the Honorable Butler Derrick, House of Representatives, GAO/RCED-89-169, and The National Regulatory Research Institute, 1989; Compendium on Water Supply, Drought, and Conservation. Prepared by Janice A. Beecher and Ann P. Laubach.

U.S. Army Corps of Engineers, 1991. The National Study of Water Management During Drought; A Research Assessment. Prepared by Planning and Management Consultants Ltd. IWR Report 91-NDS-3

U.S. Army Corps of Engineers, 1994. The National Drought Atlas. Developed by the University of Miami (Ohio); the National Data Climate Center (NOAA), and IBM's Thomas J. Watson Research Center for the Institute for Water Resources. IWR Report 94-NDS-4.

U.S. Army Corps of Engineers, 1994. The National Study of Water Management During Drought; Lessons Learned from the California Drought (1987-1992) (IWR Report 93-NDS-5).

U.S. Army Corps of Engineers, 1994. The National Study of Water Management During Drought; Lessons Learned from the California Drought (1987-1992) - Executive Summary. IWR Report 94-NDS-6.

U.S. Army Corps of Engineers, 1994 (in preparation). Trigger Planning for the MWRA Service Area. IWR 93-NDS-9.

U.S. Army Corps of Engineers, (in preparation). Human and Environmental Impacts: California Drought 1987-92. IWR NDS-94-10.

U.S. Army Corps of Engineers, Institute for Water Resources, 1994. Water Use Forecasts for the Boston Area Using IWR-MAIN 6.0. IWR 94-NDS-11.

U.S. Army Corps of Engineers, Institute for Water Resources, (in preparation). Installations Water Resources Planning Series for Fixed Army Installations, Volume III, Summary of Water Rights, State Laws and Administrative Procedures.

U.S. Army Corps of Engineers, Institute for Water Resources, (in preparation). Governance and Water Management During Drought (IWR Report 94-NDS-14). Prepared by the Advisory Commission on Intergovernmental Relations (ACIR). NDS-14 addresses the general subject of technical water management within the American democratic process. It includes papers on law, decision making, public involvement, and two case studies that provided information on political decision criteria to water managers.

U.S. Energy Information Administration, 1994. Electric Power Annual 1992. Washington, DC.

U.S. Government Accounting Office, 1993. Federal Efforts to Monitor and Coordinate Responses to Drought. Report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives; GAO/RCED-93-117. Washington, D.C.

U.S. Water Resources Council, 1983. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. Washington, D.C.

U.S. Water Resources Council, December 1978. The Nation's Water Resources 1975-2000.

Western States Water Council 1986. Western State Drought Management (prepared by A. Willardson; WSWC). The statement in the text that no Governor has had to condemn water rights because of shortages during a drought was reconfirmed with Mr. Willardson in November 1993.

Wilhite, D., 1990. Planning for Drought: A Process for State Government, International Drought Information Center, Technical Report Series 90-1. University of Nebraska-Lincoln.

National Study of Water Management During Drought Reports

Previously published reports include:

The National Study of Water Management During Drought: Report on the First Year of Study (IWR Report 91-NDS-1) prepared by the Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

A Preliminary Assessment of Corps of Engineers Reservoirs, Their Purposes and Susceptibility to Drought (IWR Report 91-NDS-2), prepared by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

An Assessment of What is Known About Drought (IWR Report 91-NDS-3) prepared by Planning Management Consultants, Ltd., Carbondale, Illinois.

Lessons Learned from the California Drought (1987-1992) (IWR Report 93-NDS-5) prepared by Planning and Management Consultants, Ltd., Carbondale, Illinois.

Executive Summary: Lesson Learned from the California Drought 1987-1992 (IWR Report 94-NDS-6) is a concise summary of NDS-5 (above), with some new information that became available after NDS-5 was published.

Computer Models for Water Resources Planning and Management (IWR Report 94-NDS-7) summarizes brand name models in eight categories: general purpose software (such as spreadsheets), municipal and industrial water use forecasting, water distribution systems (pipe networks), groundwater, watershed runoff, stream hydraulics, river and reservoir water quality, and river and reservoir system operations.

Managing Water for Drought (IWR Report 94-NDS-8) is the main report from the National Drought Study. It describes the planning method developed and tested during the National Drought Study, with information pertinent to drought from a number of related fields such as water law, hydrology, alternative dispute resolution, computer modeling, politics, public involvement, water use forecasting, economics and environmental impact measurement, and other areas.

Other reports will be published:

The National Drought Atlas (IWR Report 94-NDS-4) is a compendium of statistics which allows regional water managers to determine the probability of droughts of a certain magnitude and duration.

Drought Impacts in a P&G Planning Context (IWR Report 94-NDS-9)
Human and Environmental Impacts: California Drought 1987-92 (IWR Report 94-NDS-10) NDS-9 is a collection of papers by California researchers who attempted to measure the impacts of the drought on the California economy and environment. NDS-10 shows how drought impacts can be measured in the accounting system of Principles and Guidelines. It uses the results of NDS-8 as an example.

Water Use Forecasts for the Boston Area Using IWR-MAIN 6.0 (IWR Report 94-NDS-11) demonstrates one of the first uses of a beta test version of the new generation of MAIN. The objective of this study was to determine the relative effectiveness of long term water conservation measures.

Trigger Planning for the MWRA Service Area (IWR Report 94-NDS-13) documents the development of what might be called "just in time" water supply enhancement; a management system that can reduce economic and environmental investments in supply and demand measures while maintaining necessary water supply reliability.

Governance and Water Management During Drought (IWR Report 94-NDS-14). Prepared by the Advisory Commission on Intergovernmental Relations (ACIR). NDS-14 addresses the general subject of technical water management within the American democratic process. It includes papers on law, decision making, public involvement, and two case studies that provided information on political decision criteria to water managers.

Colorado River Gaming Exercise (IWR Report 94-NDS-15) documents the use of a shared vision model in a gaming exercise to evaluate operational and institutional alternatives for the management of the Colorado River. This report was prepared as a joint project with the Study of Severe Sustained Drought in the Southwest United States.

Shared Vision Models and Collaborative Drought Planning (IWR Report 94-NDS-16), prepared by the University of Washington for the Corps of Engineers, documents the use of the shared vision model in the National Drought Study case studies.

Lessons Learned from the National Drought Study Case Studies will be published in the Fall of 1995, contingent on the completion of the Marais des Cygnes-Osage DPS, which was delayed by the flooding on the Missouri River during the Summer of 1993.

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13. ABSTRACT *(Maximum 200 words)*

This report summarizes the findings and recommendations of the National Study of Water Management During Drought conducted by the Institute for Water Resources, U.S. Army Corps of Engineers. Recognizing that the key to better water management during drought is to improve current water resources planning and managment practices, the principles and practices of water management were revisited to develop the Drought Preparedness Study Method, an innovative, integrated and collaborative approach to drought management.

Specific topics include: problems related to water management during drought, shortcomings of existing drought response plans and measures, long term water allocation and drought, allocating water among competing activities during drought, the need for additional structural capacity, legal and institutional issues, lessons learned from the California Drought, the recommended "DPS Method" for drought preparedness, shared vision computer models, new public involvement techniques, the National Drought Atlas, and summary results from the case studies.

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