Water Resources Forecasting for Drought Assessment

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Introduction

The term *drought* means different things to different people. A meteorologist or climatologist would probably define drought in terms of precipitation deficiency. Someone interested in agriculture would probably include soil moisture and would define drought's seriousness according to the time of its occurrence within the growing season. A reservoir operator interested in generating hydropower would be concerned about reservoir inflows and reservoir levels, while a barge company would be concerned with currents and river levels.

Droughts are not sudden events like floods or earthquakes. They tend to progress slowly and occur over a much longer time scale. Time and space scales are important, because they contribute to the determination of what constitutes a drought. A dry period that occurs after a long wet period may not be considered a drought unless it lasts long enough to deplete water supplies and exhaust food reserves. Similarly, what may appear to be a very serious drought over a small local area may not be considered a drought over a larger area. Definitions may also vary regionally, depending on the local climate. Below-normal precipitation in an area that is normally dry might not be considered drought; however, the same percentage of precipitation deficit in a humid area with heavy water demands might produce a serious drought.

This paper examines drought from the viewpoint of a hydrologist, who defines drought in terms of streamflow. With knowledge of local water resources conditions and long-term probability forecasts of streamflow, water managers can assess the impacts of a drought and make risk-based decisions. This paper describes technology used by the National Weather Service (NWS) to produce extended probabilistic forecasts of streamflow and other hydrological variables. Some actual examples of applications of the technology are discussed and some products that could be made available are presented. A National Oceanic and Atmospheric Administration (NOAA) Water Resources Forecasting Services (WARFS) initiative that would improve NWS capabilities to provide forecasts for droughts is also briefly described.

National Weather Service River Forecast System

The National Weather Service River Forecast System (NWSRFS) is a software system consisting of many programs, which are used to perform all steps necessary to generate streamflow forecasts. The system includes the Calibration System (CS), the Operational Forecast System (OFS), and the Extended Streamflow

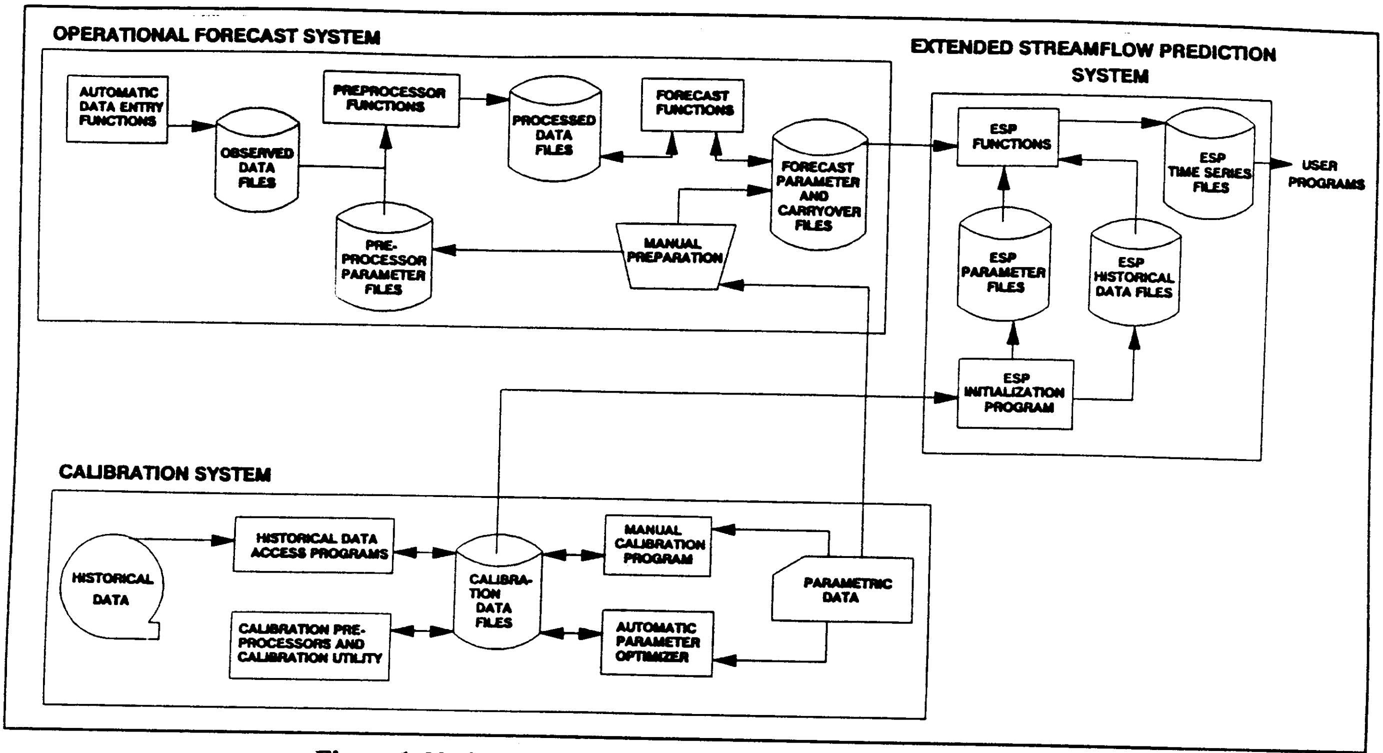

Figure 1. National Weather Service River Forecast System.

Prediction (ESP) System (Figure 1). The NWSRFS is a modular system that allows the hydrologist to select from a variety of models and to configure them in a manner that is descriptive of the basin. Each model is available to the Calibration, Operational Forecast, and ESP systems.

Calibration System

The CS performs the tasks needed to process historical hydrometeorological data and to estimate model parameters for a specific basin. The models simulate snow accumulation and ablation, calculate runoff, time the distribution of runoff from the basin to the basin outlet, and route streamflow in the channels. As part of the calibration procedure, for a particular basin, the simulated streamflow is compared statistically and visually to the observed streamflow to determine the necessary model parameter adjustments. The ideal model parameters are those that allow the closest match between simulated (predicted) streamflow and observed (actual) streamflow (Brazil and Hudlow, 1980).

Operational Forecast System

Once the models have been calibrated for a basin, the models can be used operationally with real-time hydrometeorological data to forecast streamflow. The OFS contains three major components that are needed for operational river forecasting: data entry, preprocessor, and forecast. The data entry component set of programs transfer hydrometeorological data from a variety of sources to the observed data base. The preprocessor component reads raw station data, estimates missing data as required, and calculates mean areal time series of precipitation, temperature, and potential evapotranspiration for a particular basin. These processed time series are used by the forecast component to perform requested hydrologic and hydraulic simulations. The forecast component stores parametric data for the models, as well as information that describes the basin connectivity of the river system. In addition, the forecast component maintains an account of the current model states and stores them on the carry-over files. These states describe the hydrologic condition of the basin, including the snow cover, soil moisture, and channel storage. They are needed as starting points for subsequent forecasts. The forecast component also has the ability to update these model states using observed data and to display the result of the simulation.

Extended Streamflow Prediction System

The ESP portion of the NWSRFS enables a hydrologist to make extended probabilistic forecasts of streamflow and other hydrological variables (Figure 2; Day, 1985). ESP assumes that historical meteorological data are representative of possible future conditions and uses these as input data to hydrologic models along with the current states of these models obtained from the forecast component. A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. The streamflow time

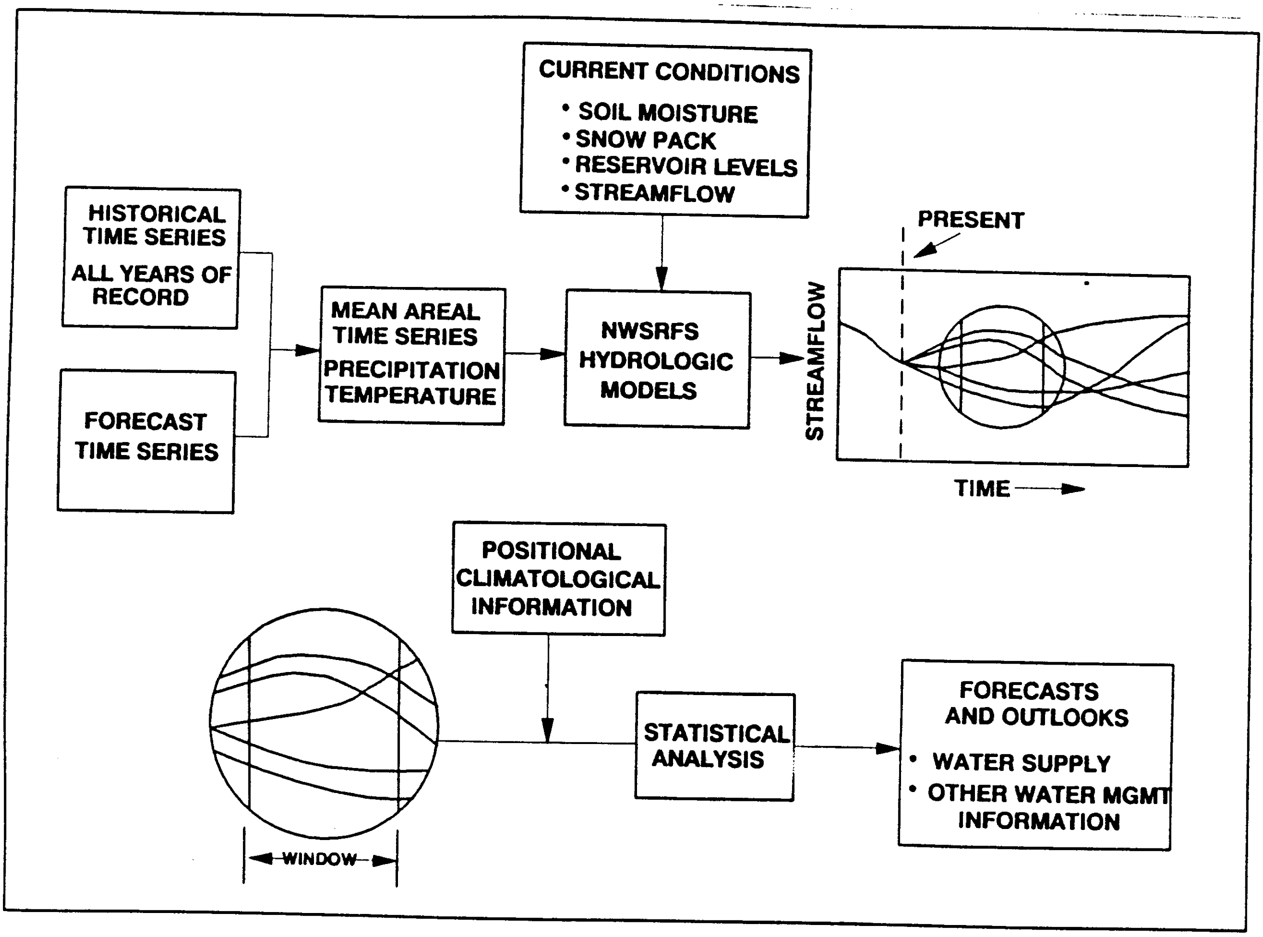

Figure 2. The ESP procedure.

series can be analyzed for peak flows, minimum flows, flow volumes, and so forth for any period in the future. A statistical analysis is performed using the values obtained from each year's simulation to produce a probabilistic forecast for a particular streamflow variable. This analysis can be repeated for different forecast periods and different streamflow variables. Short-term quantitative forecasts of precipitation and temperature can be blended with the historical time series to take advantage of any skill in short-term meteorological forecasting. In addition, knowledge of the current climatology can be used to weight the years of simulated streamflow based on the similarity between the climatological conditions of each historical year and the current year.

ESP allows flexibility in the streamflow variables to be analyzed, the capability to make forecasts over both short and long time periods, and the ability to incorporate forecast meteorological data into the procedure. Because of ESP's flexibility and conceptual basis, it has many applications, including water supply forecasts, flood outlooks, and drought analysis. The forecast information provided by ESP is particularly useful during droughts. The minimum streamflow, minimum reservoir level, or streamflow volume can be estimated for any exceedance probability level. By observing how many of the historical year's simulations dip below critical levels, the user can define the risk of running short of water. If the risk exceeds an acceptable value, drought contingency measures can be taken. The streamflow time series generated by ESP could be used as input to other simulation models to investigate how water supply operations might be improved. These streamflow time series represent possible occurrences based on both the current conditions and forecast data. ESP provides water managers with information needed to assess the severity of the drought quantitatively, so that measures can be taken to reduce to an acceptable value the risk of running out of water.

Water Resources Forecasting Services

Proper management of water resources is vital to the national economy, the quality of our environment, and our overall social well-being. Increased resource demands, pollution, and climate variability have made water a scarce resource at one time or another in most areas and have stressed our water resources systems. While some parts of the nation are experiencing water shortages, other parts may be experiencing serious flooding. Water management decisions that affect water resources systems are a daily routine. Industries and utilities must decide how much effluent can be safely discharged into an estuary without adversely affecting water quality and endangering fish and wildlife. Reservoirs are continually operated with the conflicting objectives of flood control, water supply, hydropower generation, navigation, water quality, and recreation, which work against one another by simultaneously seeking to raise or lower the reservoir pool level and to hold or release water (Figure 3). In most cases, these water management decisions are based on localized ad hoc information systems that cause inefficient and wasteful use of the nation's water resources.

The science of real-time hydrologic forecasting, and potential computer and telecommunications resources to support the associated data processing, has reached the point that significant advances can now be made in river forecasting to support

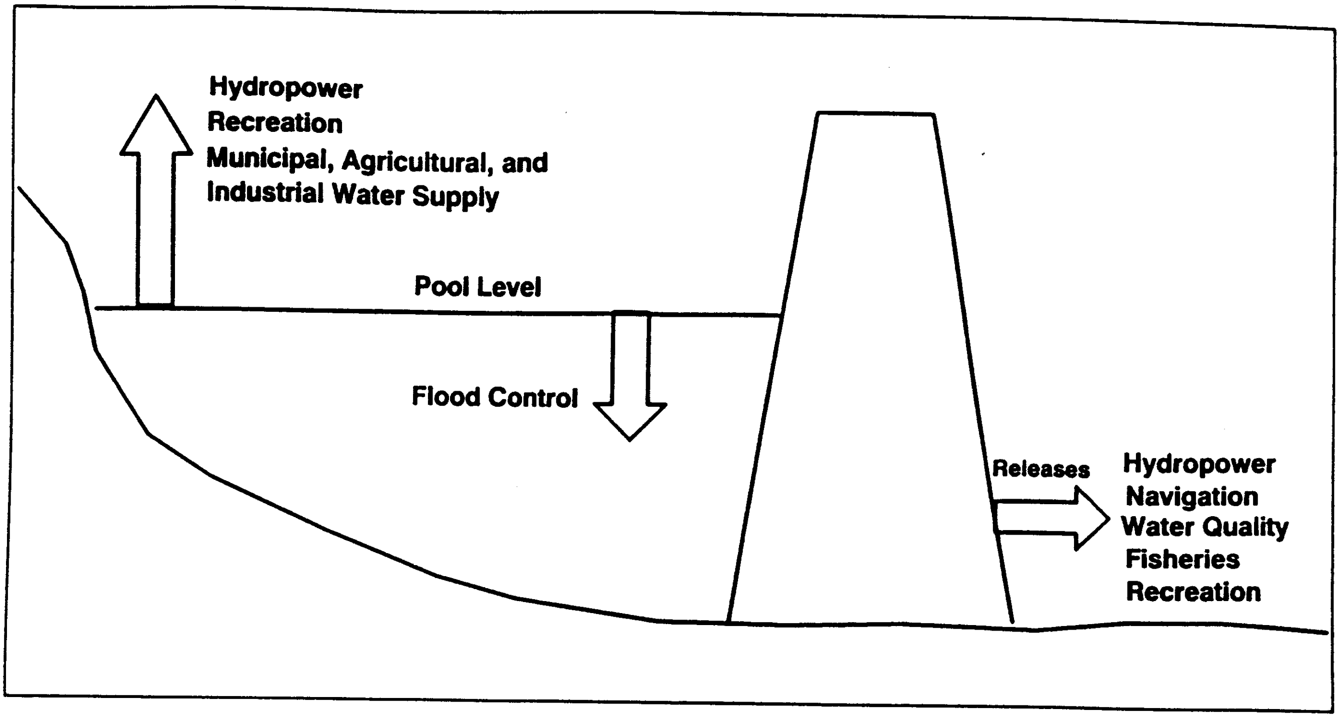

Figure 3. Conflicting objectives in reservoir operation.

the need for improved information for water managers. NWS is working with a number of other federal, state, multistate, quasi-governmental, and private sector organizations toward cooperative efforts in this area. As a part of these collaborative efforts, NOAA is planning a new initiative, WARFS.

The WARFS initiative will provide urgent improvements in NOAA hydrologic prediction services. The beginning infrastructure for WARFS is the current NWSRFS (Figure 4; Hudlow, 1989). WARFS model and data improvements within the NWSRFS will benefit all scales of forecasting, bringing badly needed improvements in flood warnings as well as longer-term forecast services. WARFS will take advantage of both hardware and software components of NWS modernization programs, including the Next Generation Weather Radar (NEXRAD), now called WSR-88D; the Automated Surface Observing System (ASOS); and the Advanced Weather Interactive Processing System (AWIPS). The NEXRAD and ASOS programs will provide much of the necessary technology to observe precipitation amounts on a nationwide basis at the temporal and spatial resolution required. Achieving the required accuracy of precipitation estimates, however, will require data management, integration, and analysis procedures that incorporate a large variety of precipitation data sources from other federal, state, and local gage networks. The AWIPS system provides a modern interactive processing environment that will be the center of all forecast operations in an office. Data analysis and quality control, forecast modeling, forecast interpretation, and product formulation will be carried out interactively at modern work stations, providing forecasters with a milieu for efficient and timely development of WARFS products and services. The data and computer systems provided by NWS modernization programs and the application of advanced hydrologic and climatic forecast models will be used in cooperation with other agencies to (1) support forecast service requirements of government and quasi-government water managers; (2) provide basic water

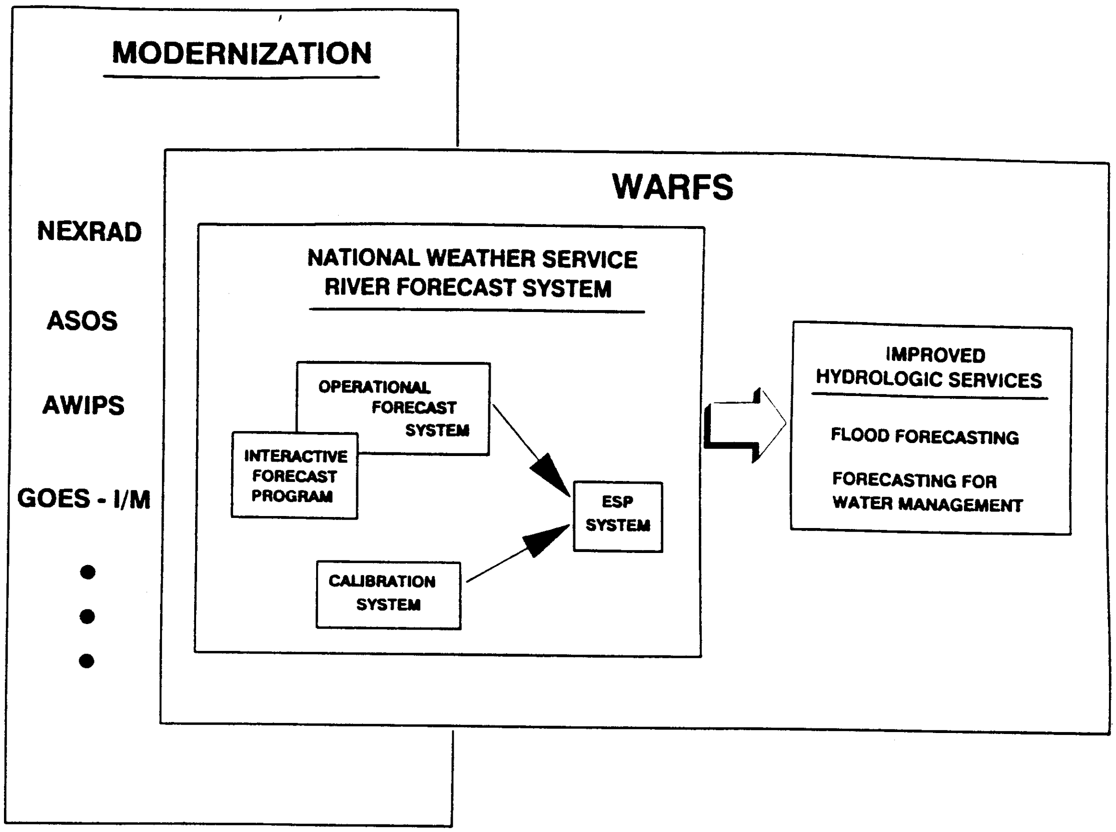

Figure 4. Water Resources Forecasting Services.

resources forecasts to private sector intermediaries, who will tailor the forecasts to serve specific industries; (3) satisfy needs for forecast services at near-, mid-, and long-term time scales for a wide variety of water use situations nationwide; (4) provide critical information on hydrometeorological forecast reliability that can be used for making risk-based water management decisions; (5) incorporate improved weather and climate forecast information into hydrologic models; and (6) improve other short- and mid-range forecast capabilities.

The advanced models, data integration techniques, and expanded historical and real-time hydrometeorological data bases will provide a strong technological base for comprehensive water resources forecasts. These forecasts will be provided on a routine basis to support day-to-day operations of water control facilities, as well as in times of special need such as during floods and droughts.

Example Applications

Extended streamflow prediction technology was developed in the mid-1970s, but because of scarce resources it has only been applied on a limited basis. It was first applied to drought analysis during the California drought of 1976 and 1977 (Twedt et al., 1978). Based on ESP-type information, the California-Nevada River Forecast Center indicated in December 1976 that water supply shortages and drought conditions would likely persist through the 1977 water year.

In 1977, the Washington, D.C., metropolitan area was also experiencing drought conditions (Sheer, 1980). NWS used an early version of ESP to provide information to a local water agency concerning the probability of future streamflow. This information was used along with information on water demands to estimate the risk of water shortages. Since that time, the Washington, D.C., metropolitan area has solved its recurring water shortage problem, primarily through better cooperation among local water agencies and improved water management using systems analysis techniques. The approach requires daily water demand forecasts, as well as ESP-type streamflow forecast information. The project was nominated for Outstanding Civil Engineering Achievement of 1983.

More recently, the Southeast has experienced extended drought conditions. Beginning in 1986, ESP forecasts were generated for the Lake Lanier Basin on the Chattahoochee River. Lake Lanier is the primary water supply source for the Atlanta, Georgia, metropolitan area. By 1988, soil moisture conditions were extremely dry. Soil moisture conditions on the first of June 1988 were much lower than on the same date in any year from 1958 to 1984, based on estimates generated from a physically based conceptual soil-moisture accounting model (Figure 5). ESP was used to produce probabilistic streamflow forecast information, such as for the

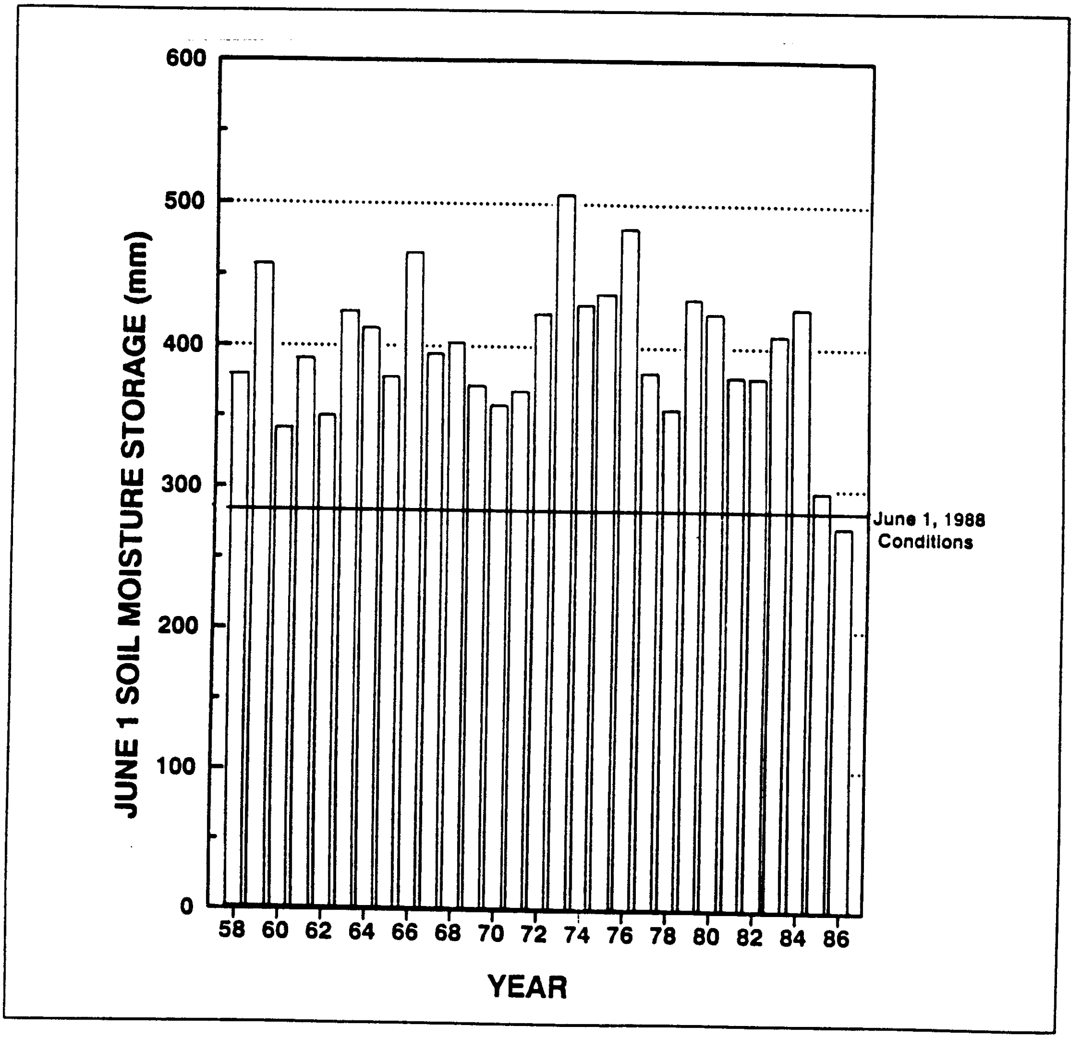

Figure 5. Comparison of 1988 soil moisture in the Lake Lanier (Georgia) Basin with historical values.

reservoir inflow volume for June 1988 (Figure 6). The reconstructed WARFS forecast was based on an ESP analysis that took into account the extremely dry soil moisture conditions that existed on June 1, 1988. The historical streamflow analysis indicates that the probability of an inflow volume of 100,000 acre-feet or larger is 76%, while the ESP analysis indicates that the probability is only 3%. If water management decisions were based only on the historical streamflow analysis, the probability of the lake level returning to normal would have been overestimated and the consequences of the drought would have been underestimated. In this example, the difference in results is particularly large because of the extreme conditions that existed in June 1988, but it illustrates the potential importance of state-of-the-art forecast information to water supply operations.

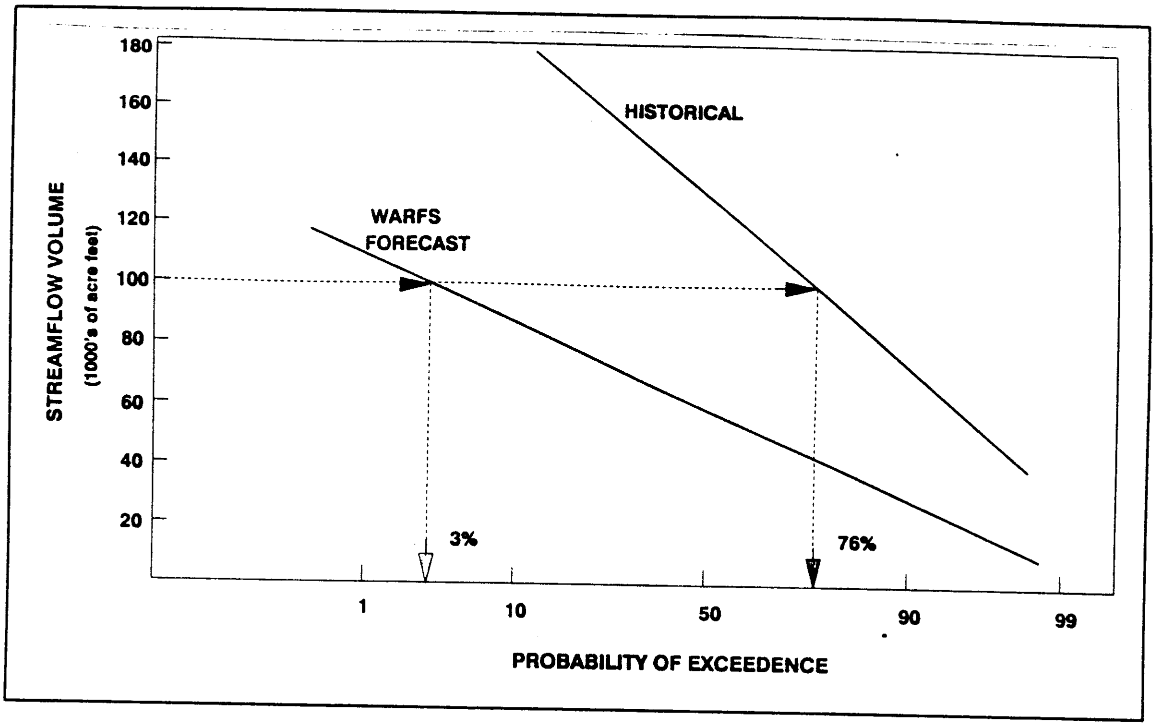

Figure 6. Reconstructed Lake Lanier inflow forecast—June 1988 inflow.

Many additional forecast products could be generated for water resources using WARFS technology. Flood potential conditions across the nation, estimated by NWS for February 28, 1990, were based on the qualitative judgment of hydrologists using information from a variety of sources (such as models, the Palmer Drought Index, and observed precipitation; Figure 7). With WARFS technology, using ESP, it would have been possible to estimate quantitatively the probabilities of flooding (Figure 8). This type of a product would provide the forecast information needed to make complex water management decisions using a risk-based analysis. Although the example is based on probabilities of flooding, the same type of information could have been generated for droughts. For example, it would also be possible to generate maps showing the probability of exceeding a threshold value of a drought index.

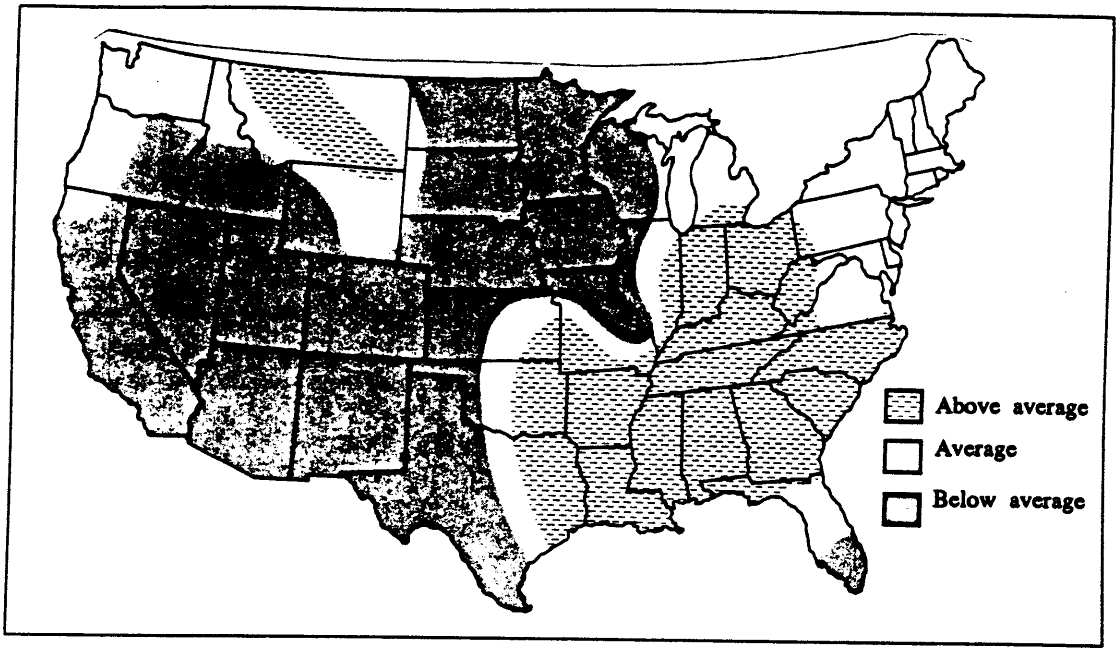

Figure 7. Flood potential (as of February 28, 1990).

Summary

Conceptual hydrologic models provide important information about the current conditions of a basin (such as snow cover, soil moisture, and reservoir levels) that, when used in the ESP system, enable a forecaster to make probabilistic statements about future streamflow. In addition, the conceptual framework provides the flexibility to incorporate meteorological and climate forecast information. The probabilistic streamflow forecasts generated by ESP can be used to make complex water management decisions using risk-based analysis.

The advanced data and computer systems of NWS modernization programs, coupled with the advanced hydrologic and climatic models implemented through WARFS and coordinated with the activities of other agencies, will provide the capability to generate comprehensive water resources forecast information on a national basis. This information will be used to improve daily operation of water control facilities, but it will be especially valuable during critical times such as droughts.

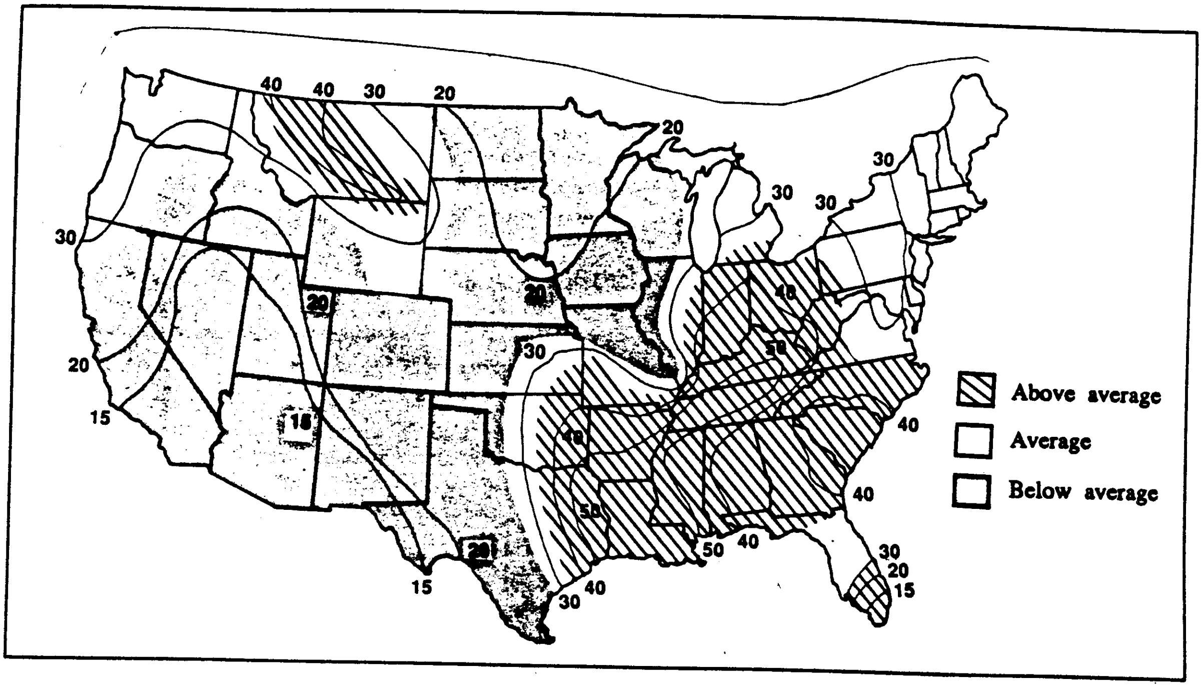

Figure 8. Hypothetical probabilities of flooding based on WARFS-type technology (as of February 28, 1990).

Acknowledgments

The author would like to thank Mr. Michael Kane, Ms. Ann McManamon, Dr. Danny Fread, and Ms. Cara McCarthy for their review of the manuscript, and Ms. Annette Cardona for her support in graphics and word processing.

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