EXTENDED STREAMFLOW PREDICTION DURING THE CALIFORNIA DROUGHT 1/

By

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Introduction

The California drought of 1976 and 1977 presented a severe test of man's ability to cope with an extremely dry weather period and the resulting water shortages. The drought's impact upon the State and its economy was extensive. The limited surface water supply supplemented by extensive ground water withdrawals was inadequate to prevent extensive rationing for domestic and industrial purposes.

In California, as well as in many other western states, water has become an extremely valuable resource. A significant portion of the State economy is water-related and all of its inhabitants are affected in some manner by available water supplies. As a result of this relationship. accurate forecasts of the amount and timing of water availability have taken on tremendous value.

Knowledge as to anticipated runoff has become increasingly valuable to the managers responsible for planning and operating the complex system of water storage and control facilities within the State. Agricultural interests have profited from advance information regarding water availability for planning equipment purchases, planting and harvest operations and allocating water to their various crops. The sizeable water-oriented recreation industry in the State is vitally affected by the availability of water supplies. Future stream levels affect the navigability of inland waterways and are of major concern to shipping interests. Domestic and industrial water users and the operators of hydroelectric projects are vitally concerned with the availability of future water supplies.

This paper discusses some of the techniques utilized by the California-Nevada River Forecast Center (RFC) of the National Weather Service (NWS) in initially identifying and regularly forecasting the extent of the drought. These techniques were also applied to provide a timely evaluation of the end of the drought. The role of the National Oceanic and Atmospheric Administration (NOAA), of which the National Weather Service is a component, was summarized by its first director who indicated that "NOAA shall provide adequate environmental forecasts and warnings on which the lives, safety, and welfare of our people, our commerce and our industry depend". The drought presented a new set of challenges to the forecast programs designed to meet the agencies' role.

As one approach toward fulfilling the forecasting and warning objective, the various RFC's regularly prepare and issue statements of future water conditions for their areas of responsibility. In many parts of the United States forecasts include an analysis of the amount of surface water which is expected to be available during the coming year and its temporal and spatial distribution.

Extended Streamflow Predictions

The procedures utilized at the California-Nevada River Forecast Center in the preparation of streamflow forecasts have evolved over a number of years. Three separate phases have been incorporated into that process which has generally been referred to as a water supply function. The final product of these phases is now referred to as Extended Streamflow Prediction (ESP) which is regularly prepared for general release meeting a variety of public interests.

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The earliest phase which was used for water supply purposes was primarily based upon a regression analysis between runoff and precipitation. Monthly precipitation to-date and normal precipitation after date were generally combined with a variety of other indices to produce statistical determinations of future runoff. Variations of this basic technique are still in use by many water agencies throughout the world. However, statistical techniques suffer from basic limitations in that their inherent linearity derived from the use of constants and invariant relationships creates a mathematical structure which loses its rationality during extreme conditions. This characteristic tends to produce the worst results during the most extreme forecast situations, and is particularly aggravated if the extreme exceeds previously known limits.

An additional deficiency in the use of such analyses for water supply forecasts is the inability of the technique to provide adequate information relating to the time distribution of runoff. The need for such information can be of great value in timely reservoir operation and will continue to increase in value as water managers become more sophisticated and demand more effective information. However, this type of analysis is waning in importance due to the availability of computer and simulation processes which provide increasingly more effective and more flexible analyses. The Proceedings of this conference for the past several decades have recorded numerous attempts at defining past weaknesses in analyses and in developing better approaches. Tarble and Burnash (1971) traced this trend and suggested a direction in water supply forecasting which is subsequently being adopted by an increasing number of Weather Service offices.

This technique consists of utilizing continuous, physically-based, conceptual hydrologic models to provide estimates of future water supply. The advantages of such an approach over conventional regression analysis, as well as the general theory supporting the technique and examples of its use, were reported by Twedt, et al (1977). The technique assumes that historical precipitation and temperature sequences in an area are reasonable representations of the type of conditions which might be expected to reoccur in that area in the future, and that the hydrologic processes occurring in the area can be accurately represented by a conceptually realistic hydrologic model. The hydrologic model used by the National Weather Service for a variety of purposes, including Extended Streamflow Predictions, was developed at the California-Nevada River Forecast Center (Burnash, et al; 1973) and is commonly known as the Sacramento Model.

Coupled with the hydrologic model is a snow simulation model which utilizes an approximate energy balance approach to simulate the accumulation and ablation of the snowpack. As a result of practical considerations as to normal data availability, the model requires only precipitation and temperature input data. Parameters of the basic energy balance equations are approximated from this input, permitting the eventual use of measured parameters should they become available. Actual snow course measurements are used to fit the model to the basin and synthetic snow courses are generated to represent various aspects and elevations within the basin and integrated into an approximate snowpack. Melt from the simulated snowpack is used as input into the hydrologic model for soil moisture accounting as long as a pack is present. Figure 1 depicts the generalized operation of the simulation system.

The model maintains a continuous accounting of important soil moisture and snowpack variables, permitting it to define the state of the hydrologic system at any given time and providing rational evaluations of future conditions. The forecast technique is based upon inputing daily temperature and precipitation sequences from past years to the model, using current hydrologic conditions to initialize the computations for each simulation. The model produces a set of streamflow regimes representing runoff sequences which could potentially occur with current initial conditions. The set of regimes is temporally and spatially distributed, enabling the selection of volumetric estimates of runoff for any future time period of interest within a year of the initial data. A frequency or probability distribution of these estimates is then developed which provides the relationship between future runoff volumes and their chance of occurrence.

The final phase of all such forecasts involves a rational analysis of the results and a comparison with historical runoff sequences to produce the published results. This phase entails an analytical element which allows the experience of a well-trained hydrologist to interact with the computerized processes.

Extended Streamflow Predictions are currently issued by the RFC for 23 basins in California and Nevada. The majority of these are inflows to major reservoirs and lakes. All forecasts are in terms of monthly accumulated volumes of flow in thousands of acre-feet. Forecasts are provided for a number of time periods beginning with the current month and extending five or more months into the future. Within each forecast period, volumes are determined at the following probability levels: Most Probable - 50% chance of being exceeded, Reasonable Maximum - 10% chance of being exceeded, and Reasonable Minimum - 90% chance of being exceeded. The historic medians for the same periods are also provided, as is a brief verbal summary of the hydrologic situation over the forecast area.

Forecasts are issued on a monthly basis (more frequently during critical periods) during the major runoff portion of the year. The predictions are made available to interested governmental agencies operating within the forecast area, various news media, and a variety of organizations and individuals who have requested this service.

Forecast Results

An index of the recent California drought in terms of volumetric departure from monthly normal precipitation has been plotted for three stations in Figure 2. These stations are representative of the north, central, and south reaches of the Sierra Nevada, and exhibit the same general trends. The major precipitation months of November through April were volumetrically well below normal during both years of the drought. The moisture-deficient pattern extends from November 1975 to November 1977. A brief description of RFC warnings during the drought period serves to clarify the use and effectiveness of the ESP techniques.

As shown in Figure 2, Water Year 1976 was one of below normal precipitation over nearly the entire state. This resulted in greatly reduced runoff to rivers and streams and caused reservoir storages to decline to record lows. During this time, the RFC prepared and issued a number of water supply forecasts. In April of 1976 the pattern was of such importance that a special press release concerning the probable effects of the drought on the public was prepared. As the state entered Water Year 1977, heavy late summer rains were followed by a high pressure ridge similar to that of the previous fall. This ridge became strongly entrenched, shunting the majority of the rainfall-producing Pacific storm fronts well to the north of California.

As early as December, 1976, the substantial soil moisture deficits computed with the hydrologic simulation model indicated little possibility of overcoming the drought with that season's rainfall. Based on these analyses and the meteorological determination that the weather pattern which was blocking storms from entering California was likely to persist for at least another two weeks, the RFC was able to confirm in late December that water shortages and drought were almost certain to continue through the 1977 water year. Press releases providing warnings of these conditions were prepared at a time when the state was only 25% into its normal precipitation year. The ability of the simulation systems to incorporate soil moisture deficiencies into future runoff conditions made such an early warning possible.

The "tunnel diagrams" of Figure 3 depict the level of forecasts for two river systems as of the first of each month during Water Year 1977. The ability of the model to incorporate current hydrologic conditions is indicated by the below average initial forecast in January and the subsequent convergence of the monthly forecasts to the actual observed runoff.

The total precipitation deficiency during Water Year 1977 was even lower than in 1976. The precipitation over California averaged only 35 percent of normal. Reservoirs and lakes dropped to record low levels and soil moisture deficits were critically low. As Water Year 1978 commenced, tremendous concern over the possibility of another year of drought was prevalent throughout the state. However, the fall season saw the establishment of more typical storm patterns, resulting in precipitation of near normal in November and above normal in December. Although substantial runoff had not yet occurred, the soil moisture deficit computed by the hydrologic model indicated that future rains would produce effective runoff. By January 6, 1978, a variety of hydrometeorological analyses by the National Weather Service indicated a high degree of probability that the drought was

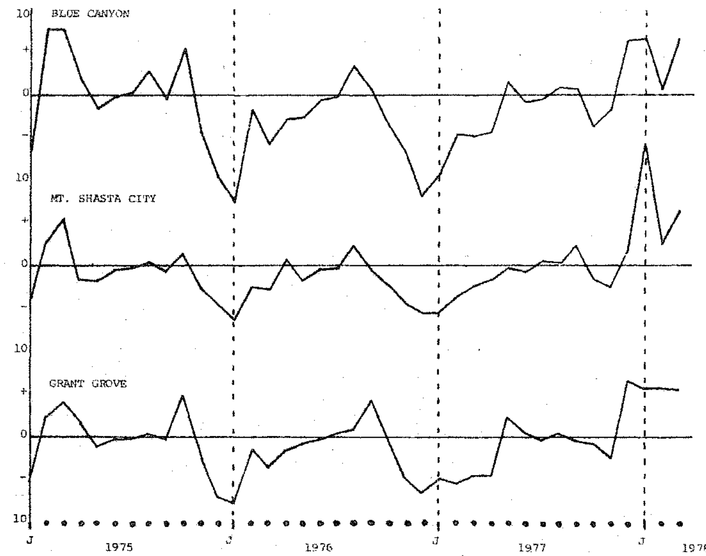

FIGURE 2. Monthly departures from normal precipitation at three stations.

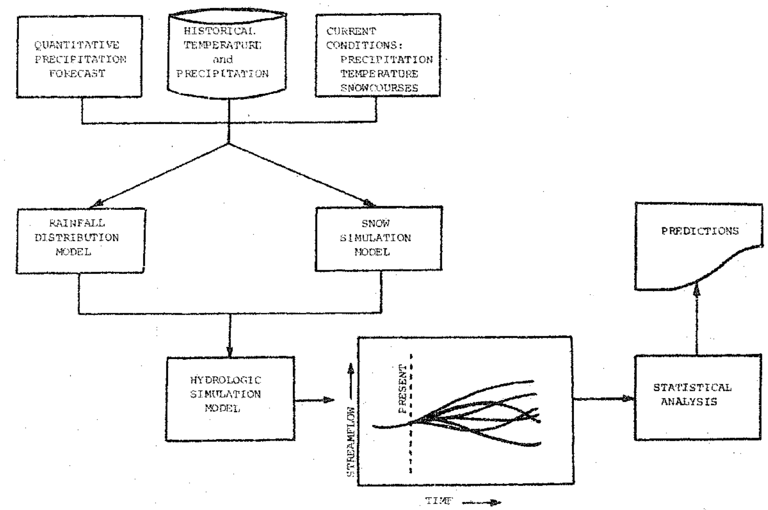

FIGURE 1. Schematic of conceptual simulation model for Extended Streamflow Predictions.

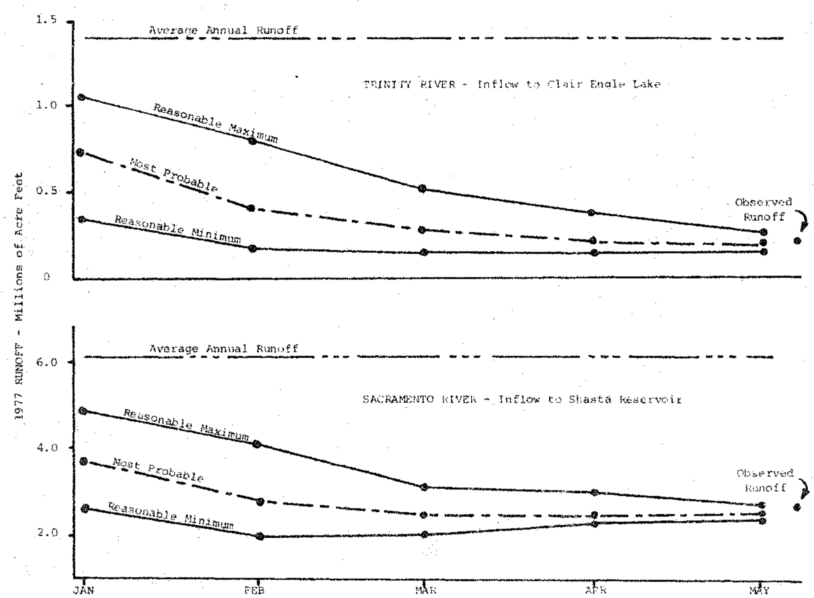

Figure 3. Monthly forecasts of Water Year 1977 runoff on two river systems.

effectively over. Due to the importance of early recognition of this change in conditions, a special advisory was issued on all press circuits. Daily re-evaluations further confirmed this analysis, and on January 16 a strong warning of the definite change was issued throughout our service area.

In both years, the hydrologic simulation model was able to define the important characteristics of the water year before more traditional approaches were able to provide any substantial information as to the character of the year.

Forecast Utilization

Extended Streamflow Predictions, when developed by means of the procedures discussed above, have demonstrated a unique capability in projecting future water supplies. However, a large amount of additional information is contained in or is readily available from an ESP analysis which is not effectively utilized, especially with regard to its probabalistic aspects. As the primary users of water supply forecasts, water managers have a tremendous need to understand and apply the concepts of uncertainty and probability when formulating decisions relating to water availability and allocation.

The ESP procedure has been developed as an attempt to recognize and consider the uncertainty inherent in such forecasts and to offer this information to the water manager to be included in his decision-making process. As needs become more specific, other information such as snow conditions, soil moisture contents, and small-scale time distributions of runoff can be extracted from such analyses as required.

A number of plans for future amplification and additions to the procedure have been developed and will be implemented as time and resources become available. Application of the procedure to additional forecast areas is being contemplated, as well as the presentation of additional information in the forecasts. Further research into the selection and application of appropriate probability distributions is also planned. Also, additional effort in the area of automating data collection and processing as well as automating more of the analysis portion of the procedure is necessary.

Summary

A tremendous interest in water supply forecasts was generated during the California drought of 1976 and 1977. The California-Nevada River Forecast Center utilized several different approaches in developing Extended Streamflow Predictions to this end. The drought was initially identified and regularly forecast, and its end confirmed through these means. This information was provided to the public via press releases, news conferences, special reports, and media indicators throughout the drought period. Additional information relating to future water supplies can be extracted from the procedure as the need develops and several plans for improvements have been formulated.

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