OPERATIONAL AND TECHNICAL CONSIDERATIONS REGARDING RECENT FORECAST SEASONS IN CALIFORNIA 1/

By

Jack F. Hannaford 2/ and Charles H. Howard 3/

Introduction

This water year, 1979, marks the fiftieth year during which the California Department of Water Resources and its predecessor agencies under the California Cooperative Snow Survey Program have prepared forecasts of water supply from California's snowmelt watersheds. Although one might have expected to have encountered almost every conceivable combination of conditions during the initial 46 years of operation, meteorologic, climatic and hydrologic conditions during the past three water years have introduced some technical forecast problems which were unprecedented in the earlier record.

Unimpaired runoff during the 1975-76 water year was well below average in all major hydrologic basins of the State, with the statewide average only about 50 percent of normal. Water year runoff from the major Sierra streams varied from a low of about 30 percent of average in the central and southern Sierra to about 60 percent in the very northern portion of the State. 1975-76 was about the fourth driest individual season since the turn of the century.

Unimpaired runoff during the 1976-77 water year was only 24 percent of average statewide. This second consecutive year of low precipitation resulted in record low runoff on most of the Sierra streams, generating not only the criest single season but also the driest two consecutive seasons since records have been kept.

The unprecedented two-year drought was followed by a season of very heavy precipitation, snowpack, and runoff in the southern Sierra and moderately heavy precipitation, snowpack, and runoff in the northern Sierra. Unimpaired runoff in the southern Sierra was in the order of 200 percent of average and in the northern Sierra about 130 percent of average. Although the heavy runoff during 1977-78 was welcomed to help replenish water supplies, there were problems related to warm storms and unusual distribution of snowpack during the winter, below normal temperatures and delayed runoff during the snowmelt season, and the effects of preceding two-year period of drought conditions.

Area Description

The Sierra Nevada, California's major source of snowmelt runoff, lies immediately to the east of California's great Central Valley. The crest of this range is about 200 miles inland from the coast, and varies in elevation from about 14,000 feet in the major basins of the southern Sierra to 6-7,000 feet in the northern Sierra. Most of the major basins extend 50 to 80 miles to the west of the crest. Substantial runoff is also produced in the much steeper watersheds immediately to the east or lee of the crest. The major Sierra basins, including the upper Sacramento lying immediately to the north of the technical northerly limit of the Sierra Nevada, include about 26,000 square miles and produce an average annual runoff in excess of 26 million acre-feet.

The following sections describe conditions during each of the three "unprecedented" seasons mentioned above along with some of the forecasting problems encountered. The description will be general throughout the Sierra Nevada, with specific description of problems related to the Kings River watershed in the southern Sierra Nevada and the Feather River watershed in the northern Sierra. The Kings River, Feather River, and other major Sierra watersheds appear in Figure 1.

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2/ Sierra Hydrotech, Placerville, California

3/ Snow Surveys Branch, California Department of Water Resources, Sacramento, California


UPPER
SACRAMENTO
FEATHER
YUBA-BEAR
TRUCKEE-TAHOE
AMERICAN
CARSON
COSUMNES
WALKER
MOKELUMNE
MONO LAKE
STANISLAUS
TUOLUMNE
MERCED
SAN JOAQUIN
KINGS
OWENS
KAWEAH
TULE
KERN

The Kings River heads in the very high elevation portions of the southern Sierra Nevada with a total drainage area of about 1,545 square miles, and an average annual runoff of 1,549,000 acre-feet. It is tributary to the Tulare Lake Basin, with no natural outlet to the sea under normal operating conditions. The Kings River supplies water to very productive agricultural lands which are generally water deficient, requiring import of water supplies as well as regulation of local flows to meet agricultural needs, even in years of much above average runoff. Underground water does provide some stability in meeting seasonal demands. In years of extremely heavy runoff on the Kings River and surrounding watersheds, agricultural land being farmed in the Tulare Lake Basin must be temporarily flooded to control and store excessive runoff, which can create substantial losses to the agricultural economy of the area. Forecasts of water supply provide an important operational tool on the Kings River as well as adjacent watersheds for management of the extremely variable surface water supply.

The Feather River is located in the northern Sierra Nevada with an area of about 3,600 square miles and an average annual runoff of 4,287,000 acre-feet. Heaviest precipitation and snowpack accumulation occurs in the 4-6,000-foot elevation zone on the westerly slope of the watershed. The eastern half of the watershed has some elevations extending over 7,000 feet, but in general consists of high elevation valleys and minor ranges with relatively light precipitation as compared to the frontal slope. Oroville Reservoir, the main storage facility of the California State Water Project, controls the flow of the Feather River Basin for operation of the State Water Project. Forecasts of water supply available from the Feather River Basin are important in decision making as to the quantity of water available to meet contract commitments from the State Water Project. Decisions must be made early in the water year (i.e., as early as February 1), but there is some latitude for operational decision making throughout the entire season based on quantity of water predicted and observed.

California Drought Period — 1976 and 1977 Water Years

General

The two year drought period (1976 and 1977 water years), represents the driest such period on record in the State of California. The occurrence of two record or near record dry years "back-to-back" has serious implications with regard to project operation, delivery of scheduled water, utilization of ground water, and even meeting requirements for domestic and municipal supply. The occurrence of these two seasons sequentially has altered thinking in many organizations as to operational criteria for water projects under deficient surface water conditions.

1976 Water Year

On February 1, 1976, in the first formal forecast by the California Department of Water Resources, it was announced that:

> "A three month winter drought is causing statewide concern that the economic damage already experienced by agriculture, and other water users, may increase unless a firm reversal in the weather develops during the remaining winter season. The 1976-77 water year to date is one of the driest of record. Continuation of below normal precipitation will result in further localized hardships, but most water commitments from the various water storage projects in the state will be met by carryover storage from last year's reserve."

Precipitation during February continued light, representing about 70 percent of average February throughout the Sierra, and gave little cause for optimism in terms of forecast runoff. However, on March 1 Federal and State water projects still expected to meet commitments for firm supplies. March continued the dry pattern set earlier, and precipitation during the month varied from 40 to 60 percent of average throughout the Sierra. On April 1 forecasts of April through July runoff were down substantially from the below normal forecast presented on February 1 and March 1. Forecasts indicated that flows on many southern and central Sierra streams would be close to equaling the record April-July low flow set in 1924. Snowpack water content was the lowest of record at about one-third of the State's snow courses.

On May 1, 1976 the Department reiterated, "We are now experiencing one of California's record dry years." Forecasts of April-July runoff were 20 to 35 percent of average on most Sierra streams, except for the upper Sacramento where about 75 percent of average was expected.

The most recent dry years with "record low" flows close to those anticipated for 1976 were 1924 and 1931. Most forecasting procedures included the dry period of the early 1930's in development of procedures, but only a very few snow measurements were made during the critically low 1924 season. As a consequence, the 1976 season fell below or at least at the extreme of the range of historical experience (see Figure 2). On many streams the "standard error" in the forecast procedure was nearly as great as the forecast of runoff itself. From a practical standpoint, however, the forecast was for near record low runoff, calling for conservation measures to be applied, so that in most cases relative forecast error was of little importance in the actual management of water supply which was already being managed for extremely dry conditions.

1977 Water Year

By the end of the 1976 water year, reservoirs had been drawn down to meet operational demands, in many cases from carryover storage. October 1976 through January 1977 precipitation over the Sierra ranged from 20 to 30 percent of average. February 1, 1977 forecasts of runoff based on median conditions subsequent to the date of forecast ranged from 25 to 30 percent of average. On February 1, California Department of Water Resources observed:

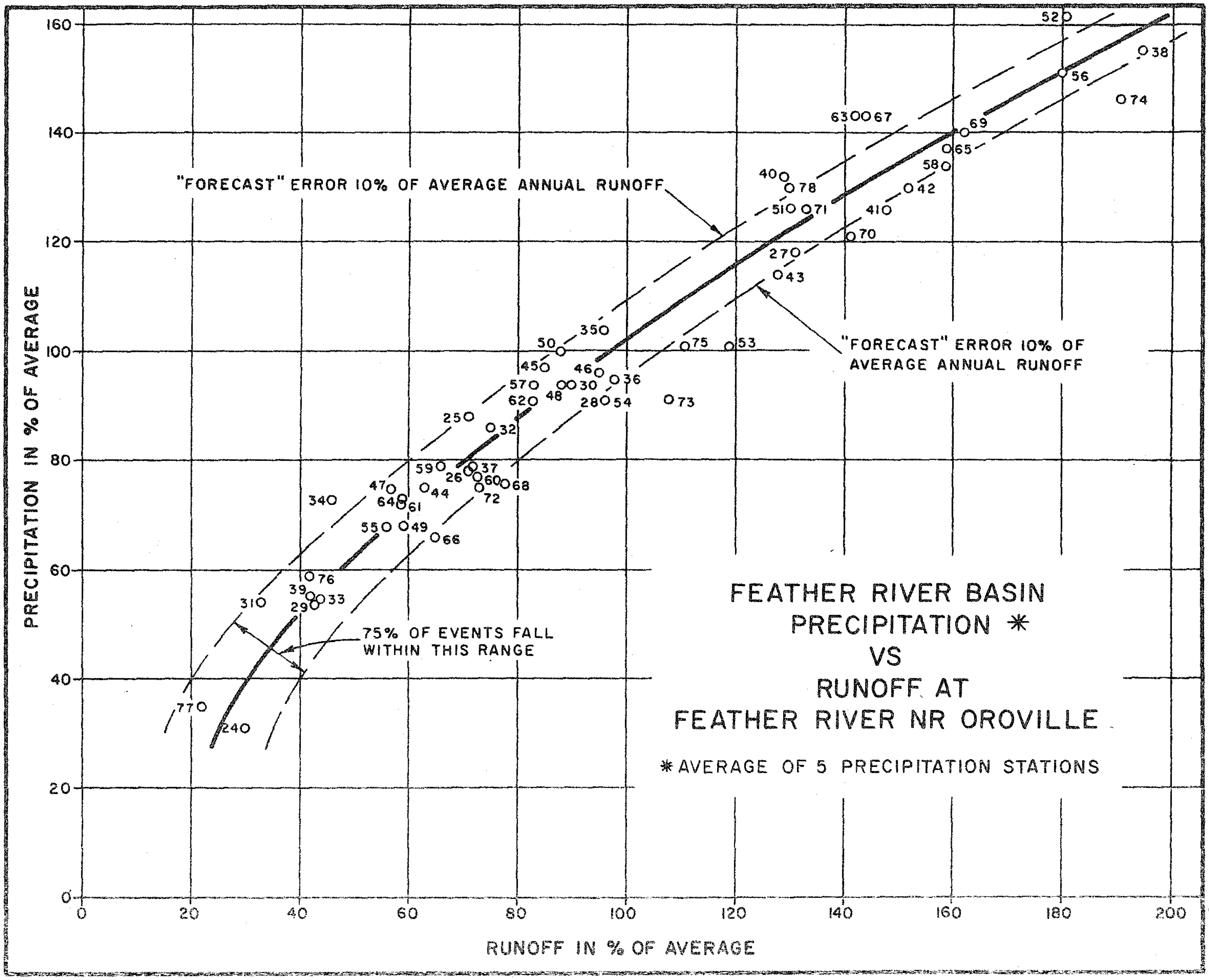
> "The continuing statewide drought, now in its second year, is touching the lives of nearly all Californians. Severity of water supply deficiencies this coming summer is documented by the first statewide Snow Surveys for the 1977 season ..."

February precipitation was again far below normal, and by the March 1 forecast, the Department of Water Resources commented "... with much of the 1977 precipitation season behind us, full relief from the drought cannot come until next winter, even if above normal precipitation should occur in the next two or three months." Forecasts of snowmelt runoff indicated that April-July streamflow volumes would be at or below the lowest flows of record in the Sierra.

By April 1, following a much below normal March precipitation, the Department indicated "... this is the driest year in California weather records". Forecasts of runoff indicated that the major Sierra and eastside Sierra streams would be at minimum flow of record for the April-July period. Projections of total water year runoff indicated that all Sierra streams from the Yuba River south and most Sierra eastside streams would establish the lowest flows of record for the 1977 water year. Forecasts of April-July snowmelt period ranged from about 15 percent of average in most Sierra streams with the upper Sacramento River above Shasta Dam at 48 percent of average.

April precipitation was again below average, and the May first forecast of unimpaired April-July runoff on the Kings River was for 17 percent of average while the water year forecast was for 19 percent of average. Above average precipitation during the entire month of May was partly responsible for bringing the observed April-July flow of the Kings River to 24 percent of average and an observed water year flow to 25 percent of average. The last gasp of May precipitation was enough to boost April-July flow of the Kings River above the previous (1924) minimum of record, but many of the surrounding basins were at minimum of record. On the Feather River Basin, the forecast April-July flow was 18 percent of average (observed at 21 percent of average) and the water year flow was forecast at 21 percent of average (observed at 24 percent of average). On the Feather River, May precipitation did little more than replenish some of the soil moisture in the relatively deep soil found in that basin. It is interesting to note that continued draw down during 1976 and 1977 at Lake Almanor, located in the volcanic area of the northern portion of the watershed, seemed to produce more volume of water than the depletion in the reservoir itself. This suggested that perhaps there may have been some depletion of a ground water body closely associated with the reservoir, a fact which took on some additional importance during 1978. Some vegetation in the intermediate elevation zones was immediately adversely effected by the drought condition, while the effect upon vegetation in other areas may not be fully recognized for several years.

As in 1976, the forecast during 1977 fell below the recent range of experience (with the exception of 1976). Forecasting was made difficult by the sparse and fragmented snowcover observed. Again, forecasts of runoff were in the same order of magnitude as the standard error of the forecast procedures, but as in 1976, the projections of record dry



FEATHER RIVER BASIN
PRECIPITATION *
VS
RUNOFF AT
FEATHER RIVER NR OROVILLE
* AVERAGE OF 5 PRECIPITATION STATIONS
"FORECAST" ERROR 10% OF AVERAGE ANNUAL RUNOFF
"FORECAST" ERROR 10% OF AVERAGE ANNUAL RUNOFF
75% OF EVENTS FALL WITHIN THIS RANGE
PRECIPITATION IN % OF AVERAGE
RUNOFF IN % OF AVERAGE

FIGURE 2

conditions had already alerted water project operators to the need for operating under the most conservative conditions. It is also interesting to note that all of the forecast probability ranges published by the Department were severely limited on the lower side by zero flow as early as February 1. This condition will be corrected in future forecast development.

1978 Water Year

General

Although the two record dry seasons of 1976 and 1977 had posed problems of their own in area of water supply forecasting and project operation, they left a legacy of forecast and operational problems for the 1978 season. Department of Water Resources officials announced that it might take as much as two and one-half years to bring California back to a normal water supply and storage situation.

September 1977 brought unusually heavy precipitation to the northern Sierra and upper Sacramento River Basin. September precipitation at Pit No. 5 Powerhouse in the Sacramento drainage was 16.90 inches, over 1,000 percent of average for the month and about 90 percent of the 17.72 inches recorded during the entire preceding eleven months of the 1976-77 water year. Precipitation amounts further to the south were much closer to the average. October precipitation varied from about 10 to 50 percent of average for the month throughout the Sierra, while November precipitation was near average in the central Sierra and well below average at the northern and southern extremes of the Sierra. By December 1, no relief from the drought condition was in sight.

Relatively heavy precipitation began in mid-December and continued on and off throughout most of the State for the remainder of the month. Unseasonably heavy amounts were recorded in Southern California. December precipitation was well above average in all portions of the Sierra, varying from approximately 135 percent of average in the northern and central Sierra to as high as 200 percent of average in the southern Sierra. December storms were relatively warm, although snowpack at the higher elevations increased substantially during the month.

The relatively heavy precipitation which began in mid-December continued almost without interruption through January 20. January precipitation amounts were well above average in all portions of the Sierra varying from about 150 percent of January average in the southern Sierra to over 200 percent of average in the northern Sierra. By the end of January, precipitation for the October-January period varied from about 125 to 150 percent of the average for that period throughout the Sierra. February 1 snow surveys indicated that snowpack water content was well above average for that date throughout all major basins of the Sierra, especially at higher elevations. Snowpack water content was more than 150 percent of the February 1 average in the southern Sierra where the higher elevations predominate. On February 1, 1978, the Department forecast above average water year runoff throughout the Sierra, varying from about 115 to 140 percent of average if median conditions of precipitation and snowpack accumulation should persist for the remainder of the season.

February precipitation varied from near average in the northern Sierra to over 200 percent in the southern Sierra. The March 1 snow surveys indicated that snowpack water content exceeded the April 1 average on all watersheds and was as great as 150 percent of that value in the southern Sierra. DWR forecasts of water year runoff made as of March 1 varied from 120 to 170 percent of average water year runoff, with the southern Sierra watersheds showing larger percentage values.

The pattern of heavy precipitation was reestablished during the first week of March, particularly in the southern Sierra. Precipitation amounts during March varied from about 130 percent of average in the northern Sierra to over 230 percent of average in the southern Sierra. April 1 snow surveys indicated that some melting had occurred in the lower elevations during March, but that at the higher elevations all basins had received substantial increases in snow stored water. The pattern of relatively high freezing levels during the storms prevented the build-up of snowpack water content at lower elevations comparable to that found in the higher elevation portions of various watersheds. This situation was particularly significant in the northern Sierra, where the lower elevation snowpack is a major contributor to the April-July snowmelt runoff. On April 1, the California Department of Water Resources projected water year runoff amounts varying from 125 to 140 percent of average in the northern and central Sierra to over 200 percent of average in the southern

Sierra, with the highest forecast amount of 266 percent of average for the Kern River at the southern extreme of the range.

Early season precipitation primed Sierra watersheds and high freezing levels contributed to immediate runoff from later storms. Runoff in Sierra watersheds was very heavy during January, particularly in the north. Flood control reservoirs reached maximum permissible storage during mid-January and early February. February runoff continued somewhat above average. Some unusually warm temperatures during mid-March contributed to snowmelt runoff from the lower elevations, while high freezing levels during March storms resulted in immediate runoff from lower elevations. March runoff was well above average for the month throughout the Sierra. Major winter flooding in the Central Valley was not as severe as might possibly have been anticipated from the high freezing levels and heavy total rainfall amounts recorded. The time-distribution of precipitation during the winter months was instrumental in limiting the severity of flooding in the Central Valley. Although total runoff volumes were large, peak flows were nominal and adequately controlled.

The nominal beginning of the snowmelt season in the Sierra Nevada is April 1. April was very cold with relatively high precipitation throughout the area further increasing the quantity of snowpack water content subject to April-July melt. April precipitation was greater than 200 percent of average in all but the very southerly portions of the southern Sierra where it was in the order of 160 percent of average. During April, snow lines dropped to about 2,000 feet in the northern Sierra and 4,000 feet in the southern Sierra, but snowpack water content at these lower elevations was almost negligible in terms of runoff production. At higher elevations, the snowpack water content increased during April, while at lower elevations, snowmelt exceeded snowpack accumulation by the end of the month.

The snowmelt season was characterized by low temperatures and snowpack accumulation during April, and slightly below to well below normal temperatures throughout the season until mid-July. During May and June, there were no extended periods of high temperatures which usually characterize the snowmelt season, resulting in a more uniform time-distribution of snowmelt runoff for 1978 than might normally be expected. Snowmelt runoff, anticipated at high rates as the result of the heavy higher elevation snowpack water content, continued at relatively low rates throughout the month of May, resulting in less depletion of snowcovered area than might normally be anticipated and relatively large snowcovered area for that date, particularly in the southern Sierra Nevada. By mid-May, the greatest snowcovered area of record for that date was observed on the Kings River watershed (as compared with observations dating back to 1952). June remained cool with no extended periods of high temperatures. June runoff, though large, continued to be delayed to some extent as a result of temperature conditions. Had a more normal temperature regime persisted in late May and early June, peak runoff rates could have been as much as 30 percent greater than those actually observed. The delayed runoff with reduced rates was advantageous to reservoir operators and water managers, particularly in the southern Sierra, since filling and possible spilling of reservoirs in early June did not occur. However, the much delayed snowmelt which left snowpack remaining in the watersheds for an extended period of time, subjected that snowpack to loss and tended to reduce the total volume of snowpack runoff from that which might have been expected under a more normal temperature regime.

Southern Sierra streams maintained flows of relatively high rates throughout July. Not until mid-July did temperatures rise to well above normal. By the end of July, flows were still relatively high and satellite data on snowcover indicated that there was still some substantial snowpack left in certain protected high elevation portions of the southern Sierra watersheds.

Water Supply Forecasts

Although there were some large observed percentage forecast errors in 1976 and 1977 attributable to the forecast procedures which may well have resulted from extrapolation of data below the previously observed extremes, such errors in terms of acre-feet were still relatively small as a result of the extremely small observed runoff. The extreme forecast dictated the most conservative approach to water management and, at least in most cases, magnitude of error was relatively inconsequential in decision making. However, in 1978 the variation from drought to surplus as the season progressed did influence some operational problems and decisions related to forecast and forecast accuracy. In general, forecast procedures then in use tended to substantially over-forecast anticipated runoff. In the process of updating forecast procedures to include the input from the three past unusual seasons, the relative level of error in the forecast procedures related to observed and measurable parameters has been analyzed. The problem associated with the extreme dry seasons of 1976 and 1977 as already been briefly described. The following discussion covers the relative magnitude of the contribution to forecast error of various factors observed during the 1978 season which it is believed can now be included in the water supply forecasting procedures to further improve on procedural error.

Magnitude of Overforecasts

In the analysis and comparison of overforecasts, the nominal snowmelt period runoff, April through July, were utilized on the Kings River in the southern high elevation of the Sierra and the Feather River in the northern, lower elevation portion. The April-July forecasts using existing procedures were adjusted for observed precipitation during April. The contribution of precipitation subsequent to April 30 for this season appeared to be insignificant for this analysis. On the Kings River, the forecast procedure adjusted for observed precipitation gave a forecast April-July runoff of 2,600,000 acre-feet. The observed April-July runoff was 2,351,000 acre-feet, resulting in a total forecast error of 249,000 acre-feet. On the Feather River, the procedure gave a forecast adjusted for observed precipitation of 2,950,000 acre-feet. The observed runoff (still preliminary at this time) was 2,136,000 acre-feet, resulting in an apparent forecast error of 814,000 acre-feet. These overforecasts represented by far the greatest forecast errors on these streams attributable to the forecast procedures within the last thirty years.

Forecast error for the snowmelt season of 1978 is summarized in Table 1 for the Kings River and Feather River watersheds along with contributory components as derived in post-season analysis.

August-September Carryover

In the southern Sierra, the delayed snowmelt season previously mentioned resulted in carryover of substantial snowpack at the higher elevations subsequent to July 31, thereby increasing runoff anticipated during the remainder of the summer. Heavy precipitation occurred early in September 1978 and the effect of that unseasonable precipitation was isolated from the snowmelt recession hydrograph by analysis. Calculations indicate a total volume of runoff during August and September of 268,000 acre-feet attributable to snowmelt and recession from the 1978 season. DWR procedures estimated 150,000 acre-feet on the basis of a more normal time-distribution of snowmelt runoff. This difference resulted in displacement of 118,000 acre-feet of the "April-July runoff" into August and September.

On the Feather River Basin, the preliminary estimates of unimpaired inflow suggests a reverse situation. Observed runoff, with some minor adjustment for unseasonable precipitation in September, would have been 188,000 acre feet, while the estimate by DWR procedures was 250,000 acre-feet. The net result was that the overforecast of April-July runoff was further aggravated by an overestimate of August-September runoff amounting to 62,000 acre-feet.

Apparent Change in Reservoir Storage

Analysis made prior to the 1978 water year, but subsequent to development of forecast procedures in use during 1978, indicated that a large reservoir on the North Fork of the Feather River, Lake Almanor, has an "apparent storage" substantially larger than the observed storage. Detailed analysis of monthly releases and changes in storage suggested that when the reservoir is filling, the true inflow is probably greater than that calculated. When the reservoir is emptying, the true inflow is probably substantially less than that being calculated. This effect of "apparent storage" may at least be partially due to the nature of the volcanic materials in which Lake Almanor is located. Results of the analysis suggests that following the extremely dry 1976 and 1977 seasons, approximately 60,000 acre-feet of runoff from the Lake Almanor basin attributable to the April-July snowmelt period would have gone into "apparent storage". No such similar situation exists in the Kings River watershed.

Elevation Distribution of Snowpack

Many of the winter storms (prior to April 1) had unusually high freezing levels, and although these storms had deposited much greater than normal snowpack at the higher elevations, the few measurements at lower elevations indicated that snowpack accumulation was much less than might have been expected as compared to the upper elevations. Review of the historic record in the southern Sierra Nevada indicated that never had 200 percent of normal snowpack at high elevations been experienced with such light snowpack at the lower elevations and such a high April 1 effective snow line (5,700 to 5,800 feet on the Kings River). During every previous season with extreme high elevation snowpack, snowpack at the lower elevations has been as great or greater in terms of percentage of average. Analysis suggests that in the Kings River Basin the average deficiency in snowpack water content which might have contributed directly to runoff (i.e., corrected for loss in areas below the observed snow line) would have averaged about 4.9 inches between 5,000 feet (an elevation typical of several of the heavier runoff seasons) and 6,700 feet (the elevation above which relatively consistent snowpack was observed in 1978). Volume of additional water available from this 176 square mile area would have been in the order of 46,000 acre-feet. The relatively steep and consistent area-elevation relationship of the Kings River watershed tends to hold the effect of unusual elevation distribution of snowpack to a minimum in this situation.

The situation is substantially different in the Feather River Basin. The effective April 1 snow line was about 5,100 feet from satellite observation, but the observed snow line was as low as 4,600 feet in the western, heavy precipitation portion of the watershed and as high as 5,900 feet in the drier eastern portion. This was about 500 to 700 feet higher than the average snow line for most seasons with similar heavy, high elevation snowpack. As in the Kings River Basin, previous seasons with extremely heavy snowpack usually had disproportionately heavy snowpack at the lower elevations. This was not the case in 1978. Analysis suggests that the average deficiency in snowpack water content which might have contributed directly to runoff (i.e., corrected for losses in the area below the observed snow line) would have averaged about 5.47 inches between 4,500 feet (the effective snow line typical of several of the heavier seasons) and 5,700 feet (the effective elevation above which relatively consistent snowpack observation was observed in 1978). As a result of the unusual area-elevation relationship in the Feather River Basin, about 38.3 percent or 1,380 square miles of the watershed would fall within this band. Assuming a contribution of runoff of 5.47 inches within this band, this would account for about 402,000 acre-feet of runoff not taken into account by the basinwide snowpack index.

Delay of Snowmelt Runoff

As mentioned previously, the snowmelt season, particularly in the southern Sierra Nevada, was extended for a considerable length of time as the result of the lack of periods of high temperature during the early melt season. The fact that water remained as snowpack in the basin for a longer period of time might tend to reduce the amount of water available to produce surface runoff as a result of increased time for evaporation directly from the snowpack and possibly some increase in evapotranspiration of water which was released from snowpack at a later date during the season. Although it is difficult to place a number on the results of this delay, some investigators have made conclusions regarding the problem.4/5/

In the Kings River, it was assumed that melt from the high elevation snowpack was delayed by about 30 days and that evaporation would be increased for 10 days in a band of wetted soils 500 feet below the snow lines. In the Kings River this would have resulted in loss of about 59,000 acre-feet.

Similar calculations were made in the Feather River Basin where snowmelt occurs earlier as a result of the much lower elevations. It was estimated that a 20-day delay in snowmelt and an increase in evapotranspiration from the band 500 feet below the snow line would result in a net loss to the watershed of 125,000 acre-feet. Note that these losses represent a true loss to runoff, not just a delay which would permit runoff to occur outside the forecast period.

Remaining Error and Antecedent Conditions

By subtracting the above effects from the observed error (see Table 1) a residual error of 26,000 acre-feet remains on the Kings River and 289,000 acre-feet on the Feather River. This error may be fully or partially attributable to any cause from data error to procedural error. However, for purposes of the investigation leading to revision of forecast procedures, it was assumed that the indicated remaining error was in fact (1) an error

4/ Peak, George W. Snowpack Evaporation Factors, Proc. WSC 1963

5/ Peak, George W. A Snowpack Evapo-Sublimation Formula, Proc. WSC 1969 attributable to inability to completely characterize the runoff relationship with the existing forecast procedures and (2) at least indicative of the relative magnitude of the antecedent effect introduced by the successive extreme dry seasons. Obviously, there may be many other contributing factors. 6/7/

On the Kings River, 26,000 acre-feet is a relatively trivial error. However, if we were to assume the entire 26,000 acre-feet attributable to antecedent conditions (i.e., deficiency in soil moisture) resulting from the previous dry seasons, we could estimate the deficiency in terms of inches. Approximately 45 percent of the watershed 8/ is covered by timber, brush, meadow and other deeper soils, while the remaining 55 percent or more is rock and talus. The 26,000 acre-foot remainder would average about .70 inch over that portion of the watershed which would have relatively deep soils. The existing forecast procedure already has accounted for approximately 100,000 acre-foot reduction in flow resulting from the prior deficient year as opposed to a preceding average season. This would be equivalent to about 2.7 inches of adjustment for antecedent conditions which has already been taken in the forecast.

Again the condition is substantially different in the Feather River watershed. Approximately 15 percent of the watershed is rock covered and was assumed to have little need to meet soil deficiency. It is interesting to note that this volcanic watershed has much more carryover effect from season to season in some of its subbasins than do the high elevation, granite subbasins of the Kings River. If it were assumed that the entire 289,000 acre-feet of remaining error were the result of antecedent conditions, this would be equivalent to about 1.77 inches in the 85 percent of the watershed which may be considered soil covered. The existing procedure used in this analysis had already made adjustment for 330,000 acre-feet as a result of antecedent conditions which would represent about 2.06 inches.

Conclusions

Studies which led up to presentation of this paper have resulted in several conclusions pertinent to future updating and development of forecast procedures in California's Sierra Nevada.

1. Snowpack Distribution is an important factor in forecasting. Both aerial and elevation distribution must be considered. An attempt is being made to utilize existing snow courses to develop high and low elevation snowpack indexes for major watersheds. In addition, snowcovered area from a NASA sponsored research project is being utilized to better describe the areal distribution of snowpack, providing one additional parameter for analysis in water supply forecasting.

2. Time Distribution of runoff during the snowmelt season can affect the volume of runoff observed in several ways. It may delay runoff beyond the forecast period, or water which remains in the basin for a longer period of time may be subject to more loss through evaporation from the snowpack as well as from evapotranspiration. New forecast procedures on the Feather River Basin will will incorporate the effect of delay in snowmelt, primarily through the use of observed snowmelt runoff rates.

3. Antecedent Conditions have always been considered as an important factor in forecasting snowmelt runoff. However, evaluation of the magnitude of this error reveals some interesting conclusions. In the Kings River Basin which is predominately rock with relatively little opportunity for long-term carryover, the existing procedure relating antecedent conditions to the previous year's snowmelt runoff may be adequate with minor alterations to define the effect on forecast runoff. However, in a watershed like the Feather River, the effects of

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6/ Fletcher, Joel E. Soil Moisture Measurement in Water Supply Forecasting, Proc. WSC 1966

7/ Farnes, Phillip E., Nelson, M.W., Freeman, T.G. Soil Moisture in Forecasting, Proc. WSC 1963

8/ Richards, Lucille. Terrain Features of Drainage Basins in the Sierra Nevada West-Side Snow Zone, Tech. Paper No. 58, U. S. Forest Service, May 1961 antecedent conditions may extend for one or more seasons. A considerable amount of investigation will be required in the Feather River Basin to develop a technique which adequately describes the effect of carryover for several seasons in this watershed.

It is hoped that the results of work described above can be incorporated in updated forecast procedures which will tend to better describe forecasts and changes in forecast of future runoff as the water year and melt season progresses.

TABLE 1

Relative Magnitude of 1978 Over Forecasts
Possibly Attributable to Various Causes

Item	Kings River 1,000 AF	Feather River 1,000 AF
Average Water Year Runoff	1,549	4,287
Average April-July Runoff	1,157	1,862
Forecast of 1978 A-J Runoff	2,600	2,950
Observed 1978 A-J Runoff	2,351	2,136
1978 Over Forecast	249	814
Carryover to August and September	- 118	+ 62
Apparent Change in Storage	-	- 60
Snowpack Distribution	- 46	- 402
Delay of Runoff From Evapotranspiration	- 59	- 125
Remaining Error	26	289
Area of Basin	1,545 sq. mi.	3,600 sq. mi.
Est. Percent of Area with Developed Soil	45%	85%
Remaining Error Expressed in Inches Over Area of Developed Soils	.70 inch	1.77 inches