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ECONOMICS OF EARLY SEASON SNOW SURVEYS

by

Jack F. Hannaford ^{1/}

INTRODUCTION

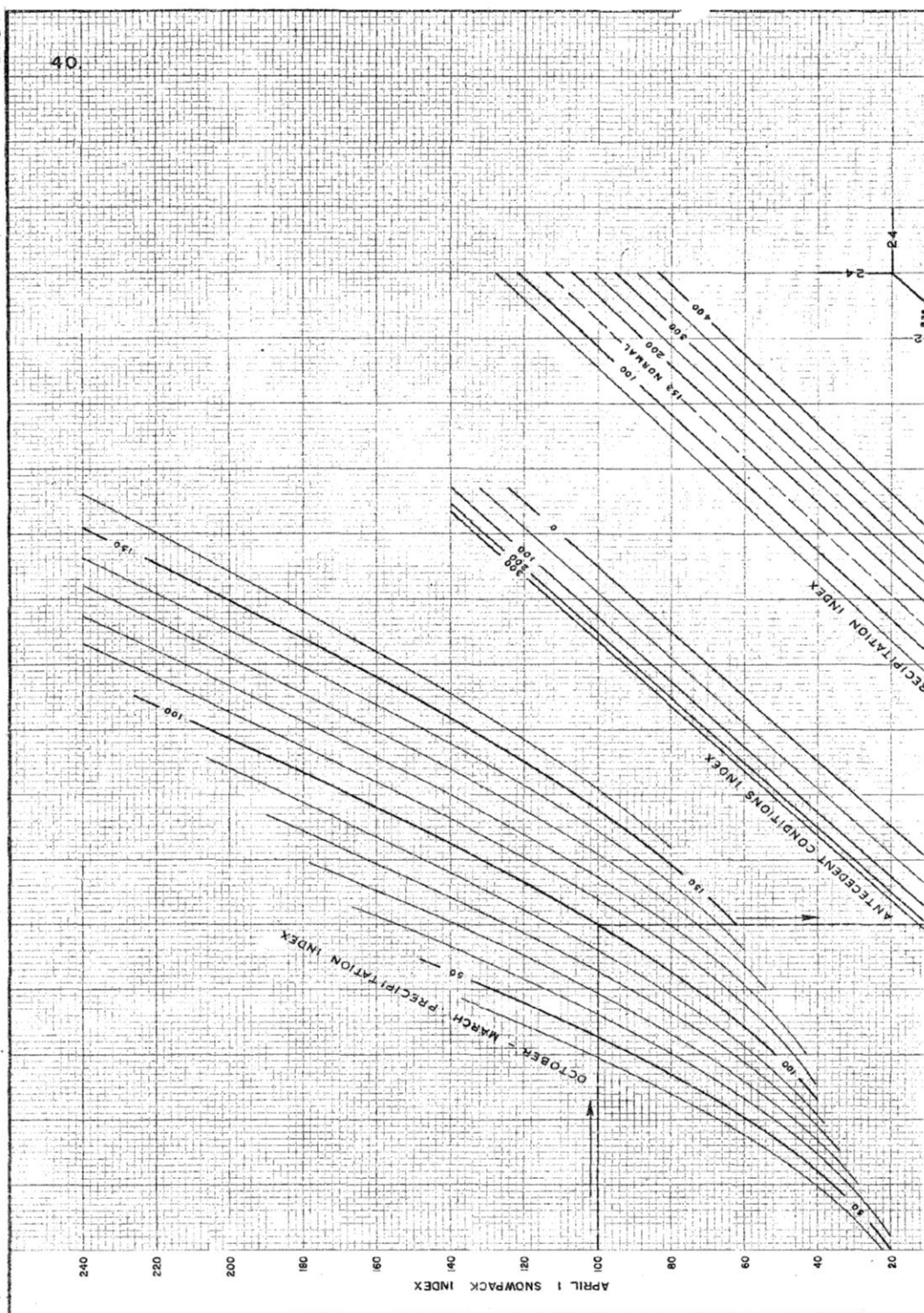
The primary purpose of snow surveys is to prepare water-supply forecasts. Snow surveying is an expensive way of gathering data, no matter how we look at it. However, information which we obtain from our snow surveys is not readily obtainable any other way and, therefore, is well worth this added cost - or is it? Experience has shown that snow surveys taken on April 1 will give us a good index to the amount of water stored in a basin on April 1. If precipitation occurring subsequent to April 1 is only a small portion of total annual precipitation, then April 1 snow surveys, corrected for this subsequent precipitation, provide a good index to spring or "snowmelt" runoff. However, just how good an index of snowmelt runoff is a February 1 snow survey, when perhaps 50 per cent of total annual precipitation normally occurs after February 1? Are early season snow surveys really worth their added cost and inconvenience, or would forecasts prepared from other types of data give us comparable results during the earlier portion of the forecast season?

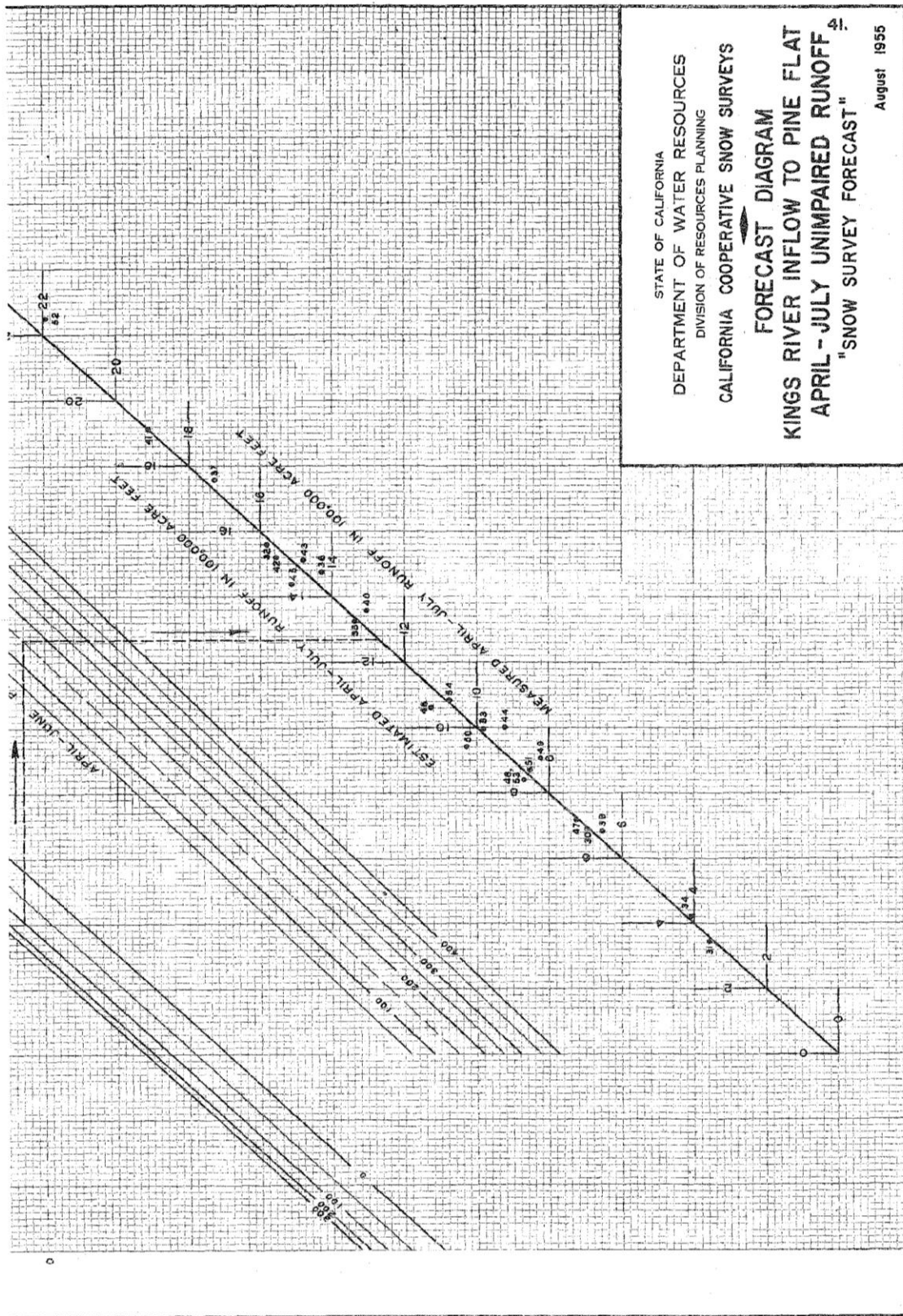
This study was prepared in an attempt to answer some of the above questions and to better substantiate our thoughts on the frequency of measurement and expansion of the network of snow surveys in California.

Any engineering economy study consists of comparisons between alternatives which produce the same final results, or alternatives which produce different results, with an evaluation of this difference. In many cases, the economic value of snow surveys has been based upon the two alternatives: (1) to make water supply forecasts using snow surveys; or (2) to make no forecasts at all. This approach ignores the fact that it is possible to prepare water-supply forecasts without using snow surveys at all. Any alternative forecast is important and should not be neglected.

This economy study will differ from most, in that no precise dollar value will be set on snow surveys or forecasts prepared from them. The common denominator will be the acre-foot, and it is left up to the reader to determine from results of the study just what use of snow surveys he can afford to make.

^{1/} Associate Hydraulic Engineer, California Cooperative Snow Surveys, Department of Water Resources, Sacramento, California.





STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

CALIFORNIA COOPERATIVE SNOW SURVEYS

FORECAST DIAGRAM
KINGS RIVER INFLOW TO PINE FLAT
APRIL - JULY UNIMPAIRED RUNOFF
"SNOW SURVEY FORECAST"

August 1955

BACKGROUND ON PRESENT METHODS OF FORECASTING

Let us first go into a little background on the forecasts presently prepared by the California Cooperative Snow Surveys, along with some of the general premises upon which this study was based.

The purpose of water supply forecasting is to prepare at a given date during the year a forecast of runoff to occur during a specific season of that year to aid in operation of facilities using, storing, or transmitting that water. All water supply forecasts must be based upon assumption of some specific weather conditions subsequent to the date of forecast. The value of a forecast is enhanced if the forecaster can offer an indication of probabilities that actual runoff will fall within, above, or below certain specified limits.

The snowmelt season in the Sierra Nevada of California is April through July. Forecasts of April-July runoff are prepared each year as of the first of February, March, April, and May. The Kings River, a typical high mountain watershed, was selected for this study. Average April-July runoff is about 1,300,000 acre-feet, while water-year runoff is about 1,700,000 acre-feet. This time-distribution of runoff gives some indication of the importance of snowmelt in this watershed. California Cooperative Snow Survey forecasts are prepared using not only snow survey data, but also winter precipitation, antecedent conditions, and spring precipitation. All information, with the exception of snow surveys, is gathered primarily for purposes other than water supply forecasting.

PREVIOUS WORK ON ANALYSIS OF FORECAST ACCURACY

Actual forecasts are prepared from a multiple-graphical forecast scheme, such as that shown on Plate 1. A rigorous statistical analysis of such a scheme with its curved lines, variable spacing, etc., presents a difficult problem.

In the 1957 Proceedings of the Western Snow Conference, a paper entitled "Graphical Forecast Errors" was presented by Fred A. Strauss and Joseph I. Burns. This paper contained a seemingly adequate analysis of forecast errors that might be expected from the multiple-graphical forecast procedure prepared for the Kings River in California as a result of variations in weather conditions subsequent to the date of forecast. Also considered were inherent errors which might be expected from deviations in the forecast scheme itself. The paper pointed out how exceedence levels could be established to estimate the limits above, below, or within which a forecast might fall for any forecast date from February 1 through July 1. The method presented in that paper has been used here to provide a means of comparing different graphical forecasting schemes at various exceedence levels.

The funnel-shaped diagram in Plate 2 is a plotting of probabilities or "exceedence levels" as adapted from the above paper. The exceedence level represents probability that the actual forecast departure will exceed (algebraically) the indicated forecast departure. If a forecast of 1,300,000 acre-feet were made on February 1, 90 chances out of 100 the runoff would exceed 1,300,000 minus 550,000 or 750,000 acre-feet. On the other hand, there is only a 10 per cent chance that the runoff will exceed 1,300,000 plus 430,000 or 1,730,000 acre-feet. Note, however, that if a 1,300,000 acre-foot forecast were made, there is a 50 per cent chance that the actual runoff will fall below (or exceed) 1,195,000 acre-feet. This situation probably results from the assumption of other than median conditions after date of forecast.

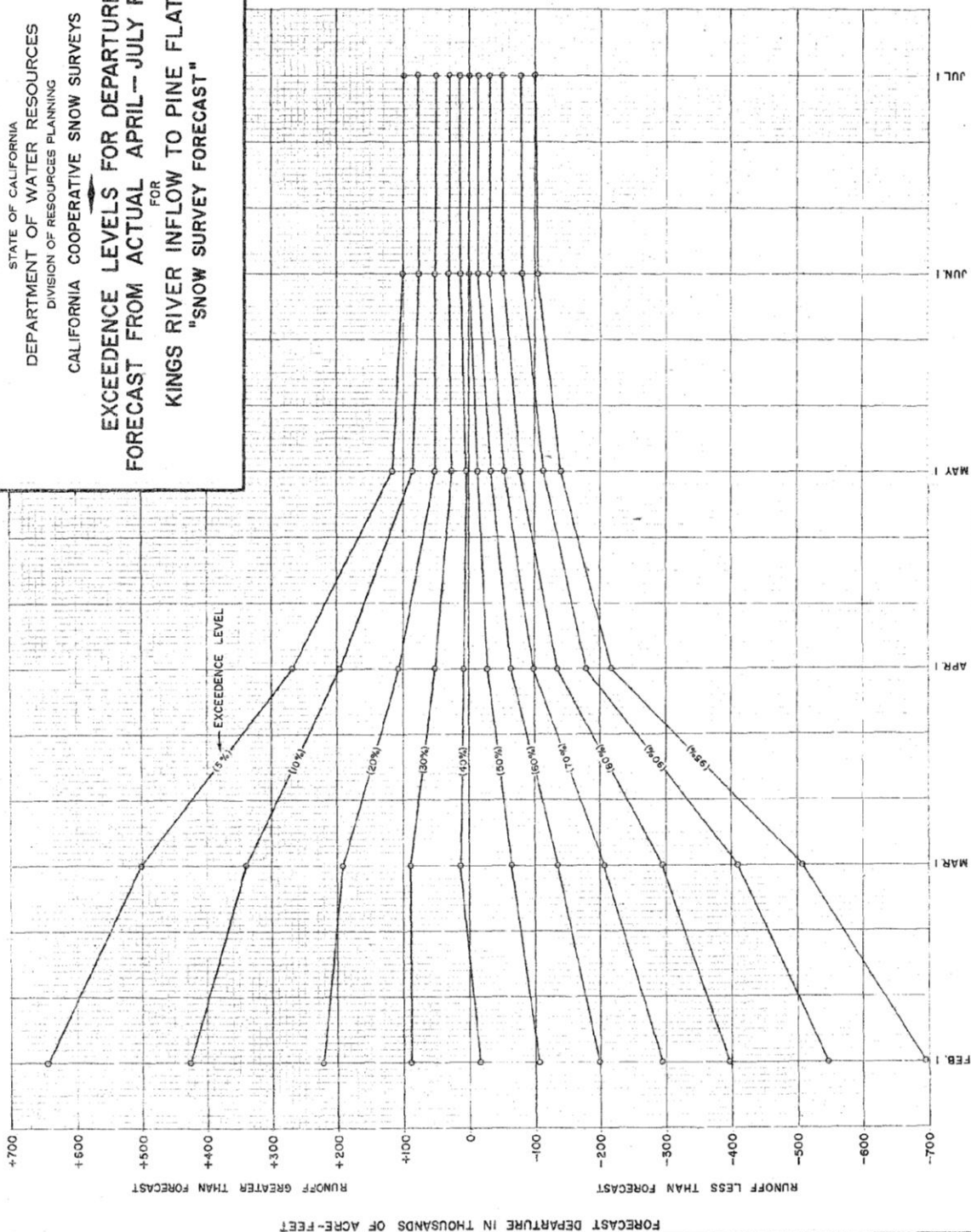
METHOD OF EVALUATION OF SNOW SURVEY DATA

In order to compare forecast results as the forecast season progresses, an alternative scheme was prepared using the same information available for the "snow-survey" forecast, excepting for the snow surveys themselves (Plate 3). Let us call this scheme the "alternative" forecast. The alternative forecast, using annual precipitation, is basically a water-year forecast. However, it was reduced to an April-July or snowmelt season forecast by graphically subtracting out October-March runoff. August-September runoff is normally small compared to, and well correlated with April-July runoff, making it possible to exclude this flow from the schemes for this analysis. Both forecast procedures could have been based upon an April-September period without altering the schemes materially. Each of the two forecast procedures was developed on 25 years of record (1930-1954).

The "snow-survey" and "alternative" forecasts presented here are probably not the most refined schemes that could be prepared, but we will assume, for purposes of this paper, that these schemes typify results that may be obtained from the data specified. We will further assume that the "snow survey" and "alternative" forecasts are the two most accurate types of forecasts available for this stream, removing the necessity for reviewing other forecast types at this point.

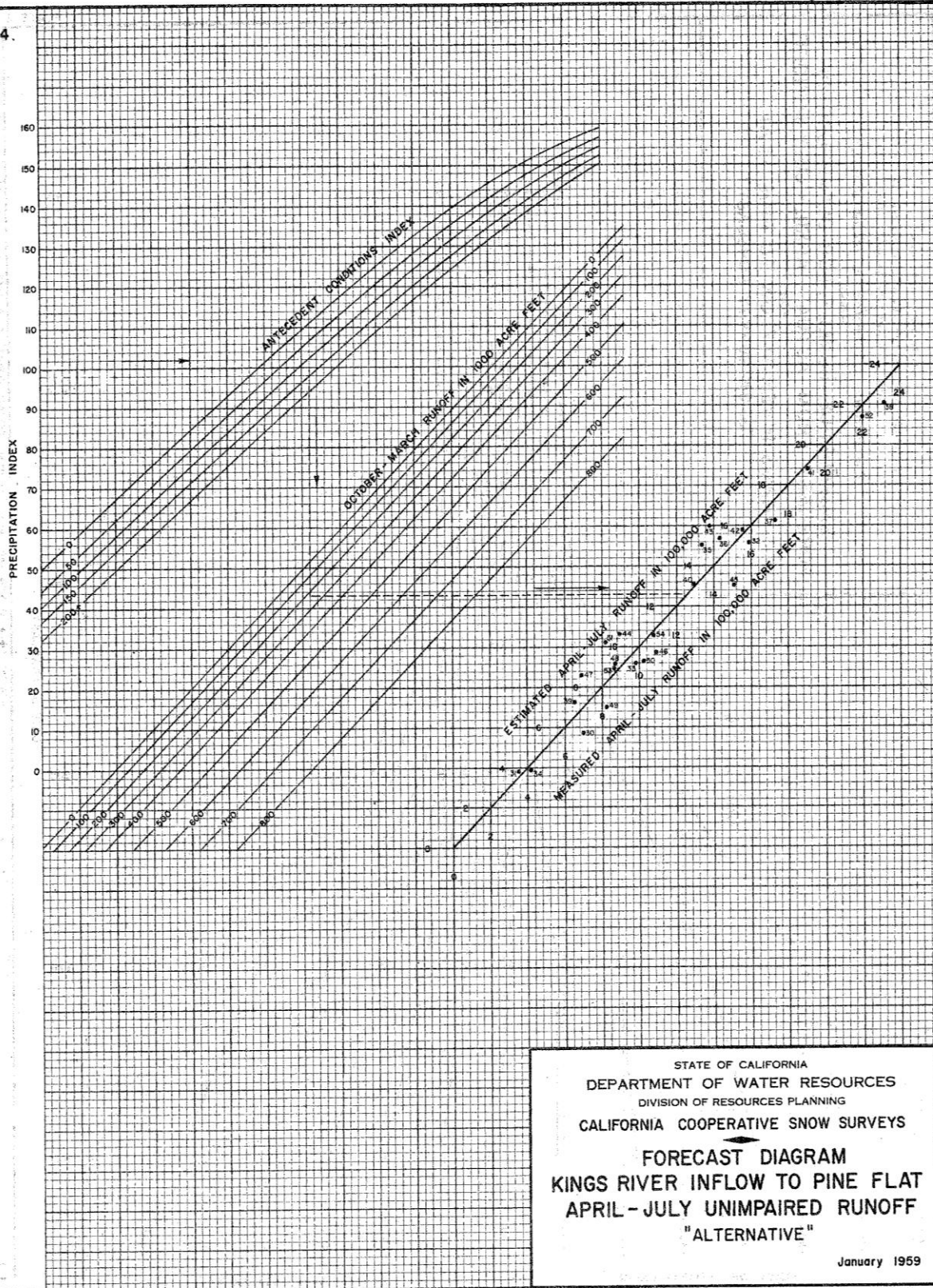
STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
CALIFORNIA COOPERATIVE SNOW SURVEYS

EXCEEDENCE LEVELS FOR DEPARTURE OF
FORECAST FROM ACTUAL APRIL-JULY RUNOFF
FOR
KINGS RIVER INFLOW TO PINE FLAT
"SNOW SURVEY FORECAST"



ADAPTED FROM STRAUSS AND BURNS "GRAPHICAL FORECAST ERRORS" DEPARTMENT OF THE INTERIOR

44



Although the snow-survey forecast has been developed for April 1 data, modified by late season precipitation, and the alternative forecast for water-year data, the same curves can be used for any other date of the year. When these schemes are used to prepare early season forecasts, it is necessary to make an assumption of precipitation, snowpack increment, and runoff subsequent to the date of forecast. Median conditions subsequent to date of forecast were assumed in this paper so that forecast discrepancies due to variations in conditions after the forecast date would cause an equal number of "high" and "low" forecasts. (In "Graphical Forecast Errors" median conditions were not used, causing considerable skew in exceedence levels as noted in Plate 2. Exceedence levels were recomputed for the snow-survey forecast using median values for the purposes of this paper.)

The following method, as outlined in "Graphical Forecast Errors," was used to prepare exceedence levels for this paper:

1. Values of precipitation and snowpack indexes (or precipitation and runoff in the case of the "alternative" forecast) which would yield a forecast of 1,300,000 acre-feet,* when combined with median conditions after date of forecast, were arbitrarily selected for the particular date of forecast.
2. The assumed values in (1) were adjusted to prepare "forecasts" by applying historical precipitation and snow-pack variances (or precipitation and runoff variances) for the period between date of forecast and end of season. All historical data required for a single forecast were taken from the same year of record. Historical data from 29 years of record (1930-1958) were used in this study.
3. A "forecast" using the historical variance was then prepared for this synthesized season. The differences between the forecast selected in Step (1) (i.e., 1,300,000 acre-feet) and the values determined by Step (3) result from our inability to forecast future weather events.

The forecast scheme also has inherent inaccuracy which must be added to inaccuracies caused by weather. The index of inherent error used here was the "standard error," although this measure is not strictly applicable to a skewed distribution. Standard error is the square root of the summation of squares of individual forecast (actually "hindcast") errors divided by the number of years of data less degrees of freedom lost in development of the forecasting scheme. Nine degrees of freedom were assumed lost in the snow-survey scheme and six in the alternative scheme. In order to estimate the "true" inherent error, it is necessary to multiply the "hindcast" errors by the ratio of "standard error" with degrees of freedom lost to "standard error" with no degrees of freedom lost.

Total forecast departure is obtained by adding algebraically the values determined in Step (3) to the "true" inherent error. These departures were then arranged in order of decreasing magnitude, algebraically, and plotted on probability paper. Exceedence levels were determined for each scheme for each month and plotted on Plate 4.

RESULTS OF EVALUATION

Confidence levels for both the snow-survey and alternative forecasts are superimposed on Plate 4 for comparison purposes. Inherent error in each of the forecasts is represented by July 1 exceedence levels, because in each of these forecasts no additional information was introduced to the forecast after July 1. Inherent error of the snow-survey forecast is much less than that of the alternative forecast at this late date, as might well be expected. Some probable reasons for this increased accuracy are listed below.

1. The snow-survey forecast is effectively based upon a shorter period of time than the alternative forecast. The forecast error for the entire water-year is concentrated in the April-July period in the alternative forecast.
2. Snow course coverage in that area of the Kings River Basin contributing the majority of April-July runoff is much better than precipitation station coverage (which is actually nonexistent in that area).
3. Data gathered specifically to represent a special time period (snow surveys to represent the April-July period) will probably give a better index to expected occurrences during that period than more general data.

At earlier dates in the season, forecast departures become greater for each forecast method as a result of inherent error plus our inability to forecast weather conditions subsequent to date of

* In "Graphical Forecast Errors," the exceedence levels were determined for three different forecasts: (1) high - 2,000,000 acre-feet; (2) average - 1,300,000 acre-feet; and (3) low - 600,000 acre-feet. The levels for the average and low forecasts almost coincided during the entire season. The levels for the high forecasts varied slightly during the early season. Preliminary computations indicate that the same conditions hold true for the alternative forecast. To simplify this presentation, only the average forecast was used in preparing the computations for this paper.

FORECAST DEPARTURE IN THOUSANDS OF ACRE- FEET

RUNOFF GREATER THAN FORECAST

RUNOFF LESS THAN FORECAST

+700
+600
+500
+400
+300
+200
+100
0
-100
-200
-300
-400
-500
-600
-700

FEB. 1

MAR. 1

APR. 1

DATE OF F

EXCEEDENCE LEVEL "ALTERNATIVE"

EXCEEDENCE LEVEL "SNOW"

(5%)

(10%)

(10%)

(20%)

(30%)

(30%)

(40%)

(50%)

(60%)

(70%)

(70%)

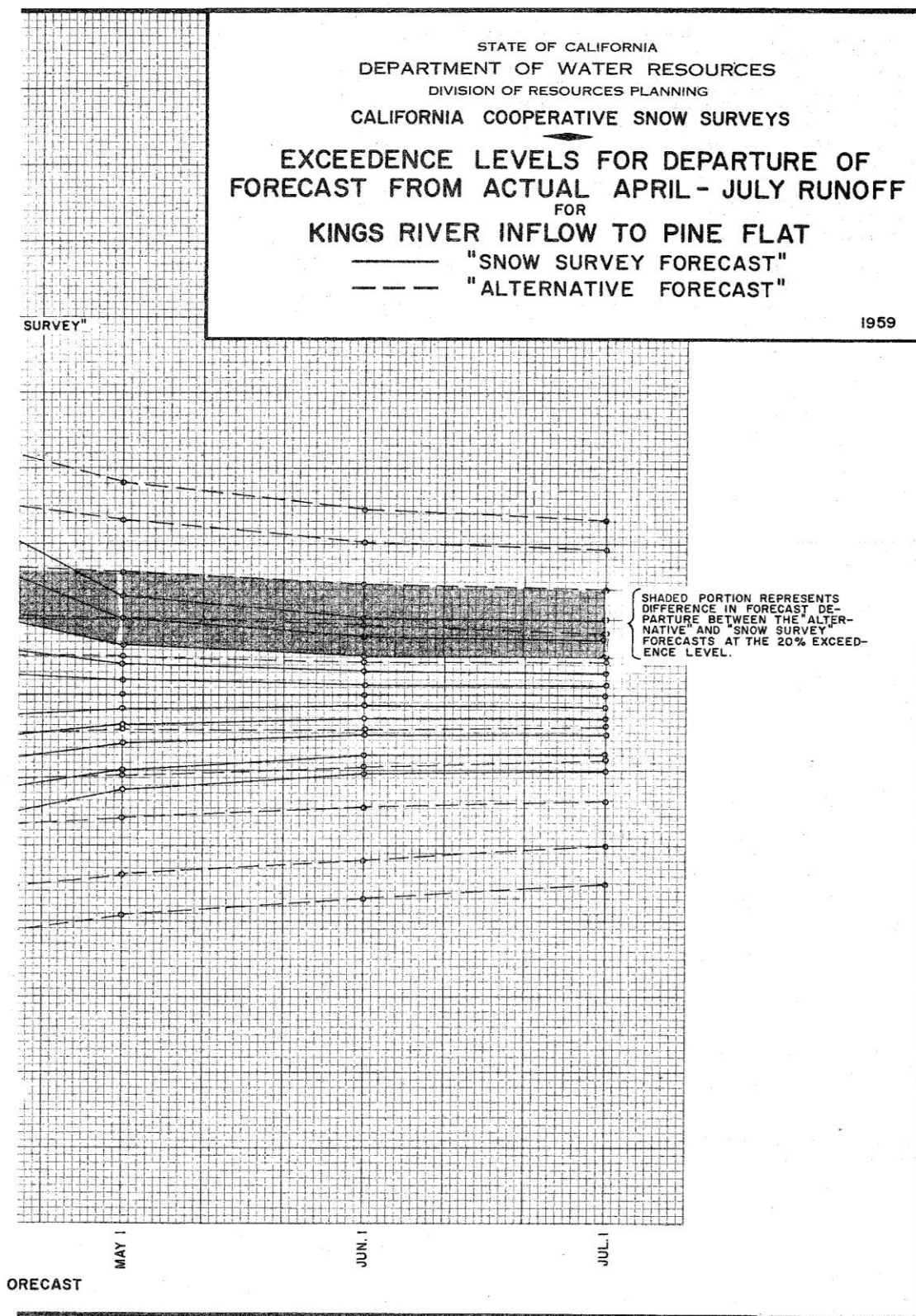
(80%)

(90%)

(90%)

(95%)

(95%)



forecast. After April 1, the snow-survey forecast seems to have a great advantage (as indicated by shaded area on Plate 4). On forecasts made prior to April 1, however, the difference in forecast departure between the two methods at any given exceedence level decreases to a point where the advantage of one forecast method over the other may no longer be significant to the user. The decrease in differences in departures earlier in the season results from the fact that departures due to our inability to forecast future weather far overshadow inherent error in either forecast method. (Let us assume that departures resulting from variance in weather and from inherent errors in the forecast schemes are completely independent variables. The probability that a departure resulting from weather with an exceedence level of 30 per cent and a departure resulting from inherent error with an exceedence level of 30 per cent would occur during the same season would be in the order of 30 per cent times 30 per cent or 9 per cent. The possibility that there may be some interdependence between these two errors should not alter the picture materially.)

How much is the prospect of increased forecast accuracy resulting from snow surveys worth to us early in the season? At the 80 per cent level, increased accuracy for a February 1 forecast resulting from use of snow data amounts to only 35,000 acre-feet, or about 3 per cent of the average April-July flow. Note that this represents only about 12 per cent of the total departure of the alternative forecast for the 80 per cent level. This relatively small increase in accuracy would probably have little effect upon planning or operation this early in the year. This certainly would not impair the value of the forecast to most users, who expect only a general picture of water supply at this early date. By April 1, the increased accuracy at the 80 per cent level is 75,000 acre-feet or about 6 per cent of average April-July flow. The increase in accuracy here represents about 40 per cent of the total error in the alternative forecast. This increase in accuracy by April 1 is undoubtedly worth the additional cost of making snow surveys when planning must be firmed up and operational procedures more rigidly set.

Although similar studies have not been prepared for other snow-melt streams in California, it is probably safe to assume that studies of most west side Sierra streams would result in comparable findings.

USE OF ALTERNATIVE SNOW DATA

Another possible method of preparing early season forecasts from snow measurements is presented here as a sidelight to this paper. Snow data, other than snow surveys, are available from which to prepare a forecast. Snow depth measurement throughout a basin are readily obtainable from aerial snow depth markers. Density of the snowpack cannot be obtained from these measurements, and hence it is impossible to find the water content. However, it is possible to make an estimate of density, either from average density for that particular date, or better yet, from densities on key courses that have been measured for water content. Using these estimated densities, we can estimate snowpack water content at aerial markers. A 5 per cent error in estimating a density of 25 per cent on February 1 (i.e., we estimate 30 per cent instead of the actual 25 per cent density) would give about 20 per cent error in snowpack water content. Median snowpack increment from February through April is about 35 percent (i.e., median February 1 water content of the snowpack in the Kings River watershed represents about 65 per cent of median April water content). The error in estimating the April 1 snowpack water content would be about 13 per cent or 75,000 acre-feet in the April-July forecast. With several reliable key courses, the 5 per cent error in estimating density throughout the basin would probably be unlikely.

Although this alternative was pursued no further, it presents an interesting possibility of substituting aerial snow depth marker measurements for all but a few key snow courses in early season forecasts.

CONCLUSIONS

In summing up, I would like to quote in part a discussion prepared by F. B. Blanchard for the 19th Annual Meeting of the Western Snow Conference in 1951. "The old question of which is better, forecasting from precipitation records or forecasting from snow surveys, is a complex and controversial one Generalization about this matter is a precarious business" However, Blanchard points out that "snow surveys provide a valuable and independent basis for forecasting. . ." (and) "Even if snow survey methods were not more accurate, they would still be worthwhile because of the independent nature of the (forecasting) process."

As Blanchard states - generalization is a precarious business. In the light of results of this study, however, I feel compelled to come to some generalized conclusions concerning the snow

survey program in California. Major emphasis should continue to be placed on April 1 surveys. I would certainly not recommend that all early-season snow surveys be discontinued. The value of basic data on early season snow cannot be entirely based upon results of water supply forecasts. However, expansion of the snow survey network for February and March measurements is definitely of secondary importance. The necessity of maintaining some of the more expensive and difficult courses for early season measurements is not as great as we may have previously thought. Study should continue into the feasibility of substituting more readily available information, such as aerial marker data or snow cover photographs, into our early-season forecasts in the interest of accuracy and economy.

The author would like to express his appreciation to Burton Hewett and Edward Hills of the Cooperative Snow Survey office who helped with much of the laborious computation required for this paper, and to Frank Jones of the Machine Computing Section of the Department of Water Resources, who reviewed the statistical approach used.

AERIAL RECONNAISSANCE OF MOUNTAIN SNOW FIELDS FOR MAINTAINING UP-TO-DATE FORECASTS OF SNOWMELT RUNOFF DURING THE MELT PERIOD

by

Walter J. Parsons and Glenn H. Castle 1/

1. The rapid increase in the need for water in the western states and the construction of numerous multipurpose storage reservoirs to control and reregulate the snowmelt runoff from high mountain basins has increased the need for more accurate forecasting of the snowmelt runoff and particularly for means of progressively adjusting the forecasts as the runoff season advances so that these reservoirs can be operated more efficiently. A promising method of making such progressive adjustments is based on the use of frequent aerial reconnaissance surveys of the mountain snow fields as they melt away.

2. The widespread snowfields on high mountain basins, although actually complex in shape and depth, can be considered for forecast purpose to be simple snow wedges on the mountain slope with their feather edge at the snowline and their greatest depth near the crestline. The total volume of such a snow wedge, which can be correlated with subsequent snowmelt runoff, can be represented as the product of the snow covered area and the average snow depth in inches of water. The snow covered area can be measured at frequent intervals by aerial reconnaissance methods. The average snow depth can be measured initially by regular snow course survey methods and subsequently adjusted for any changes which may have occurred after the date of those surveys by use of regularly available precipitation data. By means of the methods described in this paper, the remaining volume of runoff to be expected after any date in the melt season can be determined with reasonable accuracy solely by occasional measurement of the snow covered area.

3. Forecasting of the remaining runoff during the snowmelt season by this method was first attempted on the Kings River watershed, a 1,500 square mile mountain watershed on the western slope of the Sierra Nevada, east of Fresno, California. A major portion of the runoff of this river occurs between 1 April and 31 July and results from melting of high elevation winter snows. Six years of aerial snow cover data are now available for this watershed. Preliminary forecast curves have also been developed for the adjacent 2,100 square mile Kern River basin where five years of aerial snow cover data are now available. In both cases the snow cover data was obtained by direct sketching of the boundary of the snow covered area on 1 to 500,000 scale aeronautic charts during reconnaissance flights made at altitudes of 10,000 to 15,000 feet in a small high wing plane that provided excellent visibility of the ground. This method of measurement was found to be rapid, accurate, and capable of giving consistent results on Sierra Nevada basins. Direct visual identification of the edge of the snowfields as it wandered in and out of canyons, across polished granite pavements and through masking timber was more positive for an observer flying 2,000 to 5,000 feet above the terrain than could be done from subsequent office study of black-and-white aerial photographs. On-the-spot selection of a generalized line that would average the irregular edge of the

1/ U. S. Army, Corps of Engineers, Sacramento District, California