least ten years of record prior to 1949 and having 1951 to 1957 data available were used. A total of 107 stations were used for the 1956-57 record and 77 stations for the six-year seeded period record.

Because of the scarcity of the data in some regions of the state and because of station to station variability within a relatively small area in the state it is impossible to draw the iso-percentile lines with any great objectivity. They give only a rough qualitative measure of the precipitation pattern over the period covered and have, therefore, not been included in this report.

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GRAPHICAL METHOD FOR DETERMINATION OF AREA-ELEVATION WEIGHTING OF SNOW COURSE DATA 1/

By

J. F. Hannaford, C. G. Wolfe, and R. W. Miller 2/

At one time, Mark Twain stated, "History alone is a trustworthy prophet." This statement applies rather well to the science and art of water supply forecasting--science, where the forecaster can assemble history and withdraw a forecast of future conditions from this history--art, where the information leading to the forecast goes beyond the realm of history and the limits of historical data.

CALIFORNIA'S FORECAST SCHEMES

Forecasting schemes used by the California Cooperative Snow Survey to forecast runoff during the April-July snowmelt period on typical Sierra drainage basins are based upon some 28 years of historical snow survey records. The schemes in use are multiple-graphical correlations (Plate 1) incorporating data on snowpack, precipitation, and runoff. ("Multiple Graphical Correlation for Water Supply Forecasting," Proceedings of the Western Snow Conference, April, 1956) Forecasts are based upon conditions as of April 1, with appropriate adjustments made for forecast dates other than April 1. Variables used in these forecasting schemes to predict run-off during the snowmelt period are outlined in the following paragraphs.

1/ Paper presented at THE WESTERN SNOW CONFERENCE, April 16-18, 1958, Bozeman, Montana.
2/ J. F. Hannaford, C. G. Wolfe, and R. W. Miller, Assistant Hydraulic Engineer, Senior Hydraulic Engineer and Civil Engineering Associate, respectively, are employees of the California Department of Water Resources. California Cooperative Snow Surveys.

PLATE I

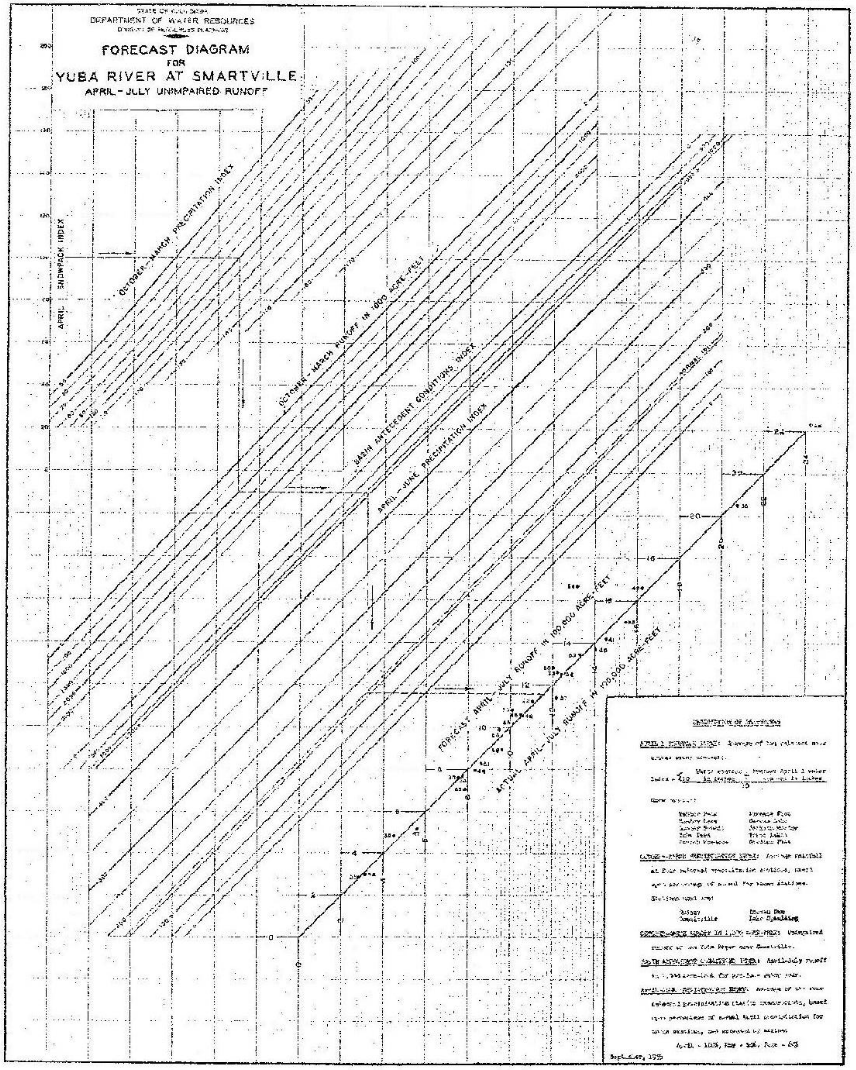


PLATE 2

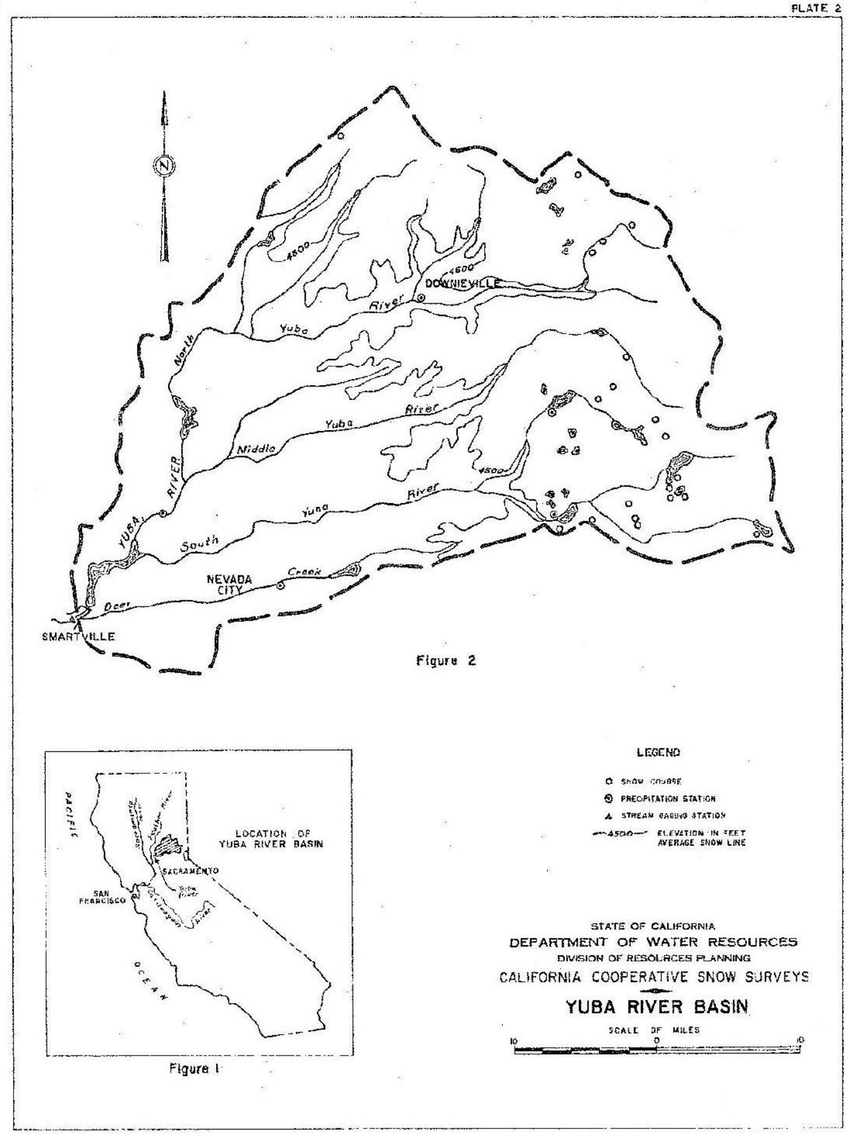


Figure 1

Figure 2

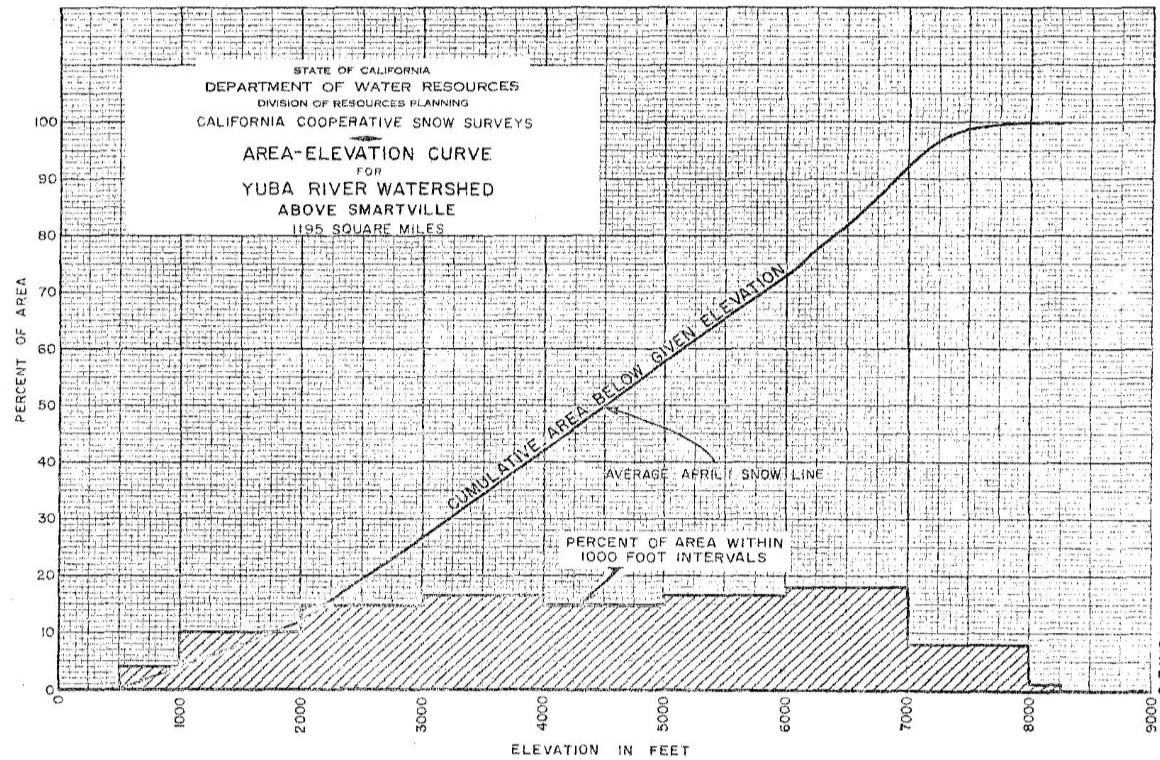


PLATE 3

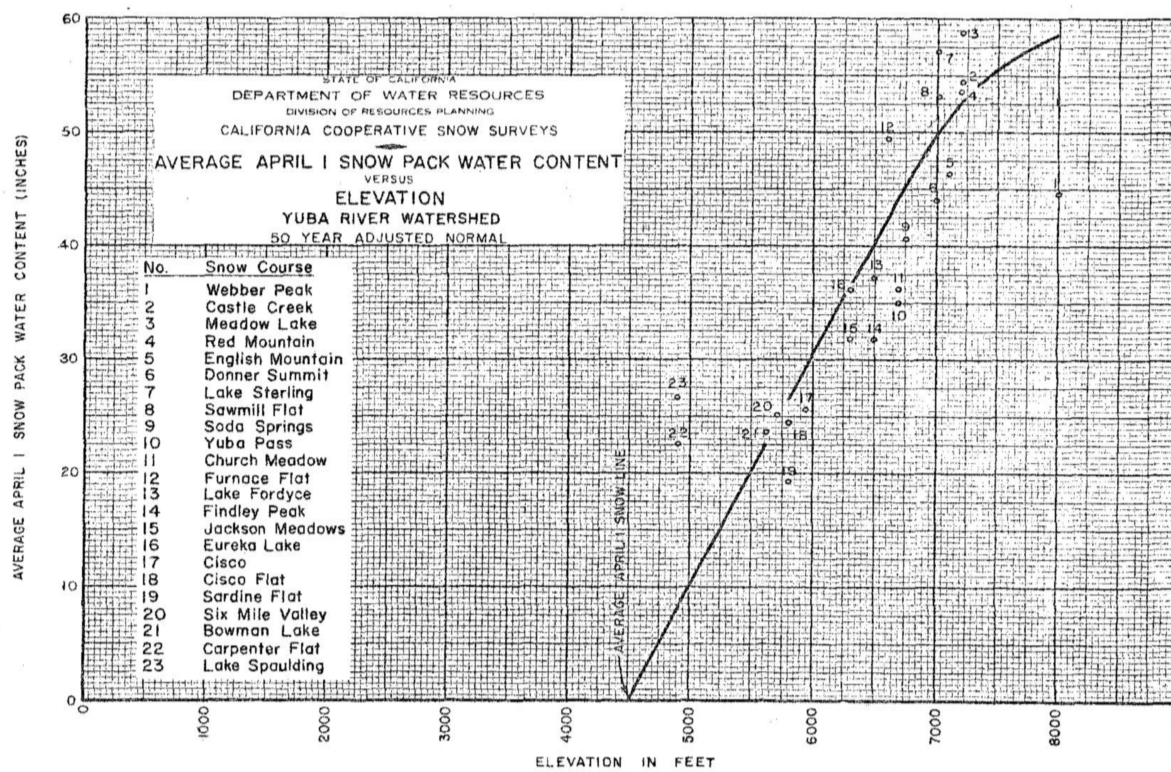


PLATE 4

1. Snowpack Index. A parameter based upon water content of the snowpack and indicative of the volume of water stored as snow in the basin. This parameter is usually based upon the arithmetic average of water contents for several selected snow courses in the basin.

2. Precipitation. A parameter evaluating the total amount of water falling upon the basin from October 1 through the date of forecast and based upon selected precipitation stations. On some streams, an additional evaluation of March precipitation has been used to account for the priming effects of March rains, particularly below the snow line.

3. Runoff. Total amount of water leaving the basin as runoff from October 1 through the date of forecast. Runoff value is subtractive in the scheme. The precipitation-minus-runoff combination gives a second index to volume of water stored in the basin.

4. Antecedent Conditions. A parameter giving some index of "wetness" of the previous water year. This parameter is more important in basins with characteristics allowing for natural carry-over storage from year to year. Generally, April-July runoff from the previous year is used as an index of "wetness."

5. Forecast Period Precipitation. This parameter is used in the schemes to estimate the effects of deviations from normal precipitation during the April-July forecast period.

PROBLEMS IN USE OF SCHEMES

Although the original schemes have proven themselves to be quite accurate under most conditions, several problems have become apparent. Forecast schemes are being continuously revised as more and better information becomes available, and an attempt is being made to alleviate such problems as revisions are made.

The first problem is common to all forecasts—data which fall beyond the limits of the data originally used in the development of the forecast relationship. For example, the floods of December, 1955, the greatest since initiation of the Cooperative Snow Survey Program in California in 1929, went beyond the limits of our historical data and left water-supply forecasters with questions as to effects of large floods upon snow conditions, snow distribution, and forecast period runoff. Effects of the floods of December, 1955, upon April-July runoff in 1956 appeared greatest in the lower elevation basins of the Cascade Range and Sierra Nevada, due primarily to the high elevation of the freezing level during portions of the December storms. The resulting unusual snowpack distribution was apparently a major contributing factor to relatively high forecast errors noticed in the lower elevation basins (Plate 1).

A second major problem has arisen from the fact that the original schemes were based upon certain essential items of data which, if delayed or unobtainable at the time of forecast, made it necessary to estimate or otherwise account for missing data. This problem can certainly become critical with a publishing deadline or operation schedule to meet. For example, a basin may have twenty snow courses. The ten which correlated best with runoff, regardless of elevation or location, may have been used in the original forecasting scheme. Although results from ten or more courses in the basin may arrive in time for the forecast, there is no assurance that the ten will be those used in the scheme. In revising the forecast schemes, it was desired to develop procedures which would use as many as possible of the data which might be available, and yet which would not penalize the scheme too heavily if some of the data were delayed.

The combination of the above problems leads us to the indicated subject of this paper—reasons for and a possible method of weighting and evaluating snowpack data to make it more effective in preparing a forecast. Snowpack data is fundamental in our forecast schemes, but because of the inherent difficulty in its collection, this information is most likely to be delayed or unobtainable at the time of forecast. In addition, snowpack is one of the most difficult variables to evaluate due to the large variations in pack throughout a basin. For these reasons, our efforts were directed toward the development of a weighted snowpack index which could be computed with a minimum of data, if necessary, but which would accurately portray the snowpack distribution over the basin.

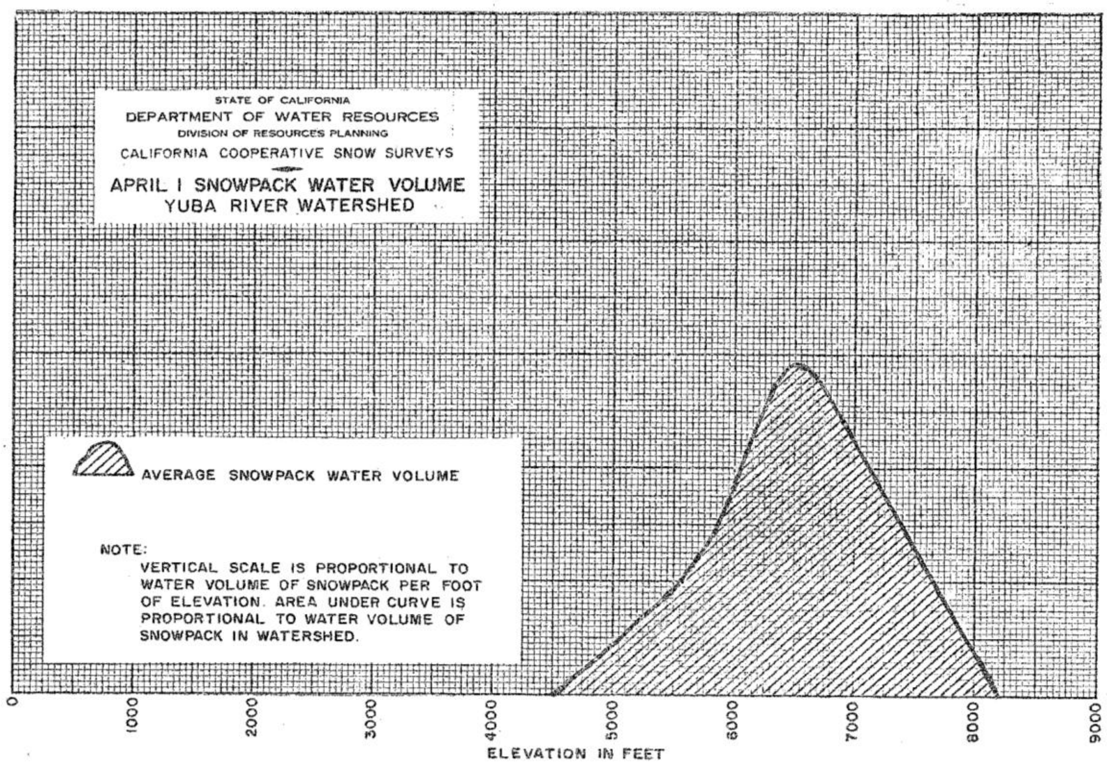


PLATE 5

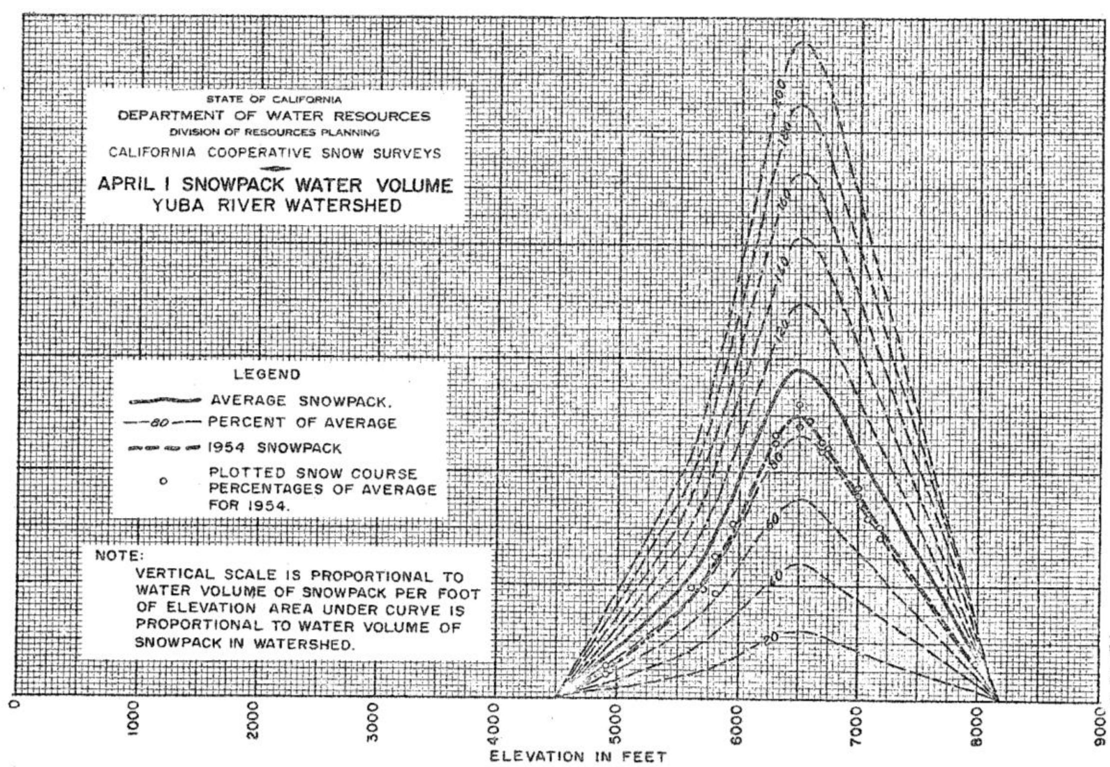


PLATE 6

BASIC CONSIDERATIONS IN EVALUATION OF SNOWPACK

Distribution of snowpack throughout a basin has proved to be very important in determining both the volume and time distribution of runoff. Although precipitation amounts over a basin vary considerably with elevation, exposure, aspect, etc., the percentages of normal at various locations over the basin for any given year are generally quite consistent. Like precipitation, snowpack water content also varies with the same factors. Unlike precipitation, however, snowpack water content based upon percentage of normal does vary greatly throughout the basin during any given year. Snowpack water content at any point in a basin is dependent upon the total amount of precipitation occurring at that point, the portion of that precipitation falling as snow, and conditions of drift and melt.

Both the amount of precipitation and the proportion of precipitation occurring as snow are largely dependent upon one item--elevation. Many studies have been made on the Sierra to show the relationship between precipitation amounts and elevation. A discussion of the relationship will not be covered here--let it suffice to say that such a relationship does exist. The same item which causes precipitation; i.e., drop in air temperature due to increase in elevation, is also responsible for determining what portion of the precipitation falls in the form of snow, or where the "snow line" for a particular storm exists.

Another factor affecting snowpack distribution is snowmelt. In general, we have assumed that large-scale melting does not occur before April 1. This is not strictly true, especially at lower elevations, making it desirable to include the lower elevation areas subject to early melt in the evaluation of snowpack.

Elevation, then, does play an extremely important role in determining the distribution of snowpack over a basin. The question remains, how can we evaluate this elevation distribution of snowpack over the basin, using as much of the limited data available as possible, and still keep the forecasting scheme flexible enough to use when portions of that data are unavailable on the date of forecast? We believe that we have developed a method of evaluating the snowpack distribution, which, though probably not acceptable from the statistician's point of view, certainly has a lot to recommend it from the forecaster's position. The method makes use of all available snow course measurements from the basin, and also the position of the effective snow line as of the date of the forecast.

BASIN SELECTED FOR STUDY

Some of the heaviest flooding of December, 1955, took place on the Yuba River drainage in the northern Sierra (Plate 2). The 1956 forecast for runoff during the snowmelt period fell considerably above the actual runoff (Plate 1). Because of the exaggerated effect of the floods upon the Yuba Basin, it was selected as a study watershed to better establish the relationship between snowpack, precipitation, and runoff. The Yuba River Basin, typical of other Sierra basins, has rather limited areal extent; the total area above the forecast point being about 1,200 square miles. Elevations range from about 250 feet at the point of forecast to over 8,000 feet in the upper watershed. Approximately half of the basin falls below the average April 1 snow line. Average runoff during the forecast season (April-July) is 1,170,000 acre-feet, while average water year runoff is about 2,350,000 acre-feet. The high runoff prior to the beginning of the snowmelt period may be attributed to the low elevation of the basin.

METHOD OF EVALUATING SNOWPACK

Plate 3 is an area-elevation curve for the Yuba River Basin. The upper curve indicates cumulative area below a given elevation expressed in percentage of the entire area. The lower bar-chart shows percentages of the area located within specific elevation ranges. Note that about 50 per cent of the basin lies below 4,500 feet, the approximate average April 1 snow line.

Plate 4 is a plotting of elevation against average April 1 water content for snow courses in and adjacent to the basin. There is a wide variation in water content from station to station, but an obvious increase in water content with elevation. The wide variation is due to the previously mentioned factors - drift, aspect, slope, etc. The estimated curve of snowpack water content was drawn through the plotted points, giving an average relationship between water content and elevation to be used in apportioning snowpack water volume by elevation.

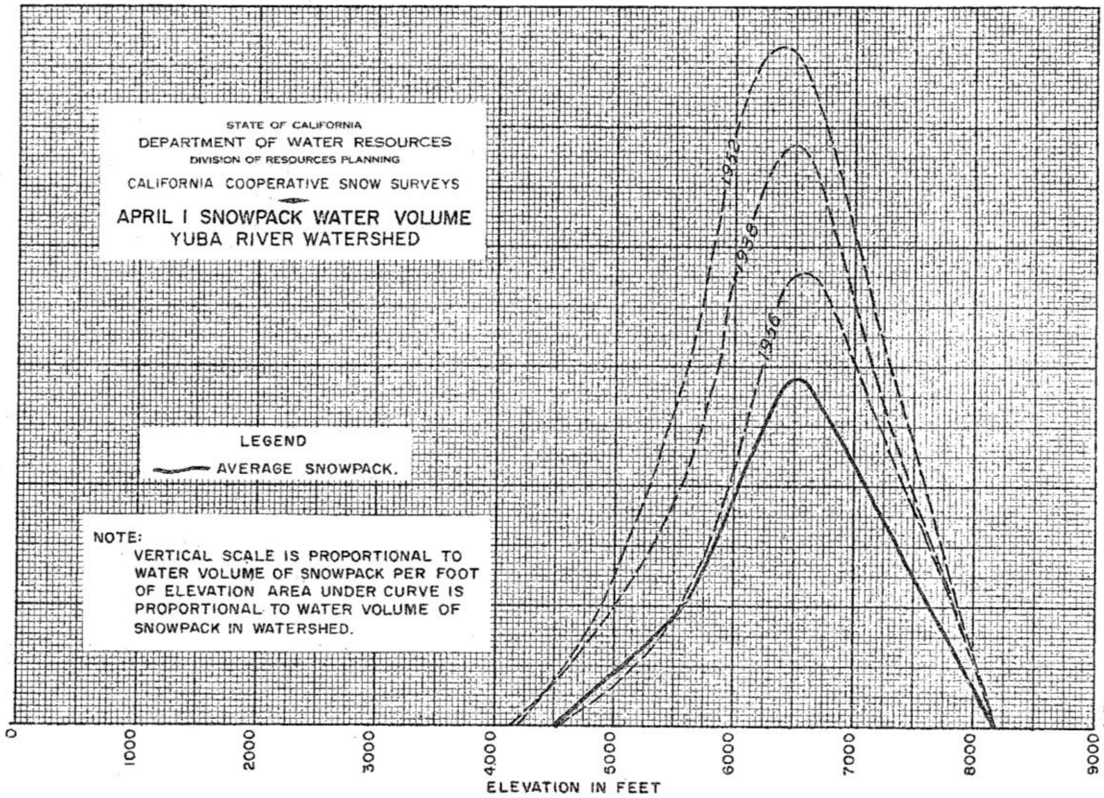


PLATE 7

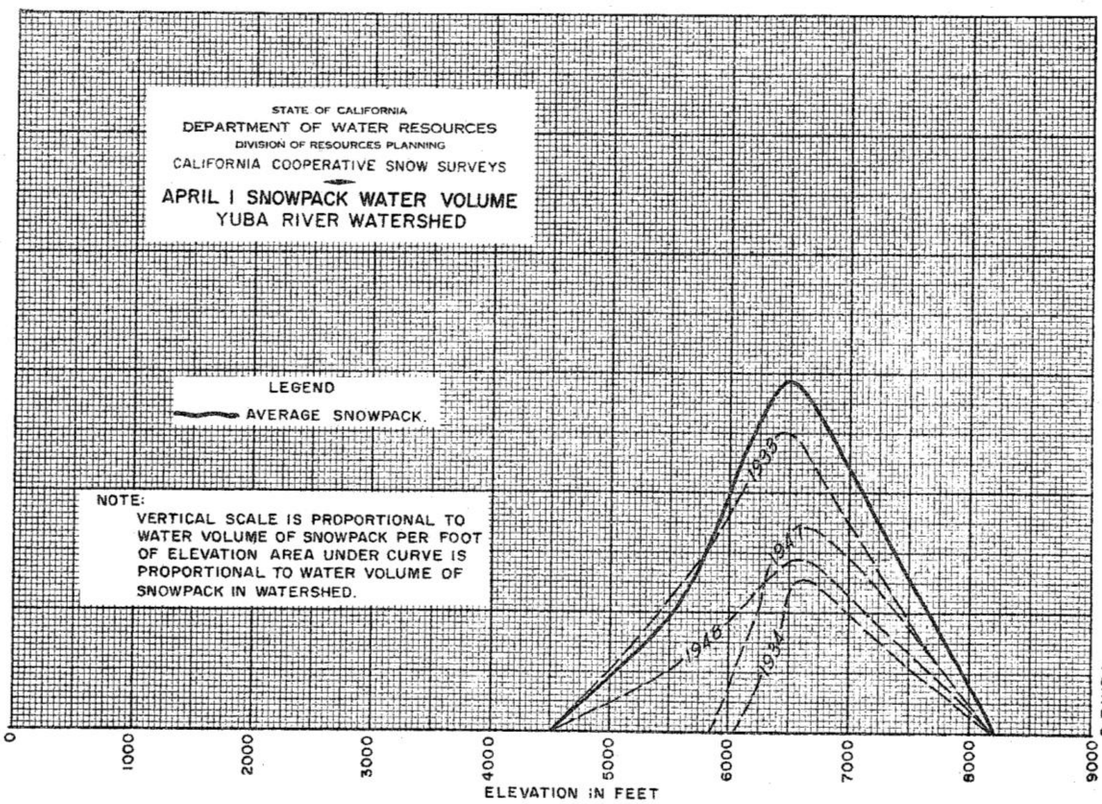


PLATE 8

By combining the area-elevation curve and the water content-elevation curve, we arrive at a curve representing volume of snow-stored water in the basin; i.e., area times depth of water equals volume of water stored. Plate 5 is a plot of the product of water content times area for a given elevation range versus average elevation of that range. Although originally plotted as a bar diagram for 250-foot elevation ranges, a smoothed curve was drawn to better depict the distribution of the snowpack. The units are of little significance for our purposes, as we are looking only for an index to compare snowpack from various years and not attempting to directly establish the actual acre-feet of water in the pack. This curve, however, does portray graphically where snow water is normally stored, and hence, which elevation ranges are of most importance in our forecasts.

In order to make a comparison of the water stored in the snowpack as of April 1 for any given year, it is necessary to minimize the effects of melt, drift, and location. To accomplish this, the water content for each course on April 1 for the given year was determined in per cent of average for that course. The percentages of average were then plotted on a form similar to Plate 6, and a curve was fitted to the points by eye. The low elevation end of the curve was located at snow line. The resulting curve represents the snowpack distribution, and the area below the curve is proportional to the water volume of the snowpack for that year. The plotting for a representative year is shown on Plate 6.

Admittedly, the plotting of a curve by eye introduces some degree of subjectivity. In order to check this subjectivity, the curves were fitted twice by two different people who were completely unfamiliar with the Yuba forecasting scheme. The resulting snowpack volumes were surprisingly consistent, although some variations did exist.

CONCLUSIONS FROM GRAPHICAL COMPARISON

Using the foregoing procedure, snow survey data from the Yuba River Basin were compared graphically, and the following observations were made:

1. The major portion of the snowpack volume in this basin falls between 6,000 and 7,000 feet elevation. The majority of the courses fall between 6,500 and 7,200 feet (Plate 6). Perhaps a review of this graphical weighting of snowpack might be useful in the selection of new courses in the basin to obtain a more representative sampling of snowpack.

2. As the volume of the overall snowpack increases, the center of mass of the snowpack generally moves to lower elevations (1952, 1938, Plate 7). The snow line usually descends in a heavy year, and even a small increase in the pack at the lower elevations extends over large areas and contributes substantially to the volume of the pack. Occasionally, an exception to this trend may be noted, such as the year 1956 (Plate 7). Following the floods of December, 1955, the snowpack at high elevations during the spring of 1956 was much above average. However, the center of mass of the snowpack did not descend, as low-elevation snow was average or below average. At higher elevations, the major portion of the December precipitation fell and remained as snow throughout the season. On the other hand, at lower elevations most of the December precipitation occurred as rain which promptly ran off, and the snowpack remained below normal throughout the season.

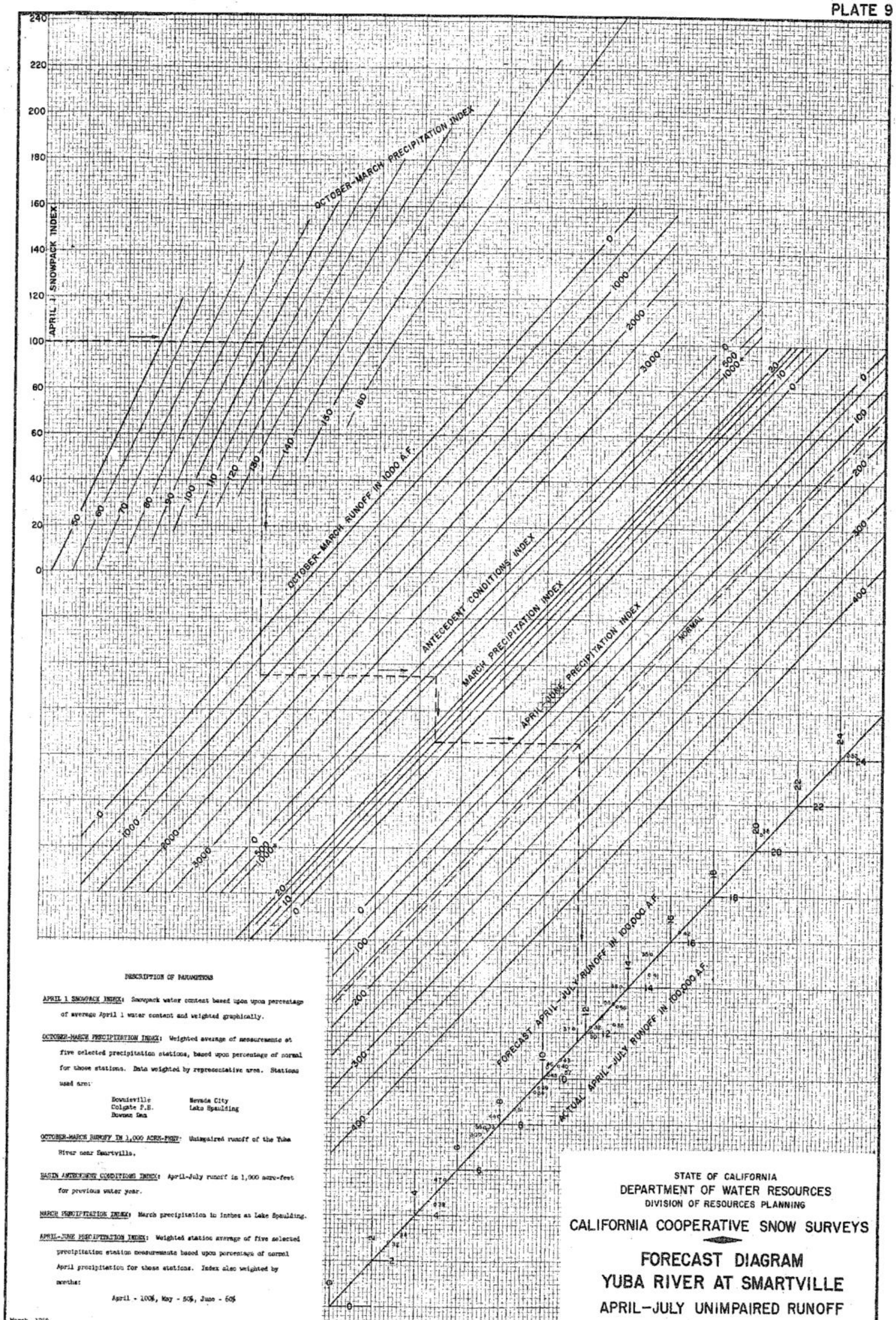
3. In very light snowpack years, the center of mass of the snowpack tends to move to higher elevations (1934, 1947, Plate 8). However, the pack may be evenly distributed over the basin on a percentage of average basis (1948, Plate 8), or in some cold years the distribution may go completely against the trend (1933, Plate 8).

From the foregoing conclusions, it is apparent that evaluation of snowpack on the basis of only a few selected courses may lead to unrealistic results.

REVISED FORECAST SCHEME

The next step was to convert this graphical comparison into a form which could readily be used in a forecasting method. The area under the curve, representing the volume of snow-stored water for any given year, was compared with the area under the average curve on a percentage basis. This percentage was used as the April 1 Snowpack Index and substituted in the forecast scheme for the original snowpack index. Since the original index was based upon the average

PLATE 9



DESCRIPTION OF PARAMETERS

APRIL 1 SNOWPACK INDEX: Snowpack water content based upon upon percentage of average April 1 water content and weighted graphically.

OCTOBER-MARCH PRECIPITATION INDEX: Weighted average of measurements at five selected precipitation stations, based upon percentage of normal for those stations. Data weighted by representative area. Stations used are:

Downieville	Nevada City
Colgate P.H.	Lake Spaulding
Bowman Dam	

OCTOBER-MARCH RUNOFF IN 1,000 ACRE-FEET: Unimpaired runoff of the Yuba River near Smartville.

BASIN ANTECEDENT CONDITIONS INDEX: April-July runoff in 1,000 acre-feet for previous water year.

MARCH PRECIPITATION INDEX: March precipitation in inches at Lake Spaulding.

APRIL-JUNE PRECIPITATION INDEX: Weighted station average of five selected precipitation station measurements based upon percentage of normal April precipitation for those stations. Index also weighted by months:

April - 100%, May - 80%, June - 60%

March, 1958

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING

CALIFORNIA COOPERATIVE SNOW SURVEYS

FORECAST DIAGRAM
YUBA RIVER AT SMARTVILLE
APRIL-JULY UNIMPAIRED RUNOFF

water content of ten selected snow courses, the entire original scheme had to be revised, as the new index is not directly comparable with the old. Plate 1 is the original forecasting diagram for the Yuba River, and Plate 9 is the revised diagram using the new snowpack index. Note that the stations used in the preparation of the precipitation indices have been changed for the new scheme. However, as mentioned previously, precipitation amounts based upon percentages of normal are generally rather consistent throughout the basin, hence the change in index resulting from a change in stations is quite small. Stations were changed to take advantage of better station locations with more readily obtainable records. Also included is a parameter covering the March precipitation separately from the seasonal precipitation. The two forecast schemes (Plates 1 and 9) are not directly comparable for this reason. The time and expense of revising a forecast scheme made it undesirable to go through the entire development of a new scheme without making all the changes which were felt necessary.

The resulting forecasts from the new scheme seem to be fairly consistent. Forecasts for years with extraordinary snowpack distribution, such as 1956, seem to fall much closer to the true runoff than on the previous scheme. As pointed out above, the schemes are not directly comparable.

Although delayed data will affect the graphical snowpack index, the errors introduced through lack of data are rarely, if ever, as great as errors introduced through similar lack of data in the former method of computing snowpack index. Effective snow line information is always readily available through observation and highway reports. The distribution of snowpack can be visually interpreted from a relatively few actual snow course measurements. Subjective information may help to fill gaps where few measurements are available. Obviously, however, the more data, the better the results will be.

A forecast scheme involving some degree of subjectivity is always questionable from the statistician's point of view. Unfortunately, the fitting of a curve to the plotted snow course data (Plate 6) is rather subjective. In its final form of refinement, the snowpack index should eventually take a form which requires less subjectivity by eliminating the necessity of drawing the snowpack volume curve by eye. However, most other methods of weighting basic data do not readily lend themselves to overcoming the problems outlined in this paper. The graphical method of weighting snowpack information, although perhaps somewhat in question due to the subjective nature of the plotting, does give some indication as to the direction in which our snowpack-elevation studies in California should progress. The method apparently offers a key to the unusual year--that year which, in the future, we hope will not "fall off the curve."

Acknowledgments

The authors would like to express their appreciation to B. E. Hewett, J. U. McDaniel, and Mrs. J. F. Hannaford who did much of the plotting and computation preliminary to this paper.

EVOLUTION IN DERIVATION OF SEASONAL STREAMFLOW FORECAST PROCEDURES

By

O. B. Van Horn[1/]

Despite the fact that the area controlled by the big Missouri dams is nearly 80 percent plains, the Corps has long been interested in accumulating mountain snow pack data. In fact, due to the foresight of G. A. Hathaway, past President ASCE and presently Engineering Consultant to the International Bank for Reconstruction and Development, the Corps arranged with the U. S. Geological Survey to start snow water measurements in the Missouri Headwaters within months of the Fort Peck Project (northeastern Montana) construction start in October 1933. These records, in conjunction with those begun in later years, are now giving a rich harvest in firming up our seasonal volume forecasts. Our good friends Ash Codd and George Peak are, under frequently trying conditions, presently doing a fine job of shepherding the snow measurement program in the Missouri Headwaters.

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