A PROPOSAL FOR INCORPORATING AERIAL SNOW-DEPTH MARKERS INTO WATER SUPPLY FORECASTS

by

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Introduction

In 1934, Dr. J. E. Church, originator of snow surveying in the western United States, wrote the following comments in regard to accuracy in forecasting snowmelt runoff . ". . .the depth of snow on the ground at the beginning of the season of runoff. . .if handled carefully, is a close rival of snow surveying." Dr. Church went on to point out, however, that since it would be necessary for snow surveyors to travel to and from the course whether they were measuring water content and depth, or depth alone, the only savings made by using only depth measurements in forecasting would be in cost of snow survey equipment and in surveyors' time in the field. In 1934, Dr. Church's logical conclusion was ". . .the expense for field operations would be identical, without the satisfaction of certainty regarding the data obtained."

Since 1934, the picture regarding measurement of snow depth has changed considerably. It has always been possible to make a point estimate of snow depth by observing a snow stake or depth marker. In general, however, a close hand visual observation of the stake has been required to make this estimate. In recent years, light planes have developed from conveyances of questionable reliability to a safe and practical means of transportation in the mountains. Visual observation of snow depth indications is possible from the air. A typical aerial snow depth marker consists simply of a stake or pole with cross arms at given intervals. Snow depth can be estimated from observation of the portion of the marker visible above the snowpack. The science of aerial photography has progressed to the point where it is possible to photograph aerial snow markers and obtain a direct indication of snow depth at the point in question. With the combination of aerial snow markers, light planes and aerial photography, it has become possible to make snow depth measurements in even the most remote mountain locations. Measurements in areas that would have taken hours or perhaps days to reach in 1934 may be taken in a matter of minutes in 1960. Still, as Dr. Church pointed out, depth measurements may not give the "satisfaction of certainty regarding the data" which snow surveying may give.

Aerial snow marker programs have been carried out in California on a fairly large scale for about ten years. The California Electric Power Company pioneered aerial snow markers in the Sierra Nevada in 1949, followed shortly by the Southern California Edison Company, the Los Angeles Department of Water and Power, the Pacific Gas and Electric Company, and the Department of Water Resources. Enough information is now available to prepare an objective evaluation of the existing aerial snow marker program and enable us to make a better decision as to the future of the aerial snow marker program. Three alternatives exist: (1) to expand the present program to alleviate deficiencies in coverage, scheduling, methods and equipment, and to eventually use markers to supplement snow surveys and perhaps substitute for some of the more remote snow courses; (2) to continue the program as it presently exists with inadequate scheduling and coverage, using aerial marker data for only general interest and qualitative estimates; or (3) to discontinue the aerial snow marker program.

Advantages and Disadvantages

Basic data obtained from aerial snow depth markers offers several important advantages over ground snow surveys. Measuring techniques and methods are simple. Travel to and from the course is rapid and easy. Over-all costs are low due to reduced travel necessary in the mountains during both summer and winter. Aerial surveys lend themselves well to scheduling, as a large number of markers may be photographed in a day or even a few hours during a break in the weather.

On the other hand, there are two very important disadvantages. Aerial snow markers give only the depth and not the water content of a course. Also, aerial markers give only a single point measurement. These disadvantages might make markers ineffective as a means of forecasting, or perhaps the advantages might outweigh the disadvantages, so that an expanded aerial marker program would prove a valuable asset in stream flow forecasting.

Outline of Study

This study was prepared to determine the applicability of aerial snow marker data to streamflow forecasting and to evaluate the reliability of aerial marker data as it applies to forecasting. In

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order to decide if aerial snow marker data is adaptable to runoff forecasting, we must find answers to the following questions:

1. To what limits can we estimate the depth of snow on a course from a photograph of an aerial snow marker? Is such an estimate adequate for our purposes in forecasting?

2. After successfully estimating the depth of snow on a course, can we prepare a forecasting scheme comparable to those presently in use?

Estimating Depth of Snow on Course

To answer the first question, we must in turn answer two other questions: (1) can the depth of snow on course be estimated from the depth indicated by the aerial marker? and (2) can the depth of snow at the marker be read correctly from an aerial photograph?

Results from nine aerial markers located on snow courses which were observed by snow surveyors at the time the courses were taken indicate that correlation between depth of snow on course and depth at marker is good (although not always one-to-one). In 127 observations taken over the last 10 years, 24 per cent showed a variation of greater than ± 3 inches depth, while only 8 per cent showed a variation of greater than ± 4 inches. Average depth for all measurements was about 65 inches. Variations for all markers for any one year appeared random, so that total error would not be cumulative. Variations in this range probably would be acceptable for forecasting.

We have made no actual studies of how ground observations of aerial markers would compare with aerial observations. However, Bill Lang of the Southern California Edison Company has stated that errors rarely exceed one inch. Studies conducted by Jack N. Washichek, U. S. Soil Conservation Service, Fort Collins, Colorado, indicate that "Errors in depth are never over three inches." In Washichek's studies, simultaneous observations were made from air and ground by observers; no cameras were used. Accuracy in this range should be adequate, at least for preparing preliminary forecasts of runoff.

Forecast Scheme Using Aerial Snow Markers

Even though 10 years of record are available on several aerial snow markers, the data were not of sufficient quality or quantity to prepare a forecasting scheme directly from the aerial photographs of markers. The following methods were used in "fabricating" aerial snow marker data to prepare a statistical study of forecast accuracy. Aerial marker data were used whenever available on the snow courses. Additional aerial marker data were fabricated from historical snow survey depth records at each course used in the forecast. Assuming that photographs of aerial markers would allow us to estimate course snow depth to the nearest three inches, course depths for each measurement were recorded to the nearest three inches (i.e., 19.4 inches depth recorded as 18 inches, 19.6 inches recorded as 21 inches). Where the correlation of snow marker depth to snow course depth had not been historically one-to-one, the necessary corrections were made.

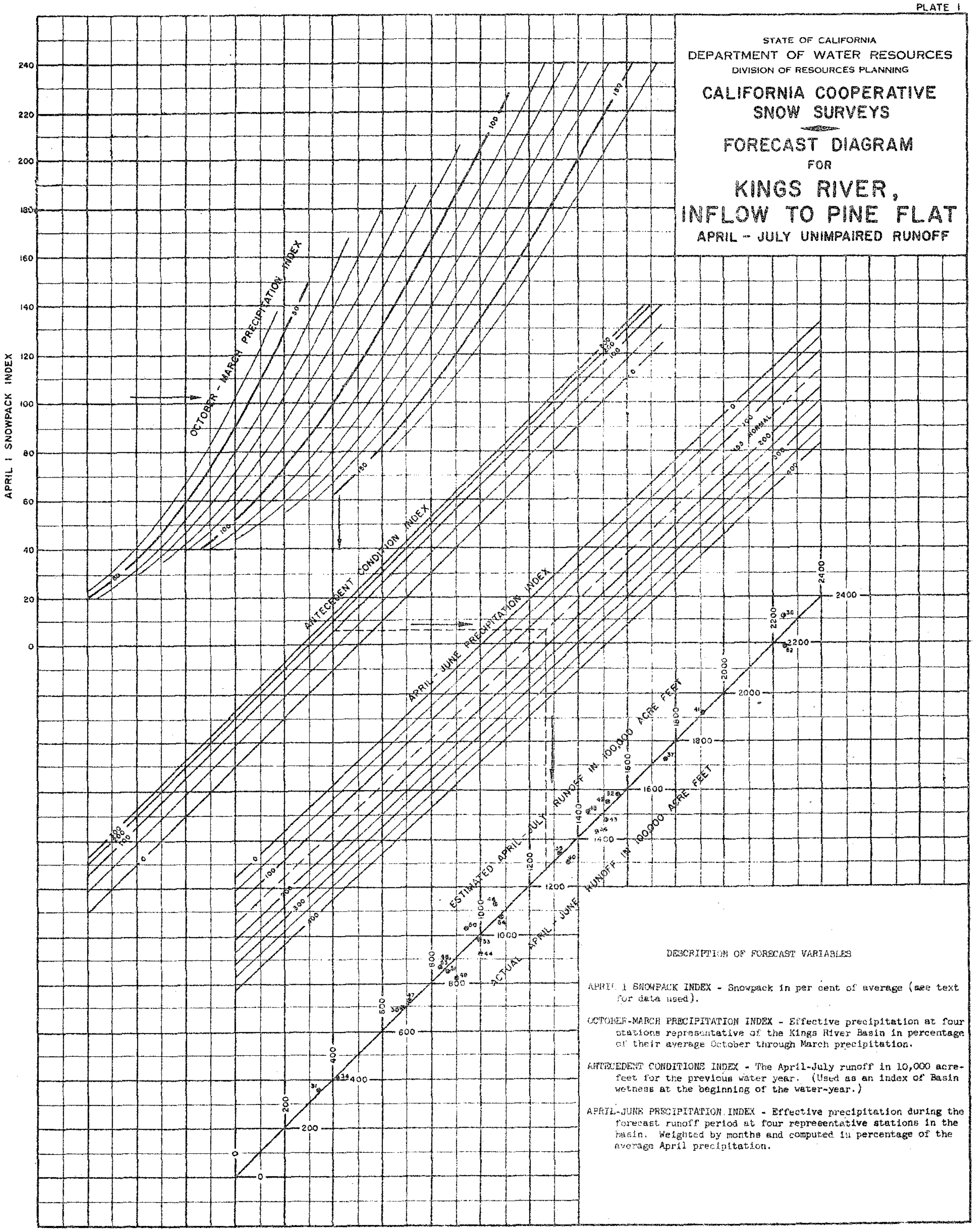
Direct use of the aerial snow markers in a forecast scheme proved unsuccessful as snow densities are apparently too variable from month to month and year to year to give results within the desired limits of accuracy. This method was abandoned after preliminary studies were completed.

From this point, we proceeded by using the aerial snow marker data to supplement snow survey data from a "key" course or courses. Snow depth was converted to water content on the basis of density for a single representative snow survey made in or near the basin. In practice, perhaps five or six such representative snow course measurements might be used to overcome the effect of a possible discrepancy in a single course density. The computed water contents were then entered directly into a forecast scheme typical of those presently used by this office.

Comparison of Results

Twenty years of actual and fabricated aerial snow marker data were worked into a forecasting scheme for the Kings River inflow to Pine Flat. Forecasts using snow survey data alone were compared with the forecasts using a key snow course plus supplemental aerial marker data for the same 20-year period. (Plate 1 shows a typical forecasting scheme.) Forecasts of April-July runoff were prepared for each month, February 1 through July 1. Results obtained from either of the two schemes are about equivalent. Forecasts prepared from snow course data do show a slight advantage (Plate 2). Note that the advantage of the forecast prepared from snow course data increases as the season advances. The fact that early season forecasts are about equally accurate by either method indicates that errors due to inability to forecast weather conditions subsequent to the date of forecast are so much larger than inherent errors that the latter are almost completely masked out. The additional inherent error in the aerial marker scheme over the snow survey scheme is indicated by the separation of lines on the July 1 forecast (Plate 2).

PLATE I



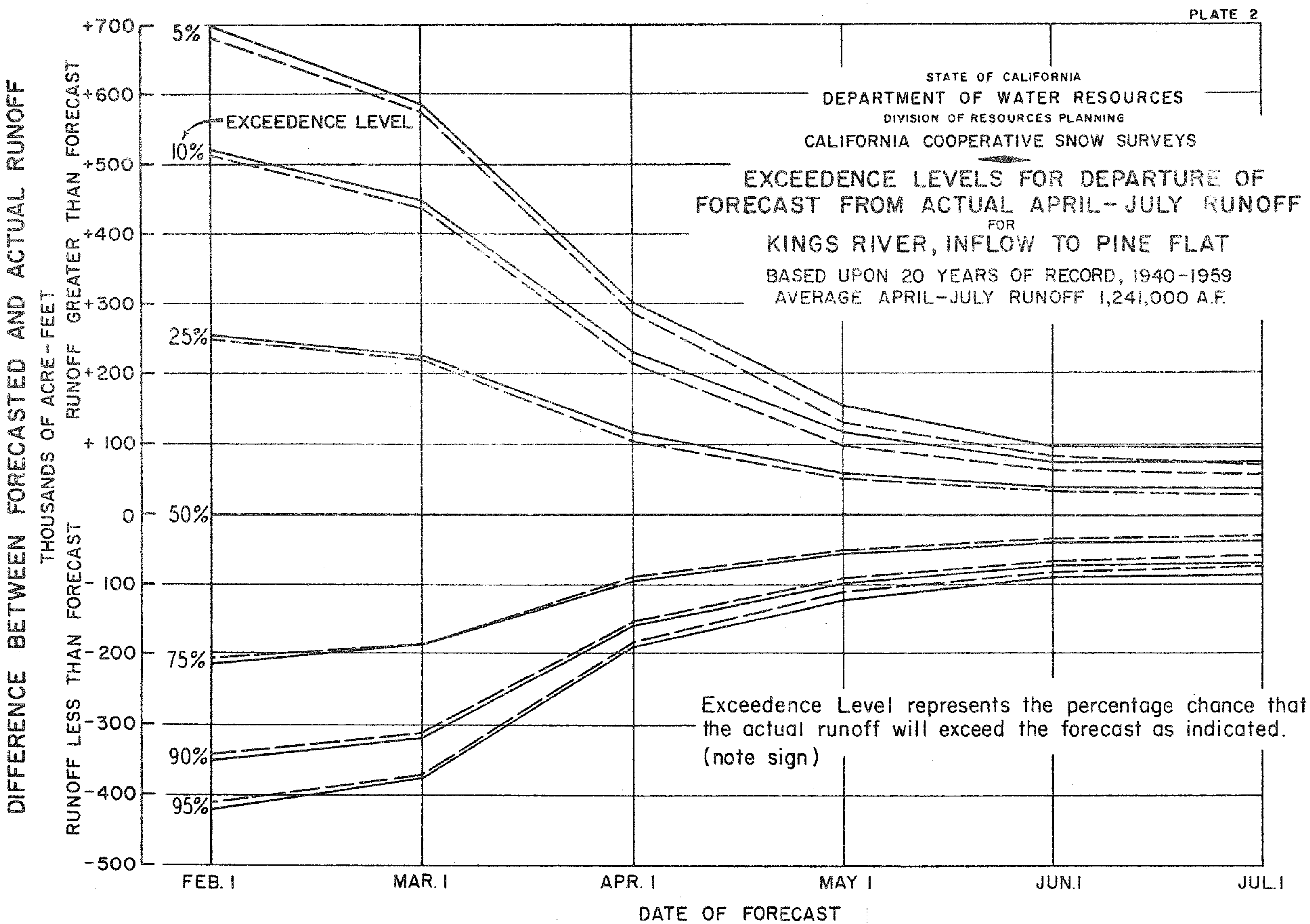
DESCRIPTION OF FORECAST VARIABLES

APRIL 1 SNOWPACK INDEX - Snowpack in per cent of average (see text for data used).

OCTOBER-MARCH PRECIPITATION INDEX - Effective precipitation at four stations representative of the Kings River Basin in percentage of their average October through March precipitation.

ANTECEDENT CONDITIONS INDEX - The April-July runoff in 10,000 acre-feet for the previous water year. (Used as an index of Basin wetness at the beginning of the water-year.)

APRIL-JUNE PRECIPITATION INDEX - Effective precipitation during the forecast runoff period at four representative stations in the basin. Weighted by months and computed in percentage of the average April precipitation.



— — — Forecast using only snow course water contents to determine snowpack index.

——— Forecast using key snow courses and aerial markers to determine snowpack index.

The July 1 forecast includes all available data (including spring precipitation) which might influence April-July runoff.

In order to check the improvement made in forecasting accuracy by supplementing "key" snow survey data with aerial marker data, a forecast was prepared using only the "key" snow course as the snow index. The improvement effected by use of aerial markers was very definite, particularly in years with unusual snowpack distribution over the basin.

Conclusions

It may be concluded from the foregoing study that, at least on the Kings River, good forecasting results may be readily obtained using snow depth marker data to supplement key snow course water content data. Results are comparable with forecasts using all snow course water content data available. Compared with forecasts using snow course data, the forecasts using aerial markers are about equivalent on February 1 and March 1. Subsequent to April 1 forecasts employing snow course water content data do show a slight advantage.

On the basis of other studies cited herein, it is apparent that aerial observation of snowpack will give us sufficiently accurate snow depth information for use in forecasting.

Results of this study might lead us to the following conclusions concerning the future possibilities of an aerial snow marker program. It should be pointed out that these conclusions have been reached by logical application of the results of this study, and they do not represent a statement of policy or proposed program of the Department of Water Resources.

Aerial coverage may be profitably extended over the entire snow survey forecasting network of about 150 courses _if_ results of similar studies of other streams in the State give comparable results. This might eventually lead to a reduction in frequency of ground measurement of snow courses, with reduced sampling especially in the early season (February and March), but emphasis should continue to be placed upon the April 1 ground surveys. Aerial markers might be used to extend our coverage into remote and difficult-to-sample areas. Difficult, dangerous, or overly costly ground surveys might eventually be completely eliminated by substituting aerial markers. Even though it is agreed that the accuracy of any single measurement may be greater for the course than for the aerial marker, still the aerial markers do offer an inexpensive means of greatly increasing both areal coverage and frequency of measurement within a given basin.

Problems in Setting up an Expanded Program

Prior to any major expansion of an aerial snow marker program, perhaps a pilot study should be initiated to check on the validity of assumptions made in this study and to aid in development of equipment and methods.

The first step in a major expansion of an aerial snow marker program designed to prepare forecasts would be to extend marker coverage to include at least those courses now used in forecasts (about 150 throughout the State). The reason for placing markers on snow courses whenever possible would be to take advantage of the existing records at these courses in preparing runoff relationships. It should be borne in mind, however, that most courses were not originally placed with aerial observation as a consideration. Consequently, it is possible that many of the courses presently used in forecasting would not be suitable at all for aerial observation. Secondly, a tentative network of key courses should be set up, with ease of accessibility, ease of measurement, and representativeness of the area being prime considerations. Frequency of ground measurement on key courses should be stepped up to include February, March, and April. Snow surveyors should begin to read and record depth at aerial markers as well as make the survey at all locations where a marker is installed, so that an overlap of record may be developed during the early years of newly installed markers.

Methods and equipment must be standardized before an expansion is made to eliminate as far as possible any expensive errors which could lead to loss of data or incorrect results. Perhaps one of the foremost problems would be identification of markers from the air and from aerial photographs. Some code or numbering system would have to be perfected to eliminate possibility of error. Aerial markers should be standardized in height and construction to eliminate errors in reading and to make parts interchangeable for easy repair and replacement. Snow depths in northern California may pose a problem in structural design of a marker adequate for perhaps 30 or 40 feet of snow found in this area. Criteria for marker location and exposure should be developed to make the marker data as representative of the course as possible. Criteria should be set up to help the fieldman installing markers to pick the most suitable site for aerial observation. Photographic procedures, processing methods, filters, film, etc., should be perfected and standardized. Methods of interpreting and filing data also have to be developed. Timing of flights and ground surveys should be synchronized if possible to eliminate changes in density between measurements.

Epilogue

Is it conceivable that aerial snow markers will eventually replace snow surveying as a means of sampling snow? Certainly not! At best, aerial markers only provide supplementary information. It is necessary to have water content measurements from at least key snow courses to provide adequate knowledge of snow-stored water. The primary advantage readily apparent from expansion of the aerial marker program would be better areal coverage early in the forecast season at equal or possibly reduced costs, as compared with present methods.

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