PREDICTING SNOW COURSE SNOW WATER EQUIVALENT

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INTRODUCTION

A reliable forecast of the quantity of snowmelt runoff is a prerequisite for informed management decisions in irrigated agriculture, flood control, power generation, and other important areas. The forecasts are most critical during periods of above or below normal precipitation. Since long term precipitation forecasts in excess of 1 month are not readily available or reliable, this paper presents a method of calculating probabilities of additional snow water equivalent (SWE) from the intermonthly autocorrelation structure of SWE at a snow course site. These probabilities can be used to modify streamflow forecasts or to indicate the degree of risk associated with a particular management decision. Snow water equivalent was used as a surrogate for streamflow since it effectively reflects the variability of atmospheric inputs to the the snowmelt-runoff system. Futhermore, the variability of streamflow forecasts over a forecast period are not necessarily the result of the input variability.

METHODS

The prediction method used depends on the autocorrelation of SWE at a snow course site between succeeding months. The recursion equations used are:

$$\hat{w}_{i,j+1} = \bar{w}_{j+1} + (m_j y - \bar{w}_j) + e_j z_i \quad j=1 \qquad (1)$$

$$\hat{w}_{i,j+1} = \bar{w}_{j+1} + (m_j \hat{w}_{i,j-1} - \bar{w}_j) + e_j z_i \quad j \neq 1 \qquad (2)$$

where the subscript j indicates the month and the subscript i is associated with each of 9 exceedance probability levels and m_j is the slope of the regression line between months and is given by:

$$m_j = r_j \frac{\sigma_{j+1}}{\sigma_j} \qquad (3)$$

where r_j is the SWE correlation coefficient between months and σ is the standard deviation of SWE.

In equation 1, y is the current, measured SWE. In equations 1 and 2, $\hat{w}$ is the predicted SWE for succeeding months at i probability levels, $\bar{w}$ is the mean SWE for the month, z is a standard deviation associated with probability level i and is obtained from tabulated values of the cumulative normal distribution; and e is the prediction error between months and is given by:

$$e_j = \sigma_{j+1} (1 - r_j^2)^{1/2} \qquad (4)$$

where all terms are as previously defined. This algorithm differs from the procedure proposed by Zuzel (1981), since it does not require the use of random numbers. A flow chart of the method is shown in Figure 1.

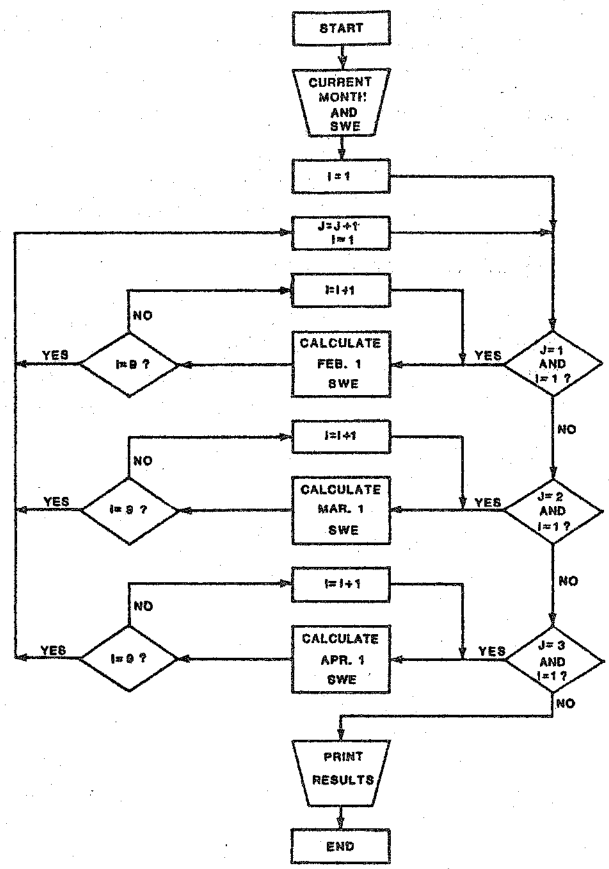

Figure 1. Flow chart of the recursive prediction algorithm. Equation (1) is used when j=1, Equation (2) is used when j≠1.

Forty-four years of January through April SWE data from the Diamond Lake snow

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course in southwestern Oregon were used to develop and test the prediction procedure. This site was chosen because of the completeness of the record and the large variability of SWE for all monthly readings. Three years of monthly data were deleted from the data base and reserved for testing the procedure. These three years were chosen because they represented the April 1 SWE which was nearest to the long term mean, $\bar{w}_4$ and one standard deviation above and below the long term mean, $\bar{w}_4 \pm 1\sigma_4$. The entire algorithm was encoded for computer use. Input requirements are the observed mean and standard deviation for the months of January through April, the correlation coefficients between successive months the current month and SWE. Output is the predicted SWE for succeeding months at exceedance probability levels of 0.1 through 0.9 in steps of 0.1. The program also incorporates an algorithm which associates the snow course name with its parameters ($\bar{w}_j \sigma_j$, r_j) so that the parameters need only be entered once and all names and parameters are saved in the data base when the program terminates.

RESULTS AND DISCUSSION

Analysis of the data base showed that large variations in SWE occurred in all months at this site. Table 1 shows the statistical characteristics of the historical data base in addition to the required input parameters. The variability of this site is indicated by the large disparity in monthly maximum and monthly minimum SWE for all months differing on the average by a factor of about 35.

Table 1. Statistical characteristics of snow water equivalent at the Diamond Lake, Oregon snow course.

Month	j	$\bar{w}_j$ (mm)	σ_j (mm)	r_j	y(max) (mm)	y(min) (mm)	Years
Jan	1	206	137	1.000	528	18	41
Feb	2	356	191	0.742	800	26	41
Mar	3	465	206	0.915	975	23	41
Apr	4	546	234	0.894	1034	30	41

Testing of a model with probabilistic outputs is not possible in the usual sense of predicted versus observed values. One can only demonstrate that the outputs are reasonable when compared to the historical record. Figures 2 through 4 show the results of predicting a mean April 1 SWE, $\hat{w}_4$ (Figure 2) and $\hat{w}_4 \pm 1\sigma_4$ (Figures 3 and 4) from the associated January 1 SWE. In these figures the dashed lines represent the predicted SWE associated with the indicated exceedance probability level, while the points connected by a solid line are the observed monthly SWE's. In only one case, $\hat{w}_4 + 1\sigma$, did the predicted SWE exceed the historical maximum (Figure 3; P = 0.1) and in no cases was the predicted SWE less than the historical minimum.

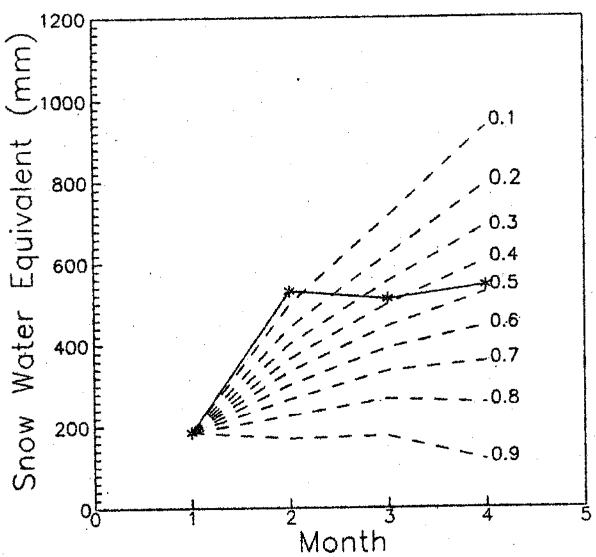

Figure 2. Predictions of SWE at the indicated exceedance levels. Observed SWE is indicated by the points connected by the solid line. April 1 SWE is average (546 mm).

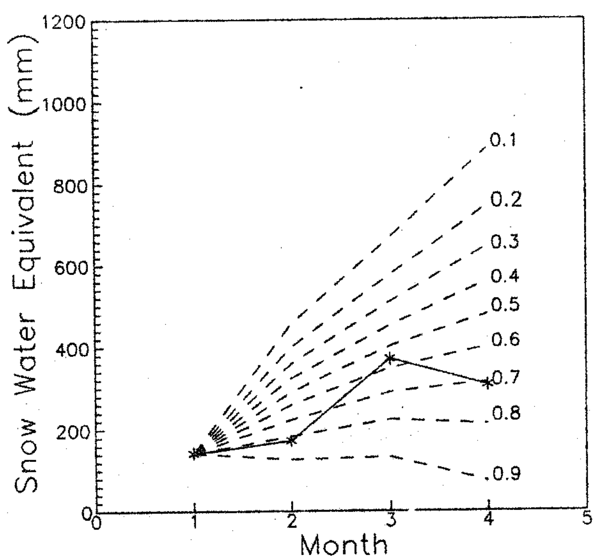

Figure 3. Predictions of SWE at the indicated exceedance levels. Observed SWE is indicated by the points connected by the solid line. April 1 SWE is 1 standard deviation below average (312 mm).

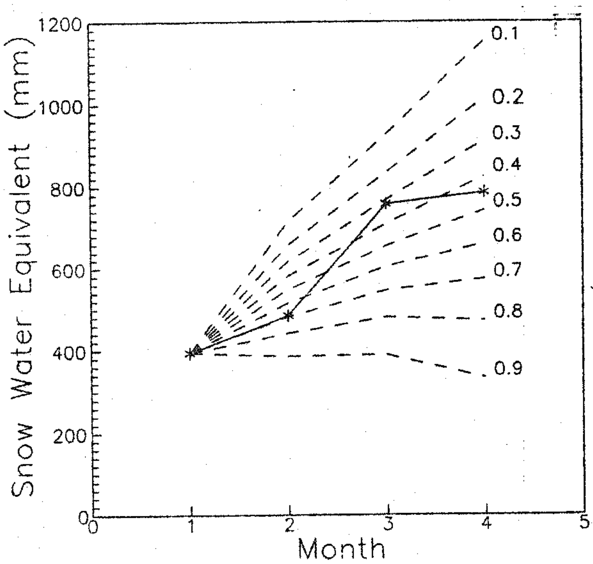

Figure 4. Predictions of SWE at the indicated exceedance levels. Observed SWE is indicated by the points connected by the solid line. April 1 SWE is 1 standard deviation above average (780 mm).

A more rigorous test can be performed by comparing the predicted versus the observed values at the most probable exceedance probability level, P = 0.5. Figure 5 shows the results of this comparison for all prediction intervals (1 to 3 months). The correlation coefficient between observed and predicted SWE is 0.80 with a standard error of 100 mm water. From these results one can conclude that the algorithm produced reasonable predictions of SWE over the 3 month period.

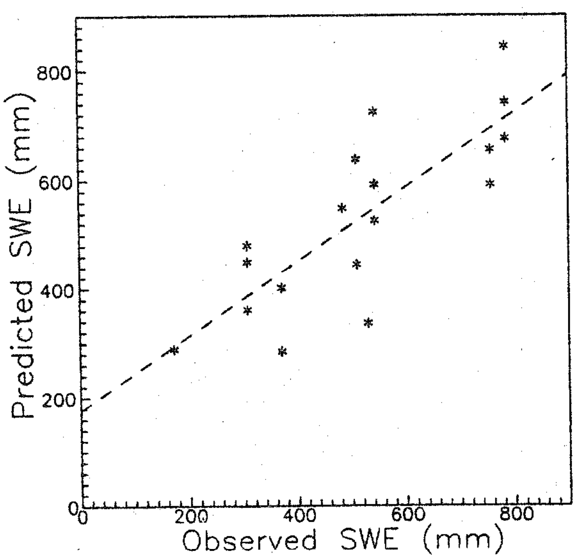

Figure 5. Observed versus predicted SWE for all prediction intervals at the 0.5 exceedance probability level.

SUMMARY

An algorithm for predicting future snow course SWE has been presented. Acceptable results were obtained for high, average and low years for all exceedance levels. This procedure can easily be extended to include the months of May and June where this is desirable. The results of these predictions combined with the judgement of the analyst, can be used to modify streamflow forecasts based on the probabilities of additional snowfall.

REFERENCES

Zuzel, J. F. 1981. Conditional flow simulation: A stochastic forecast model. Water Resources Research 17:595-601.