EARLY FORECASTS OF SNOWMELT RUNOFF USING SNOTEL DATA IN THE UPPER RIO GRANDE BASIN

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ABSTRACT

Forecasts using SNOTEL data on November 1 and December 1 gave the best estimates of spring snowmelt runoff volumes almost as frequently as forecasts on March 1 and April 1 for the Upper Rio Grande basin in Colorado during 1983-2001. Forecasts for 2002, a record drought year, greatly overestimated flow volumes regardless of prediction month. Attempts at improving predictions using the El Nino/La Nina Southern Oscillation Index were not successful.

INTRODUCTION

Statistical forecasts of snowmelt runoff for a given melt season generally begin on January 1 even though earlier estimates could be quite useful to water resource managers. Variables used in statistical forecasts are commonly snowpack water equivalent (swe) data from either snow courses or SNOTEL sites, accumulated autumn precipitation, snow depth at index markers and stream discharge rates (Steppuhn 1981, Singh and Singh 2001). Use of snow course swe data must necessarily wait for results of mid- to late-winter snow surveys. Since SNOTEL sites continuously record snow pack accumulation in the early winter season, SNOTEL swe data offer an opportunity to forecast flows as early as November 1 or December 1 each year.

Statistical forecasting generally suffers from poor performance during extreme events that are not well represented in the historical data set. Even though the SNOTEL network on the Upper Rio Grande Basin contains sites with up to 20 years of data, the record low snowfall and drought during 2002 would be expected to be a forecasting challenge using a statistical approach.

Recent studies have shown that El Nino/La Nina Southern Oscillation conditions in the South Pacific can influence snowfall in western North America. It is well known (Kunkel and Angel 1999, Smith and O'Brien 2001) that strong La Nina conditions can shift the jet stream and cause heavier snowfall in the northwest United States. These studies suggest that the extent of a Southern Oscillation effect may be limited to regions north or west of south central Colorado, but no tests have been conducted for the Upper Rio Grande Basin. The availability of monthly mean values of the Southern Oscillation Index (SOI), essentially a difference in atmospheric pressure between Tahiti and Darwin, offers an opportunity to test for effects of La Nina/El Nino conditions on snowmelt runoff in the Upper Rio Grande Basin.

The major objective of this study was to determine the usefulness of SNOTEL data in making early-season snow melt runoff forecasts on November 1 and December 1 as compared to later-season forecasts from January 1 through April 1 for the Upper Rio Grande basin. We also tested the SNOTEL relationships for prediction of flows in 2002, a record drought year, and attempted to improve flow forecasts using El Nino/La Nina Southern Oscillation Index. This is the second paper in a series (see DeWalle et al. 2002) on use of SNOTEL data to improve forecasts of snowmelt runoff for the Upper Rio Grande basin.

METHODS

Snow pack water equivalent data were obtained from the USDA Natural Resources Conservation Service website for SNOTEL sites in the Upper Rio Grande basin on the first of each month from November to April for 1983 to 2002. The analysis included seven SNOTEL sites considered to be representative of snow pack in the Upper Rio Grande basin (Slumgullion, Upper Rio Grande, Beartown, Middle Creek, Upper San Juan, Wolf Creek

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Paper presented Western Snow Conference 2003

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Summit, Lily Pond, and Cumbres Trestle). Stream discharge data were obtained from the US Geological Survey website for the Rio Grande at Del Norte, CO. Using stepwise linear regression at a 0.05 significance level, we developed prediction equations to forecast April-September runoff volume (ac-ft/1000), seasonal peak daily flow rate (ft^3 s^{-1}), and Julian Date of peak flow at the Del Norte gage using swe values measured on the first of each month from November to April. The best prediction month (November to April) for stream flow volumes for each year was determined by using a jack-knife regression procedure. In this procedure, equations were re-run excluding data for each year being tested and then the new equations were used to predict flows for the excluded year. To test equations under extreme conditions, we used the best prediction equations for 1983-2001 to predict flow volume in 2002, a record low snowfall year. Finally, using the entire 1983-2002 data set we determined the impact on forecast accuracy of adding monthly mean Southern Oscillation Index (Australian Commonwealth, Bur. Meteor. SOI Archives website) and stream discharge on the first of each month as independent variables.

RESULTS AND DISCUSSION

Utility of Early Predictions

Prediction accuracy for runoff volumes, as indicated by R^2 and standard errors of monthly equations, increased from November 1 to January 1, and then surprisingly remained relatively constant or decreased slightly between January 1 and April 1 (Figures 1 and 2). Forecasts of melt volumes using late season SNOTEL data appeared to offer a surprisingly small advantage over early season forecasts. Prediction accuracy was the highest for runoff volumes, intermediate for peak flow rate, and lowest for date of peak flow. As snow melt runoff volumes increased, the peak flow rate increased and the time of peak flow occurred later in the spring. Prediction accuracy for seasonal peak flow rates gradually increased from November 1 to April 1. Thus, forecasts of peak flow rates would be expected to be more accurate in April than in November. Just the opposite effect was noted for forecasts of the date of peak flow. Peak flow date forecasts were most accurate in November 1 and December 1 and unexpectedly quite poor later in the winter.

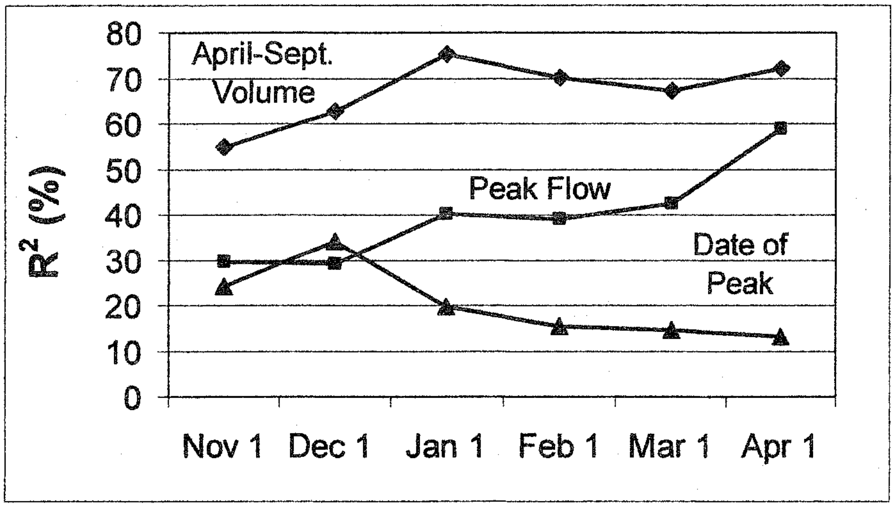

Figure 1. Variation by month of R^2 for equations by month of prediction equations for volume of spring snowmelt runoff, peak daily runoff rate, and date of peak runoff based on 1983-2001 data.

The stepwise prediction equations for 1983-2001 generally only contained swe data from one of the seven possible SNOTEL prediction sites. Middle Creek emerged as the SNOTEL site that appeared as a significant predictor most frequently. Multivariate methods may have improved estimates by including information from more SNOTEL sites, but obviously considerable data redundancy exists among SNOTEL sites used in this analysis.

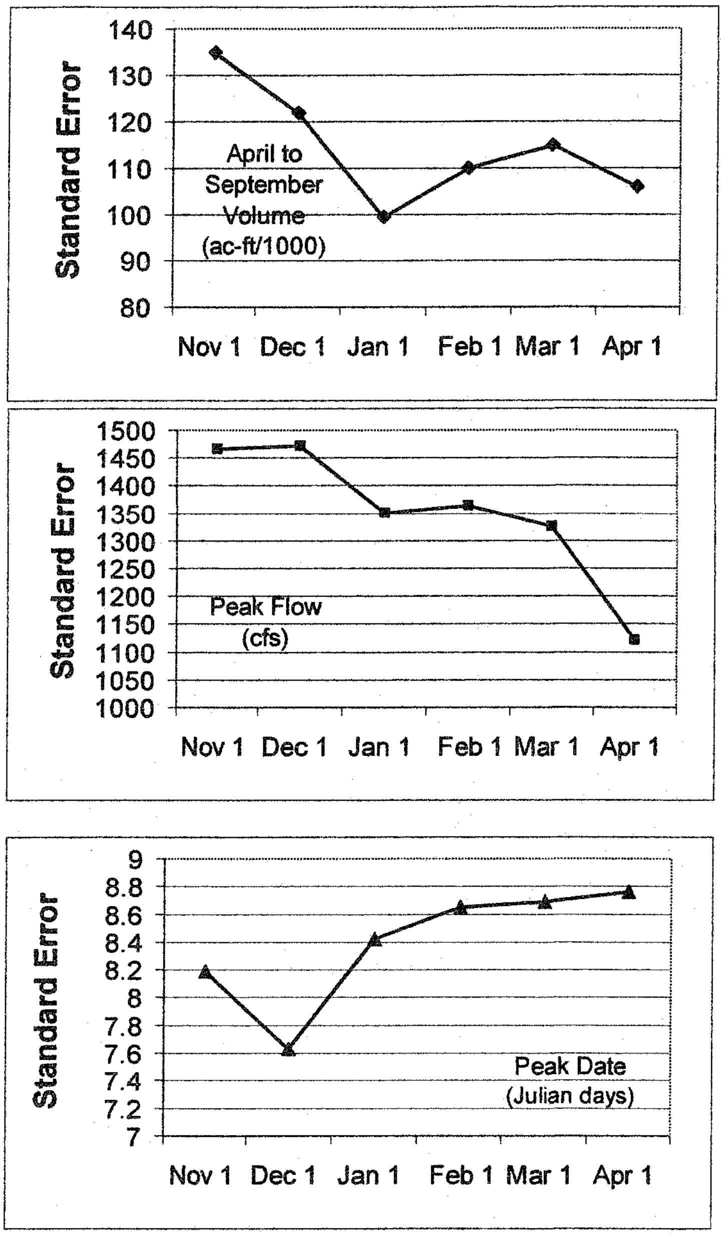

Figure 2. Variations in standard errors of equations by months for 1983-2001 data: (upper) snowmelt runoff volumes, (middle) peak daily flow rate, and (lower) date of peak flow.

Best Prediction Month

The best prediction month in each year was determined by comparing the actual runoff volume with the forecasted runoff volume based upon equations for each month from the jack-knife statistical analysis. The most accurate forecasted runoff volumes were within ±10% of the actual runoff volumes regardless of the month used to predict for every year except 1992 when the closest forecast (April 1) overestimated by 35% (Figure 3). The forecasted runoff volumes based on November 1 swe were the best estimators of actual runoff volume in 5 of the 19 years. December 1, January 1 and March 1 forecasts were each the best estimators in 3 of the 19 years. February was the only prediction month that did not provide the best estimate in any year. April was the best forecast month in five years. Overall, November 1 and December 1 forecasts were the most accurate in nearly half of the analyzed years, a frequency of "best estimates" that tied the frequency of best estimates for the March 1 and April 1 forecasts combined for the 1983-2001 data.

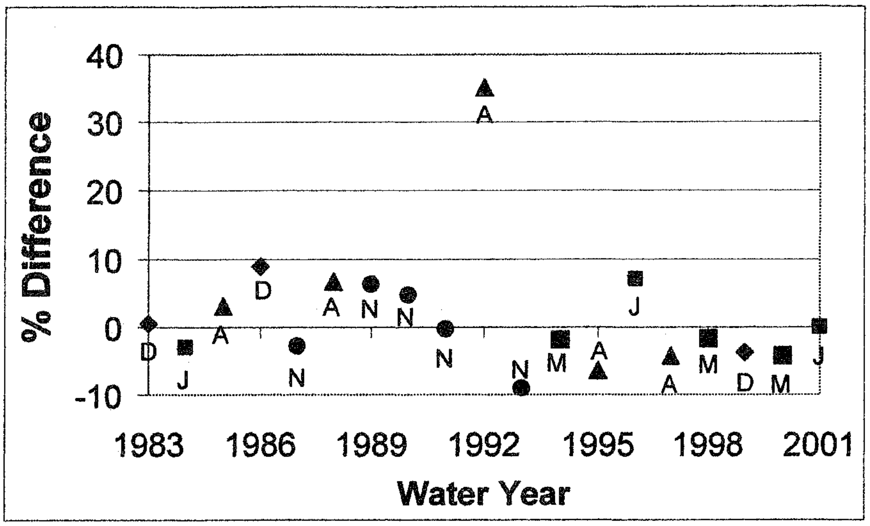

Figure 3. Best prediction month and forecast errors (%) for April-September snowmelt runoff volumes (N=Nov, A=April) for each year at Del Norte, CO from 1983-2001.

Predictions for 2002 Drought Year

Drought plagued the western U.S. in 2002 resulting in decreased snowfall and runoff volumes. Runoff volume for 2002 was lower than in any other year in the data set. Forecasted values started low on November 1 and dropped with each successive month of prediction. Our best prediction made using the April 1 equation, still overestimated seasonal flow volume by 73% (Figure 4).

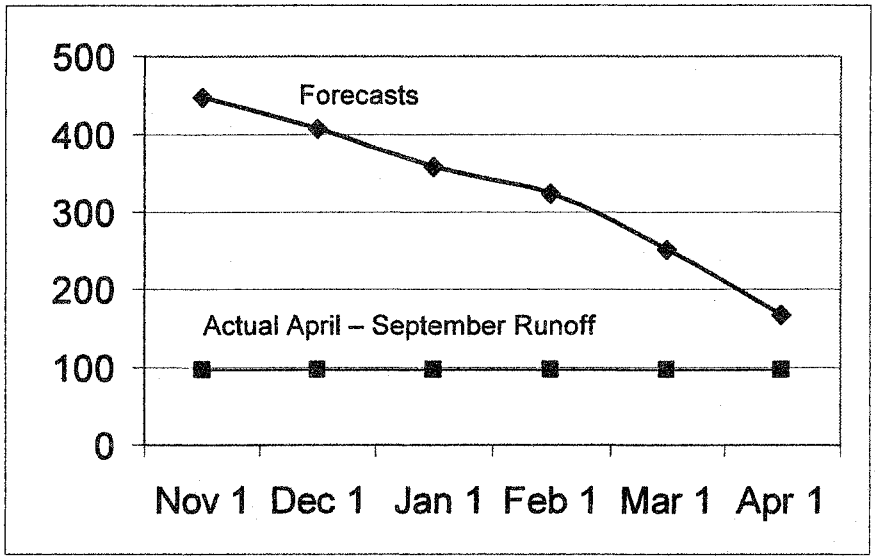

Figure 4. Actual April-September snowmelt runoff (ac-ft/1000) for the 2002 record drought year compared with the progressively declining monthly forecasts based upon equations for the 1983-2001 period.

Final Equations for 1983-2002

The final equations derived for prediction of snow melt runoff at the Del Norte gage for 1983-2002 data, including the record drought year, are shown in Table1. The SOI did not appear in any equation as a significant predictor for any of the three flow variables. Stream flow rate at the Del Norte gage appeared as a significant variable only once, in the prediction of the date of peak flow on March 1. Middle Creek was again the primary SNOTEL site found to be significant in flow predictions, but Beartown, Cumbres Trestle, and Upper San Juan SNOTEL sites also appear in some equations.

Table 1. Final Prediction Equations for Snowmelt Runoff Volumes, Peak Flow Rates and Time of Peak Flow on the Upper Rio Grande at Del Norte, CO for 1983-2002 Data

Forecast Date	Equation	R^2 (%)	Standard Error
Runoff Volume	V = April-Sept volume, ac-ft/1000		ac-ft/1000
Nov 1	V = 390 + 67.0 BT*	53	153
Dec 1	V = 286 + 40.3 MC	62	138
Jan 1	V = 191 +39.6 MC	74	112
Feb 1	V = 122 +37.8 MC	72	117
Mar 1	V = 68.2 + 32.5 MC	73	116
Apr 1	V = -31.5 + 30.9 MC	78	104

Peak Flow	Q = peak flow rate, cfs		cfs
Nov 1	Q = 4631 + 566 CT	30	1467
Dec 1	Q = 3722 +273 CT	29	1479
Jan 1	Q = 3410 +232 MC	41	1352
Feb 1	Q = 2929 + 228 MC	40	1357
Mar 1	Q = 2342 + 211 MC	44	1317
Apr 1	Q = 801 + 195 BT	59	1120

Date of Peak Flow	JD = Julian Date of peak flow, Jan 1= 1		J D
Nov 1	JD = 148 +1.68 USJ	20	8.71
Dec 1	JD = 143 + 1.00 USJ	33	7.99
Jan 1	ns	ns	ns
Feb 1	ns	ns	ns
Mar 1	JD = 127 + 0.118 Q Mar 1	35	7.83
Apr 1	ns	ns	ns

* MC, BT, CT and USJ are snowpack water equivalents in inches at the Middle Creek, Beartown, Cumbres Trestle and Upper San Juan SNOTEL sites on the forecast date; ns = not significant; Q Mar 1 = the flow rate in cfs at the Del Norte gage on March 1.

Use of equations in Table 1 to predict the volume and peak snowmelt runoff for January 1 can be simply accomplished. If the Middle Creek SNOTEL snowpack water equivalent was 5.5 inches, then the volume of runoff from April through September would be 408,800 acre-feet using the appropriate equation in Table 1. The peak daily runoff rate would be 4,686 cfs using the January 1 equation from Table 1. The January 1 equation for predicting the date of peak runoff each spring was not significant.

The same basic relationships between early and late-season forecasts that appear in Figures 1-2, can be seen for the equations in Table 1, indicating that inclusion of the 2002 drought year did not alter the seasonal pattern of equation performance. However, the best prediction for 2002 flow volume was on April 1. Thus, the March and April forecasts ended up with a slight advantage over November plus December as the best months.

CONCLUSIONS

1. Early season forecasts of snowmelt runoff volumes using SNOTEL data on November 1 and December 1 produced best estimates of snowmelt runoff volumes almost as frequently as late season forecasts on March 1 and April 1 in the Upper Rio Grande Basin. Regional weather patterns that influence snowpack water equivalent appear to be consistent throughout the winter from November through April on this basin allowing early-season snowpack data to index future runoff almost as well as late-season data.

2. Weather patterns that influence snowfall and snowmelt runoff in the Upper Rio Grande Basin do not appear to be related to variations in La Nina and El Nino cycles as indexed by the Southern Oscillation Index.

3. Some SNOTEL sites, such as Middle Creek, appeared to explain more of the variations in snowmelt runoff than other sites in or around the Upper Rio Grande Basin. Site characteristics of such "good" SNOTEL sites need to be defined and used to help locate future SNOTEL sites for runoff prediction.

4. Errors in flow forecasts were much greater in the 2002 drought year than near-normal years. Prediction errors were within ± 10% in 18 of the 19 years of record excluding 2002; however, flow volumes for the 2002 record drought year were overestimated by 73%. This confirms the weakness of statistical forecasts for extreme conditions, like droughts, that are not well represented in the data set and points to the need for other deterministic or process-based models as well as statistical.

ACKNOWLEDGMENT

The senior author gratefully acknowledges support from USDA/ARS Jornada Experimental Range during summer 2000 when this research was initiated.

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