ESTIMATING SNOW COURSE WATER EQUIVALENT FROM SNOTEL PILLOW TELEMETRY: AN ANALYSIS OF ACCURACY.

BY

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INTRODUCTION

In the late 1970's, the USDA Soil Conservation Service (SCS) began installing an automated mountain snowpack data collection and telemetry system know as SNOTEL (for SNOw TELemetry). The system reports snowpack water equivalent (SWE), cumulative precipitation and air temperature parameters on a daily basis. The purpose of this system is twofold: to provide real time hydrometeorological data for streamflow modeling; and second, to replace manual snowpack data collection for seasonal streamflow volume forecasting. This paper concerns the accuracy of SNOTEL data for the second purpose.

STREAMFLOW FORECASTING

The SCS snow survey program uses SWE data collected at various key index sites, known as snow courses, to generate seasonal streamflow volume forecasts. The SWE is measured by inserting a hollow aluminum or steel tube down through the snowpack to the ground, then withdrawing the tube and its snow core for weighing to determine the water content. This process is repeated for several samples, and the individual water contents are averaged to derive one mean SWE value for each snow course.

Snow courses are usually measured around the first of the month from January to June. Additional measurements are made for some snow courses in the middle of the month. When all the necessary data are collected, seasonal streamflow forecasts are made and published each month (January through May) for the coming runoff season. The SCS, in conjunction with the National Weather Service, produces forecasts for over 500 streams in the western U.S. Most volumetric streamflow forecast methods are empirical in nature. They are derived from regression analysis between snow course data, precipitation, soil moisture, and observed streamflow in a basin. In most cases, at least 20 years of data are used in deriving these regression equations.

SNOTEL DATA SITE CONSIDERATIONS

Prior to installation of the SNOTEL system, an analysis was made to determine which snow courses in a basin were the highest correlators to runoff. Candidate sites were selected from this list that promised uniformity of snow cover and were indicative of snowpack conditions for that elevation and aspect within a basin. Each site was then visited and the specific location of the SNOTEL site was selected.

The principle snowpack sensor used at SNOTEL sites are called snow pillows: steel, butyl rubber, or hypalon envelopes filled with an antifreeze solution. These pillows weigh the water content of the overlying snowpack. An electronic pressure transducer translates this weight into an equivalent voltage and telemeters it to a central master station.

In most cases, the data collected by the snow pillow sensor and the data collected manually at the colocated snow course are not identical. The reason for this is twofold. The snowpack is being measured by two different sensors, either of which may under or over-measure, depending upon conditions (Farnes et al, 1982), (Schaefer and Shafer, 1982), (Smith and Boyne, 1981). In addition, specific physical site location differences between the snow course and snow pillow may affect snow accumulation patterns, and aspect

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and exposure differences may contribute to differential melt in late spring. For these reasons, both snow course and SNOTEL data have been collected since installation of the SNOTEL system to determine their relationship to one another.

ESTIMATION OF SNOW COURSE DATA

In order to incorporate SNOTEL data into the streamflow forecasting procedure and to reduce expensive manual measurements, linear regression relationships were established between SNOTEL and snow course data at each of 61 SNOTEL sites in Idaho. This allowed snow course estimates to be made directly from SNOTEL telemetry for inclusion into the streamflow forecast equations. Regression equations were produced using SNOTEL pillow manometer and snow course SWE data. The pillow manometer (visual standpipe readings) was chosen in lieu of telemetry for two reasons: some sites had manual readings of pillow manometers taken at the time of snow course measurements prior to installation of radio transceivers; also, some of the early years of pillow telemetry data had not been verified and edited. By using pillow manometer readings, corrected for specific gravity of the antifreeze solution, more data was available for correlating to snow course measurements than if pillow telemetry was exclusively used. An analysis of all SNOTEL sites in Idaho and Colorado indicated that there was no significant difference between pillow manometer and pillow telemetry readings when the telemetered data base was properly verified and edited (Schaefer and Shafer, 1982). Figure 1 shows a typical pillow manometer/telemetry relationship for an Idaho SNOTEL site.

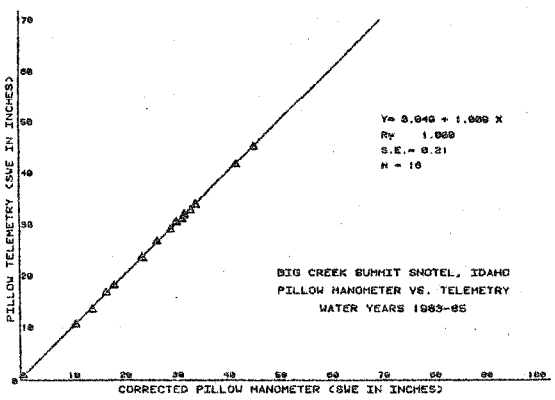

Figure 1. Typical pillow manometer/telemetry relationship for an Idaho SNOTEL site.

Due to physcial site location differences between the snow pillow and the snow course, the relationships for the accumulation period do not necessarily hold true for the ablation period (usually May and June). For example, if the snow course had a more southerly or open exposure than the pillow, it would begin melting earlier and perhaps faster, even though the accumulation patterns were similar. Figure 2 shows the differences in accumulation and melt relationships for such a site.

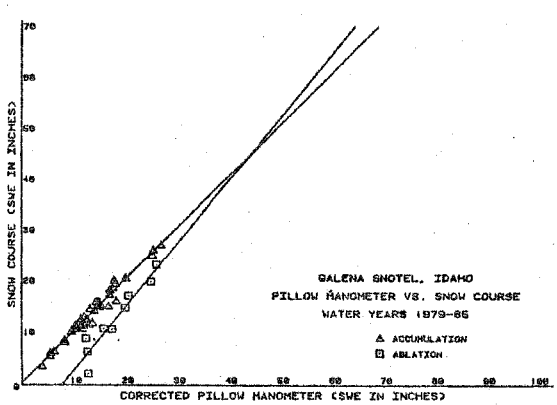

Figure 2. Differential accumulation/melt relationships between snow pillow and snow course for an Idaho SNOTEL site.

In order to reliably estimate snow course data during both the accumulation and ablation periods, the data for each site were split into two sets for regression analysis: January through April, and May through June. To estimate a May fifteen snow course reading, for example, one would use the ablation regression equation, while the accumulation equation would be used to estimate any data during the January through April period.

ANALYSIS OF ESTIMATING ERRORS

Water year 1985 was used as a test of the snow course estimating equations developed using previous years' data. When a snow course with a colocated SNOTEL site was measured during 1985, the SNOTEL pillow telemetry on that day was used to produce a snow course estimate. Accumulation or ablation equations were chosen depending upon whether or not melt had occurred on the pillow prior to the time of measurement. In the 1985 test year, an unusually warm spring caused snowmelt to begin at almost all elevations across the state during the first week of April. The accumulation season is therefore defined as measurements taken through the April first snow surveys.

Sites which had an estimated snow course value of less than 2.5 cm SWE were ignored in the analysis. This situation could occur late in the ablation season, when daily melt rates can be in excess of 5 cm. The time delay between early morning SNOTEL telemetry and the arrival of a surveyor to measure the snow course could greatly exaggerate the apparent estimating error. Regression equations with a correlation coefficient (R-value) less than 0.75 were also excluded from the analysis, since operational snow course estimates would not be made using an equation with such a low R-value.

For each snow course estimate, an error term was computed by the following equation:

$$\text{Error} = \text{SCE} - \text{SCA} \qquad (1)$$

Where: SCE = Estimated Snow Course Reading
SCA = Actual Snow Course Measurement

The sign of the error term indicates over (+) or under-estimation (-). To normalize error terms due to the magnitude of the SWE, the errors were converted to percent error by the following equation:

$$\text{Percent Error} = \frac{\text{Error}}{\text{SCA}} \times 100 \qquad (2)$$

Where: Error = Estimation error (from Equation 1)
SCA = Actual Snow Course Measurement

Figure 3 is a histogram of these percent errors, separated into systematic and random error categories.

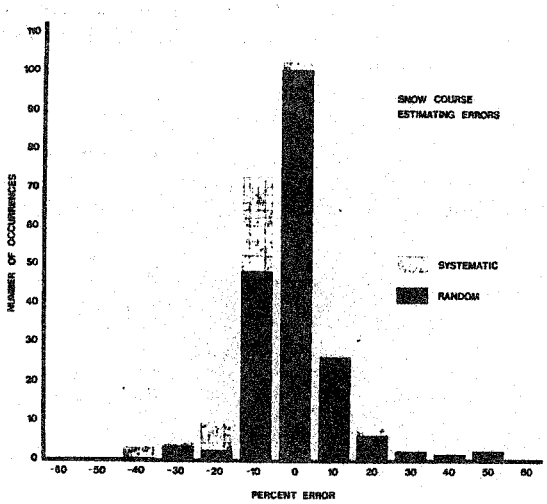

Figure 3. Snow course estimating errors (percent): systematic and random.

SYSTEMATIC ERRORS

Eight SNOTEL sites had systematic errors throughout the January - June measurement period. After examining each site's data in detail three explanations were found:

1. Flat Snow Pillow: One SNOTEL site developed a slow leak in the pillow during January, resulting in a substantial underestimation of the snow course SWE during February - May.

2. Snow Tube Scale Recalibration: A scale used to weigh the water content of the snow samples was sent back to the factory for recalibration in summer of 1984. Subsequent analysis indicated that since 1972 the scale, used on five snow courses with colocated SNOTEL sites, was underweighing the snow samples by eleven percent. Therefore, SNOTEL/Snow Course relationships developed for these courses were based on erroneous data, and 1985 snow course estimates were all well below the actual measured SWE for these five sites.

3. Improper Transducer Excitation Voltage: The pressure transducers used to convert the pillow hydrostatic head to an analog voltage require an operating voltage of 7.5 volts DC. A routine summer maintenance procedure requires this excitation voltage to be temporarily changed to 5.0 volts for testing purposes.

   For two SNOTEL sites, this voltage was inadvertently left at 5.0 volts at the conclusion of the maintenance test. A controlled lab test indicated that a pressure transducer with only 5.0 volts excitation voltage undermeasures by 37%. Consequently, snow course estimates for these two sites were well below the actual measured SWE.

The data from these eight sites were deleted from the following analysis to eliminate systematic bias.

RANDOM (UNEXPLAINED) ERRORS

Removing data that is biased by systematic errors leaves us with random, or unexplained errors. These errors are caused by the natural variability of snow accumulation along with measurement problems inherent in both manual and automated snow measuring practices (Schaefer and Shafer, 1982). Analysis of these random errors provides a hydrologist with an expected level of accuracy when estimating snow course measurements from SNOTEL telemetry.

The random errors in Figure 3 appear to have a slight positive skew, which is sub stantiated by a chi-square test for normality. As Figure 4 indicates, the high positive error terms which cause this skewness are all from ablation season estimates. When expressed as inches of SWE instead of percent, these errors in the 35-55 percent classes are actually rather low, and are associated with observed snow course values of less than 14 cm. These estimating errors could be accounted for by snow melt that occurs between the time of early morning telemetry and actual snow course measuremet. A chi-square test for normality using the raw error terms (inches of SWE) supports the hypothesis that the data is normally distributed.

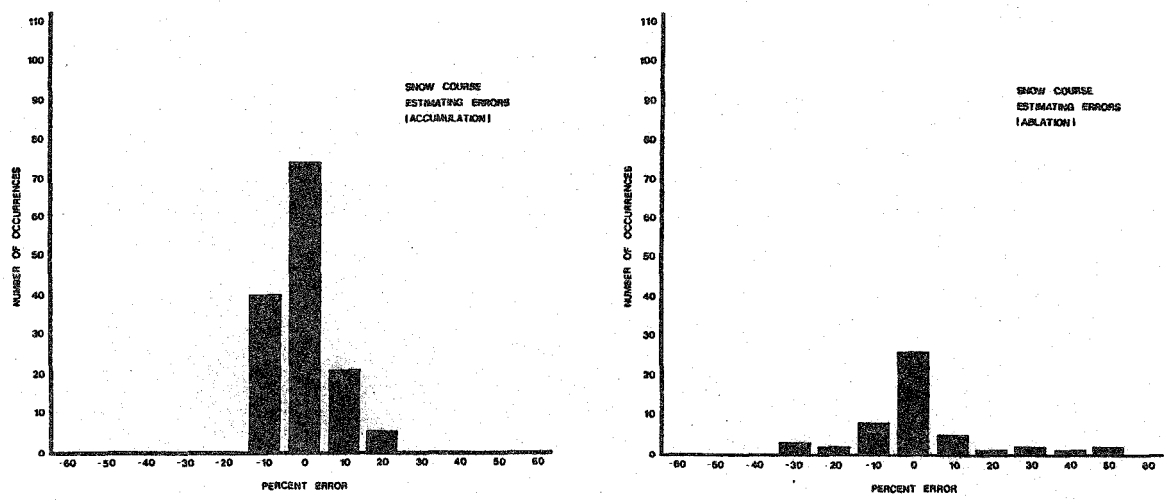

Figure 4. Random snow course estimating errors (percent): accumulation and ablation season.

Table 1 is a statistical summary of the snow course estimating errors. All error types are divided into accumulation and ablation categories. The absolute values of all the percent error terms were averaged, resulting in an average error of 5.6 percent for the accummulation season, and 11.8 percent for the ablation season, with standard deviations of 9.5 and 21.4 percent, respectively.

TABLE 1
STATISTICAL SUMMARY

	Mean	Variance	St. Dev	N	Median	Mode
Percent Error - Accumulation	-0.6	52.7	7.3	140	-1.6	0
Percent Error - Ablation	2.6	370.3	19.2	51	-0.6	0
Absolute Percent Error - Accumulation	5.6	91.1	9.5	140	4.4	0
Absolute Percent Error - Ablation	11.8	456.4	21.4	51	4.8	0
Raw Errors (inches) - Accumulation	-0.3	1.6	1.2	140	-0.3	-0.7
Raw Errors (inches) - Ablation	-0.3	3.5	1.9	51	-0.2	0
Absolute Raw Errors (inches) - Accumulation	1.0	3.3	1.8	140	0.7	0.5
Absolute Errors (inches) - Ablation	1.3	6.1	2.5	51	0.9	0

SUMMARY/CONCLUSIONS

Manual snow courses have been measured in Idaho since 1921, and seasonal streamflow forecast equations have been developed using this relatively long period of corresponding data between snowpack and streamflow. Installation of the SNOTEL system, which began in 1978, will ultimately provide forecasters with real time data for streamflow modeling purposes. Until an adequately long period of data is available for modeling purposes, SNOTEL can be used to estimate snow course data for inclusion in seasonal streamflow volume forecasts.

There are two important benefits from this. Snow courses which correlate well with nearby SNOTEL sites can be reliably estimated, reducing manpower and equipment expenses. This is especially important in early season forecasts, when forecast accuracy is not as critical as it is later in the season (April or May). Since snow course estimates can be made quickly from daily SNOTEL telemetry, streamflow forecasts can be updated any time of the month. During extremely high or low snowpack years, this ability to update forecasts is valuable for water management decisions which must be made daily.

The higher error term and dispersion associated with ablation season snow course estimates are in keeping with the lower correlation coefficients and higher standard errors of the estimating equations (Figure 2). This is a function of differential snowmelt between the pillow and snow course. It is doubtful that melt season correlations could be improved significantly through the use of refined equipment (pillows, pressure transducers, etc.) or improved manual measurement practices. Important melt season measurements which must be more accurate than the 11.8 percent average error realized in this paper should be obtained by direct manual measurement.

The average absolute estimating error of 5.6 percent (accumulation season) cannot be translated directly into a corresponding average streamflow forecast error of 5.6 percent. Snow course data is only one of several factors used in the multiple regression streamflow forecast equations. The variability accounted by the snow course factor ranges from about 40 to 80 percent in forecast equations used in Idaho. (Beard, 1986)

Before the transition is made from snow course to SNOTEL data for forecasting purposes, a careful analysis must be made to determine what effect, if any, this will have on streamflow forecast accuracy. The analysis of snow course estimating errors presented in this paper will provide the foundation for a sensitivity analysis of streamflow forecasts based upon telemetered SNOTEL values.

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