EVALUATION OF THE USE OF SOIL CONSERVATION SERVICE SNOW COURSE DATA IN DESCRIBING LOCAL SNOW CONDITIONS IN ARIZONA FORESTS

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Introduction

Snowmelt is the major source of runoff from mountain watersheds throughout the western United States. Over 75% of Arizona's surface water originates from winter storms over the state's mountainous ponderosa pine (Pinus ponderosa) and mixed conifer forest watersheds. The USDA Soil Conservation Service (SCS) maintains a system of permanent snow courses throughout the mountains of Arizona and pertinent portions of New Mexico to evaluate snowpack conditions. The snow courses, usually in forest openings, provide an index of snow conditions within a river basin. The SCS correlates data averages and other parameters with streamflow to determine anticipated flow volumes, for use in allocating water, and in planning for downstream irrigation, hydroelectric, and domestic-industrial water supplies.

The SCS snow courses do not necessarily provide unbiased area-wide snow depth, water equivalent, and snow density values for a given river basin, primarily because of the wide variability in snow accumulation patterns. In addition, many of the forest openings which contain snow courses act as "snow traps" which accumulate more snow than the surrounding forest (Rhea and Grant 1974). Court (1963), working in the central Sierra Nevada of California, determined that snow courses represented conditions on sites 2,600 feet higher in elevation producing an overestimation of about 2 inches. Conversely, Rhea and Grant (1974) indicate that snow courses in very open or in densely forested sites tend to underestimate snow water equivalents. There are times when more localized snow information would be helpful; for example, for engineering, forest management and research, and for recreation planning. The SCS courses are often the only available winter climatic data for isolated areas.

Our first objective was to evaluate how well SCS snow courses represent conditions in the surrounding area by comparing SCS data from selected Arizona snow courses with snow measurements from the nearest experimental watershed snow courses. The watersheds, maintained by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station and located throughout the ponderosa pine and mixed conifer forests of central and eastern Arizona, were established to evaluate effects of forest management practices on water yields. The watersheds contain intensive snow survey grids which sample a range of local topographic and forest stand conditions.

Our second objective was to attempt to evaluate the ability of several snow-elevation relationships to estimate average snow water equivalent on the experimental watersheds. These relationships were derived from published SCS data (USDA Soil Conservation Service 1975) or were published previously (i.e., Cary and Beschta 1973). In areas where there are no snow courses but where snow information is necessary, such a relationship would be a helpful estimating tool. This relationship has interested several other investigators; including Court (1963) in California, Rhea and Grant (1974) in Colorado, and Storr and Golding (1974) in Alberta, Canada.

Study Area

The first part of the study compared snow water equivalent and snow density from four SCS snow courses and from seven snow courses on neighboring experimental watersheds. Each watershed snow course was paired with the nearest SCS snow course:

SCS Snow Course	Experimental Watershed
Newman Park	Beaver Creek Watershed-15
Heber	Stermer Ridge
Beaver Head	Castle Creek West Fork
Beaver Head	Castle Creek East Fork
Hannagan Meadows	Thomas Creek North Fork
Hannagan Meadows	Thomas Creek South Fork
Hannagan Meadows	Willow Creek East Fork

The study sites sample a wide geographical area (figure 1), from south of Flagstaff to the eastern White Mountains, and are in the headwaters of four major Arizona river basins (table 1). The experimental watersheds exhibit a wide range of characteristics (table 2). The first four watersheds are in the ponderosa pine type, and the others are in the mixed conifer forest zone. Mixed conifer forests generally contain uneven-aged stands of seven coniferous species and quaking aspen (Populus tremuloides). The most common tree species are Douglas-fir (Pseudotsuga menziesii), aspen, Engelmann spruce (Picea engelmannii), and white fir (Abies concolor).

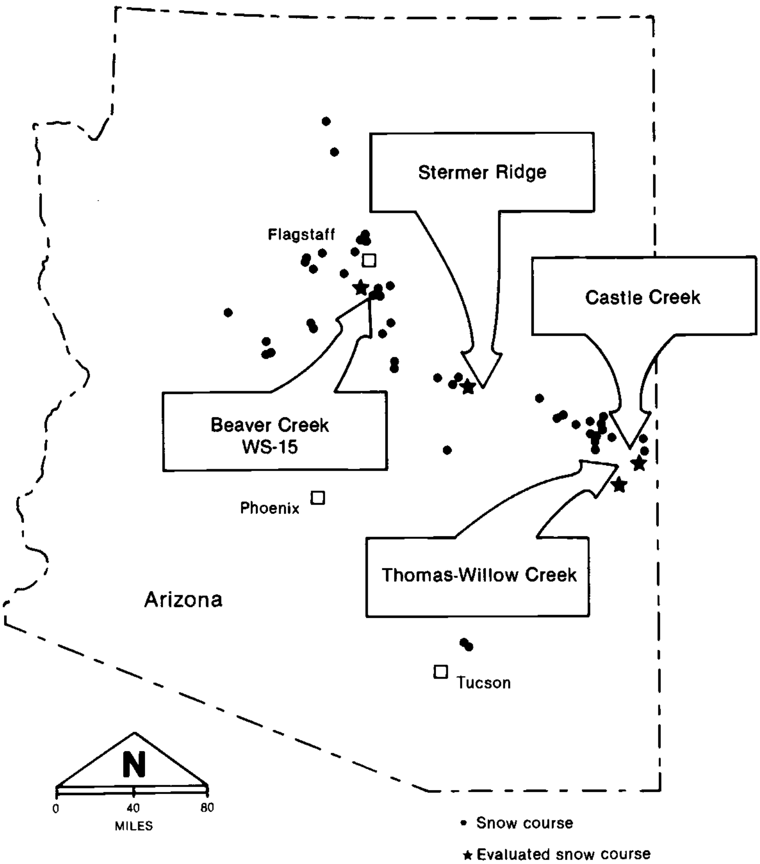

Figure 1. The SCS has measured snow at 57 locations within Arizona and pertinent portions of New Mexico starting in 1938. The four locations used in our analysis are emphasized; e.g., Newman Park, Heber, Beaver Head, and Hannagan Meadows.

Table 1. Characteristics of the SCS Snow Courses (USDA Soil Conservation Service 1975)

Name	Twp.	Rge.	Elev. (feet)	Aspect	Drainage	Record begun
Newman Park	19N	6E	6750	SE	Verde	1963
Heber	11N	15E	7600	NE	Little Colorado	1950
Beaver Head	4N	30E	8000	NE	San Francisco (Gila)	1938
Hannagan Meadows	3N	29E	9090	N	Salt	1964

Table 2. Characteristics of the Experimental Watersheds

Watershed	Area	Elevation	Slope	Aspect	Ave. precip.	Ave. basal area	Distance[3/] to SCS course
	(acres)	(feet)	(%)		(inches)	(ft^2/ac)	(miles)
Beaver Creek Watershed-15	163	6735-7160 mean: 6950	15	S-SW	25	96	9 1/4
Stermer Ridge	121	6900-7050 mean: 6975	9	NW	18-25	67	9 1/2
Castle Creek West Fork	900	7850-8583 mean: 8105	14	SE	25	116[1/] 60	1 1/2
Castle Creek East Fork	1163	7835-8477 mean: 8076	14	NW	25	139	[2/]
Thomas Creek North Fork	467	8350-9250 mean: 8880	25	E-SE	29	187	3 3/4
Thomas Creek South Fork	562	8350-9150 mean: 8880	20	E	29	186[1/] 146	3 1/4
Willow Creek East Fork	489	8880-9330 mean: 9069	20	E	30	73	1 1/4

1/ Data reflects pre- and post-treatment conditions.
2/ The Beaver Head snow course is in the upper third of the watershed.
3/ The distances are between the SCS snow courses and the approximate center of the watershed.

The watersheds also reflect different land management histories. The Beaver Creek and Stermer Ridge watersheds were harvested by group selection prior to the early 1960's. Castle Creek West Fork was harvested by a combined patchcut on one-sixth of the area and selection harvest on the remaining five-sixths in 1965-1966. This harvest did not cause a major change in average snow accumulation. Castle Creek East Fork and Thomas Creek North Fork are both in virgin condition. Snow surveys on Thomas Creek South Fork reflect both virgin and, since 1978, treated conditions (patchcutting and selection method). It is too early to know if the treatment affected snow accumulation; therefore, the data were combined. Willow Creek was treated in 1972 by a combined selection method and overstory removal harvest. Overstory density varies from 135 square feet per acre to 32 square feet per acre, depending on treatment.

Study Methods

Field Procedures

All snow measurements were made with a Mt. Rose (or Federal) snow sampler. The common procedure is described in detail in Agriculture Handbook 169 (USDA Soil Conservation Service 1959). The typical SCS snow course contains about 10 permanent stakes, but courses vary from 5 to 14 stakes. Multiple samples are more accurate than point samples because of snow variability. Most Arizona snow courses are measured on or about January 15, February 1, February 15, March 1, March 15, and April 1, except in the most inaccessible locations where measurements are made on fewer dates, or during long snow seasons, when additional measurements are made.

The experimental watershed snow courses usually consist of several lines of sample points which run perpendicular to the main drainage (table 3). This design allows samples to be obtained from a variety of topographic and forest overstory sites. Two to four measurements are made at each point during each survey. Surveys were not made at set dates, but tended to follow major storms in an attempt to measure the peak seasonal accumulation which could be correlated with streamflow. Some surveys did not include all of the points or lines because of manpower or weather problems, and there were several (generally dry) winters when Watershed-15 and Castle Creek were not measured.

Table 3. Snow Course Characteristics of the Experimental Watersheds

Watershed	No. lines	No. points	Length of record (years)	Number of data pairs	Year begun
Beaver Creek Watershed-15	6	86	6	18	1968
Stermer Ridge	3	30	4	12	1973
Castle Creek West Fork	4	54	7	14	1964
Castle Creek East Fork	4	49	6	13	1964
Thomas Creek North Fork	6	62	7	30	1974
Thomas Creek South Fork	5	46	7	30	1974
Willow Creek East Fork[1/]	-	60	3	11	1978

[1/]The Willow Creek snow course consists of a series of loops which criss-cross the watershed.

Office Procedures

SCS-Watershed Comparison.--Snow water equivalent (in inches) and density (water equivalent ÷ depth) data for each date and watershed snow course were averaged. The differences between SCS and watershed averages were analyzed. Only measurement dates within 7 days of each other were considered. Analysis was by paired t-test and linear regression for the watershed comparisons.

Elevation-Water Equivalent Comparison.--In the analysis of the elevation-snow water equivalent relationships, linear and polynomial (curvilinear) regression ($Y = a + bX + cX^2$) procedures were initially applied to the long-term SCS records (USDA Soil Conservation Service 1975) (which vary from 7 to 37 years). The section of the polynomial curve within the range of our data was used. Separate regressions were developed for each of the six sampling dates. The linear model was dropped because the data showed significant curvilinearity (figure 2), reflecting the decreased occurrence of intermittent melting with increased elevation. Some lower elevation snow courses can become bare during the winter, while the highest courses do not have significant melting until spring. Coefficients of determination (r^2) for the curvilinear model ranged from 0.75 to 0.86. Part of the unexplained variation can be attributed to differences in storm track (some storms do not affect the entire state); aspect; surrounding topography, which can shelter or over-expose a course to storm affects; and adjacent forest stand conditions. Ffolliott et al. (1972) found that the spatial arrangement of forest cover (i.e., basal area) affects the distribution of peak seasonal accumulation of snow water equivalent. Water equivalent estimates were derived from each of the curves for the six sampling dates, using mean watershed elevation as the independent variable. Estimates and measured values were compared by paired t-test. For each date, only watershed mean values derived from at least three measurements were included. We could not compute 6 acceptable means for each of the four ponderosa pine watersheds; however, the 12 acceptable mean values were grouped for the t-test analysis.

The regressions developed by Cary and Beschta (1973) for each sampling date were also evaluated. These were of transformed linear regressions, where $Y = \log_{10}$ (water equivalent +1.0). Cary and Beschta based their equations on data from up to 22 SCS snow courses. The r^2 values ranged from 0.47 to 0.65, and all were significant at the 10% level.

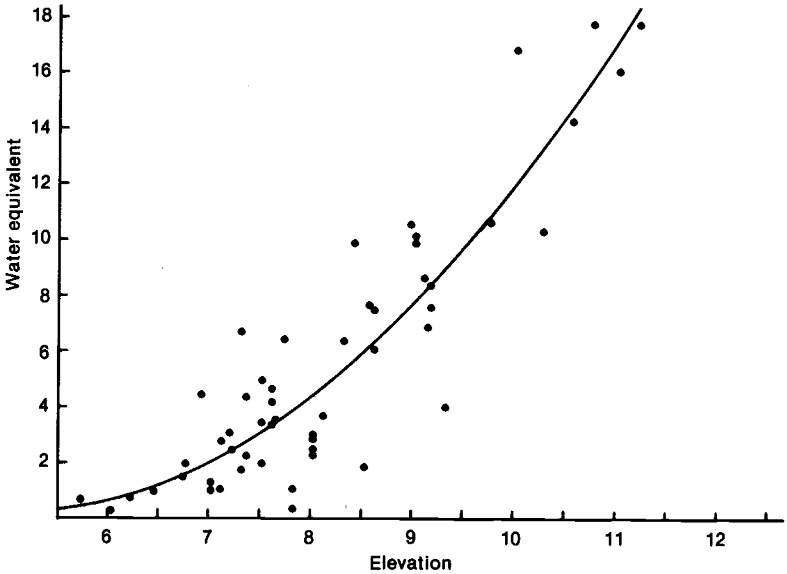

Figure 2. The polynomial relationship of elevation of SCS snow courses (in thousands of feet) vs. average water equivalent (through 1975, in inches) for the March 1 survey (r^2 = .82).

Estimates for each date were also made from linear regressions of SCS data (through 1980) from 11 stations selected by the authors, including the 4 used above, which represented a range of elevations or were located near the watersheds. The additional seven snow courses were: McNary (7,200 feet), Mormon Lake (7,350 feet), Happy Jack (7,630 feet), Coronado Trail (8,000 feet), Hawley Lake (8,300 feet), Cheese Springs (8,600 feet), and Fort Apache (9,160 feet). The use of selected stations reduced the data variation present in the complete record and was easier to manipulate. Covariance analysis indicated that the six "selected eleven" regressions were not significantly different from linear regressions derived from the entire SCS record.

Results and Discussion

SCS-Watershed Comparison

Snow water equivalent.--The first step in evaluating the relationship between the SCS and watershed snow measurements was to determine whether the data could be interchanged without modification. The paired t-test indicated highly significant differences (1% level) for the Heber-Stermer Ridge, Hannagan Meadows-Thomas Creek, and Willow Creek comparisons, and significant differences (5% level) for the Beaver Head-Castle Creek West Fork data, (although the latter average difference was only 0.4 inch). No significant differences were found for Beaver Head-Castle Creek East Fork and for the Newman Park-Beaver Creek Watershed-15 pairs. The results of the Beaver Head-Castle Creek East Fork pair are not surprising, since the SCS snow course is within the experimental watershed. The results of the Newman Park-Beaver Creek WS-15 pair may again reflect the fact that SCS snow courses tend to represent conditions at higher elevations. Beaver Creek WS-15 is generally at a higher elevation than Newman Park and receives equivalent moisture, even though they are separated by 9 miles. Other watersheds are at similar or lower elevations than the associated SCS courses. Distance and topography may have also had an influence, especially in the White Mountains with its numerous valleys and ridges. The terrain between Newman Park and Watershed-15 is relatively flat.

The data suggested linear regression analysis (figure 3). All regressions were highly significant; r^2 values ranged from 0.86 for Newman Park-Watershed-15 to 0.97 for Hannagan Meadows-Willow Creek East Fork. Standard errors of estimate ($s_{y.x}$) varied from 0.4 inch for the two Beaver Head-Castle Creek comparisons to 1.2 inches for the Hannagan Meadows-Thomas Creek South Fork comparison. Coefficients of variation ranged from 12 to 32%. The large Thomas Creek data base allowed us to develop regressions for the heavy snowfall years (i.e., 1979, 1980) and for the average-low snowfall years. These regressions were significantly different from each other. Significant regressions could be developed between the watersheds and more distant SCS snow courses; however, r^2 values decreased, e.g., the Thomas Creek North Fork r^2 is 0.89 when Hannagan Meadows is used and 0.74 when Fort Apache is used. The regressions indicate that data from SCS snow courses can be used to estimate average snow water equivalents on neighboring areas. These results could be of immediate practical help to researchers, because the regressions would allow them to consider abandoning some of the labor-intensive watershed courses and still obtain good estimates of snow conditions, provided the accuracy is satisfactory for the specific experimental objectives. Less accuracy would probably be required for normal management activities. However, this technique can only be used if paired sets of measurements are available for a sufficient number of years and range of snowfall conditions.

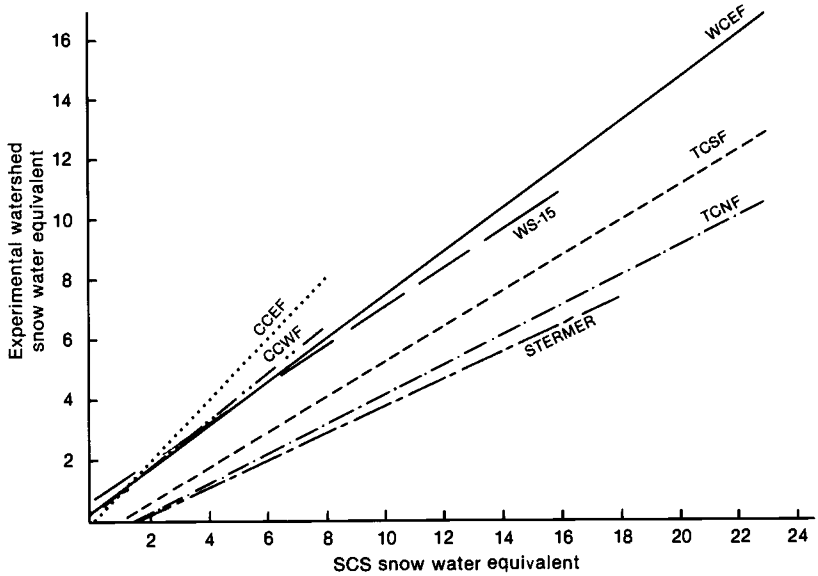

Figure 3. Significant regressions relating Soil Conservation Service survey and Forest Service experimental watershed snow water equivalents (in inches). CCEF = Castle Creek East Fork, CCWF = Castle Creek West Fork, WCEF = Willow Creek East Fork, WS-15 = Beaver Creek Watershed-15, TCSF = Thomas Creek South Fork, TCNF = Thomas Creek North Fork, Stermer = Stermer Ridge.

Snow Density.--Snow density is another important characteristic. Because snow density increases as the season progresses, it is used to evaluate snowpack condition relative to the onset of melt. The water equivalent at aerial markers is calculated by multiplying snow depth by the density recorded at a neighboring location. Snow densities from the SCS and watershed snow courses were compared to each other by linear regression. Data from the Castle Creek watersheds could be combined, as could those from the Thomas-Willow complex (figure 4). All regressions were significant, but r^2 values were below 0.50. The standard error of the estimate for Thomas-Willow was 0.04 gm/cm^3; this would result in a possible error of 0.5 inch, if a water equivalent were calculated for a 12-inch deep snowpack. This is comparable to the $s_{y.x}$ values for the water equivalent regressions. Density varies depending on exposure, aspect, topography, and canopy cover. Relatively low watershed snow densities could also result because measurements were keyed to periods immediately following storms, when density is lower while the SCS is scheduled by date giving the snowpack a chance to ripen. High relative snow watershed densities could reflect shallower snowpacks which could become denser and melt at an earlier date. Similar regressions could be used to estimate snow density, as long as the high degree of variability and lack of precision is recognized.

Elevation-Water Equivalent Comparison

None of the three (curvilinear, Cary-Beschta or selected eleven) regression models successfully estimated all watershed measurements. They all estimated the ponderosa pine mean water equivalent

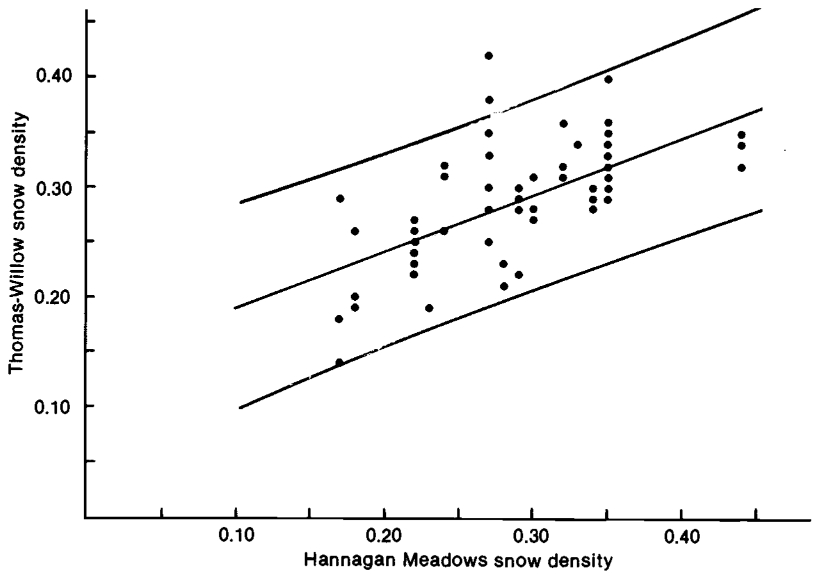

Figure 4. Comparison of snow density values for the SCS, Hannagan Meadows, and the Thomas-Willow Creek snow courses.

measurements well, with an average difference of 0.4 inch. However, none of the three estimated Willow Creek or Thomas Creek North Fork satisfactorily. Average differences were 1.1 inches and 2.3 inches, respectively. The curvilinear or selected eleven models, which are derived from statistically similar data, did not estimate either Thomas Creek watershed well. Estimates from the Cary-Beschta model compared well with Thomas Creek South Fork readings, with an average difference of 0.03 inch.

The Cary-Beschta regression model, although not consistent, appeared to give closer estimates than the curvilinear or selected eleven regressions. These two overestimated values for all watersheds, except for Beaver Creek. The consistent results in the ponderosa pine are probably caused by the large number of snow courses at or below 8,000 feet (ranging from 54% of the sample for the curvilinear to 77% for the Cary-Beschta regressions). The overestimations for the curvilinear model are indicative of the relatively large number of readings above 8,000 feet, while the tendency toward underestimation (e.g., of the Cary-Beschta regressions) reflects the reverse. Overestimates are, of course, also related to the fact that the relationship is based on data which generally tend to overestimate snow accumulations.

In view of Court's (1963) observations in California, we decided to solve the curvilinear equations for the six dates (because of its large data base) for elevations using the watershed measurements as the dependent variables. The subtraction of the calculated elevation from the actual elevation yielded the following differences (in feet):

Beaver Creek Watershed-15	- 819
Stermer Ridge	+ 98
Castle Creek West Fork	+ 747
Castle Creek East Fork	+ 535
Thomas Creek North Fork	+1039
Thomas Creek South Fork	+ 677
Willow Creek East Fork	+ 264

Except for Beaver Creek Watershed-15 and one date for Stermer Ridge, (which recorded more snow than expected), results consistently indicated that the measured watershed averages were characteristic of lower elevation sites. It appears that Arizona SCS snow courses represent snow conditions at sites which are on an average, (with standard error) 363 ± 229 feet higher in elevation. The average would be 560 ± 139 feet without Beaver Creek, Watershed-15. Rhea and Grant (1974) attempted to compensate for this deviation by relating water equivalent to an average elevation obtained from an area within a

1.5-mile radius circle around each snow course.

The curvilinear relationship, by definition, does not give a constant water equivalent increase per 1,000 feet increase in elevation. Average increases varied from 1.8 inches per 1,000 feet on January 15 to 4.6 inches per 1,000 feet on April 1. Court (1963) determined an average increase of 5.2 inches per 1,000 feet for the late March readings in Kings River Basin. A reason for the increasing rate with time is that in Arizona, low elevation sites (below 7,500 feet), often melt off completely between storms, while areas above 9,000 feet accumulate snow steadily with little or no melt. The relationship varies with type, frequency, and magnitude of storms.

Conclusion

Comparisons were made between Soil Conservation Service snow survey data and snow data from nearby Forest Service experimental watersheds to evaluate the use of the SCS data to describe local conditions. SCS snow courses are generally within forest openings which tend to collect more snow than the surrounding area. SCS data could not be used directly to describe watershed conditions, except when the snow course was within the watershed or when the watershed was at a higher elevation than the snow course. However, highly significant linear regression relationships could be developed from the paired data. These could be used to estimate snow water equivalents on the watersheds, and could, (depending on experimental requirements), allow researchers to reduce or eliminate intensive snow surveys. Similar relationships can be developed where a record of paired measurements exists. Linear regressions were also developed comparing snow density, but they contained a high degree of variability.

Paired data from SCS snow courses and from the local area are usually not available. Estimates from several elevation-average water equivalent relationships, which were developed from SCS data for each of the six measurement dates, were compared to the watershed values. All gave reasonable estimates for the ponderosa pine zone but were less satisfactory for the mixed conifer sites. The SCS courses tended to measure snow conditions which were more representative of sites an average of 363 feet higher in elevation. More research, coupled with an intensive review of existing information, could produce a generally useful relationship, possibly using multiple regression procedures, for estimating local snow conditions.

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