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Comparison of Areal Snow Storage Sampling Procedures for Rangeland Watersheds

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The accuracy of photogrammetry in determining snow depth in mountainous rangeland watersheds was evaluated on a 0.41-km^2 subbasin of the Reynolds Creek Experimental Watershed, located in the Owyhee Mountains of southwestern Idaho. Random checking of over 50 points indicated that at a photo scale of 1:6000, snow depths were determined with a standard error of ± 15 cm for a mean snow depth of 1.2 m. On the average, only 6% of the snow depths less than 15.2 cm were photogrammetrically determined to be negative, and these were generally during the late melt season. The lag time between photography and the usable result and the need for a field survey to set ground control for each flight relegates this technique to a research tool, rather than an operational forecasting tool. Preliminary evaluation of snow water content on the watershed showed the water content varied according to aspect and deep drift locations. The deep drifts usually had a 6% greater snow water content than the nondrift areas.

Simple random, random stratified and two systems of square grids orientated in different directions were tested to determine the best sampling system to determine mean areal snow depth for a watershed. The grid system orientated in the direction of the predominant wind required fewer samples to produce the same accuracy for the snow cover ranging from 100 to 17%.

Introduction

Accurately forecasting snowmelt runoff from mountainous watersheds is an economic necessity to efficiently operate reservoirs providing flood control, irrigation water, and hydroelectric power. Since most of the snowmelt runoff originates from mountainous watersheds that represent a small portion of the contributing land area, knowing the quantity and distribution of snow should greatly aid in improving reservoir management. The great variability of snow depths and melt rates in mountainous areas makes this information extremely difficult to obtain; therefore, most forecasting procedures are based on snow-depth measurements taken at snow courses. This method assumes a statistical relationship between snow water equivalent at the site and the volume of subsequent runoff. In mountainous areas of the West, falling snow is strongly influenced by wind interacting with local topography (Cox et al. 1975; Rawls and Jackson 1979) to produce an irregular areal distribution of snow; thus making index snow courses unreliable for representing the areal snowpack on rangeland watersheds.

Cooper (1965) investigated the use of photogrammetric techniques for determining snow depths and concluded that it is a practical means of accurately determining the volume of snow on rangeland areas. Also, aerial photography (Abal'yan et al. 1971) and satellite imagery (Ferguson and Lapczak 1977) have proven successful for determining areal extent of snow cover; however, these types of imagery cannot be used for determining snow depth (McGinnis et al. 1975).

Another approach to estimating an areal mean snow depth has been to stratify the area by topographic and land use characteristics and then determine representative snow depth and densities for each strata (Gray et al. 1978). Adams (1976), Steppuhn and Duck (1974) and Woo and Marsh (1978) have substantiated that this approach significantly improved the calculation of the areal mean snow depth. Also a grid square sampling technique for representing snow cover has been successfully applied (Dickison and Daugharty 1978). This technique has been popularized because it is adaptable to computer operations. Leaf and Kovner (1972) developed areal snowpack sampling requirements for forested subalpine watersheds based on watershed stratification by elevation. Airborne gamma surveys have proven to be effective in obtaining snow water equivalent in shallow snow packs (Peck and Bissel 1973). The literature is essentially void of techniques for sampling the areal snowpack of rangeland watersheds. Therefore, the purpose of this paper is to evaluate various sampling techniques for determining a mean areal snow depth and water content on mountainous rangeland watersheds.

Study Area

The study area is located within the Reynolds Creek Experimental Watershed in the Owyhee Mountains of southwestern Idaho, about 80 km southwest of Boise, Idaho (Fig. 1). The watershed, operated by the USDA–SEA–AR Northwest Watershed Research Center, ranges in elevation from 1,402 to 2,195 m and is covered with sagebrush rangeland, except for scattered stands of Douglas and

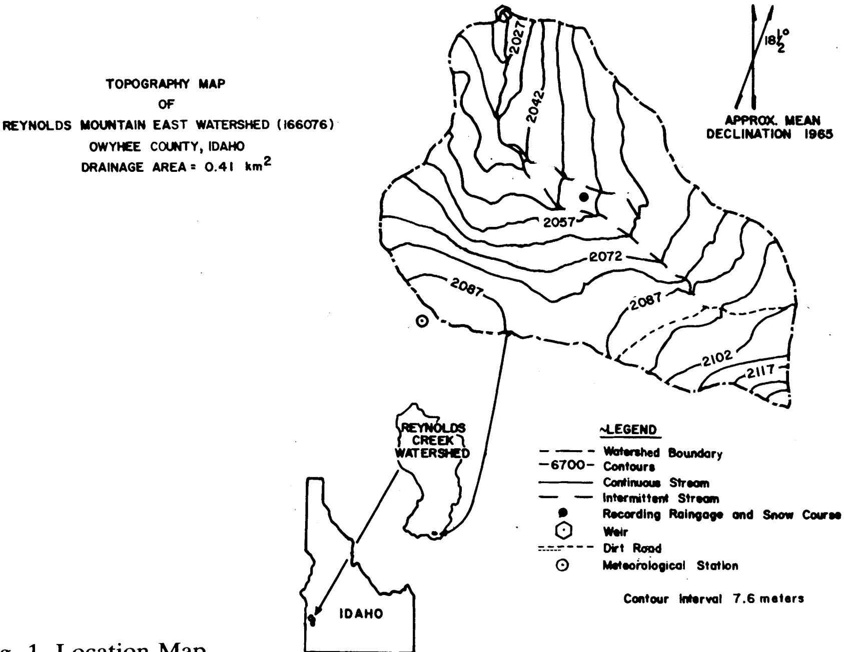

Fig. 1. Location Map.

alpine fir, juniper and aspen and meadows. The topography is characterized by north and northwest trending ridges with gently inclined windward slopes and steep north and east facing lee slopes. Annual precipitation ranges from about 25 cm at the lower elevations to 152 cm at the higher elevations. Most of the precipitation at the higher elevations comes in the form of snow with a predominately southwestern wind (Johnson and McAuthor 1973). This area is representative of large areas of southern Idaho, Oregon and Washington.

The Reynolds Mountain East Watershed located in the upper 2,012 to 2,134 m elevations of the Reynolds Creek Experimental Watershed (Fig. 1) was used for this study. This 0.41 km^2 watershed is primarily a sagebrush mountain meadow with a few scattered stands of scrub aspen, willow, and Douglas fir. The vegetation and topographic characteristics of the watershed are summarized in Table 1. The data base included photogrammetrically determined snow depths on a 7.6 m square grid system (6,776 points per date) for March 7, and April 14, 1966; March 17, and May 15, 1967; March 12, and 26, 1969, and April 30, and May 23, 1969. The snow depths were determined using the photogrammetric technique described by Cooper (1965). Snow cover and snow depths for these dates are summarized in Table 2.

The accuracy of the photogrammetric method was checked using snow depths determined by field sampling and by photogrammetry at 35 randomly selected stations (Fig. 3) for March 7, and April 4, 1966, and March 12, and 26, and April

Table 1 - Percentage of Reynolds Mountain East Watershed Area in Vegetation, Slope and Aspect Classes.

Vegetation Cover Classes (%)			
0-25	26-50	51-75	76-100
16	18	6	60

Slope Classes (%)				
0-10	11-20	21-30	31-40	41-50
13	48	21	16	2

Aspect Classes (°)			
0-90	91-180	181-270	271-360
32	4	11	53

Table 2 - Snow Depth Characteristics

	Percent Snow Cover			Mean Snow Depth (m)			Standard Deviation of Mean Snow Depth (m)			Maximum Snow Depth (m)	
Date	Total Watershed	Non-Drift[1] Area	Drift[1] Area	Total Watershed	Non-Drift Area	Drift Area	Total Watershed	Non-Drift Area	Drift Area	Non-Drift Area	Drift Area
May 23, 1969	17	5	77	1.20	0.38	1.47	0.98	0.38	0.97	2.19	4.60
April 30, 1969	58	50	100	1.25	0.77	2.45	1.05	0.48	1.12	3.93	5.36
March 26, 1969	98	99	100	1.56	1.17	3.48	1.16	0.67	1.17	4.60	5.79
March 12, 1969	100	100	100	1.60	1.20	3.58	1.17	0.65	1.16	4.85	5.88
May 15, 1967	86	83	100	1.00	0.80	1.85	0.69	0.47	0.79	3.51	5.82
March 7, 1967	94	95	100	1.19	0.94	2.39	0.78	0.50	0.79	2.59	4.51
April 4, 1966	81	77	100	0.67	0.48	1.38	0.52	0.32	0.55	2.04	3.32
March 17, 1966	100	100	100	0.92	0.78	1.63	0.53	0.39	0.54	2.29	3.60

[1]As identified in Figure 3

30, 1969. Regression analysis of these data indicated that snow depths could be determined photogrammetrically with standard error of ± 0.15 m over a range of depths from .03 to 1.8 m. The results of this analysis are graphically illustrated in Fig. 2. Also, we examined the problem of photogrammetrically determining negative snow depths for shallow snow conditions. For the dates studied, only 6% of the total number of snow depths less than 0.15 m were photogrammetrically determined negative. The accuracy of the photogrammetric method for determining snow depths resembled that determined by Cooper (1965); thus further verifying that photogrammetry can be an accurate and useful tool for determining snow depths. However, because of the lag time between photography and the usable result and the need for a field survey to set ground control for each flight (Cooper 1965), this method is a research tool rather than an operational forecasting tool.

Analysis

Snow Density Stratification

Data for the 1967 and 1969 dates (except for May 23, 1969, when no water content data were collected) were used to determine how snow density varied over the watershed. For each date, 16 or 35 of the points shown in Fig. 3 were sampled. The average snow density for the five dates was 39% with a standard deviation of 5% and range between 21 and 56%. Because of the snowpack distribution, the mean snow density will not give a good indication of the distribution or total snow water. Thus, we decided to examine whether stratification of the watershed on the basis of snow density would be an improvement. The sample size eliminated the use of pattern-recognition techniques (Duda and Hart 1973) to determine snow density stratification; however, examination of the data indicated a difference in snow density with aspect – the east or west side of the stream. This corresponds to the deep and shallow snowpack, as illustrated in Fig. 3 (Rawls and Jackson 1979). Dividing the snow density with respect to location (east or the west side of the stream) produced a mean snow density for each area that differed significantly at the 5% level, using the F statistic for all dates, except May 15, 1967. The mean snow density for the west zone for all dates was 42% with an average standard deviation of 4% and the mean snow density for the east zone was 36% with an average standard deviation of 4%. Each zone had from 6 to 22 samples per date. This analysis indicated that snow density in rangeland watersheds can be divided with respect to aspect and general snow depths. Therefore, stratification is essential since most of the snow water is located in drifts on a small portion of the watershed.

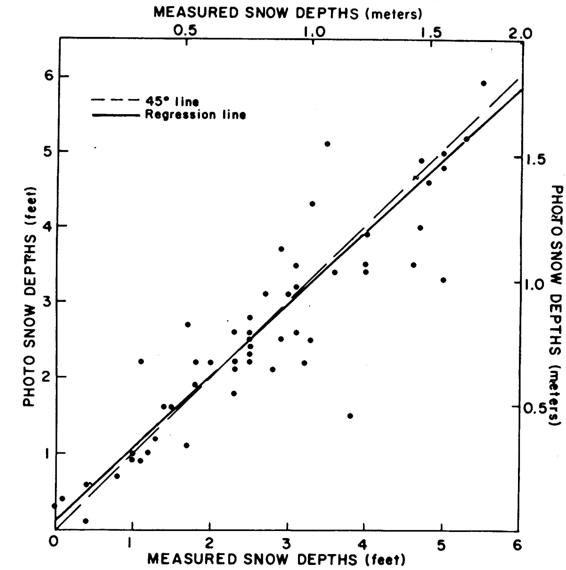

Fig. 2. Comparison of Photogrametric and Measured Snow Depths for March 7, April 4, 1966 and March 12, March 26 and April 30, 1969.

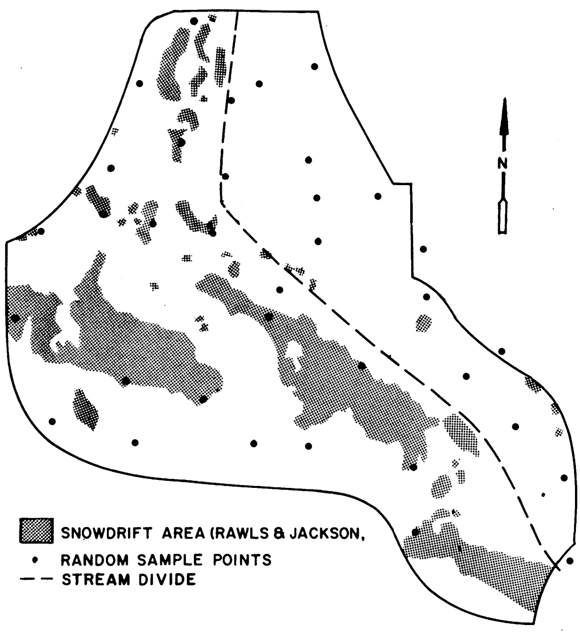

Fig. 3. Snow depth stratification and random snow water content sample points.

Sampling Methods to Determine Mean Areal Snow Depth

Four methods of sampling mean watershed snow depth, including simple random, random stratified, and two grid systems orientated in different directions, were investigated to determine a sample size-error relationship.

The two grid systems studied were (1) the base 7.6 m square grid system (6776 points) of snow depths orientated with rows perpendicular to the north-south transect and (2) a 10.8 m square grid system orientated with rows perpendicular to the northeast-southwest transect. The northeast-southwest grid was contained in the base grid system and was orientated so that the columns were perpendicular to the predominant wind direction (Johnson and McAuthor 1973; Rawls and Jackson, 1979). To determine the sample size-error relationship, we first determined the mean areal snow depth for different grid sizes in multiples of 7.6 m or 10.8 m. For each grid size, there are a number of different combinations of the sample points to determine the mean snow depth for the watershed for a particular grid size. The number of combinations increases according to the square of the grid size divided by the base grid size 7.6 m or 10.8 m. For example, the 15.2 m grid size will have four $((15.2/7.6)^2)$ combinations. In developing the mean areal snow depth, only grid points which had snow were used. Assuming that the base 7.6 m grid accurately represented the true areal mean snow depth, we determined a standard error of estimate for each grid size for each of the eight dates.

Simple random and stratified random sampling were also investigated for sampling mean areal snow depth. Using the chi square standard, we determined that the snow depths for the total watershed and for each strata were normally distributed (0.005 significance level) and the normal sampling statistics could be used with confidence.

Simple random sampling leaves the selection of the sample entirely to chance and each member has an equal chance of being chosen. The standard error of the mean of a simple random sample of size n is

$$S_y = \frac{S}{\sqrt{n}} \left(1 - \frac{n}{N}\right) \qquad (1)$$

where $(S/\sqrt{n})$ is the standard error of a sample mean and $(1\text{-}n/N)$ is the finite population correction with N equal to the total sample size. In practical applications, the finite population correction is near 1 and can be omitted when n/N is less than 0.1 (Cochran 1953). For this study, the finite population correction factor was omitted.

For the stratified sampling, we used the two strata scheme developed by Rawls and Jackson (1979) that separated drift and nondrift areas in the watershed, as shown in Fig. 3. Instead of using proportional sampling (where the proportion of samples is the same for each stratum), we used an optimum allocation where the number of samples from each strata, n_i, is proportional to $N_i S_i / C_i$. Where N_i is the maximum number of samples in the stratum or samples that could be drawn from the stratum; S_i is the standard deviation of the mean snow depth for all the samples in the stratum, and C_i is the cost of taking a sample.

Assuming that the cost of sampling is the same for each stratum, n_i should be proportional to N_iS_i. For this study, we assumed the cost of sampling for the different strata was the same. However, if field sampling was performed the drift area would be more expensive than the nondrift area.

Using the snow depth statistics given in Table 2, we determined how the total number of samples should be divided between the two stratum for optimum allocation. This analysis indicated that for March 17, and April 4, 1966; March 7, and May 15, 1967 and March 12, 26, 1969, when snow cover ranged from 81 to 100%, 75% of the samples were in nondrift areas and 25% of the samples were in the drift areas. For the April 30, 1969, when there was 58% snow cover, 69% of the samples were in nondrift area and 31% were in the drift areas. Whereas for May 23, 1969 when there was 17% snow cover, 35% of the samples were in the nondrift areas and 65% were in the drift areas. The optimum allocation of samples between strata was about equal to the ratio of snow cover area in each strata to the total watershed snow cover (Table 2).

We grouped the data into four snow cover classes with that for March 17, 1966; March 7, 1967; and March 12, and 26, 1969 being in the 100% snow cover class. Snow cover for April 4, 1966 and May 15, 1967 were in the 84% class; that for April 30, 1969 was in the 58% class; and that for May 23, 1969 was in the 17% class. We averaged the results for the dates in the class for the 100 and 84% snow cover classes.

For all eight dates, we calculated the number of data points needed to obtain a 10.5 and 2.5% standard error of estimate of the mean areal snow depth (S') for the four sampling methods. These were based on the assumption of a normal probability distribution, the standard error of estimate of a single sample, s, and the following equation

$$n \equiv \frac{S}{S^{\prime}} \tag{2}$$

The results for the different cover classes is given in Figs. 4 to 7.

Comparing Figs. 4 to 7 for the various cover classes indicated that as the amount of snow cover decreased the number of sample points needed to obtain the same accuracy increased for the four sampling methods. The variability between the sampling methods also increased as the amount of snow cover decreased.

The simple random sampling method at a 10% standard error for all cover classes required essentially the same number of sample as the other methods; however, for the 5 and 2.5% standard error of estimate considerably more samples were required, especially for the 2.5% standard error of estimate. Random stratified sampling showed a similar error pattern but to a much lesser degree of variation. Both grid methods of sampling required essentially the same number of

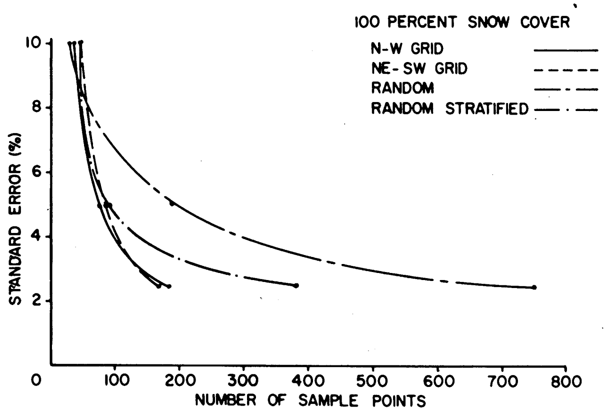

Fig. 4. Standard error vs number of sample points for 100% snow cover.

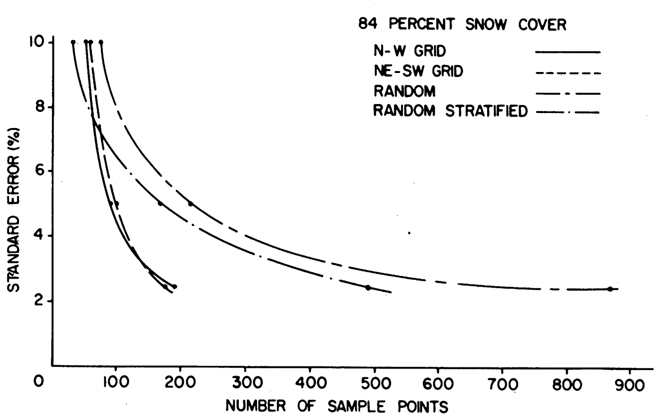

Fig. 5. Standard error vs number of sample points for 84% snow cover.

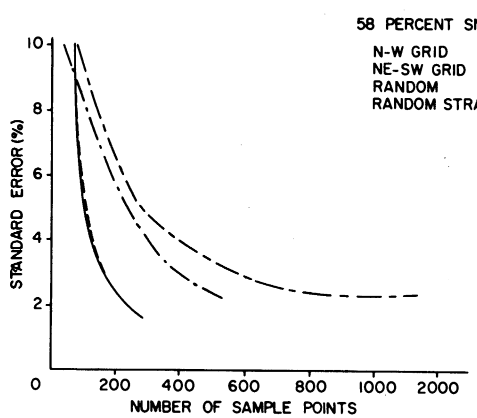

Fig. 6. Standard error vs number of sample points for 58% snow cover.

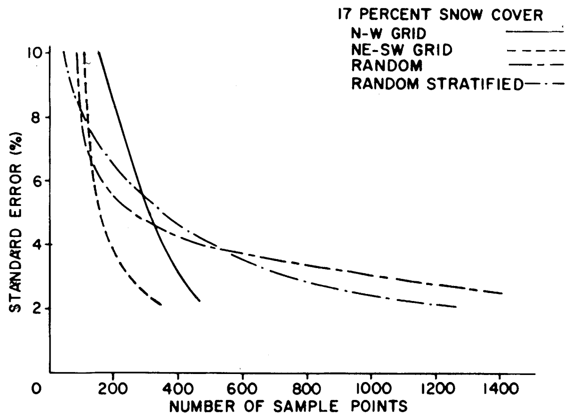

Fig. 7. Standard error vs number of sample points for 17% snow cover.

samples to produce the same accuracy for all snow cover classes, except at 17% snow cover where the northeast-southwest grid method required considerably fewer samples than did the north-south grid method. Also, about the same number of samples were required for the two grid systems to obtain the same accuracy for snow cover classes of 100 and 84%. The northeast-southwest grid system required about the same number of samples to obtain the same accuracy for snow cover classes of 59 and 17%.

Conclusion

Photogrammetric techniques to determine snow depth were tested and proved to be capable of measuring snow depths with a ± 0.15 m standard error of estimate for a mean depth of 1.2 m. The lag time between photography and the usable result and the need for a field survey to set ground control for each flight makes the technique a research tool, rather than an operational one. For the rangeland watershed studied, the snow water content could be stratified according to aspect and snow depth with the snowdrift areas having on the average a 6% greater density than the nondrift area. Four methods of sampling, including simple random, random stratified and two grid methods orientated in different directions were investigated. For a 10% standard error of estimate, all methods required essentially the same number of samples; however, for higher accuracy levels (lower standard error of estimate), the northeast-southwest grid system (set up perpendicular to the direction of the predominant wind) was superior for all cover classes. As the total watershed snow cover decreased, more samples were needed to produce the same level of accuracy.

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