AREAL WATER EQUIVALENTS FOR PRAIRIE SNOWCOVERS BY CENTRALIZED SAMPLING 614-76

By

H. Steppuhn 1/

Introduction

Snow water forms an important economic component of prairie agriculture. Yields from dryland crops, such as barley, wheat, flax, and forage, relate closely to the available soil water. Melt waters from snow provide a major portion of the annual soil water reserve. Snowmelt also contributes substantially to farm ponds and reservoirs. These facts coupled with the flood threat posed by a rapid snowmelt call for accurate quantifications of prairie snowcovers. No hydrologic model can successfully predict snowmelt volumes without accurate knowledge of the mean water equivalent covering the landscape of interest.

Operationally, no snowcover can be adequately measured without implementation of a sampling scheme. This is equally true for any remote sensing technique. The objective of this paper is to describe a short-cut method for sampling prairie snowcovers to obtain areal mean water equivalents.

The Prairie Snowcover

The snowcovers suggested for sampling by the centralized technique occur over the Great Plains (called the Prairies, in Canada) of North America from Kansas to Alberta. Areal distributions of snowcovers in this region are highly variable and depend on snowfall patterns, redistribution by wind, and differential rates of melt. Prairie snows usually originate from eastward-moving cyclonic storms which vary in duration and magnitude from a three-hour cloud cover to a three-day blizzard. These storms are often followed by periods of snowmelt which differ in length and intensity depending on location and time-of-year. Thus, except for localized accumulations, prairie snowcovers over most agricultural fields are characteristically shallow, but variable.

Centralized Sampling

The greatest source of error in estimating areal mean water equivalents stems from the very extensive areas over which rather limited sampling must extend. If one assumes that each snow core measurement accurately describes the absolute water equivalent covering the immediate one square meter of land, a sample of 100 observations over 1000 km^2 results in a sample density of

$$\frac{100\ m^2}{1000\ km^2} = \frac{1}{10{,}000{,}000}$$

Aerial measurement by sensing the snowcover attenuation of terrestrial gamma radiation may ease sampling, but will not eliminate it. If for the same cost aerial surveys increased sample coverage from 100 m^2 to 10 km^2, sampling density would still equal only 1%. In a cooperative project, the U. S. National Weather Service performed aerial gamma surveys of the 1975 snowcover over the Souris River Basin (16,900 Mi^2) in North Dakota and Saskatchewan (Larson, 1975). They flew 23 lines totalling 250 miles using a 1500-foot sensing width, which resulted in 70 Mi^2 of sampled area and a sampling density of

$$\frac{71\ Mi^2}{16{,}900\ Mi^2} \quad \text{or } 0.42\%.$$

Centralized sampling reduces sample size, but retains sampling accuracy and the mechanics required to quantify this accuracy. The method offers a short-cut for determining areal mean water equivalents by (1) exploiting the close relationship between rural landscapes and snow distribution, (2) separating sampling for snow depth from sampling for vertical density, and (3) sampling for density selectively based on a central depth statistic.

1/ Research Hydrologist, Division of Hydrology, University of Saskatchewan, Saskatoon, Saskatchewan.

Stratification by Landscapes A number of investigators have suggested that prairie snowcovers are distributed in relation to terrain and vegetation (Kuz'min, 1960; McKay, 1963; Lakshman, 1973). Steppuhn and Dyck (1974) capitalized on this dependency in a stratified sampling scheme based on landscape units classed by terrain and land use. Each survey was confined to a single climatic region where snowfall amounts were relatively uniform. Each unit was composed of scattered parcels of land, featuring similar landscape and ranging in area from 3 to 600 hectares. Their method sampled only those parcels suggested by an estimated variance and an error tolerance chosen for each landscape type. Mean snowcover estimates and their errors were determined for each landscape unit and totalled by weighted-area to obtain areal mean values.

The merits of landscape stratification for sampling prairie snowcovers were again verified in 1974. Coefficients of variation for snow depth by landscape type, obtained from a comprehensive survey in Saskatchewan and outlined in Table 1, show significant reduction compared to the coefficient resulting from non-stratified sampling. Clearly, stratification will reduce sample numbers and consequently is retained in the centralized sampling outlined here.

Separation of Snowcover Variables The snow water equivalent at any location is the product of depth, d, and the vertically-integrated density, ρ. If this relationship is extended to mean areal values, a term for possible covariance must be added,

$$\bar{w} = \bar{\rho}\ \bar{d} + (\text{cov}).$$

Under the assumption of linear covariance, $\bar{w}$ and its associated sampling error, $s_{\bar{w}}$, can be evaluated by

$$\bar{w} = \bar{\rho}\ \bar{d} + r_{\rho d}\ s_{\rho}\ s_{d} \qquad \text{and}$$

$$s_{\bar{w}} = (\ \bar{\rho}^2\ s_{\bar{d}}^{\,2} + \bar{d}^2\ s_{\bar{\rho}}^{\,2} + s_{\bar{\rho}}^{\,2}\ s_{\bar{d}}^{\,2} + s_r^{\,2})^{0.5}$$

where $r_{\rho d}$ is the correlation coefficient between depth and density,

$s_r^{\,2}$ is the variance associated with the regression,

s_{ρ} and $s_{\bar{\rho}}$ are standard deviation and error for density, and

s_d and $s_{\bar{d}}$ are standard deviation and sampling error for depth.

The covariance between depth and density in shallow prairie snowcover is usually negligible. Snowcover measurements in Saskatchewan by Lakshman (1973) and others, including our own, indicate little covariance for snow depths up to 75 cm $\pm$ 10 cm and a slightly positive correlation between 85 and 110 cm.

Sampling separation provides significant advantage. Working in Ontario, Dickinson and Whitely (1972) were among many who have observed consistently less sample variability for density than for depth. This observation led to the conclusion that statistically-valid water equivalents can be derived from separate sampling where depth measurements outnumber those for density four-fold or more.

Central Depth Statistic The number of density determinations can be further reduced by sampling under the guidance of a central depth. Figure 1 is a plot of snowcover water equivalent as a function of depth. Data were obtained from a Saskatchewan Snow survey covering a 200-hectare land unit in undulating terrain and grain stubble cover. If the relation, $w = \rho d$, applies to these data, and if the variables were sampled randomly, their best functional fit would be a straight line of the form $\hat{w} = b\ \hat{d} + a$, where $b = \bar{\rho}$ and $a = 0$. A comparison of the best fit and the zero-thru-mean fit in Figure 1 shows close agreement, indicating that mean density, $\bar{\rho}$, does equal $\hat{w}/\hat{d}$ at any point along a line constructed through the origin and $(\bar{d}, \bar{w})$.

Table 1. Snow Cover Depth Statistics by Landscape Type, 1974, Bad Lake, Saskatchewan

Landscape Type	No. Obs.	Mean Depth	Coeff. of Variation	Landscape Type	No. Obs.	Mean Depth	Coeff. of Variation
		(cm)				(cm)	
Plain				Sharp Slope			
Fallow	360	41.5	.155	Pasture	400	111.5	.199
Stubble	216	46.4	.133	Scrub	869	126.5	.239
Rolling Plain				Broad Lowland			
Fallow	668	49.4	.151	Fallow	395	101.1	.188
Stubble	180	58.8	.083	Stubble	435	95.2	.084
Pasture	578	56.2	.174	Pasture	219	97.0	.114
Gradual Slope				Scrub	537	112.3	.183
Fallow	324	50.4	.202	Topland			
Stubble	180	47.4	.147	Fallow	507	22.9	.277
Scrub	183	65.6	.240	Stubble	218	37.6	.136
				Pasture	181	21.2	.434
Slough							
Fallow	180	46.1	.110	Farm Yard	72	129.1	.182
Stubble	108	46.6	.139				
			All Types Non-stratified			68.1	.502

Fifty-eight pairs of data were plotted in Figure 1, which in conventional sampling would result in 58 density values for the determination of an areal mean. The variability in these data suggests a short-cut method with a reduced sample size. Viewed collectively over all depths, the 58 water equivalents span a 7.0 cm range from 2.3 to 9.3 cm (Figure 2). If, however, one views only those data plotted at a specific depth, say at the mean depth (nine points), a narrower distribution occurs and equivalents range only 3.2 cm. Thus, by restricting density sampling to some central depth, the mean in this case, sample size was reduced 9/58 or 1/6.4, but the areal mean density increased only 2.1% from 0.221 to 0.226, and standard deviation changed slightly from 0.041 to 0.046.

The validity of centralized sampling rests on three main assumptions, namely (1) that measurement errors are small relative to errors due to sampling, (2) that the frequency function for water equivalents about the parametric regression line at the central depth is congruent with the function for all depths collectively, and (3) that snow depths over the area under survey are adequately and representatively sampled.

Application

If centralized sampling is truly a short-cut to determining areal water equivalents, estimates using the method should compare favorably with those obtained by comprehensive sampling. Consequently, snowcover measurements from 23 units and parcels, 5 to 250 hectares in area, were compared by the two methods. The units represented 16 landscape types which form most of those prairie lands supporting snowcovers less than one meter thick. Data included measurements taken in 1972 through 1975. Four mean areal densities and their standard deviations were determined for each unit: one from the comprehensive sample and three from samples chosen at central depths near (1) the arithmetic mean, (2) the mode or the most frequently occurring depth, and (3) the median or mid-depth in its ascending array.

Areal mean densities derived from the four samples within each of the 23 units are presented in Table 2. A summary of these comparisons reveals:

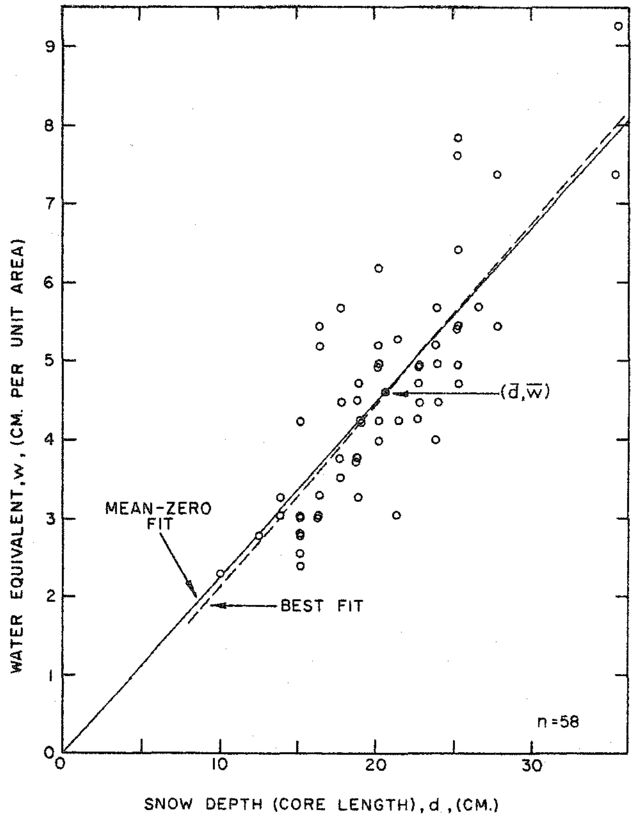

Figure 1. Snow water equivalents obtained by core sampling and plotted as a function of depth, 1975, Undulating plain, grain stubble, Bad Lake Basin, Saskatchewan
Best fit equation: $\hat{w} = 0.23\,\hat{d} - 0.23$
Standard error: 0.85 cm $r^2 = 0.65$

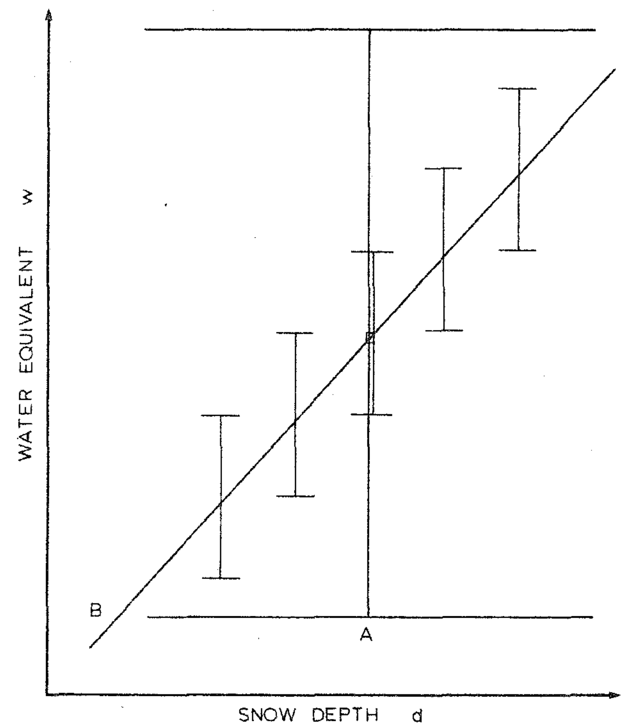

Figure 2. Comparitive ranges in water equivalents (A) for all depths and (B) for selected depths along the regression

Table 2. Areal mean snowcover densities for various landscapes in Saskatchewan by comprehensive and centralized sampling

Landscape	Year	Comprehensive sampling			Centralized depth sampling														
					Mean					Mode					Median				
		No. Obs.	Mean density	Std. dev.	Mean density	% Dev.	Std. dev.	No. Obs.	Reduction	Mean density	% Dev.	Std. dev.	No. Obs.	Reduction	Mean density	% Dev.	Std. dev.	No. Obs.	Reduction
Pasture Plain	1972	39	.168	.066	.160	-4.8	.071	5	1/7.8	.170	1.2	.040	6	1/6.5	.170	1.2	.040	6	1/6.5
Pasture Topland	1972	88	.163	.061	.172	4.6	.082	13	6.8	.154	-5.5	.049	10	8.8	.154	-5.5	.049	10	8.8
Fallow Plain	1973	54	.260	.042	.261	0.3	.020	7	7.7	.265	2.0	.042	7	7.7	.246	-5.5	.026	10	5.4
Hayfield Topland	1973	59	.207	.027	.210	1.5	.021	10	5.9	.213	2.8	.022	11	5.4	.211	1.9	.024	10	5.9
Stubble Plain	1973	50	.240	.028	.230	-4.2	.038	6	8.3	.232	-3.2	.036	7	7.1	.241	0.2	.033	10	5.0
Fallow Plain	1974	55	.236	.047	.225	-4.7	.043	11	5.0	.223	-5.5	.050	8	6.9	.227	-3.8	.047	10	5.5
Stubble Plain	1974	36	.233	.040	.219	-5.9	.059	7	5.1	.245	5.2	.037	7	5.1	.221	-5.2	.065	6	6.0
Fallow Und-lating plain	1974	38	.259	.038	.258	-0.3	.036	7	5.4	.261	0.8	.043	5	7.6	.259	-0.2	.035	7	5.4
Stubble Undulating plain	1974	29	.245	.034	.234	-4.5	.029	5	5.8	.242	-1.3	.039	6	4.8	.228	-6.8	.027	6	4.8
Fallow Gradual slope	1974	34	.251	.040	.240	-4.5	.029	5	5.7	.240	-4.5	.029	5	5.7	.240	-4.5	.029	6	5.7
Fallow Topland	1974	45	.281	.061	.291	3.5	.086	8	5.6	.265	-5.8	.047	8	5.6	.296	5.2	.081	9	5.0
Stubble Topland	1974	36	.242	.035	.247	1.9	.020	7	5.1	.246	1.6	.020	4	9.0	.237	-2.2	.037	7	5.1
Pasture Undulating plain	1974	61	.248	.047	.238	-4.2	.022	11	5.6	.241	-2.9	.074	11	5.6	.254	2.4	.045	10	6.1
Pasture Topland	1974	17	.234	.062	.226	-3.3	.070	3	5.7	.228	-2.6	.024	2	8.5	.226	-3.3	.070	3	5.7
Pasture Gradual slope	1974	38	.266	.043	.279	4.9	.022	5	7.6	.262	-1.6	.039	6	6.3	.279	4.9	.022	5	7.6
Stubble Broad lowland	1974	31	.254	.042	.247	-2.8	.046	6	5.2	.239	-3.3	.030	6	5.2	.224	-11.8	.023	5	6.2
Pasture Broad lowland	1974	28	.271	.041	.264	-2.6	.021	5	5.6	.272	0.4	.014	5	5.6	.264	-2.6	.021	5	5.6
Stubble Plain	1974	60	.254	.028	.259	2.1	.030	10	6.0	.250	-1.5	.050	7	8.6	.259	2.0	.025	11	5.4
Fallow lowland plain	1974	35	.262	.037	.258	-1.5	.028	6	5.9	.250	4.6	.024	6	5.8	.246	-6.0	.025	5	7.0
Stubble Lowland plain	1974	27	.242	.030	.234	-3.4	.022	5	5.4	.255	5.5	.036	4	6.8	.238	-1.5	.028	5	5.4
Stubble Plain	1975	52	.205	.040	.213	3.9	.033	9	5.8	.213	3.9	.033	9	5.8	.196	-4.4	.030	10	5.2
Fallow Undulating plain	1975	37	.297	.050	.284	-4.3	.050	7	5.3	.298	0.3	.060	5	7.4	.278	-6.3	.038	7	5.3
Stubble Undulating plain	1975	58	.221	.041	.226	2.1	.046	9	6.4	.213	-3.6	.026	7	8.3	.242	9.4	.038	6	9.7
Averages for the 23 Landscapes						±3.3%	-10.1%		1/6.0		±3.1%	-9.6%		1/6.7		±4.8%	-12.5%		1/5.9

Central depth statistic	% deviation of the central density from the comprehensive value		Average sample reduction	Ave. decrease in standard deviation for density
	Average for 23 units	Maximum for 23 units		
mean	3.29%	5.89%	1/6.03	10.1%
mode	3.13	5.84	1/6.70	9.6
median	4.82	11.81	1/5.89	12.5

Conclusions

Centralized sampling offers an efficient short-cut for determing mean, error-qualified, areal water equivalents in prairie snowcovers less than one meter in depth. The snow covering any land parcel of interest is initially surveyed for depth, and assigned a chosen or field-computed central depth. A density survey follows, which samples only those locations dictated by the central value. Variations are also possible. The surveyor may base his central depth on the mode from a rapid, 12-point vanguard depth reconnaissance which is immediately followed by the main survey.

Any depth can be chosen to guide the density survey. However, choosing a central depth near the center of the w/d regression eases field work, because these depths occur more frequently. If, as in some snowcovers, density is not independent of depth, the valid central statistic will be limited to the mean depth.

Centralized sampling may also find utility in research. The method features a reduction in field effort with little sacrifice in accuracy, or an increase in accuracy with the same sample size. Experiments involving plot comparisons would realize particular benefit. The method has already been used by the author to compare snowcovers under various agricultural treatments.

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LITERATURE CITED

Dickinson, W. T. and H. R. Whitely, 1972. A sampling scheme for shallow snowpacks. I.A.H.S. Bull. Vol. 17, No. 3, pp. 247-258.

Kuz'min, P. O., 1960. Snowcover and snow reserves. Gidrometoerologicheskoe Izdatelsko, Leningrad. Translation U. S. National Science Foundation, Washington, D. C., 1963. pp. 99-105.

Lakshman, G., 1973. Drainage basin study. Progress Report No. 8, E73-6, Saskatchewan Research Council, Saskatoon, Saskatchewan, 18p.

Larson, L. L., 1975. An application of the aerial gamma monitoring techniques for measuring snow cover water equivalents on the Great Plains. Proc. of Symposium on Snow Management on the Great Plains. Research Committee, Great Plains Agricultural Council, Pub., No. 73, Univ. of Nebraska, Agricultural Experiment Station, Lincoln, Nebraska.

McKay, G. A., 1963. Relationships between snow survey and climatological measurements, I.A.S.H. Pub. No. 63, IUGG Assembly, Berkeley, Calif. pp. 214-227.

Steppuhn, H. and G. E. Dyck, 1974. Estimating true basin snowcover. Proceedings of Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources. U. S. National Academy of Sciences, Washington, D. C. pp. 314-324.