ESTIMATING TRUE BASIN SNOWCOVER

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ABSTRACT

Hydrologic studies often require accurate estimates of the mean depth, density and water-equivalent of the snowcover on a basin. Measurements in Canada indicate consistent similarities in the areal variations of snowcovers within areal units having similar landscape features. Forests, pastures, cultivated fields, ponds, etc., within the same climatic region tend to accumulate snow according to recurring patterns unique to specific terrain and land use.

Snow samples collected within similar areal units usually exhibit similar frequency distributions. These results, combined with the observation that snowcover variance for density is consistently lower than for depth, form the base for a ready, but statistically valid, method of estimating true snow water-equivalents. The method is operationally orientated and features flexibility depending on data requirement, funding and desired level of confidence.

VARIABLES AND VARIABILITY

Hydrologic studies often require knowledge of mean depth, density, and water equivalent of the snowcover on a basin. Since snowcover is an areal phenomenon and basin areas are rather extensive, all measures of absolute, or true, snowcover are estimates derived from areally-distributed snow surveys. Valid use of these estimates require concurrent measures of associated confidences. The degree of confidence depends directly on the number of observations per sample and inversely on the inherent variability of each snowcover variable.

Areal variability occurs over three geographic fields; (I) regional, (II) local, and (III) micro.

(I) Regional variability reflects climatic differences in precipitation, radiation, air temperature, etc. Regions with similar climate measure from 1 to 1,000,000 km^2 depending on latitude, elevation, orographic influences, and proxcimity to large lakes and seas. Burns (1973) outlined climatic regions for Northwestern Canada (Figure 1). A 1972 snow survey (Steppuhn, et al.), covering the Mackenzie Valley portion of Northwest Canada, showed a definite correspondence between climatic regions and large-scale snowcover patterns.

(II) Snowcover variability over local, within-region fields, stem from numerous influences and are often observed and reported. Anderson (1967) and others, working in forested mountains, have related snow accumulation to local terrain variables of elevation, slope, and aspect and to forest variables of canopy density, tree species, tree heights, and forest openings. MacKay (1963) and Kuz'min (1960) emphasized the interaction of terrain and wind in establishing snowcover patterns over prairie. Snowcover variances caused by locally-induced differences in melt rates are common. · Co-operative snow investigators (1956) listed influences causing local differences in melt rates, including hillslope aspect and forest cover. West (1961) added cold air drainage as a factor of snowmelt, and Zotikov and Moiseeva (1972) considered differential melt caused by soil on snow. Natural events, such as avalanches,

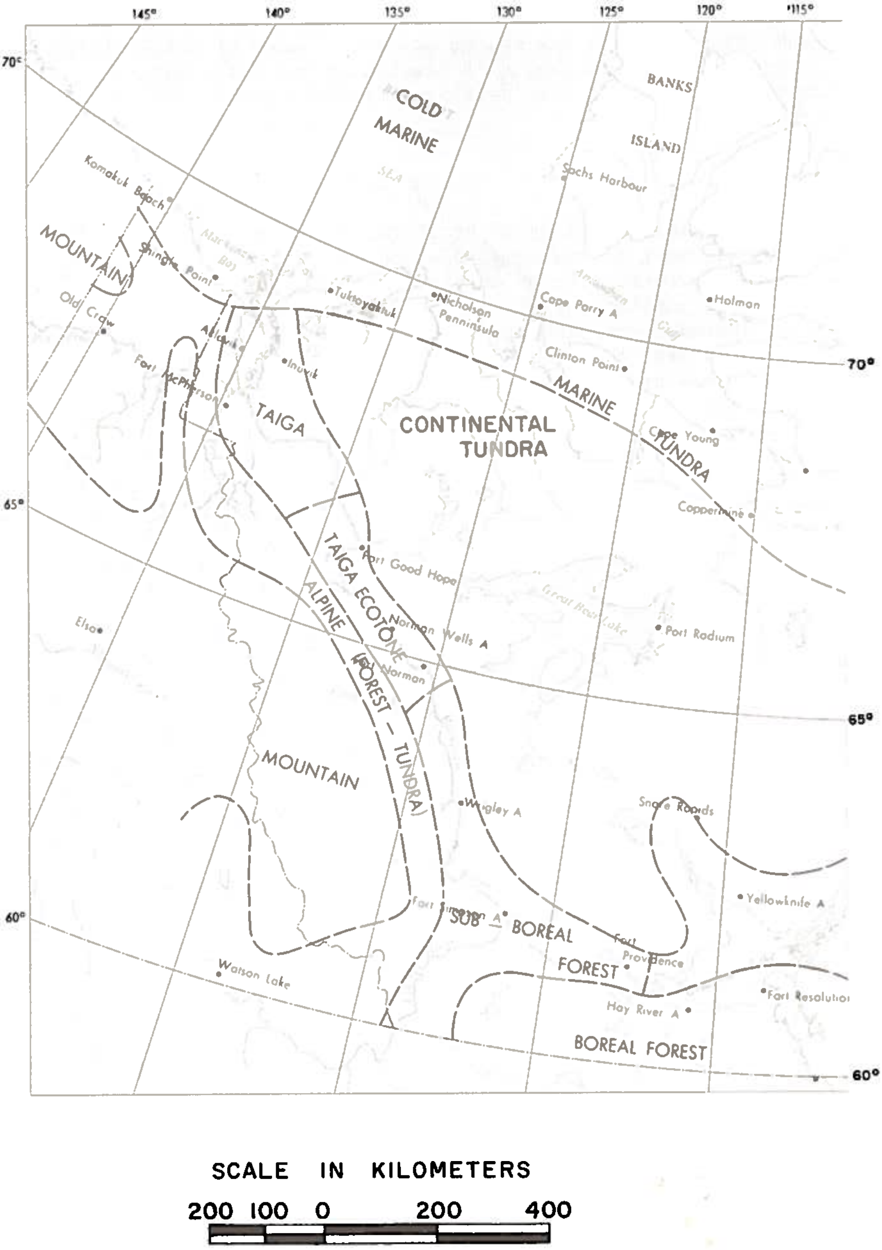

Figure 1. Climatic Regions of Northwest Canada (Burns, 1973)

also alter local snowcover patterns. Lakshman (1973), for one, found distinct relations between snowcover and agricultural land use, while Meiman (1968) concluded from his literature review that forest management practices usually, but not always, affect snow accumulation.

(III) Micro scale variability in snowcover refer to differences which occur within a few square meters. Causes of these differences include: surface roughness of vegetation and soil; internal alterations, such as depth hoar development; processes related to transport, such as dune deposition.

SAMPLING

Statistical sampling is predicted on two major requirements; samples (1) must be randomly selected and (2) must include a complete, accurate representation of population variability. When an areally-distributed population is sampled, the random requirement is satisfied (1) by systematically sampling the population which is assumed randomly distributed over the area, or (2) by completely randomizing the selection of those areal units to be sampled, or (3) by some combination of (1) and (2).

Applied to basin snow surveys, neither random selection nor complete coverage is easily assured. If we accept research results linking snow accumulation to terrain, vegetation, and land use, the assumption of an areally random snowcover is invalid; landscape distributions are not random. Randomizing the selection of sample units is also difficult because the practice demands free access to all basin subunits. Any restriction in basin coverage would limit representativeness of the survey.

Clearly, we must adopt some form of stratified sampling, where snowcover variability is distributed somewhat uniformly throughout each stratum. The unitized sample design reported in this paper combines stratified sampling with subsampling (Steel and Torrie, 1960). This tri-level design consists of subunits, j, within areal units, i, within strata, h. The area of each basin is partitioned into K number of strata, where each stratum, h, contains M_h number of areal units and each areal unit, i, contains N_i number of subunits. Approximate minimum sizes for strata, areal units, and subunits comprising a 100-km^2 basin approach 100 ha, 1 ha, and 1 m^2, respectively. Snowcover observations are taken in n number of subunits (points), m number of areal units (snow courses), and k number of strata (landscape classes). Usually, $m < M$, $n < N$, and $k = K$.

Designed primarily to sample local and micro snowcover variability, this sampling scheme functions most effectively when strata-subdivision is confined to areas within a single climatic region. Maps, aerial photographs, satellite imagery, and previous surveys are used to define and delineate areal units which exhibit similar landscapes and are scattered throughout the basin. Similar units form distinct landscape classes or sampling strata which reflect basin terrain and winter land use. Landscape classes from three snow surveys are recorded in Table 1.

Under this unitized sample design, randomization is partially derived from each of four sources: (I) Micro variability of snowcover is of such a scale that its areal distribution within each areal unit is strongly random. For example, systematic sampling of snow depth in Canadian forests frequently exhibits a random component of variance about the snow course mean, which relates to the peripheral fall of intercepted snow around coniferous trees. (II) Local variability also tends to be somewhat randomly distributed. Snow depth data sampled from 100 different areal units were tested for normality by the third-moment test for statistical symmetry. A symmetrical

Table 1. Landscape Classes for Three Snow Surveys in Canada

I. Bier Basin near Watson Lake, Yukon

CLASS	AREA	
	Hectares	% of Area
(a) Upland Forest of Pine & Spruce	1121	67.3
(b) Organic Forest of Spruce	472	28.3
(c) Large Brushy Clearing	73	4.4
Total	1666	

II. Bad Lake Basin near Rosetown, Saskatchewan

CLASS	AREA	
	Hectares	% of Area
(a) Upland Crop Stubble	117	3.2
(b) Plains Crop Stubble	160	4.4
(c) Lowland Crop Stubble	60	1.6
(d) Upland Pasture	1400	38.5
(e) Plains Pasture	1200	33.0
(f) Lowland Pasture	700	19.2
Total Surveyed	3637	

III. Battle Basin near Ponoka, Alberta

CLASS	
(a) Stubble Plain	(h) Fallow Undulating Plain
(b) Stubble Topland	(i) Herbaceous, Broad Lowland
(c) Stubble Undulating Plain	(j) Brushy Broad Lowland
(d) Hayfield Plain	(k) Brushland Plains
(e) Hayfield Undulating Plain	(l) Woodland Undulating Plain
(f) Fallow Plain	(m) Pasture Plain
(g) Fallow Topland	(n) Recent Clearing Plain

frequency distribution was indicated in over 40% of those units located in a prairie environment and in over 60% of those units within a forest. (III) Sample areal units within each landscape class are selected randomly irrespective of location except in cases where access is difficult and costly. (IV) The directional orientation of each snow course and the spacing of sample points along the course may be chosen randomly. In practice, these choices must also insure adequate sampling coverage of the areal unit.

Incorporation of stratification into the sampling scheme tends to reduce sample variance. Table 2 provides information on the comparative gain in variance reduction resulting from establishment of (1) areal units and (2) landscape strata. Snow data, obtained from Bier Basin, Yukon and expressed as ratios of variance among groups to variance within groups, indicated a ratio gain for the landscape grouping which was four times greater than for areal unit groupings. A similar comparison in Table 3 for snow depth data from Battle Basin, Alberta again showed significant gains in variance reduction for landscape stratification. Snowcover depth and density statistics from Bad Lake, Saskatchewan also support stratification (Table 4). Comparative variation, as expressed by the coefficient-of-variation (standard deviation/mean), averaged considerably lower for individual class-values than when combined.

Table 2. Summary of Variance-Ratios by Landscape Class for Snowcover Depth, 1973, Bier Basin, Yukon

CLASS	Variance-Ratio*	
	$\left(\frac{\text{Among Areal Units}}{\text{Within Areal Units}}\right)$	$\left(\frac{\text{Among Classes}}{\text{Within Classes}}\right)$
Upland Forest	9.19	
Organic Spruce	1.58	
Large Clearing	4.43	
Classes Combined		44.05

*Ratio of variance between means of the groups to variance between observations within the groups

Table 3. Summary of Variance-Ratios by Landscape Classes for Snowcover Depth, 1973, Battle Basin, Alberta

CLASS	Variance-Ratio*	
	$\left(\frac{\text{Among Areal Units}}{\text{Within Areal Units}}\right)$	$\left(\frac{\text{Among Classes}}{\text{Within Classes}}\right)$
Stubble Plain	3.42	
Hayfield Plain	9.01	
Brushland Plain	6.26	
Classes Combined		16.62

*Ratio of variance between means of the group to variance between observations within the groups

Table 4. Summary of Snowcover Statistics by Landscape Class, 1972, Bad Lake, Saskatchewan

CLASS	No. of Snow Courses	Depth (cm)		Density (g/cc)	
		Mean	Coeff. of Variation	Mean	Coeff. of Variation
h	m_h	$\bar{d}_h$	Cv_h	$\bar{\rho}_h$	Cv_h
Upland Stubble	2	34	.291	.14	.163
Lowland Stubble	1	53	.282	.16	.215
Plain Stubble	3	21	.320	.22	.154
Upland Pasture	9	14	.703	.16	.370
Lowland Pasture	9	62	.634	.27	.339
Plain Pasture	7	27	.608	.19	.363
Classes Combined		34	.935	.20	.440

The lowering of sample variance by stratification has merit; statisticians (Cochran, 1953) recommend the practice wherever possible. Reducing snow sample variance increases confidence about the sample mean, reduces the number of snow courses required, increases the probability that snowcover is similarly distributed over each areal unit comprising each class, and diminishes the importance of complete class-wide dispersion of snow courses. Consequently, data obtained from accessible snow courses may be extrapolated with greater validity to remote reaches of the basin.

Areal frequency distributions of snowcover observations over areal units and classes often are not symmetrical. Figure 2 illustrates the non-symmetry associated with snow depths measured in the upland-pasture class at Bad Lake, Saskatchewan. Under the unitized sample design, normal statistics still apply to non-symmetrical depth data. The central limit theorem states that the means of all samples taken from the same population will tend to follow a normal distribution irrespective of the population distribution.

Snow surveys are rarely designed to separately sample depth and density. Separate sampling is advantageous, if the areal variability of the two variables differ appreciably. If density variance were less and relatively normal, the advantage would compound, considering the comparative difficulty associated with density measurement. The similarity between water equivalent and depth frequency distributions, shown in Figure 2, suggests a dominance of depth over density in influencing resultant water equivalent. The Figure also indicates what repeated symmetry tests have confirmed, namely, that class-wide density distributions are usually symmetrical, if not normal.

Results from studies of prairie snowcovers give additional support for separate sampling of depth and density. Lakshman (1973) related water equivalent to snow depth for 1970, 1971 and 1972 data from four basins in Saskatchewan. He consistently found linear correlations of 0.85 or greater, inferring a high covariance between depth and density or a relatively low density variance. Coefficients-of-variation from the 1972 survey at Bad Lake, Saskatchewan, compared in Table 4, averaged twice as great for depth as for density.

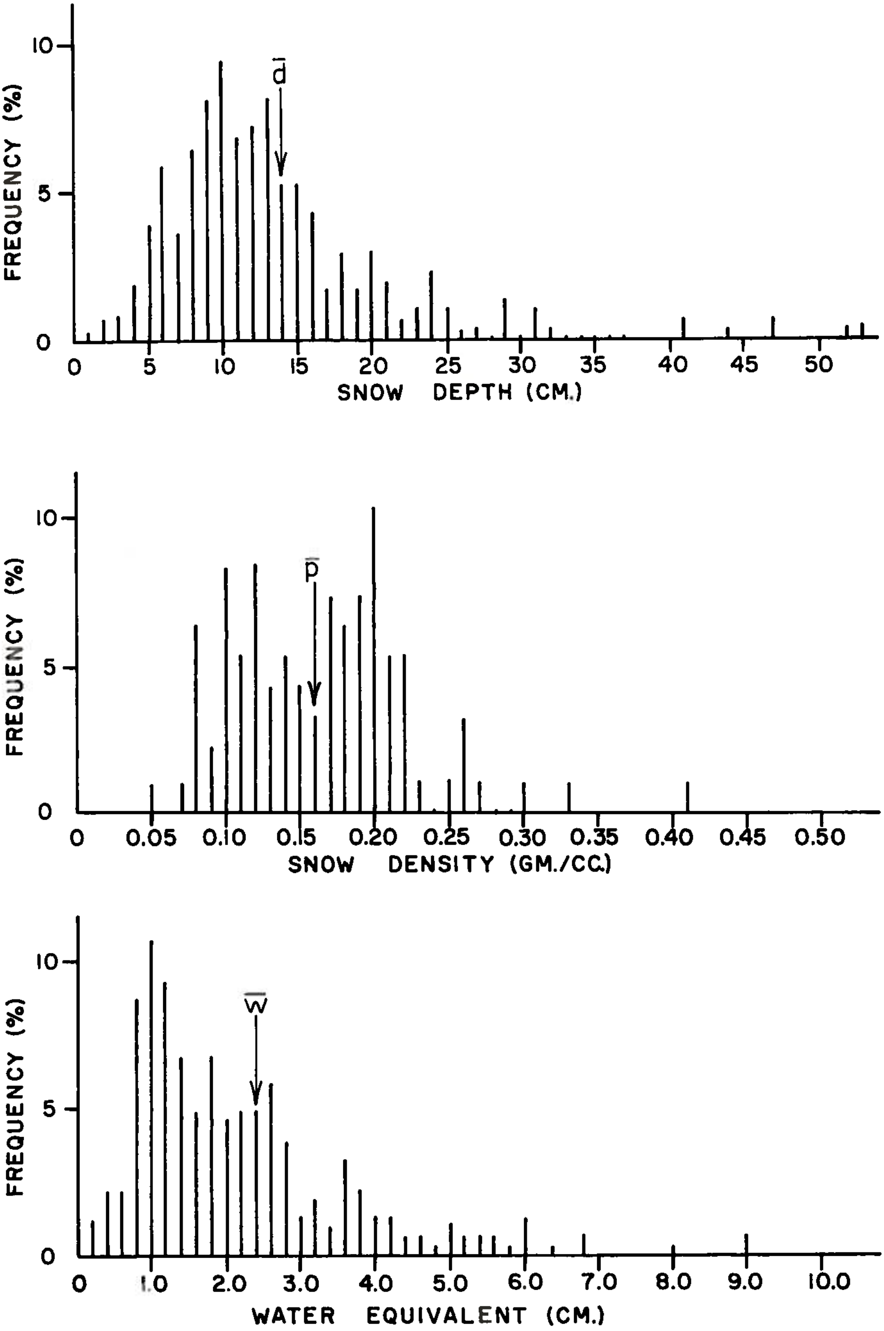

Figure 2. Frequency Distributions of 312 Snowcover Measurements over Upland-Pasture, Bad Lake Basin, Saskatchewan

Statistics associated with the unitized sample design exist for each unit. An observation is denoted by x_{hij}, where h refers to the landscape class, i, to the snow course, and j to the observation point. Equations for computation of sample means for snow courses, $\bar{x}_i$, landscape classes, $\bar{x}_h$, and the basin, $\bar{x}_b$, and of corresponding error variances, $s^2_{\bar{x}i}$, $s^2_{\bar{x}h}$ and $s^2_{\bar{x}b}$ are

$$\bar{x}_i = \frac{1}{n} \sum_j x_{hij} \quad , \quad s^2_{\bar{x}i} = \frac{\sum_j (x_{hij} - \bar{x}_i)^2}{n(n-1)}$$

$$\bar{x}_h = \frac{1}{m} \sum_i \bar{x}_i \quad , \quad s^2_{\bar{x}h} = \sum_i \frac{\frac{1}{n_i} (\bar{x}_i - \bar{x}_h)^2}{m-1}$$

$$\bar{x}_b = \sum_h \frac{A_h \bar{x}_h}{A_b} \quad , \quad s^2_{\bar{x}b} = \sum_h \left(\frac{A_h}{A_b}\right)^2 s^2_{\bar{x}h}$$

where A_h and A_b are areas of class and basin, respectively. Equations for computation of confidence intervals, CI, at levels, i, h, or b are of the form, $CI = 2|t_\alpha s_{\bar{x}}|$, where t_α is the t-value at the selected α-level of confidence and $s_{\bar{x}}$ is the sample error of the mean.

METHODOLOGY

Unitized sampling has been used to estimate the maximum winter snowcover over basins in four climatic regions; prairie, parkland, forest and tundra. The methodology for this sampling can be illustrated by reviewing its application to Bier Basin near Watson Lake, Yukon, in Northwest Canada (Figure 1).

Snow Survey

An aerial reconnaissance preceded the snow survey. This reconnaissance supported the supposition that three major groups formed the basin's landscape. Distributed as shown in Figure 3 and tabulated by area in Table 1, these landscape classes were (1) upland forest of pine and spruce, (2) organic spruce wetland, and (3) large brushy clearing.

Figure 3 locates the twenty snow courses selected for survey. Allocations according to landscape class were ten, five and five for upland forest, organic spruce, and large clearing, respectively. Although random selection of course location was partially successful, access influenced some site choices.

Snowcover depths and densities were observed at points approximately ten paces apart along randomly oriented courses. A scaled-rod was used to read 36 or more depths per course. Vertically-integrated snowcover densities were obtained by weighing snow cores of known length taken with 4.6 cm or 8.0 cm diameter sampling tubes. Although the number of density observations per course were not consistent, the total number per landscape class was ample to yield a statistically-valid class mean. Rational for this practice hinges on the assumption that class-wide, snowcover densities are symmetrically and near-normally distributed about the mean of the class.

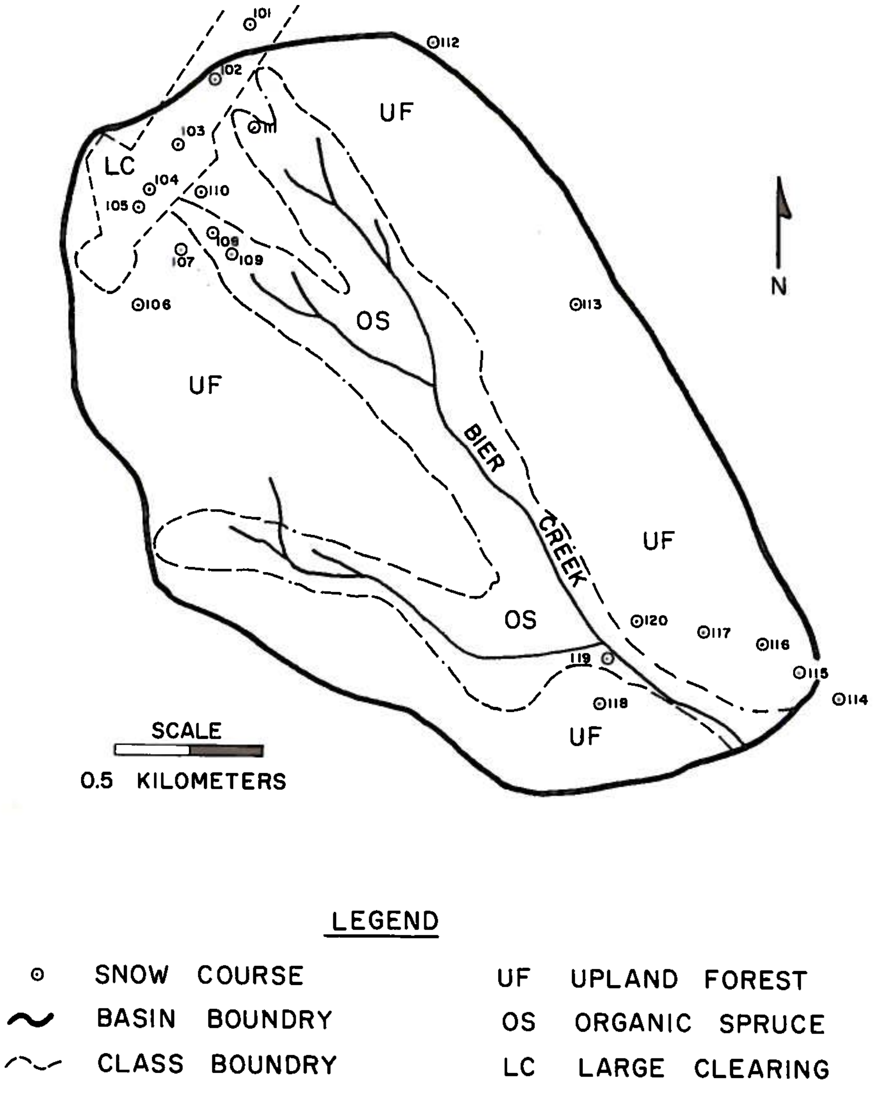

Figure 3. Bier Basin near Watson Lake, Yukon, Canada

Course and Class Statistics

Snowcover depth and density data from the Bier Basin survey were initially summarized and statistically analyzed according to the manner in which each variable was sampled. Depth data were summed by snow course and density data by landscape class. Statistical means and variances for depth are presented by course in Table 5, while density statistics, including error variances and confidence intervals, are listed by class in Table 6. Table 6 also includes class-wide means, error variances and confidence intervals for snowcover depth derived from the course means recorded in Table 5.

Table 5. Snowcover Depth Statistics by Snow Course for 1973 Survey of Bier Basin near Watson Lake, Yukon

Depth in cm.			Depth in cm.		
No. of Obs. n	Mean $\bar{d}_i$	Variance s_i^2	No. of Obs. n	Mean $\bar{d}_i$	Variance s_i^2
Upland Forest			**Organic Spruce**		
36	60.5	29.16	36	69.9	42.20
59	61.7	62.26	37	70.9	77.10
37	58.9	72.00	36	70.6	54.00
36	57.4	74.20	38	71.6	71.42
48	66.0	56.00	37	67.6	47.49
36	66.0	61.55	**Large Clearing**		
36	67.6	58.78	36	74.4	34.13
36	65.5	41.23	36	76.2	34.26
37	60.7	24.90	40	79.3	36.58
38	59.2	45.42	36	76.5	22.13
			36	77.5	14.90

Table 6. Snowcover Statistics by Landscape Class, 1973, Bier Basin, Yukon

Variable	Statistic*	Landscape Class, h		
		Upland Forest	Organic Spruce	Large Clearing
Depth (cm)	$\bar{d}_h$	62.36	70.10	76.76
	CI/2	5.77	2.62	3.05
	$s^2_{\bar{d}h}$	12.25	2.51	3.44
	m_h	10	5	5
Density (g/cm^3)	$\bar{\rho}_h$	.206	.197	.172
	CI/2	.008	.011	.021

Continued ...

Table 6. Snowcover Statistics by Landscape Class, 1973, Bier Basin, Yukon (Continued)

Variable	Statistic*	Landscape Class, h		
		Upland Forest	Organic Spruce	Large Clearing
Density (g/cm^3)	$s^2_{\bar{\rho}h}$	.0000223	.0000482	.000156
	z_hN	41	21	18

* Snowcover Statistics Legend:

$\bar{d}_h$	Class mean depth
CI	Confidence interval at $\alpha = 0.1$
$s^2_{\bar{d}h}$	Error variance of mean depth
m_h	Number of snow courses
$s^2_{\bar{\rho}h}$	Standard error of mean density
z_h	Number of density observations

Class Verification

The next step in analysis centered on verification of the chosen landscape classification. Within each class, depth samples from each snow course should exhibit some uniformity in variance about the course mean. Bartlet's test for homogenity of variances (Steel and Torrie, 1960) was applied to the Bier Basin depth data. Test results are given in Table 7. Depth variances for the organic spruce and large clearing classes showed within-class homogenity at α - probabilities of 0.05 or more. Sample variances within the upland forest were about as uniform ($\alpha = 0.01$) as when this class was combined with organic spruce. All other class combinations proved non-homogeneous.

Table 7. Summary of Homogenity Tests for Depth Variance

Class Group	Highest α-Level of Significance Indicating Homogenity							
	Homogeneous ⟷ Non-homogeneous							
	0.2	0.1	0.05	0.025	0.01	0.005	0.001	< 0.001
Large Clearing LC			X					
Upland Forest UF					X			
Organic Spruce OS	X							
LC + UF								X
LC + OS								X
UF + OS					X			
LC + UF + OS								X

Any combination of classes whose depth variances are homogeneous should be tested for equality of means. That is, do these class means diverge sufficiently to justify the retention of more than one unified class? Applicable statistical tests include the t-test, the Wilcoxan rank sum test, and the F-test. Applied to the upland and organic combination, the F-test significantly inferred the existence of two divergent means each representing a unique class. Had the results indicated an equality of means, formation of a single class from the two would have been justified.

Future Snow Surveys

Snow surveys provide information to suggest statistically-sufficient sample sizes for future surveys. These suggested sizes include the number of depth observations per snow course, n_i, the number of snow courses per class, m_h, and the number of densities per class, z_h. Procedures necessary to determine suggested sizes are usually based on temporal extrapolation of variances.

Fixed n_i-values for all snow courses may not insure adequate sampling coverage over each areal unit. The optimum n_i is that number yielding a sample which defines the depth-frequency of areal unit i with a confidence of about 5% for its mean and 10% for its standard deviation. Means, $\bar{d}$, and standard deviations, s, computed for a series of snow depth samples are tabulated in Table 8; each succeeding sample contains fewer observations but covers the same snow course. The 5 and 10 percent deviation levels for $\bar{d}$ and s suggest an n_i-value between 26 - 32.

Table 8. Statistics from Repeated Samples of Snow Depth Taken Over an Areal Unit (B1), Upland-Pasture Class, Bad Lake, Saskatchewan, 1972

No. of Obs. n	Mean Depth $\bar{d}$	Deviation %	Standard Deviation s	Deviation %
64	13.85	0	8.817	0
57	13.97	1	8.925	1
54	14.10	2	8.990	2
51	13.31	4	7.838	11
48	14.31	3	9.461	7
46	13.56	2	7.956	10
43	14.37	4	9.285	5
38	13.33	4	8.093	8
32	13.26	4	8.052	9
26	14.61	5	9.897	12
22	14.61	5	10.241	16
18	14.59	5	10.940	24
16	12.47	10	6.581	25
13	16.02	16	12.144	38
11	12.00	13	6.757	23
8	16.12	16	14.371	63

The suggested number of snow courses, m_h, depends on the within-class variance, $s^2_{(wt)hi}$, which is equal to the remainder of total class variance, s^2_{hi}, minus the variance between snow course means, s^2_h. Values for m_h may be found by the relation

$$m_h \ge 2(t_\alpha + t_\beta)^2 (s^2_{(wt)hi})(CI)^{-2},$$

where t_α and t_β are t-values for α and β at ∞ degrees of freedom, and CI is a chosen confidence interval based on a specified α-probability. Confidence intervals relate to error tolerance, E, by $CI = 2|E|$. Calculated m_h-values for Bier Basin at $\alpha = 0.1$, $\beta = 0.8$ and $E = \pm 0.1\bar{d}_h$ cm were upland forest 5, organic spruce 5, and large clearing 2.

The basis for determining z_h number of future density observations is the class-wide density variance, s^2_h. The computational equation is $z_h \ge t^2_\alpha s^2_h E^{-2}$. Suggested z_h-values for upland forest, organic spruce and large clearing classes in Bier Basin for an E of ± 0.02 g/cc were 6, 7 and 19, respectively.

Water-Equivalent Statistics

Verification tests of selected landscape classes in Bier Basin were followed by determination of class-wide water equivalents, $\bar{w}$. If variance between class mean depth, $\bar{d}_h$, and density, $\bar{\rho}_h$, is negligible, $\bar{w}_h = (\bar{\rho}_h)(\bar{d}_h)$. Concurrently, if $s^2_{\bar{w}h}$, $s^2_{\bar{\rho}h}$, and $s^2_{\bar{d}h}$ designate error variance of mean water equivalent, mean density and mean depth, respectively, $s^2_{\bar{w}h} = (s^2_{\bar{\rho}h})(s^2_{\bar{d}h}) + (\bar{d}^2_h)(s^2_{\bar{\rho}h}) + (\bar{\rho}^2_h)(s^2_{\bar{d}h})$. In practice, this equation reduces to

$$s^2_{\bar{w}h} \approx (\bar{d}^2_h)(s^2_{\bar{\rho}h}) + (\bar{\rho}^2_h)(s^2_{\bar{d}h}), \text{ because}$$

$\bar{d}^2_h >> s^2_{\bar{d}h}$ and $1.0 > \bar{\rho}^2_h >> s^2_{\bar{\rho}h}$. If covariance between $\bar{d}_h$ and $\bar{\rho}_h$ is significant,

$$\bar{w}_h = (\bar{d}_h)(\bar{\rho}_h) + (r_{d\rho})_h\ (s_d)_h\ (s_\rho)_h \quad \text{and}$$

$$s^2_{\bar{w}} \approx (\bar{d}^2_h)(s^2_{\bar{\rho}h}) + (\bar{\rho}^2_h)(s^2_{\bar{d}h}) - 2\ (\bar{d}_h)(\bar{\rho}_h)(r_{d\rho})_h\ (s_d)_h\ (s_\rho)_h,$$

where $r_{d\rho}$ is the correlation coefficient between within-class, common-point observations of snow density and depth, while s_ρ and s_d are the respective standard deviations of the sample observations. Class confidence intervals, $CI_{\bar{w}h}$, at selected α-probabilities are determined in the usual manner, $CI_{\bar{w}h} = 2|(t_\alpha)(s_{\bar{w}h})|$.

Table 9 records Bier Basin water equivalent statistics by landscape class. Although class mean water equivalents averaged within one cm of each other, a review of Table 6 will reveal significant class differences in depth and density; these data suggest that equal masses of snow formed snowcovers of differing compositions depending on landscape.

Basin landscape may also significantly influence snowcover water equivalent. Class mean water equivalents from the 1972 Bad Lake, Saskatchewan survey were:

Upland Stubble	5.1	±	0.9 cm	at	$\alpha = 0.1$
Lowland Stubble	9.3	±	2.5 cm	at	$\alpha = 0.1$
Plain Stubble	4.5	±	0.6 cm	at	$\alpha = 0.1$

Upland Pasture 2.4 ± 0.2 cm at $\alpha = 0.1$
Lowland Pasture 18.6 ± 1.6 cm at $\alpha = 0.1$
Lowland Pasture 6.1 ± 0.5 cm at $\alpha = 0.1$

Table 9. Water Equivalent Statistics by Landscape Class, 1973, Bier Basin, Yukon

Variable	Statistic*	Landscape Class, h		
		Upland Forest	Organic Spruce	Large Clearing
Water Equivalent (cm)	$\overline{w}_h$	12.85	13.82	13.21
	CI/2	1.285	0.973	1.667
	$s^2_{\overline{w}h}$	0.606	0.348	1.021

* Snowcover Statistics Legend:

$\overline{w}_h$	Class mean water equivalent
CI	Confidence interval at $\alpha = 0.1$
$s^2_{\overline{w}h}$	Standard error of mean water equivalent

Basin Statistics

A weighted summation procedure for Bier Basin resulted in statistics describing true basin snowcover. Class mean values for depth, density and water equivalent were weighted by area ratios, R_h, derived as the quotient of class area, A_h, over basin area, A_b, i.e., $R_h = A_h/A_b$. Class error variances for each variable were also weighed, but by R_h^2. Weighted values were summed for each class, yielding the following estimates of the true snowcover over Bier Basin:

Basin mean depth in cm = 65.3 ± 4.1 at $\alpha = 0.1$
Basin mean density in gm/cc = 0.202 ± 0.020 at $\alpha = 0.1$
Basin mean water equivalent in cm = 13.1 ± 0.9 at $\alpha = 0.1$

CRITIQUE

The unitized sampling method features flexibility. For example, only preferred landscape classes need be surveyed; classes such as lakes and ponds may be ignored. Also, to lower costs, classes may be combined, or the assumption of normality may be extended to snow depths. The method offers a relatively rapid snow survey by keeping the number of density measurements to a minimum.

Possible disadvantages of unitized sampling include: (1) the method is predicated on the existence of snowcover differences between basin landscapes. If for specific storms, or specific times during winter accumulation, basin snowcover were areally uniform, landscape stratification would be superfluous. Experimentation with the unitized method have been limited to maximum winter snowcovers. (2) As developed, unitized sampling applies only to ground surveys; adaption to remote surveying has not been attempted. (3) The method has never been used in climates where significant winter precipitation includes rainfall. (4) Landscape classes which affect snowcover are unique to each climate region and often to each basin. Some degree of discretion must accompany basin classification. (5) The method has not been applied to basins with large ranges in elevation.

Estimates of absolute or true snowcover depth, density and water equivalent find ready use in management and research. Hydraulic models often require absolute values for precipitation inputs. Basin-wide winter energy budgets require estimates of snowcover depth and density for heat flow determination. The areal extrapolation of data from precipitation gauges or indexing snow courses depends on calibration by true snowcover values. True snowcover estimates also provide guidance in selecting suitable locations for these gauges and indexing courses. Finally, this method can fulfill a need for a valid, reliable and ready means of determining "ground truth" in evaluating new techniques and instruments in snow surveying.

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