A REPORT ON THE VARIABILITY OF SNOW WATER EQUIVALENT MEASUREMENTS AT A SITE

by

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INTRODUCTION

Each year a large amount of money is spent to obtain snow water equivalent data from snow courses. In most cases the snow course data are utilized as an "index" to estimate the amount of water stored in the snow pack. This study was carried out to evaluate some of the problems encountered when attempting to make an "absolute" estimate of the snow water equivalent. This report does not attempt to review previous work; however, Wilson (1966), McKay (1967, 1968) Kapanev (1969), Dickinson and Whitely (1971), and Leaf and Kovner (1972) present some of the problems associated with adequately sampling snow water equivalent.

A square 6 by 6 grid (36 sample points) with a grid spacing of 25 feet was established on a relatively flat open field. The site was located adjacent to a meteorological station in the North Nashwaaksis Stream Basin, N.B. as shown schematically in FIGURE 1.

During the winter of 1968, three visits were made to the site. During each visit the 36 sample points were sampled with a Mt. Rose Snow tube. After the snow depth, and the spring scale measurements were made, the contents of the snow tube were carefully transferred to a labelled plastic bag. The weight of each snow core sample was obtained to the nearest gram in a shelter near the sample site after all 36 samples were obtained. The sampling sequence is shown in FIGURE 1.

The condition of the snow pack on the three days during which the visits were made are outlined as follows:

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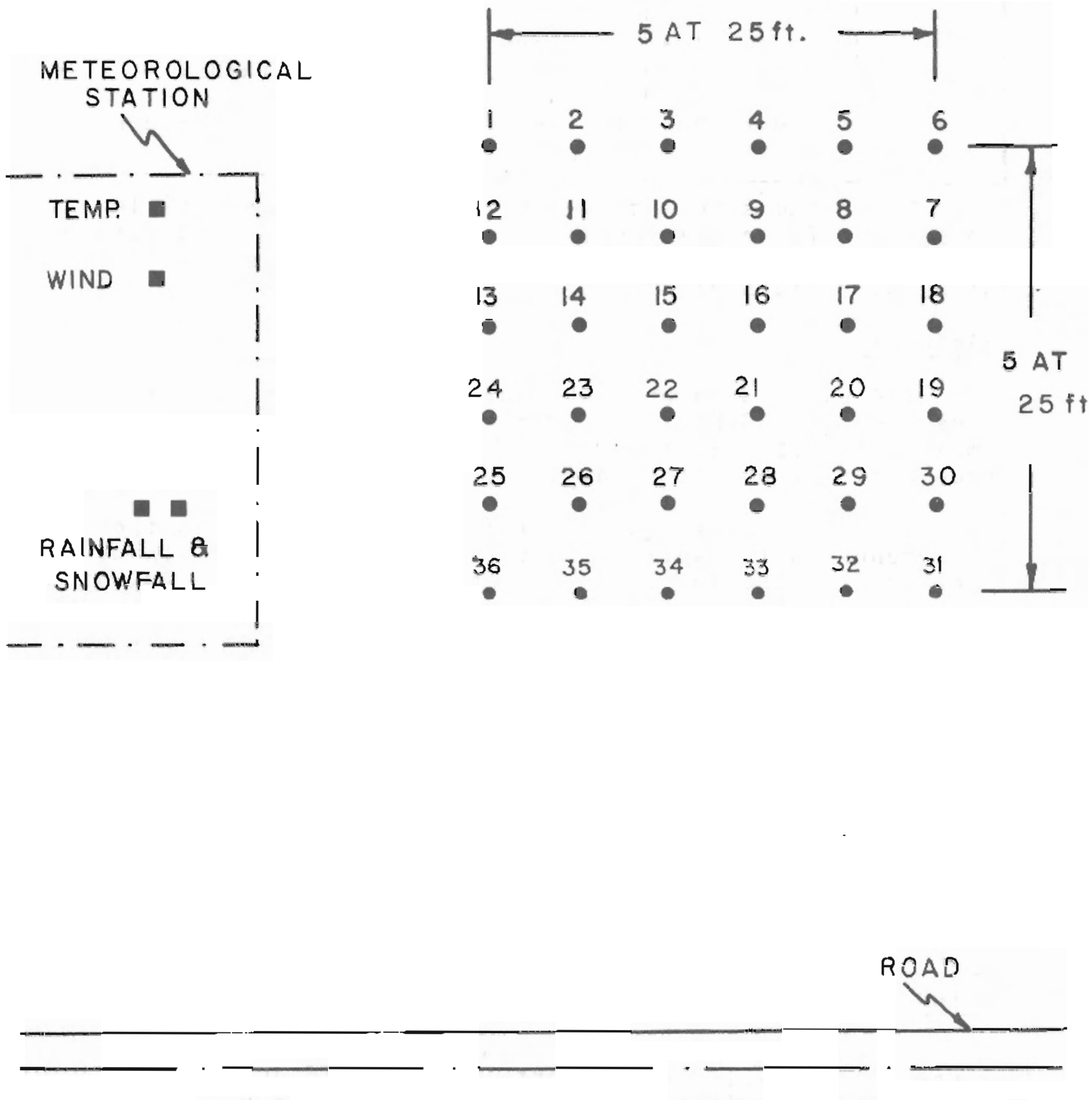


NOTE: NUMBERS ON GRID INDICATE SAMPLING SEQUENCE USED IN THE STUDY.

FIGURE I. SCHEMATIC LAYOUT OF SAMPLING GRID IN OPEN FIELD

Data Set	Date	Condition above bottom of pack	Condition at bottom of pack
1	27 Jan 1968	Light surface crust, no dominant ice layers	Grass easily obtained
2	13 Feb 1968	Ice layer in pack	Grass easily obtained
3	10 Mar 1968	Ice layers in pack	Ice at ground

Since the site was in the open, it was susceptible to some drifting. Winds in the open field also made it impossible to obtain spring scale readings if the velocity was in excess of about 8 miles per hour.

BASIC DATA

The basic data obtained during the three field visits are presented in TABLE 1. The variation of the depth is due to small variations in the elevation of the ground and also due to some drifting over the sample area.

The snow water equivalent for the snow tube is the difference in the spring scale readings with and without the snow core in the sampler. The snow tube water equivalent is presented to the nearest 0.5 inch.

The snow water equivalent presented for the snow core collected in the plastic bag was obtained by utilizing the weight of the sample and the fact that the inside diameter of the snow tube was 1.485 in. Since the weights were obtained to three significant figures, the snow core water equivalents were also presented to three significant figures.

FIGURE 2 presents the sequence of snowfall, rainfall and temperature at the meteorological station adjacent to the sample site for the period 1 January to 10 March 1968.

COMPARISON BETWEEN SNOW TUBE WATER EQUIVALENT AND SNOW CORE WATER EQUIVALENT

There are obvious difficulties in obtaining good measurements of snow water equivalent in the field during cold and/or windy periods. If the snow cores are transferred to previously labelled plastic bags, the amount of work under adverse field conditions may be minimized. This procedure also does not rely on the calibration of the snow tube spring scale. The main difficulty in this procedure is that of ensuring that there are minimum losses of snow when the core is being transferred into the plastic bag. This does not seem to be a problem unless thick ice layers are encountered.

The snow tube water equivalents as obtained in the field and the corresponding snow core water equivalents are presented in FIGURES 3 and 4. The snow tube spring scale was calibrated

TABLE 1 BASIC DATA FOR THE SAMPLE SITE

Sample Point	27 January 1968			13 February 1968			10 March 1968		
	Depth in	Snow Tube W.E. in	Snow Core W.E. in	Depth in	Snow Tube W.E. in	Snow Core W.E. in	Depth in	Snow Tube W.E. in	Snow Core W.E. in
1	21	4.5	4.55	12	3.5	3.70	18	3.5	4.23
2	21	4.5	3.39	20	4.5	4.40	21	2.5	3.42
3	19	4.0	4.02	13	4.0	4.02	12	2.5	3.07
4	29	7.5	7.03	20	5.5	5.22	20	3.0	3.60
5	22	4.0	3.24	16	6.0	5.77	11	3.0	3.64
6	24	6.5	6.03	19	6.0	5.60	15	3.0	3.25
7	20	5.5	5.62	16	4.5	4.30	12	2.5	3.07
8	21	6.0	5.82	14	4.0	3.94	11	2.5	2.86
9	25	7.5	7.20	18	5.5	5.14	23	3.0	3.31
10	20	5.0	4.66	15	5.0	4.55	12	2.5	2.96
11	26	8.0	7.34	20	6.5	6.05	18	3.0	3.10
12	20	6.0	6.10	16	6.0	5.77	18	2.5	2.82
13	20	7.0	6.42	16	7.0	7.25	10	1.5	2.12
14	26	7.5	7.20	20	6.5	6.16	24	5.5	5.60
15	20	5.0	4.34	14	4.0	3.77	17	4.5	5.08
16	28	6.5	5.96	17	6.0	5.42	19	3.0	3.42
17	23	5.5	4.84	18	6.0	5.04	21	4.0	4.37
18	24	6.5	5.96	18	6.0	5.10	16	2.5	3.07
19	20	4.5	4.73	19	6.0	5.39	18	5.5	5.82
20	24	5.0	4.76	15	5.0	4.93	18	3.0	3.07
21	26	5.5	5.37	19	6.5	6.05	18	5.5	5.40
22	18	4.0	3.92	14	4.5	3.88	17	3.5	3.46
23	20	6.0	5.85	20	7.5	6.76	17	4.5	4.90
24	22	6.0	5.75	16	6.0	5.39	16	3.0	2.86
25	23	5.0	4.76	16	5.0	4.68	19	3.0	2.82
26	24	6.5	6.07	18	6.0	6.05	14	3.0	3.39
27	24	6.5	6.45	17	5.5	5.07	19	3.0	3.49
28	27	6.0	5.69	18	6.0	5.85	18	2.5	2.22
29	22	6.0	5.58	17	6.0	5.50	21	4.5	5.04
30	20	4.0	3.67	14	5.0	4.93	17	5.0	4.93
31	20	5.5	5.04	13	4.5	4.40	18	5.5	5.85
32	23	4.5	4.05	16	6.0	5.46	20	5.0	5.05
33	22	5.5	5.68	17	6.0	5.39	17	5.5	5.32
34	22	6.0	5.36	16	6.0	5.77	18	6.0	6.06
35	24	7.5	6.60	17	6.0	5.40	18	6.0	4.34
36	22	7.0	6.50	17	6.5	6.26	18	6.0	6.27

Notes: 1. Snow Tube W.E. is water equivalent as obtained from the spring scale in the field.

2. Snow Core W.E. is water equivalent of snow core in plastic bag as obtained from controlled weighing after field trip.

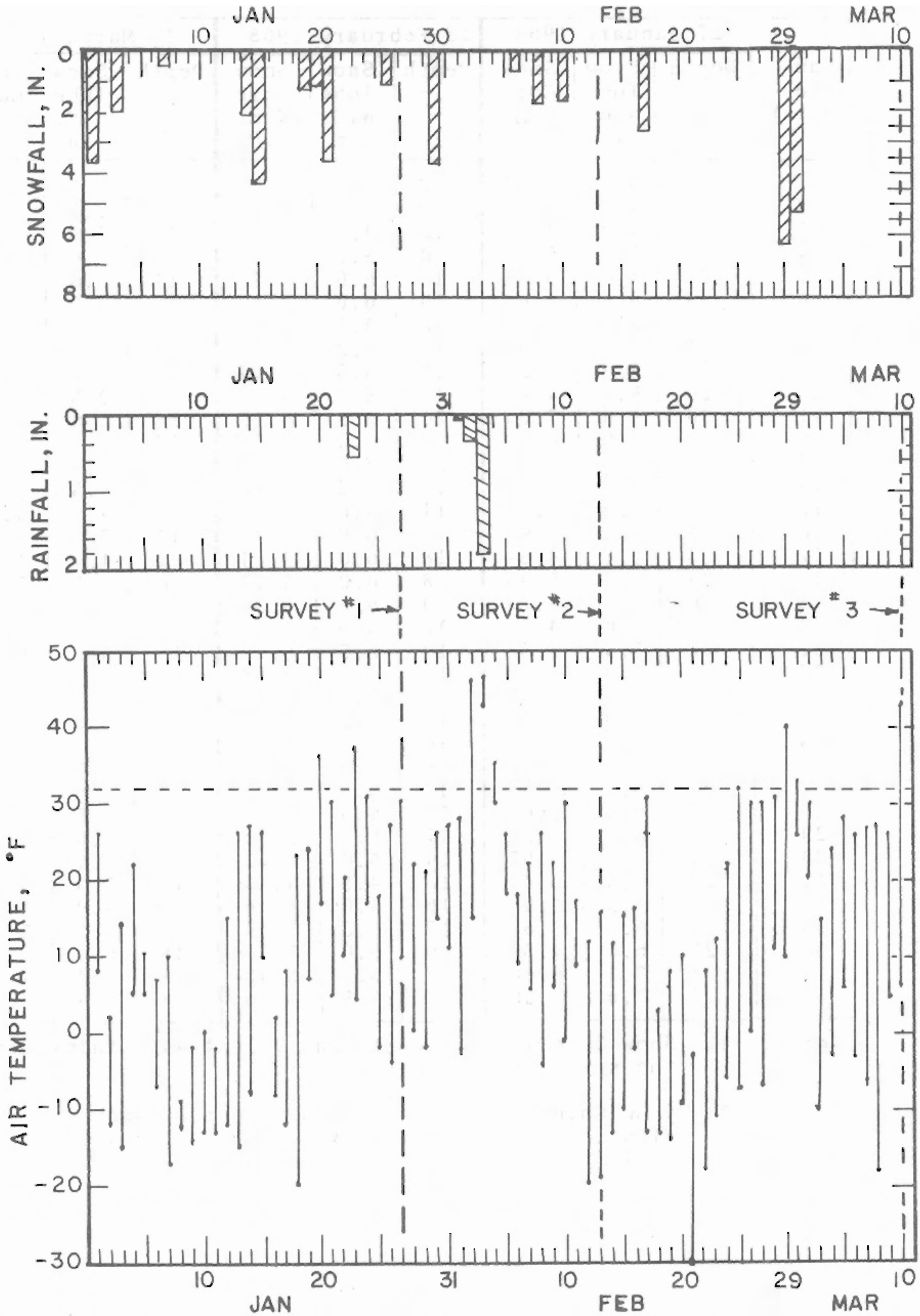


FIGURE 2. SEQUENCE OF SNOWFALL, RAINFALL, AND MAXIMUM AND MINIMUM TEMPERATURES – 1 JANUARY 1968 TO 10 MARCH 1968

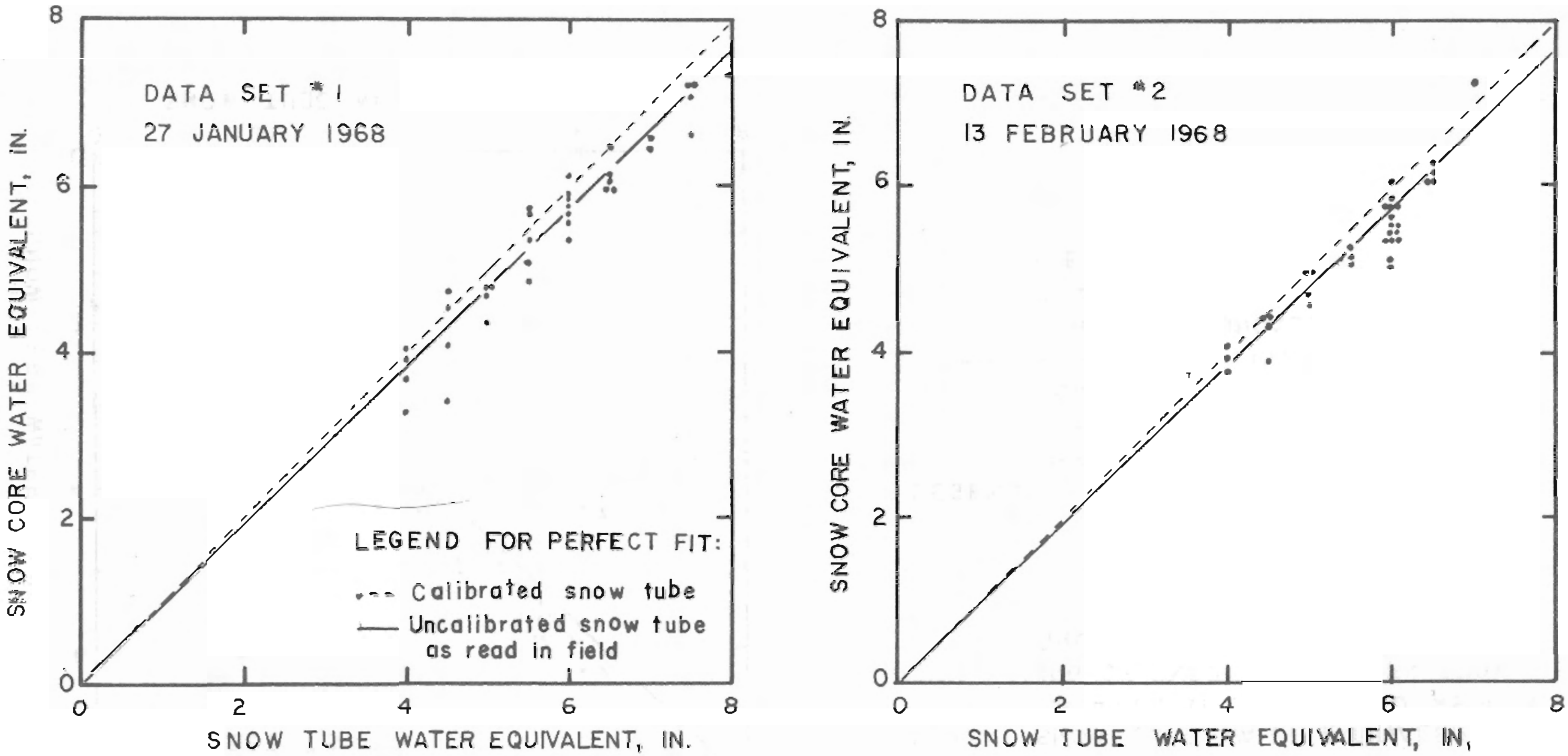
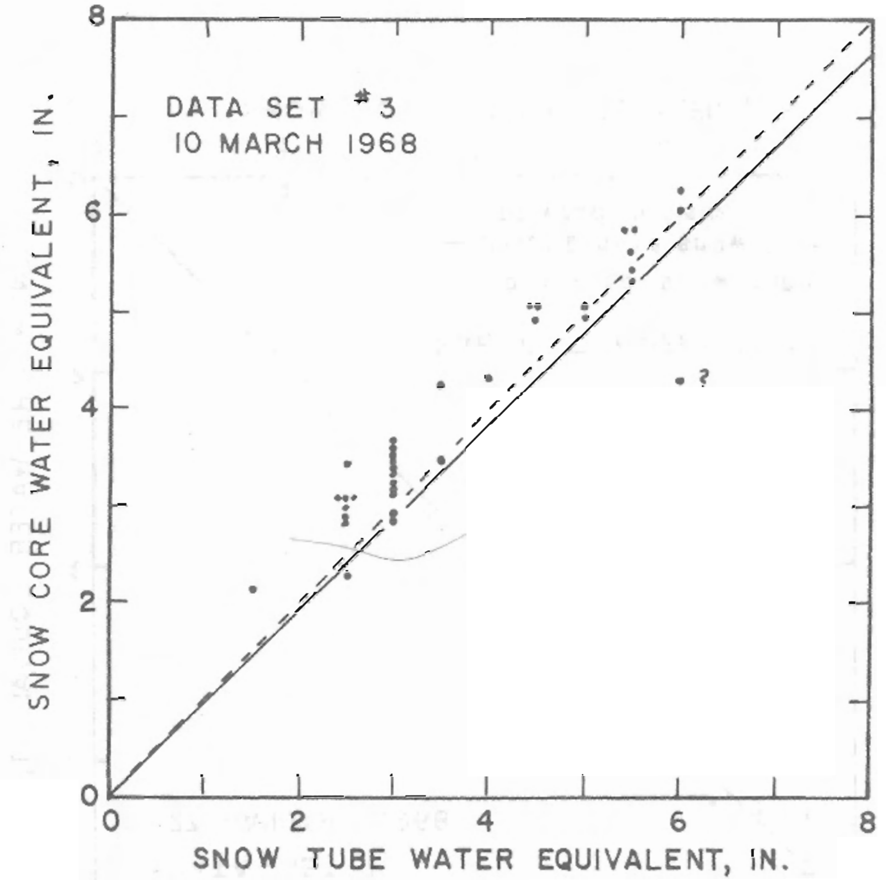


FIGURE 3. SNOW CORE WATER EQUIVALENT VERSUS SNOW TUBE WATER EQUIVALENT FOR DATA SETS #1 AND #2



NOTE: SNOW CORE WATER EQUIVALENT OBTAINED BY CONTROLLED WEIGHING OF SNOW CORE TAKEN FROM SNOW TUBE

LEGEND:

---- PERFECT FIT LINE FOR SNOW TUBE WITH CALIBRATED SPRING SCALE

—— PERFECT FIT LINE FOR SNOW TUBE WITH UNCALIBRATED SPRING SCALE AS MEASURED IN THE FIELD

FIGURE 4. SNOW CORE WATER EQUIVALENT VERSUS SNOW TUBE WATER EQUIVALENT FOR DATA SET # 3

in the fall of 1967 and it was found that the scale was reading about 4 percent too high over the range of the scale. If this factor is considered, the line for perfect agreement is shown by the solid line in FIGURES 3 and 4.

If the snow core water equivalent data are accepted as the best estimate of the snow water equivalent at the sample points, it is noted that the maximum deviation of the snow tube water equivalent is about 1.0 inch. In the majority of the cases, the deviation was less than 0.5 inch water equivalent.

For Data Set #3, the snow core water equivalent was consistently greater than the snow tube water equivalent; whereas, the values were scattered on both sides of the line for perfect agreement for Data Sets #1 and #2. This suggests that a constant error was made in the snow tube measurements in Data Set #3. The snow core water equivalents are used for subsequent analyses.

COMPARISON OF DATA SETS

The means, standard deviations, and coefficients of variation for the three data sets are presented in TABLE 2. These results indicate that the standard deviations are largest for Data Set #3 which was obtained when there were ice layers in the pack and when there was an ice layer at the surface of the ground. The F-test indicates that the variances of Data Sets #1 and #2 are from the same population at a level of significance of 5 percent.

The average densities for the three sample dates are as follows based on the snow core water equivalent:

Data Set	Date	Density gm/cm^3
1	27 Jan 1968	0.24
2	13 Feb 1968	0.32
3	10 Mar 1968	0.23

The average density of the snow pack for 10 March 1968 was less than that for the early survey dates. This can be explained by making reference to FIGURE 2. Over 10 inches of snow fell a few days before the final survey. The snowfall was followed by relatively low temperatures, so that the new snow was not greatly metamorphosed. Consequently, the average density is not always a satisfactory measure of the pack characteristics late in the season unless the recent history of the pack is observed.

ESTIMATE OF SAMPLE SIZE

The variability of the snow core water equivalents for the 36 sample points are shown in FIGURE 5 for Data Sets #1 and #2. It is difficult to select one or two representative points for the 125 ft x 125 ft sample area. Consequently, a statistical approach as outlined by Neville and Kennedy (1964) was utilized to determine the sample size required to make an estimate of the "absolute" water equivalent of the sample area.

TABLE 2 MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR BASIC DATA

Data Set	Date	Case	Mean, in	Standard Deviation, in	Coef. of Variation
1	27 Jan 68	Depth	22.6	2.7	0.12
		Snow Tube W.E.	5.78	1.13	0.20
		Snow Core W.E.	5.43	1.10	0.20
2	13 Feb 68	Depth	16.7	2.2	0.13
		Snow Tube W.E.	5.57	0.92	0.16
		Snow Core W.E.	5.23	0.84	0.16
3	10 Mar 68	Depth	17.2	3.3	0.19
		Snow Tube W.E.	3.74	1.30	0.35
		Snow Core W.E.	3.98	1.17	0.29

Note: 1. Sample Size is 36 in all cases

2. Snow Tube W.E. is Snow Tube Water Equivalent as measured in field

TABLE 3 SAMPLE SIZES FOR SPECIFIED DEVIATIONS OF THE SAMPLE MEAN FROM THE TRUE MEAN

Case	Deviation of Means $\lvert \bar{x} - \mu \rvert$	27 Jan 68 n	13 Feb 68 n	10 Mar 68 n
Depth, in	1.5	12	9	19
	2.0	7	5	11
	2.5	5	3	7
Snow Tube Water Equiv., in	0.50	20	13	26
	0.65	11	8	16
	0.75	9	6	12
	0.85	7	5	9
Snow Core Water Equiv., in	0.50	19	11	21
	0.65	11	7	13
	0.75	9	5	10
	0.85	7	4	8

Notes: 1. Standard Deviation for population assumed to be standard deviation for sample of 36.
2. Level of significance is taken to be 5 per cent.
3. $\lvert \bar{x} - \mu \rvert$ is deviation of sample mean from true mean.
4. n is the sample size

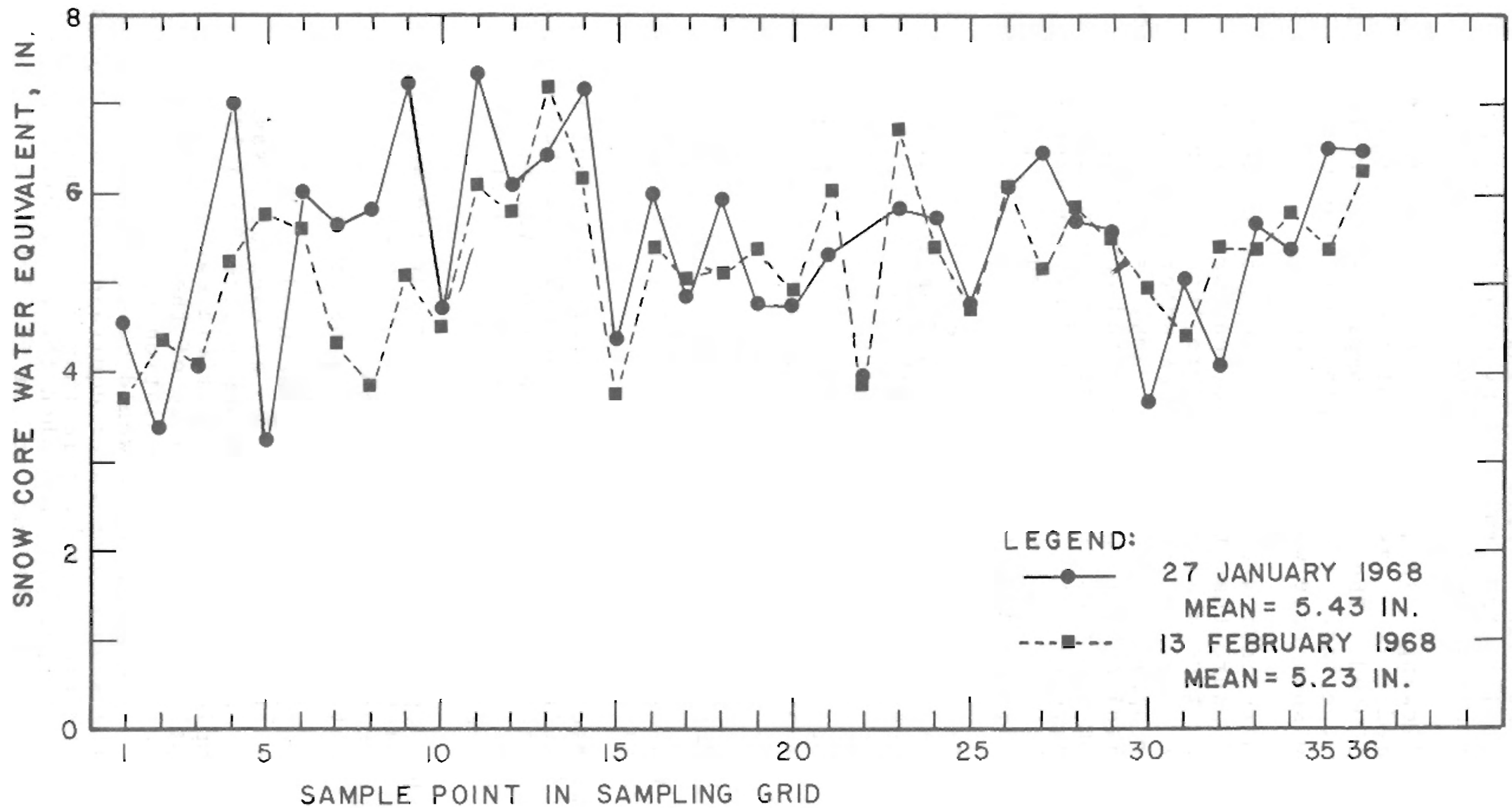


FIGURE 5. VARIATION OF SNOW CORE WATER EQUIVALENT OVER SAMPLING GRID

If it is assumed that the population variance is equal to the variance obtained from the sample of 36, it is possible to make an estimate of the sample sizes such that the observed mean will not deviate from the true mean by more than a specified amount at a given level of significance.

For the following cases, the 5 percent level of significance has been accepted. It is assumed that the sample means are normally distributed. The required sample sizes are presented in TABLE 3 for the cases of snow depth, snow tube water equivalent, and snow core water equivalent.

These results indicate that a sample size of about 10 is required to ensure that the sample mean depth will not deviate from the true mean depth by more than 2.0 inches. The required sample size for the snow tube water equivalent does not differ appreciably from the sample size for the snow core water equivalent for the same adopted deviation of the sample mean from the true mean. A sample size of about 10 is required to ensure that the sample mean does not differ from the true mean by more than 0.75 inches. A sample of about 20 is required if the deviation is to be reduced to 0.50 inches.

The results indicate that the sample size could be increased if the snow pack has ice layers in it and an ice layer on the ground, if an "absolute" estimate of the snow water equivalent is required.

It is to be emphasized that these results apply to the 125 ft x 125 ft sample area which was located in a relatively flat open field.

SUMMARY AND CONCLUSIONS

The following points are related to the estimation of the "absolute" water equivalent:

1. Estimates of the "absolute" water equivalent are difficult to make due to the accuracy of the sampler used, the variation of the water equivalent over the sample site selected, and the selection of representative sampling sites.

2. When samples have to be taken in adverse weather conditions (extreme cold and/or high winds), it may be expedient to retrieve the snow core in a plastic bag for controlled weighing after the field trip.

3. Some objective means should be used to determine the number of sampling points to be used at a sampling site. In this case, the sample size for a 125 ft x 125 ft sample site in flat open field was based on the assumption that the variance of the 36 samples in the site was equal to the population variance. A random sample size of about 10 would be required to ensure that the sample mean water equivalent would not deviate from the true mean by more than 0.75 inches. More samples should be taken when there are excessive ice layers in the pack and/or ice layers on the ground.

RECOMMENDATIONS

If this type of study is to be repeated, it is suggested that the following additional information be obtained:

1. An approximate vertical section of the snow pack in the vicinity of the sample site. This would show the extent of major ice layers and the condition at the snow-earth interface.

2. The elevation of the surface of the earth at each sample point should be tied into a datum to clearly show the variation in depth of the snow pack due to small depressions, etc., at the ground surface and due to the drifting at the snow surface.

ACKNOWLEDGEMENTS

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REFERENCES

1. Dickinson, W.T. and Whiteley, H.R., "Snowpack Sampling for the Estimation of Liquid Water Equivalent", Discussion Paper, Proceedings of Hydrology Symposium No. 8, Runoff from Snow and Ice, Vol. 2, Quebec City, Quebec, May 1971, N.R.C., Ottawa, pp 11-30.

2. Kopanev, I.D., "Rationalism of a Snow Measurement Network", Soviet Hydrology: Selected Papers published by the American Geophysical Union, No. 6, 1969, pp 555-560.

3. Leaf, C.F. and Kovner, J.L., "Sampling Requirements for Areal Water Equivalent Estimates in Forested Subalpine Watersheds", Water Resources Research, Vol. 8, No. 3, June 1972, pp 713-716.

4. McKay, G.A. "Snow Measurement Practices", Proceedings of the 24th Annual Eastern Snow Conference, Niagara Falls, Ontario, 1967, pp 29-34.

5. McKay, G.A., "Problems of Measuring and Evaluating Snow-cover", Proceedings of Workshop Seminar on Snow Hydrology, Fredericton, N.B., Feb. 1968, Canadian National Committee, I.H.D., Ottawa, pp 59-62

6. Neville, A.M. and Kennedy, J.B.; Basic Statistical Methods for Engineers and Scientists; International Textbook Company, 1964, 325 pg.

7. Wilson, J.A., "Determination and Uses of Best Individual Sampling Points on Individual Snow Courses", Proceeding of the 34th Annual Western Snow Conference, Seattle, 1966, pp 82-86.