SNOW MEASUREMENT IN THE PRAIRIE ENVIRONMENT

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INTRODUCTION

On the Prairies, snow represents the main and vital source of the manageable fresh water supply. In these semi-arid regions, in the absence of severe, localized thunderstorm activity, melt released by snow accounts on the average for approximately 80 to 85 percent of the surface runoff volumes. Thus, this water represents the major component available for storage in dugouts and sloughs.

Similarly the rate of melt release from shallow Prairie packs may produce flood peaks important to the design of hydraulic structures. Packs that cause flood peaks usually develop during melt-free winters and are retained until late in the season when climatological conditions favor high melt rate. Factors contributing to rapid melt rates and high discharge rates are: (a) the pack is shallow and has little capacity to store heat, consequently it reaches isothermal conditions very rapidly; (b) the soil temperature is generally less than 32°F, often resulting in low infiltration rates; and (c) considerable heat flux may be advected to the pack from adjacent fallow land.

The amount and rate of runoff and the amount of water retained as soil moisture depends in part on the spatial distribution of the snow pack at the time of melt. On the Prairies, because of the expanse of areas of flat or gently-rolling topography, the sparsity of tall, dense vegetative growth, and the usually strong surface winds (monthly average 10 to 16 mph), severe drifting and redistribution of the pack may occur during the winter months. Essentially, two major problems evolve in the determination of areal distribution of available water in the snow, namely: (a) measurement of the snow water equivalent at a point in relation to the ground catch, and (b) evaluation of the spatial and temporal distribution of the accumulations and their physical properties.

RECEIVED FOR PUBLICATION
SEPTEMBER 25, 1969

POINT MEASUREMENT AND GROUND ACCUMULATION

Several studies, for example those conducted by Kuz'min (3) and McKay (4) have reported on the relative retention of snow on various surfaces and, the relation between the water equivalent of snow as measured by standard meteorological equipment with measurements taken on the ground. In these respects, it must be recognized that under Prairie conditions the densities of freshly-fallen snow may range from 0.035 to 0.175 gm/cc. It is evident, therefore, that if simple "stick" or "ruler" measurements are made and multiplied by an assumed constant density (usually 0.1 gm/cc) to determine the water equivalent of the pack on the ground, there may be appreciable differences between reported gauge and ground measurements. McKay (4) reported that most Prairie snow courses retain approximately 60 percent of the accumulated snow reported by adjacent climatological stations.

During the winter of 1968/69 a field program was established within the Bad Lake International Hydrologic Decade Representative Basin, located approximately 35 miles southwest of Rosetown, Saskatchewan, to compare the "ground catch" with measurements taken from "Shielded" Fischer and Porter (F-P) precipitation gauges. In total, nine sites or gauges were used in the investigation, each of which was located under highly exposed conditions. At each site, snow stakes were placed at the corners of a square grid located on the perimeter of a 400-ft diameter circle surrounding each F-P gauge (see Fig. 1). Periodically during the season, measurements were made of snow depths at the stakes and the gauge catch. These measurements were supplemented by data obtained from six snow samples taken with a six-inch diameter aluminum tube from within the test area (see Fig. 1). These samples were reduced to water equivalents by melting. A summary of the data collected is tabulated in Table 1.

Results:

A comparison of the accumulated water equivalent of the snow on the ground (as determined by averaging the snow density samples) with that recorded by the F-P gauges is shown plotted in Fig. 2. As shown in the figure, in all cases, the "gauge catch" underestimated the ground accumulation. On the average, the "gauge catch" was only 47 percent of the average water equivalent of the snow pack on the ground, however, the

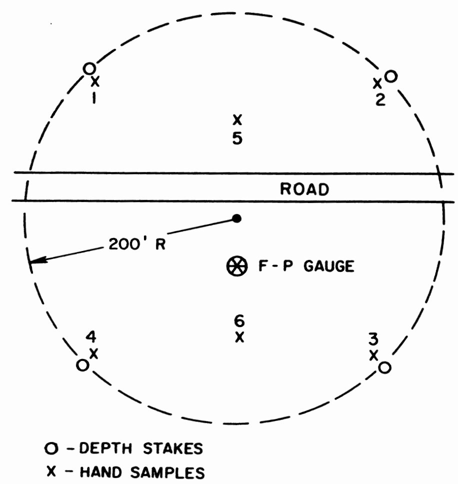

Figure 1. Typical Fischer and Porter Precipitation Gauge Site with Hand Sample Locations Indicated.

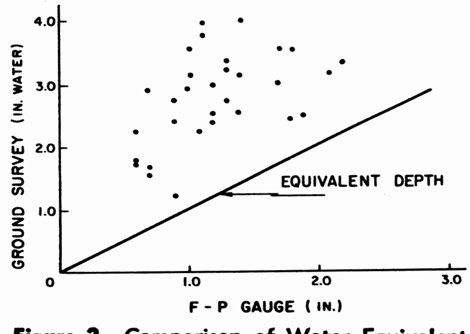

Figure 2. Comparison of Water Equivalent of Snowpack Determined by Ground Survey with Measured F-P Gauge Readings.

TABLE I. SNOW CATCH DATA - WINTER 1968-1969

Station	F-P Gauge catch (in. water)	Snow Catch: Ave. depth at 4 snow stakes (in. snow)	Ave. depth of 6 snow samples (in. snow)	*Ave. depth of snow (in. snow)	Ave. depth of melt water (in. water)	Snow density (gm/cc)
101						
Feb. 11	0.6	6.8	6.9	6.9	1.74	.250
Mar. 2	0.7	7.4	6.9	7.1	1.68	.243
Mar. 10	0.9	9.1	10.4	9.9	2.78	.267
103						
Jan. 21	0.9	6.6	6.8	7.6	1.21	.179
Mar. 1	1.7	12.5	11.7	12.0	3.00	.258
Mar. 11	1.7	13.0	13.5	13.3	3.56	.264
Mar. 24	1.8	13.9	13.6	13.7	3.54	.260
104						
Jan. 20	0.7	7.7	7.7	7.7	1.59	.208
Feb. 18	1.2	13.4	12.3	12.7	2.56	.209
Mar. 2	1.3	12.5	11.2	11.7	2.74	.246
Mar. 12	1.3	14.0	13.3	13.6	3.36	.252
105						
Feb. 11	1.1	7.6	8.9	8.4	2.26	.255
Feb. 18	1.2	9.6	9.8	9.8	2.40	.244
Mar. 4	1.3	10.6	10.5	10.6	2.70	.257
Mar. 12	1.4	10.9	12.1	11.6	3.16	.260
106						
Feb. 4	1.8	12.5	11.5	11.9	2.43	.211
Feb. 21	1.9	13.2	10.9	11.9	2.50	.230
Mar. 4	2.1	13.5	12.3	12.8	3.18	.256
Mar. 13	2.2	14.6	13.6	14.0	3.32	.244
107						
Feb. 12	0.9	9.0	9.5	9.3	2.39	.252
Mar. 5	1.0	13.5	12.6	13.0	3.16	.251
Mar. 25	1.1	14.0	13.2	13.5	3.76	.286
108						
Jan. 21	0.6	7.5	8.5	8.1	1.97	.232
Mar. 1	1.0	10.8	11.6	11.3	3.16	.272
Mar. 11	1.0	12.5	11.4	11.9	3.56	.310
Mar. 24	1.1	13.6	14.0	13.9	3.96	.283
110						
Feb. 4	1.4	12.1	12.0	12.1	2.56	.213
Feb. 24	1.2	10.5	10.8	10.7	3.02	.280
Mar. 5	1.3	13.8	12.8	13.2	3.26	.255
Mar. 25	1.4	15.6	14.2	14.8	4.01	.284
111						
Feb. 4	0.6	11.2	10.5	10.8	2.23	.212
Feb. 24	0.7	10.5	10.7	10.6	2.90	.271
Mar. 3	1.0	12.3	11.8	12.0	2.92	.248
Mar. 5	1.3	13.8	12.8	13.2	3.26	.254

*Average depth of snow determined from weighted average of columns 3 and 4.

values for individual samples ranged from 25 to 78 percent. Similar results have been reported by other investigators; for example, Black (1) estimated that the measured precipitation at Point Barrow, Alaska (under highly-exposed conditions) was underestimated by 200 to 400 percent.

Undoubtedly, several factors contributed to the undercatch by the gauges such as gauge characteristics, height of orifice and hand-sampling errors. Under the highly-exposed conditions it is assumed that the predominant factor influencing the result was the wind velocity during the storm event. Wilson (6) found that the average values for the gauge catch deficiency, as a percent of the true catch for snow, varied from 0 percent with a wind velocity of 0 mph to as high as 73 percent when the wind velocity was 50 mph.

In other respects the winter of 1969 was somewhat unusual inasmuch as only in a few cases during the measurement period was there a decrease in the depth of snowpack at any of the sampling sites, and an increase in the average depth of snowpack was usually reflected by a corresponding increased depth recorded by the gauges. This result infers that during the year no significant redistribution of the snowpack on the area occurred. This was substantiated by visual observations of the lack of appreciable gully accumulations. Preliminary analysis of wind records indicated relatively low wind velocities for the period, and also, the temperatures during the month of January were much below the long-time normal average.

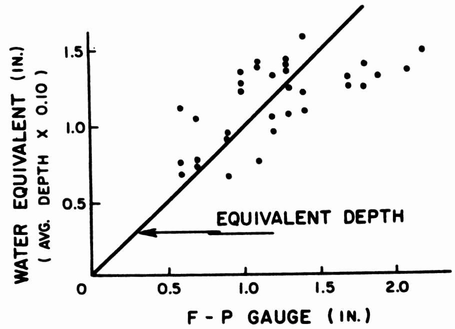

Figure 3. Comparison of Water Equivalent of Snowpack as Calculated by Ground Survey (Avg. Depth x 0.10) with F-P Gauge Readings.

Another comparison made with the data was to plot the gauge readings against the water equivalent of the snowpack on the ground using the snow depth measurements and assuming a density of 0.1 gm/cc. This graph is shown in Fig. 3. It is interesting to note from the graph that, based on the assumption of a snow density of 0.1 gm/cc, the ratio between ground retention and gauge readings is approximately 1:1.

McKay (4), in a study which utilized the same density assumption reported that, "Most prairie snow courses retain only about 60 percent of the accumulated snow reported at adjacent climatalogical stations". Although the results reported in Fig. 3 are not in agreement with McKay's findings it is recognized that there were several important differences between the studies which would have contributed to this result. These differences were:

1) McKay's study was based on freshly-fallen snow whereas the results reported herein utilizes the entire snowpack,

2) McKay's data were based primarily on the catch recorded by standard unshielded MSC gauges rather than F-P shielded gauges, and

3) Many measurements used by Mc Kay were taken from gauges located in farmyards. The exposure conditions in these yards would favor overcatch because they would act as natural snow traps caused by surrounding obstructions, for example hedges and buildings. In contrast, all F-P gauges were highly exposed.

For years it has been assumed that the density of freshly-fallen snow is 0.10 gm/cc. Whereas, the results presented in Fig. 3 would tend to support and in part explain the acceptance of this assumption, it should be reiterated that the comparison (Fig. 3) is made on the total depth of snow which has been subjected to climatic elements and subsequent metamorphism. When the differences in depth readings were taken (assuming they represented freshly-fallen snow having a density of 0.10 gm/cc) and plotted with differences in gauge readings, a similar result occurred. In general, it was found the average density of the "freshly-fallen" snow approached the snowpack average density of 0.25 gm/cc (see Table 1).

In Table 1, it can be observed in general, that only small changes in the density of the snowpack occurred during the measurement period.

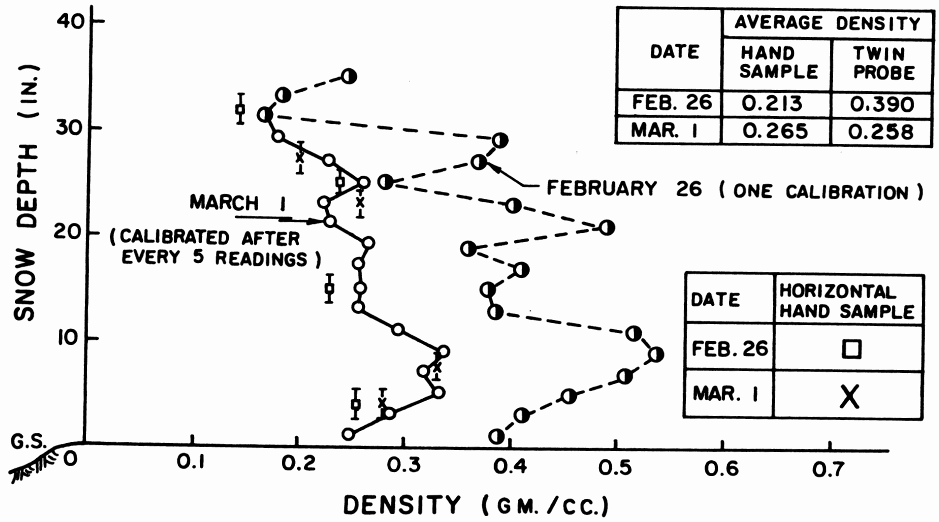

Figure 4. Comparison of Snow Density Measurements as Affected by Recalibration of Equipment

SNOW DENSITY MEASUREMENTS WITH NUCLEAR EQUIPMENT

Another segment of the study was concerned with the evaluation of the accuracy - of - measurement and the operation of a twin-probe density gauge to obtain snow density measurements when used under cold weather conditions. The particular instrument used in the study was the Troxler SC-10, Two-Probe Density Gauge manufactured by the Troxler Electronics Laboratories, Raleigh, North Carolina.

Instrument Operation

A major problem of concern in operation of the density equipment, particularly as applied to measurement in deep snowpacks, is the "drift" which may occur in the readings and the consequent effect they have on errors-in-measurement.

Two tests were conducted to study this effect. On February 26, 1969, a complete traverse of a pack approximately 3 feet in depth was made in 2-inch increments with only an initial calibration of the equipment. On March 1, 1969, a similar traverse of the pack was made only the system was recalibrated after each set of five readings. On completion of each test, horizontal "hand samples" were taken with a 2½ inch aluminum sampling tube in the snow profile between the tubes in which the density measurements had been made.

A comparison of the data obtained from these tests is shown in Fig. 4. From these data, it is evident that without frequent recalibration significant errors-in-measurement of the average density of a snowpack may occur. For example, the average density of the pack as determined by the system (without recalibration) was 0.390 gm/cc compared with an average density calculated by "hand samples" of 0.213 gm/cc. Conversely, in the second test, with frequent recalibration, the average densities were in good agreement: 0.258 gm/cc compared with 0.265 gm/cc found by "hand sampling". Some difference in the results obtained by the two sampling methods would naturally be expected since the average density computed from the hand samples was computed as the simple arithmetic average of a few values whereas that average determined by the instrument was the integrated value of the curve taken in 2-inch increments.

The principal findings of this study indicate that frequent recalibration of the equipment is needed to reduce the errors - in - measurement, if one-minute count readings are taken at small depth increments. This may possibly be compensated for by reducing the count rate time at any depth. In no case, however, would it appear that the instrument should be used continuously for periods more than about 10 minutes without recalibration.

Temperature Effects

Both Kriz (2) and Smith *et al.* (5) have shown that the count rate obtained from the Troxler two-probe apparatus depends upon the temperature at which the equipment is operated. Both agree that the scintillation detector is the component which is affected by temperature changes. When the system was operated in the range of 60°F to 100°F, Kriz found that for a particular operating setting a peak count rate was obtained between 72°F and 88°F. Higher photomultiplier tube voltage produced a peak at a higher temperature. Smith *et al.* found that at 3°C the count rate increased by approximately 0.3% per degree C, and at 20°C it increased approximately 1.2% per degree C.

If, for a given temperature, the percent change per degree were actually constant for all count rates, no error in density would occur because the basic equation which governs the passage of radiation through a homogeneous material is

$$I = I_o e^{-\mu \rho x} \qquad \text{.......... 1}$$

where I = measured beam intensity,

I_o = unattenuated beam intensity,

e = base of the natural logarithms,

ρ = density of the material,

μ = mass attenuation coefficient, and

x = length of attenuation path.

All calculations are carried out in terms of the ratio of the counts ob-

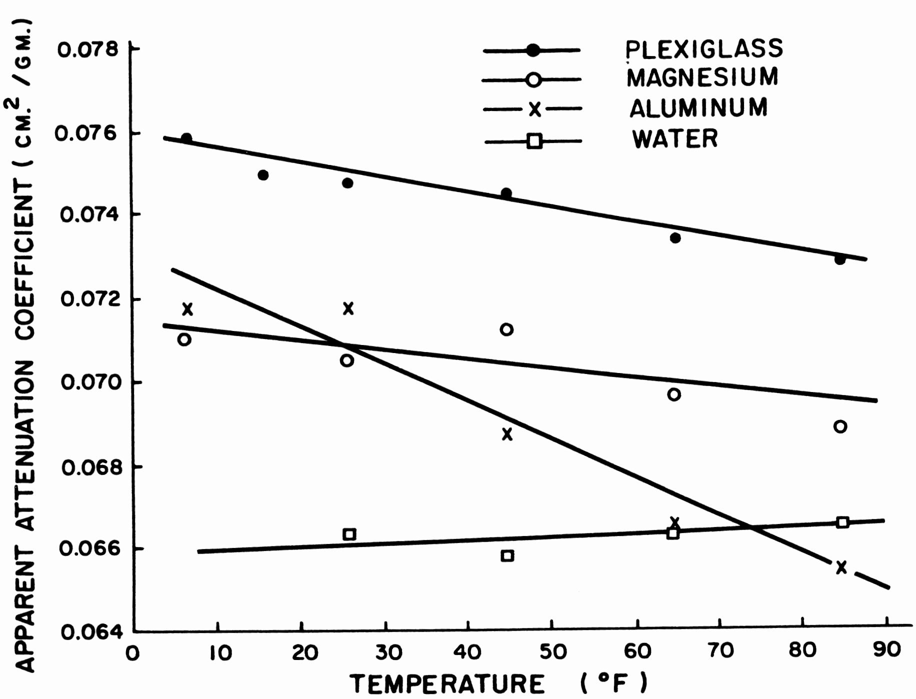

Figure 5. Apparent Attenuation Coefficient Versus Temperature

tained from the material to the counts obtained from a standard or an unattenuated beam. If, however, the percent change is not constant for all count rates, a calibration for temperature effects is necessary.

This correction can be accomplished by obtaining an apparent attenuation coefficient as a function of temperature. Fig. 5 shows the results obtained when the apparent attenuation coefficients for plexiglass, magnesium, aluminum and water are plotted against temperature. Water, the least dense of the materials and consequently, the one with the highest count rate for a given thickness exhibits only a small change in the apparent attenuation coefficient. Plexiglass and magnesium exhibit a moderate change in apparent attenuation coefficient while aluminum, the densest material, exhibits a large change in apparent attenuation coefficient. Consequently, although a single attenuation coefficient could be used for water or snow, it would appear that the attenuation coefficient used for the standard would have to be corrected for different temperatures.

CONCLUSIONS

The principal findings of the study are as follows:

1. Under highly-exposed, prairie conditions, shielded Fischer-Porter precipitation gauges were found to catch, on the average, only 47 percent of the snow-water equivalent of the snowpack retained on the ground.
2. Reasonable estimates of melt water available in snowpacks can be made from precipitation gauge measurements only when supplemented by snow-water equivalent measurements.
3. Considerable care and patience, including frequent recalibration of the equipment, are required if satisfactory results are to be obtained from the gamma transmission method for determining snow density.
4. For accurate snow density measurements, the apparent mass attenuation coefficient of the calibration standard should be corrected for temperature; however, the apparent mass attenuation coefficient for water does not require a temperature correction.

SUMMARY

Comparisons are made between snow measurements taken from shielded Fischer and Porter (F-P) precipitation gauges, and snow depth and water equivalent measurements taken at points located on the perimeter of a 400-ft diameter circle surrounding each F-P gauge. Under highly-exposed prairie conditions, the F-P gauges caught, on the average, only 47 percent of the snow-water equivalent of the snowpack retained on the ground. Consequently, reasonable estimates of melt water available in snowpacks can be made from precipitation gauge measurements only when supplemented by snow-water equivalent measurements.

Comparisons are also made between snow densities obtained from measurements made with a twin-probe gamma radiation apparatus and hand samples. It was found that frequent recalibration of the gamma radiation equipment is necessary if satisfactory measurements are to be obtained. It was also found that the apparent attenuation coefficient for calibration standards such as plexiglass, magnesium, and aluminum required temperature corrections however, the apparent attenuation coefficient of water varies only slightly with temperature.

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