DENSITIES OF PRAIRIE SNOWPACKS[1/]

By

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Introduction

On the Prairies, snow reserves are a main and vital source of manageable fresh water supply. In these regions, in the absence of severe, localized thunderstorm activity, the melt released by snow may account for as much as 80 - 85% of the surface runoff volumes, and thus represent the major component available for storage for domestic water supplies.

In addition, 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, whereby they are retained until late in the season when climatological conditions favor high melt rates. Under such circumstances, rapid melt rates may result because: (a) the pack is shallow with little capacity to store heat, and therefore, it reaches isothermal conditions very rapidly, (b) the soil temperature is generally less than 32°F, and thus the infiltration rate of the soil is low, and (c) considerable heat flux may be advected to the pack from adjacent fallow land.

Snow Density

Snow depth information although easily obtainable does not provide a good measure of the water reserve over an area because of the variability of snow density. A vertically-averaged sample of the snow pack density taken prior to active melt reflects the influence of many factors of the preceding winter's climate. Density changes in snow may result from any or all of the following processes:

(1) Heat exchange to the pack as a result of conduction, condensation and radiation.

(2) The pressure caused by the weight of overlying snow.

(3) Wind.

(4) Temperature and water content variations within the pack.

(5) Percolation of melt water through the pack.

Densities of Freshly-Fallen Snow

Densities of freshly-fallen snow have been observed to range from 0.004 to 0.34 (McKay 1970). In 1970, in effort to obtain some estimate of the density of freshly-fallen snow under the Prairie Environment, a simple experiment was conducted. In the tests, four, 16-inch square, white, ceiling tile were placed in a square pattern along the perimeter of a circle of approximately 100 foot radius. After each snowfall, the amount accumulated on the tiles was melted and an average value of the snow density obtained. Three sites were sampled and the results obtained are summarized in Table 1.

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Table 1. Density of Freshly-Fallen Snow

Date 1969/70	Location	Depth on Tiles (in)	Density	Snow[a] Condition
Dec. 22	1	2.3	0.049	N
	2	1.8	0.045	N
	3	1.3	0.040	N
Dec. 29	1	1.3	0.070	N
Jan. 22	2	4.5	0.041	N
	3	3.5	0.059	N
Mar. 10	1	0.3	0.125	N & D
	2	0.70	0.040	N
	3	0.70	0.251	N & D
Mar. 11	1	0.80	0.225	D
	2	0.80	0.223	D
	3	0.80	0.240	D

[a]N - New Snow, D - Drifted

From the data given in Table 1 it can be observed that,

1. The average density of freshly-fallen snow on the Prairies is approximately 0.045. This value seems to be somewhat independent of time. Although this observation was evident for the period and year of measurement, it is recognized that it cannot be assumed to be generally applicable. The density of freshly-fallen snow is time-variable dependent on prevailing meteorological conditions.

2. The marked effect of drifting on snow-density measurements is indicated by the samples taken on March 11, 1970 which showed an average snow density of 0.23. These samples were obtained under near blizzard conditions. Assuming, the density of new snow was 0.040; the results indicate a six-fold increase in density caused by drifting in a period less than twenty-four hours. These results agree with those reported by Church (1943) in which he observed that snow with initial density of 0.036 - 0.056 increased to a density of 0.176 after twenty-four hours of drifting.

Many difficulties arise in obtaining accurate density measurements of freshly-fallen snow under highly-exposed Prairie conditions. Emphasis has been placed on the necessity of sampling as soon as possible after the snow occurs to minimize the effects of compaction by wind. In addition, continual ground drift mandates that the collecting surface be cleaned regularly. Conversely, in many cases the surfaces may be blown free of snow during the storm. Finally, it is difficult to obtain an accurate measure of snow depth because of the shallow depth accumulations and, therefore, the error-in-measurement may be appreciable. Although the tiles functioned reasonably well for their intended purpose, it is recognized there is a difference in the coefficient of friction of the tile compared to a snow surface, and therefore, a difference in their retention coefficients.

Seasonal Variation in Snow Density

During the winters of 1968/69 and 1969/70 periodic measurements were made in the field at the Bad Lake IHD Representative Basin of snowpack densities. Ten sites within an area of approximately 25 square miles were sampled. On each sampling date, six samples were taken with a six-inch diameter aluminum tube from within a 400 diameter circle. The samples were averaged to obtain a representative value for each location. In total, 74 values were obtained. Note: the standard "Mount Rose" sampler or "Prairie Kit" were found to be inadequate for obtaining accurate measures of the water equivalent of the shallow packs. The snow depths ranged to a maximum of approximately 16 inches.

Snow densities obtained at different sampling dates are plotted in Fig. 1 with the average seasonal change delineated by the solid line marked, "Bad Lake". As noted by the curve the average density of the packs increased only slightly from 0.22 - 0.24 during the months of January and February. During March, the increase was more rapid, reaching a density of approximately 0.28 by March 24. This trend would be expected because of conditioning of the snow pack prior to active melt. In both years, runoff commenced during the second week in April.

The results are in agreement with those given by McKay (1970) for Regina as shown plotted on the Figure. The main differences between the curves is that major changes in the densities of snow packs near Regina occur at an earlier date than those at Bad Lake. This trend would be expected because of differences in latitude of the two locations; Bad Lake - 51°18'N, Regina - 50°29'N. Hence ripening or conditioning of packs near Regina would probably occur earlier than at a more northern latitude. In addition, the Regina region may also be influenced by Chinook activity.

The average snow density calculated from all samples was 0.23. It is of interest to note that this value is the same as that obtained for drifted snow. In view of the fact that Prairie snow packs do not exhibit major changes in density during the winter months, or periods free of active melt, then reasonable predictions of snow water equivalents useful for flood forecasting may be obtained from depth measurements using an assumed snow density of 0.23. It is important to recognize that if the depth measurements are made late in the season when the pack is ripening or its density changing with time then care must be exhibited in selecting a density for the pack.

Snow Pack Density Profiles by Gamma Radiation

The two probe gamma radiation apparatus, has been used by Smith et al. (1967) and Gray et al. (1970) to obtain density profiles of the snow pack. In both studies the equipment used was a commercial product manufactured by Troxler Electronics. It consisted of a 5 mc Cesium 137 source, a NaI thallium activated crystal detector with associated photomultiplier and preamplifier, a pulse height analyzer, and a scaler-timer-high voltage supply. The scaler also contained a ratemeter. Smith et al. spaced the source and detector access tubes 12 inches (30.5 cm) center to center, while Gray et al. used a 24-inch (61 cm) spacing.

The equipment had been designed so that the source-detector system would "see" only a 1/2 inch (1.77 cm) layer when the pulse height analyzer was set so that scattered radiation was not counted. To obtain a density profile of the pack many readings, generally of one minute duration, had to be taken. Smith et al. attempted to overcome this difficulty by moving the source and detector slowly through the pack while recording the count rate from the ratemeter. The source and detector were moved by hand and the rate of travel was timed with a stop watch. They concluded that a scanning rate of 5 seconds per inch produced a more exact density profile reading than even the readings obtained from stationary counting.

Gray et al. not only found the length of time to take many individual readings quite objectionable, but also found that because of calibration drift in the instrument it had to be recalibrated several times while obtaining readings on a single profile of only a few feet. To overcome this difficulty it was decided to adopt a scanning system as proposed by Smith et al. This would reduce the time required to obtain a density profile and consequently the system would only have to be calibrated once for each profile.

The Equipment and its Operation

Rather than moving the source and detector by hand, which could prove quite monotonous and inaccurate, they were each attached to a 1/2 inch square rack and a small electric motor was used to drive the racks at a speed of 15 inches (38.1 cm) per minute.

Because of calibration difficulties with the pulse height analyzer at low temperatures, the original scaler and pulse height analyzer were replaced by a Hewlett-Packard 5201L combination scaler-analyzer and a Hewlett-Packard 6515A high voltage supply. The BCD output from the scaler was fed into a Hewlett-Packard 5050B digital printer.

To calibrate the instrument under operating conditions, readings were taken on a 10-inch (25.4 cm) thich plastic block of known density and known mass attenuation coefficient. When the traversing mechanism was in operation and a profile was being scanned, counts were read and automatically recorded for 0.2 sec. intervals.

To determine the ability of the equipment to detect abrupt changes in density, a machined plastic block with various heights of notches was scanned. The variation in width of the block served as an apparent variation in density. This block would correspond to a very layered profile with instantaneous density changes. Figure 2(a) shows the calculated densities and the actual apparent densities of the block. Figure 2(b) shows the apparent densities that the source detector system should "see". The latter densities are different from the actual apparent density because at all times the source-detector system "sees" a 1/2 inch thick layer. The mean deviation between the densities calculated at the individual points and the densities that the source-detector system was "looking at" was 0.014 gm/cm^3. Figure 2(a) shows that the true change in density can be detected if a layer is greater than 1/2 inch thick. However, if a layer is less than 1/2 inch, only a change proportional to the thickness of the layer will be detected.

Figures 3 and 4 are examples of actual snow density measurements taken in the field on March 13, 1970. Figures 3 (a) and 3 (b) are repeated measurements on the same profile. In Figure 3 the mean deviation between the two plots is 0.023.

The average profile densities for Figures 3 and 4(b) (shown at bottom) range from 0.2355 to 0.2459. These values are in good agreement with the densities for drifted snow shown in Table 1 and those determined from hand samples. It is worthy of comment that it appears that the average density of drifted snow varies only slightly over a large range of depths, and that the occurence of minor melt layers in the profile do not materially affect the average density of a vertical-integrated sample. The average profile density for Figure 4(b) was 0.1866, a value that is considerably different from the others. This profile was in the midst of low brush (2 feet) which prevented the snow from becoming packed as densely as in the open areas.

Summary

During the winters of 1968 and 1969, several studies were undertaken related to snow in the highly-exposed Prarie Environment.

It was found that the average density (during December-March) of freshly-fallen snow on the Prairies was approximately 0.045. Problems related to the physical measurement of freshly-fallen snow are discussed, and it is shown that freshly-fallen snow may increase in a density to a value of approximately 0.23 within 24 hours after the occurrence of the snow. This density is approximately equal to the average density which the pack maintains during the winter months (melt-free period).

It is shown that the seasonal variation in snow pack density does not change appreciably during periods prior to active melt. Because of this fact water equivalent estimates may be made from measured depths using an assumed density of 0.23.

A two probe gamma radiation apparatus was modified so that the source and detector travel at a rate of 15 inches (38.1 cm) per minute through the snow profile. When repeated measurements of a single profile were made the mean deviation in densities for point readings throughout the profile was 0.023. The difference between the average densities for the entire pack, on repeated measurements, was approximately 0.005. Measurements made on a notched plastic block show that the system is capable of accurately detecting changes in density due to layering, if the layers are greater than 1/2 inch thick.

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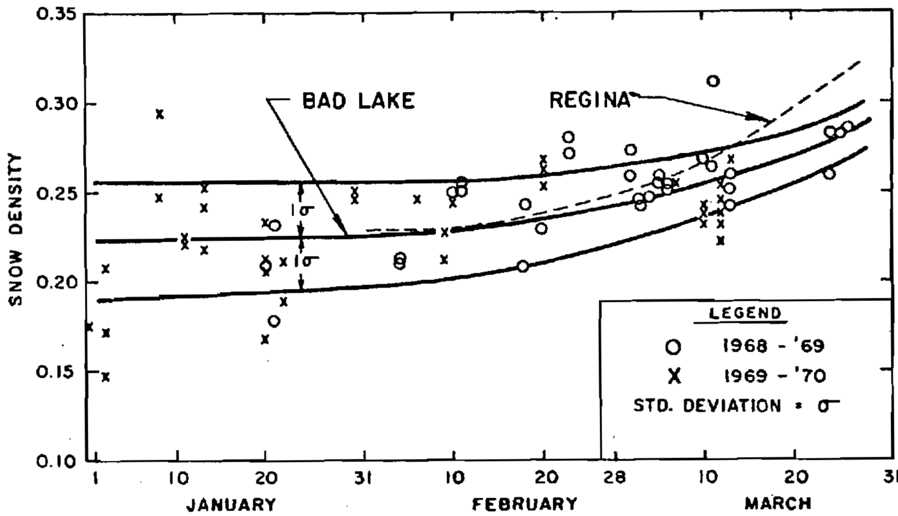

Figure 1. Seasonal Variation in Snow Density

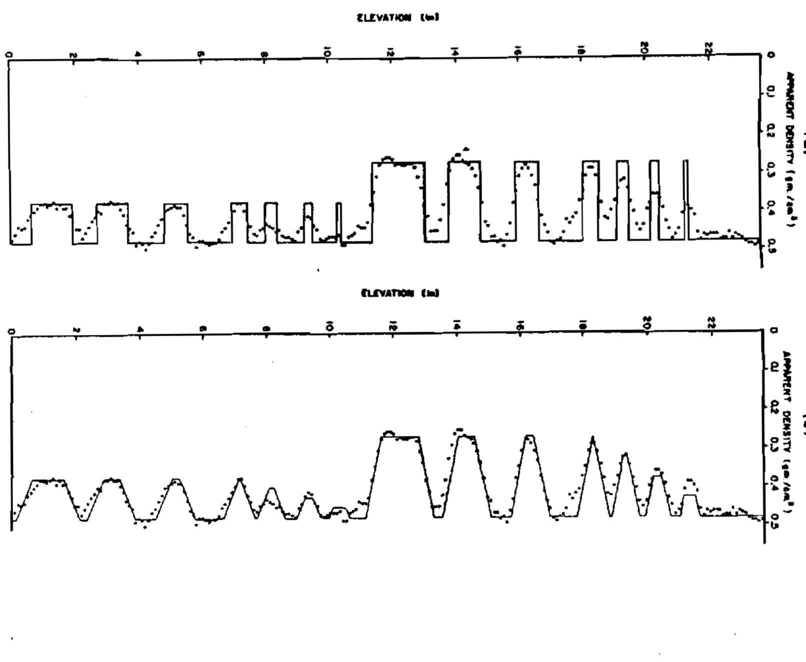

Figure 2. Apparent Density of Notched Plastic Block as Determined by Gamma Ray Scanning
(a) Actual Notches in Block
(b) Notches as "Seen" by Source-Detector System

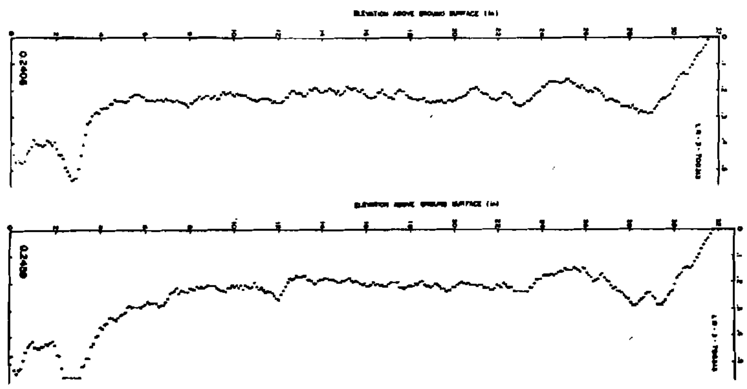

Figure 3. Snow Density Profiles (Repeated Profile)

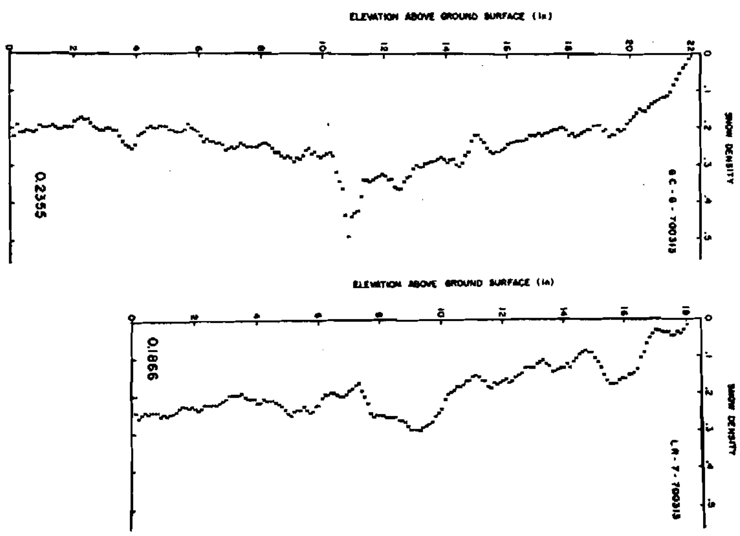

Figure 4. Snow Density Profile

LITERATURE CITED

Church, J. E. 1943. The human side of snow. The Scientific Monthly. Vol LVI, 211-231.

Gray, Don M., Norum, D. I. and G. E. Dyck. 1970. Snow measurement in the Prairie Environment. Journ. Canadian Soc. of Agric. Engrs. (In Press).

McKay, G. A. 1970. Precipitation. Section II, Handbook on Principles of Hydrology. Mortimer Printers Ltd., Ottawa (In Press).

Smith, J. L., D. W. Willen and M. S. Owens. 1965. Isotope snow gauges for determining hydrologic characteristics of snowpacks. In isotope Techniques in the Hydrologic Cycle (G. E. Stout, Editor). Geophysical Monograph Series, No. 11. American Geophysical Union. pp 11-21.