DENSITY OF FRESHLY FALLEN SNOW

J. G. Potter (*)

Canadian Meteorological Service, Toronto, Canada

Since 1843 it has been the custom in Canada to measure the depth of the freshly fallen snow in inches and assume that 10 inches of freshly fallen snow were equivalent to one inch of water in estimating the water equivalent of the snowfall. The earliest reference which we can now find for the basis of this assumption is the following statement from "Instructions to Observers" (1878):

"A long series of experiments conducted by General Sir J.H. Lefroy, formerly Director of the Toronto Observatory, led to the conclusion that this relation, (1 to 10) is true on the average. It is not affirmed that it holds true in every case, as snow varies in density. In the long run, the error occasioned by assuming it to be true is not greater than such that attends other methods sometimes affirmed to be more accurate."

Captain Lefroy arrived at Toronto in 1841 and the above method of estimating the water equivalent of the snowfall at Toronto was adopted for the winter of 1843-44. Captain Lefroy remained in Canada until the spring of 1853. Thus there is some doubt as to whether he used data for two winters only, or whether he continued his experiments beyond the time when the method of estimating the water equivalent of snowfall was first adopted. The method he used to measure the density is not known.

"Freshly fallen" snow is regarded in Canada as that which has fallen since the time the last observation was made. It usually refers to the snowfall in the last six hours at our Principal Climatological Stations at present, although this period has varied in the past, while at Ordinary Climatological Stations it refers to the snowfall during the 12 or 24 hour period between observations.

After measuring the density of freshly fallen snow at Saskatoon, Currie (1948) stated that it required 13 inches of freshly fallen snow to obtain the equivalent of one inch of water. Rae (1950) states that 5 inches of freshly fallen snow in the Arctic are equivalent to one inch of water. Since we have no information on the conditions under which Captain Lefroy carried out his original investigations, and two published references to the density of freshly fallen snow in later years have thrown doubt on the accuracy of his conclusions, a systematic check on the error in precipitation measurements resulting from the use of this conversion factor in different snowfall regions in Canada appears desirable.

During the field testing by the Meteorological Service of Canada of a snow-gauge with a modified nipher type shield (Fig. 1) it was suggested in late 1956

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that the observers attempt to measure the depth of the catch of snow in the gauge as well as its water content. This suggested measurement is particularly difficult to make in that the inner container of the snow gauge is made of copper with a ten inch diameter opening at the top and is 22 inches deep. Under certain conditions there is considerable adherence of the snowflakes to the side of the gauge and even with the shield there may be enough turbulence inside the gauge that the snow may not collect uniformly. At some stations there were comments made by the observing staff that it was impossible under any condition to accurately measure the depth of the snow in inches. At other stations where the experimental snow gauges were installed the staff carried out these observations consistently for 2 1/2 winters. They submitted records which contain not only the depth of snow caught in the gauge and its water equivalent, but also the air temperature at the time of observation, a description of the amount of drifting in surrounding areas in the last six hour period, and a brief description of the type of snow i.e., whether it is fluffy, moist, and whether there had been any occurrences of rain or ice pellets since the time of the last observation. While these data have certain limitations due to the difficulty of measuring the snow depth inside the container, yet from the measurements of the depth of snow and the actual water content it is possible to calculate the density of the freshly fallen snow caught in the snow gauges.

In abstracting the data to be used from the original records, the monthly amounts of the depth of the freshly fallen snow and the total water equivalent were found using only those occasions when the temperature at both the beginning and ending of the period were below freezing and there had been no liquid precipitation. Then the data for the same months for each station for the various years were added together. In most cases there were reports for three winters for the period Oct.-Jan. and reports for only two winters for the months Feb.-Apr. When the total winter content is divided by the total depth in inches, we have the average density in grams per cubic centimetre as listed on the second line for each station in Table I. In this table data are only listed for months when the sum of the catches for that month of freshly fallen snow was 10 inches or more. In the final column of Table I are listed similar data based on the total catch for all months.

When the average densities for the snowfall season in Table I are examined it will be noted that those for the first 3 stations in the Maritime Provinces are very close. That for Montreal also fits this group. There is then a sharp break and the average densities for Trenton and Fort William are over 25% lower. The average densities for Rivers, Grande Prairie, Fort Nelson, and Watson Lake, are not far from that given for Saskatoon by Currie, but those for Lethbridge and Whitehorse are again comparable to the higher average seasonal density of the snowfall in the Maritimes.

When an average density is computed based on the average density for each station the result is 0.095 gms/cm^3. The weighted mean based on the total catch at these 12 stations is 0.099 gms/cm^3.

The variation in the average densities from station to station suggests that these may be related to different climatic regions. However, due to the difficulty in measuring snow depth in the present container, caution should be used in any further use of these results other than the suggestion of the variation and the possible need for further study of this variation under more suitable conditions.

Since the original adoption of the conversion factor was based on "On the average" or "In the long run", the possible error introduced by using it for single storms was also investigated by listing the variation in density for the heavier snowfalls. In this case, only snowfalls when the catch in the gauge during a six hour period measured one inch in depth or more were considered. The same temperature criteria were applied. From these data it was possible to select snowfalls which had the least and the greatest density during the period at each station. The results are listed in Table II.

The extremes of density for individual snowfalls as listed in Table II illustrate that it may require 25 or even up to 50 in. of fresh snow to give the equivalent of 1 in. of water in some snowfalls, while at other times 5 in. or less of snow may be equivalent to 1 in. of water. It will be noted that Table II does not include occurrences such as a 6 hour period at Trenton when, with the temperature ranging from 22 to 27° F. and a mixture of snow, ice pellets, and freezing rain falling, a solid mass with a density of .53 gms/cm^3 was caught in the gauge. When the 1 to 10 ratio is applied to single snowfalls the water equivalent may be underestimated by approx. 100%, or overestimated with considerably greater error. Such estimates would be of major concern in any storm study for hydrologic purposes, and are likely a contributing error to runoff forecasts when such forecasts, based on earlier snow surveys, are up-dated by compensating for precipitation falling after the time of the survey.

To meet the need for more exact information on the water content of freshly fallen snow the Meteorological Service of Canada will modify its present method of observing snowfall. All Principal and Ordinary Climatological Stations will continue to measure the snowfall depth in inches as at present. The requirements for this type of information are many and will continue to be met. However, in the near future at Principal and a few selected Ordinary Climatological Stations the water equivalent of the snowfall caught in a snow gauge will be measured. In 1961 there should be almost 100 of these gauges in operation and another 150 - 200 stations will be similarly equipped as soon as possible. Ordinary Climatological Stations not equipped with a snowgauge will continue for the time being to estimate the water equivalent as in the past.

The snow gauge adopted as the Meteorological Service of Canada standard gauge is illustrated in Fig. I. The modified Nipher shield of spun aluminum is mounted on an adjustable stand which allows for an adjustment in height from 5 ft. to a maximum of 12 ft. While in operation the height of the shield will be adjusted to keep the rim at 5 ft. above the snow cover in the vicinity of the gauge. Two copper catchment containers of 5 in. internal diameter and approximately 22 in. deep are supplied with each gauge and the exposed container is replaced with an empty one at each observation. The catchment of snow is melted and the water content measured by a graduate supplied with the snow gauge.

References

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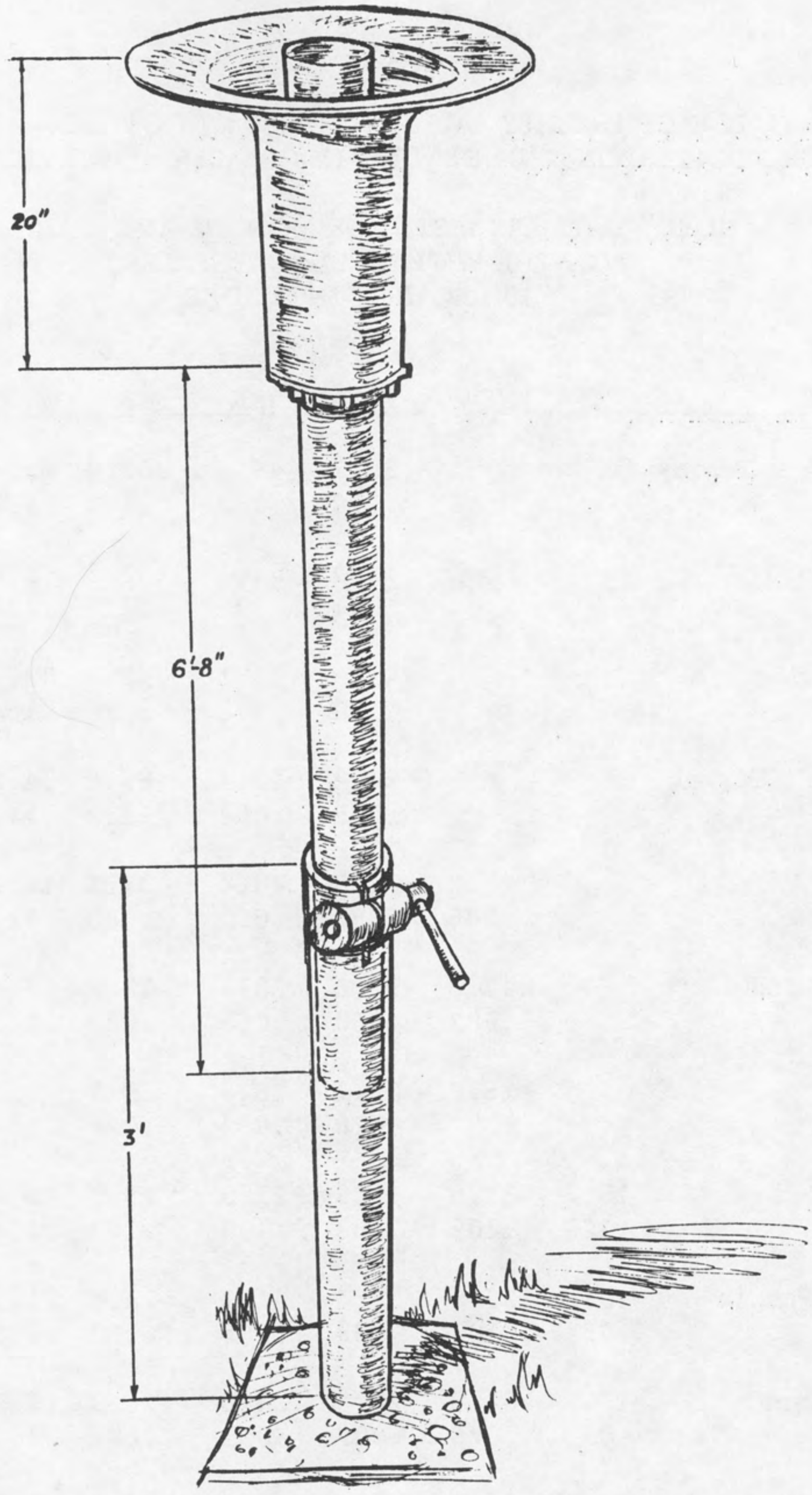

Figure I - Meteorological Service of Canada standard snow gauge with modified Nipher shield and adjustable stand.

TABLE I

TOTAL CATCH OF FRESHLY FALLEN SNOW (in.) OCT 1956 - JAN 1959
WITH THE CORRESPONDING DENSITY IN GRAMS/cm^3 ON THE SECOND LINE

NOTE: DATA ARE LISTED BY MONTHS AND TOTAL. MONTHS WITH TOTAL CATCH LESS THAN 10 ins. NOT INCLUDED

STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	TOTAL
St. John's (Torbay)			39.2	49.4	105.8	69.4	16.6	368.8
			.110	.082	.103	.098	.083	.103
Greenwood			13.0	53.1	33.3	45.9		164.6
			.091	.095	.117	.124		.104
Summerside			43.8	71.2	73.4	32.1	29.0	256.7
			.100	.113	.120	.104	.106	.107
Montreal (Dorval)			24.2	45.4	65.6	34.2		225.6
			.095	.094	.110	.114		.104
Trenton		27.2	32.5	48.4	35.1	14.7		158.9
		.086	.067	.080	.083	.113		.082
Fort William		12.3	17.0	29.1	13.9	11.4		92.1
		.082	.080	.065	.082	.065		.074
Rivers		25.8	22.1	18.3	28.2	16.8		111.2
		.087	.078	.082	.074	.114		.085
Lethbridge	15.7	31.6	15.9	21.9	25.9	13.1	10.0	135.9
	.123	.102	.088	.100	.104	.114	.124	.105
Grande Prairie	40.6	25.9	53.4	41.2	24.8	21.6		209.6
	.092	.100	.093	.085	.100	.105		.095
Fort Nelson	17.5	32.8	27.5	28.6	25.9	15.2		166.4
	.092	.076	.097	.091	.086	.081		.087
Watson Lake	14.3	31.9	45.7	24.6	39.1	21.7		184.2
	.092	.082	.085	.089	.084	.081		.085
White Horse	13.9	14.7	25.9	21.9	21.5			130.9
	.114	.113	.103	.094	.105			.103

TABLE II

RANGE OF DENSITY FOR SNOW CATCHES OF 1 in. OR MORE
OCT 1956 - JAN 1959 TEMPERATURE 30° F. OR LESS

	Least	Greatest
St. John's (Torbay)	.04	.28
Greenwood	.03	.28
Summerside	.04	.20
Montreal (Dorval)	.04	.19
Trenton	.02	.19
Fort William	.04	.10
Rivers	.02	.22
Lethbridge	.04	.23
Grande Prairie	.04	.14
Fort Nelson	.04	.14
Watson Lake	.05	.15
Whitehorse	.04	.12