# EVAPORATION FROM SNOW COVERS IN EASTERN CANADA

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Hydrologists charged with the responsibility of estimating the amount of runoff from melting snow have long been interested in estimating the amount of evaporation from a snow cover. Although there have been a number of investigations on snow evaporation, it has been difficult to find an analysis that gives an order-of-magnitude for evaporation from the comparatively shallow snow covers that are subject to the weather conditions typical of Eastern Canada. The purpose of this report is to review the literature and experiments on evaporation from snow covers in other countries and to make a preliminary evaluation of some snow evaporation measurements taken at Ottawa during the 1956-57 season.

The theory of evaporation from snow covers will not be discussed in this report; Diamond has given a good analysis of the theory which would be of value to engineers (1). Trabert (2) was one of the first to develop an equation for predicting theoretical rates of snow evaporation. Sverdrup (3) developed an equation for predicting the rate of evaporation and melt from a snow cover which, from a theoretical viewpoint, is still a classic. Light (4) used Sverdrup's equation for heat and water flux to develop an equation for predicting theoretical rates of snow evaporation.

The basic theory of evaporation from a snow cover is the same as evaporation from a water surface. Good résumés of this theory, particularly the turbulent-exchange theory on which some evaporation formulas are based, are given by Thornthwaite (5) and E. R. Anderson and others (6).

The main problem in evaporation studies is to obtain reliable measurements under field conditions. Evaporation rates from open water, bare soil, or grass have been estimated by measuring the rate of evaporation from some standard pan or tank and from these measurements obtaining a coefficient which could be used to estimate evaporation from the surface area in question (7, 8). Evaporation rates from snow covers have usually been measured by filling pans with snow and placing them into the snow cover so that the surface of the pan is flush with the snow surface. The pans are usually painted white or are made of plastic to minimize radiation effects. The rate of evaporation from the pan is assumed to be representative of that from the larger snow surface area.

De Quervain (9) found that radiation did affect the evaporation rate if the pans were too shallow. Pans also interfere with the possible upward flow of vapour through the snow cover and there is some question as to what effect this has on the rate of evaporation from the snow surface. It is also impossible to obtain reliable results from pans during periods of precipitation or blowing snow. Some field measurements of evaporation were made in the Fraser Experimental Forest using a volumetric method and the pan method (10). Because of difficulties of measurement they were unable to obtain good comparisons between the two methods. It is apparent that the use of pans to measure snow evaporation has several drawbacks which make it difficult to obtain continuous, reliable records. Nevertheless, their use appears to be the only way that the order-of-magnitude of snow evaporation rates can be ascertained.

Later in this report the pan evaporation measurements of several workers in different countries will be compared. The coefficients calculated from these studies for the various snow evaporation formulae will be compared with the evaporation coefficient calculated from the snow evaporation measurements taken at Ottawa during the 1956-57 season.

## Field Measurements at the Ottawa Site

Snow evaporation was measured at Ottawa by placing circular pans (4 cm. deep with 355 sq cm. area) filled with snow, flush with the snow surface and weighing the pans at different time intervals. The weight loss or gain during the time period was assumed to be due to evaporation or condensation from the snow surface during the period of observation. The light aluminum pans were painted white to reduce the absorption of radiation from the sun.

The observation site was in an exposed location near an area where standard meteorological observations are made. The standard meteorological records obtained at this station were used in all calculations.

There were many days when it was impossible to obtain reliable measurements because of weather conditions. Whenever there was blowing snow, precipitation, or melting snow, observations were not taken because of uncertainty in the measurements. Furthermore, during the 1956-57 season, the duration of the snow cover was below normal in the Ottawa area and the opportunities for observation were limited.

## Analysis of Results

For each day during which evaporation was measured, the evaporation rate was calculated from the following equation:

$$Q = 0.00011\, p\, U_a \quad (e - e_s) \qquad (1)$$

Where Q = evaporation rate, gm/cm.$^2$/min.

$p$ = mean density of air, gm/cm.$^3$

$U_a$ = mean wind speed, cm./sec. (at height a cm.)

$e$ = vapour pressure of air in Stevenson Screen, millibars

$e_s$ = saturated vapour pressure over ice at the mean temperature of the snow surface.

The form of this empirical equation was developed from the more complicated Sverdrup equation (3) by assuming constant values for surface roughness and air pressure.

The mean wind speed was obtained by averaging the hourly wind speed values during the period of observation. The vapour pressure of the air was calculated from the mean relative humidity value recorded at 8.30 a.m. and at 4.30 p.m. The vapour pressure at the snow surface was calculated by assuming that the mean snow surface temperature is equal to the mean air temperature recorded in the Stevenson Screen.

Figure 1 shows the relationship between the calculated evaporation rate and the measured evaporation rates at the Ottawa site. The measured evaporation rate is the average rate from the three evaporation pans. Table I lists the results used to calculate the values shown in Fig. 1.

Calculated Evaporation Rates During the Month of March

The evaporation observations listed in Table I were all made during the colder winter months. During the spring melt period, which occurred in March in 1957, no evaporation measurements were made. Whenever melting conditions occur, water is present with the snow in the pan and it is doubtful whether evaporation rates from this mixture are the same as evaporation rates from a wet snow surface where the free water can drain downward. The order-of-magnitude of evaporation rates during the spring melt period were estimated using Equation (1) and the appropriate meteorological data. Whenever the snow was melting the vapour pressure was assumed to be equal to the saturated vapour pressure over ice at 32°F. Condensation was treated as negative evaporation.

The average calculated evaporation loss from the snow cover during the month of March for the years 1953-57 inclusive are plotted on Fig. 2. This total monthly evaporation loss was obtained by accumulating the calculated rates for a 10-hour day from 8 a.m. to 6 p.m. Because of the uncertainty of relative humidity values during the night, the evaporation rates were not calculated for this period. It is generally assumed that evaporation losses will be less during the night when there is no heat supplied by radiation and when the relative humidity values are higher than during the daylight hours. Croft (11) found that evaporation losses from a snow cover during the daylight hours were three to four times as great as losses during the night period.

Figure 2 thus only indicates total evaporation losses during part of the day and is only intended to indicate that average losses from a snow cover are generally under one inch of water during a month of spring runoff, and are generally much less than the precipitation during that month.

## Comparison of Evaporation Coefficients

The general form of Equation (1) is the same as that used by other investigators of snow evaporation. Research workers at the Central Sierra Snow Laboratory (12) have used the following form: $Q_e$ equals $K_e$ $(e_a - e_s)$ $V_b$; where $Q_e$ is the amount of evaporation or condensation, $e_a$ and $e_s$ are the vapour pressure of the air and the saturated vapour pressure over ice at the mean snow surface temperature respectively, $V_b$ is the wind speed, and $K_e$ is a constant. In addition, they calculated a $K_e'$ equal to $8.5\ K_e\ (Z_a Z_b)^{1/6}$, where the subscripts a and b identify the levels of measurement of the wind speed and air vapour pressure respectively, and $K_e'$ is the value of the coefficient when the wind speed and vapour pressure are measured one foot above the snow surface.

They have compared the evaporation or condensation constant $K_e'$ for several workers as follows:

| | | |
|---|---|---|
| Central Sierra Snow Laboratory Snow Investigations | (1954) | 0.0540 |
| Sverdrup | (1936) | 0.0674 |
| De Quervain | (1951) | 0.0770 |

By using the same units of vapour pressure in millibars, mean wind speed in miles per hour, evaporation or condensation in inches, and heights of measurement in feet, it was possible to calculate a $K_e'$ from the Ottawa measurements given in Table I. The mean $K_e'$ thus obtained was 0.046 which compares reasonably well with the 0.054 value obtained by the investigators at the Central Sierra Snow Laboratory. The fact that these coefficients are in the same general range strengthens the confidence in the use of this form of equation to determine the order-of-magnitude of snow evaporation rates.

## Comparison of Measured Evaporation Rates

There have been a surprising number of measurements of snow evaporation rates but, because of the difficulties of measurement, most of the records are sporadic and all the results must be qualified because of these difficulties. Although it is difficult to compare evaporation rates because of differences in sites and weather conditions, it was considered that, if the reported mean monthly rates and reported maximum daily rates were tabulated, a check on the order-of-magnitude of evaporation losses would be obtained. In addition, the references provide a useful bibliography on snow evaporation. This tabulation of references and reported evaporation rates are listed in Table II.

All the reported measurements appear to be within the same general range. The mean monthly rates compare favourably with the monthly rates calculated for the Ottawa site.

Discussion of Results

It is reasonable to conclude that the order-of-magnitude of snow evaporation from large snow covered areas can now be determined using present techniques, but it is difficult to determine the degree of accuracy of these calculated evaporation losses. Kaitera's experiments indicate that evaporation rate varies a great deal with exposure (20). Evaporation losses from a snow-covered slope facing north will be less than from a similar slope facing south under comparable conditions. Evaporation losses from snow cover is sheltered sites protected by forest cover will be much less than evaporation from snow cover in exposed sites. Evaporation losses must be calculated for representative sites which are typical of conditions over the area in question.

TABLE I

LIST OF DATA USED TO CALCULATE VALUES SHOWN IN FIGURE 2

| Date | Wind Velocity Ua cm/sec. | Vapour Pressure Difference e-es mb | Density of air $gm/cm^3$ $(x\ 10^{-3})$ | Calculated Evaporation Rate $gm/cm^2/min.$ $(x\ 10^{-4})$ | *Measured Evaporation Rate $gm/cm^2/min.$ $(x\ 10^{-4})$ |
|---|---|---|---|---|---|
| Dec. 6/56 | 134.1 | 1.08 | 1.30 | 0.208 | 0.15 |
| Jan. 3/57 | 268.2 | 0.61 | 1.36 | 0.244 | 0.122 |
| | 246.9 | 0.61 | 1.36 | 0.225 | 0.147 |
| Jan.17/57 | 219.5 | 0.21 | 1.40 | 0.071 | 0.02 |
| Jan.18/57 | 179.8 | 0.32 | 1.38 | 0.089 | 0.08 |
| | 179.8 | 0.32 | 1.38 | 0.089 | 0.10 |
| Jan.24/57 | 460.3 | 0.57 | 1.36 | 0.392 | 0.45 |
| | 460.3 | 0.57 | 1.36 | 0.392 | 0.46 |
| Jan.28/57 | 268.2 | 1.36 | 1.33 | 0.540 | 0.45 |
| Feb.11/57 | 292.6 | 0.95 | 1.35 | 0.415 | 0.53 |
| Feb.12/57 | 499.9 | 0.57 | 1.36 | 0.43 | 0.56 |
| Feb.19/57 | 524.3 | 1.50 | 1.32 | 1.14 | 0.95 |
| Feb.20/57 | 597.4 | 1.18 | 1.33 | 1.03 | 1.14 |
| Feb.22/57 | 170.7 | 1.61 | 1.32 | 0.40 | 0.47 |

* Average of 3 pans - 450 sq cm in area

TABLE II

Evaporation rates from snow during the spring melt period

| Investigator | Maximum Daily (in. of water/day) |
|---|---|
| De Quervain (9) | 0.032 |
| Ångstrom (13) | 0.051 |
| Kehrlein (14) | 0.050 |
| Shults (15) | 0.020 |
| Rudovits (16) | 0.019 |

| Investigator | Mean Monthly (in. of water/month) |
|---|---|
| Guy (17) | 0.31 |
| Poliakov (18) | 1.18 |
| Chmoicz (19) | 1.15 |
| Kaitera (20) | 0.48 |
| Fitzgerald (21) | 0.60 |

Any formula used to calculate snow evaporation is limited by the basic accuracy with which the variables of wind speed and vapour pressure can be measured. The measurement of accurate vapour pressure differences by standard meteorological instruments leaves much to be desired, particularly at low temperatures. The measurement of wind speeds is not too difficult for one site, but it is questionable how representative such observations are of the average conditions required for the calculation of evaporation losses over a large area. Attempts to estimate evaporation rates from a large area must take into account these factors.

One condition not covered by any evaporation formula is the effect on evaporation when the wind is strong enough to disturb the snow surface. In exposed areas where the wind can move large quantities of snow, this factor might result in evaporation rates considerably higher than a general evaporation equation would indicate. This factor usually is not important when the snow cover is melting as wet snow is cohesive and is not generally moved even by strong winds.

The only time the order-of-magnitude of snow evaporation amounts might be significant compared to snow melt is when there is a shallow snow cover and the snow-melt period is extended over several weeks. In this case, the evaporation from small pools of water and from exposed saturated soil near the snow cover might be of importance. When the snow-melt period is short, such as during the Chinook conditions reported by Hoover (22), the evaporation from the snow should be much less than the snow melt. As Diamond (1) points out, the theory of evaporation indicates that in these cases a much larger amount of snow must be melted than evaporated.

The order-of-magnitude of snow evaporation amounts might be of significance from a heat balance point-of-view for certain special investigations. From a hydrological viewpoint, evaporation losses from a large watershed area are likely to be less than the errors in obtaining samples of the total water content of the snow cover. For this reason, and because of the great difficulties in obtaining representative measurements of snow evaporation rates, it appears that hydrologists will have to be satisfied with calculated evaporation rates which can give an indication of the order-of-magnitude of snow evaporation losses.


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NOTE: EACH POINT REPRESENTS THE AVERAGE RATE FROM 3 PANS.

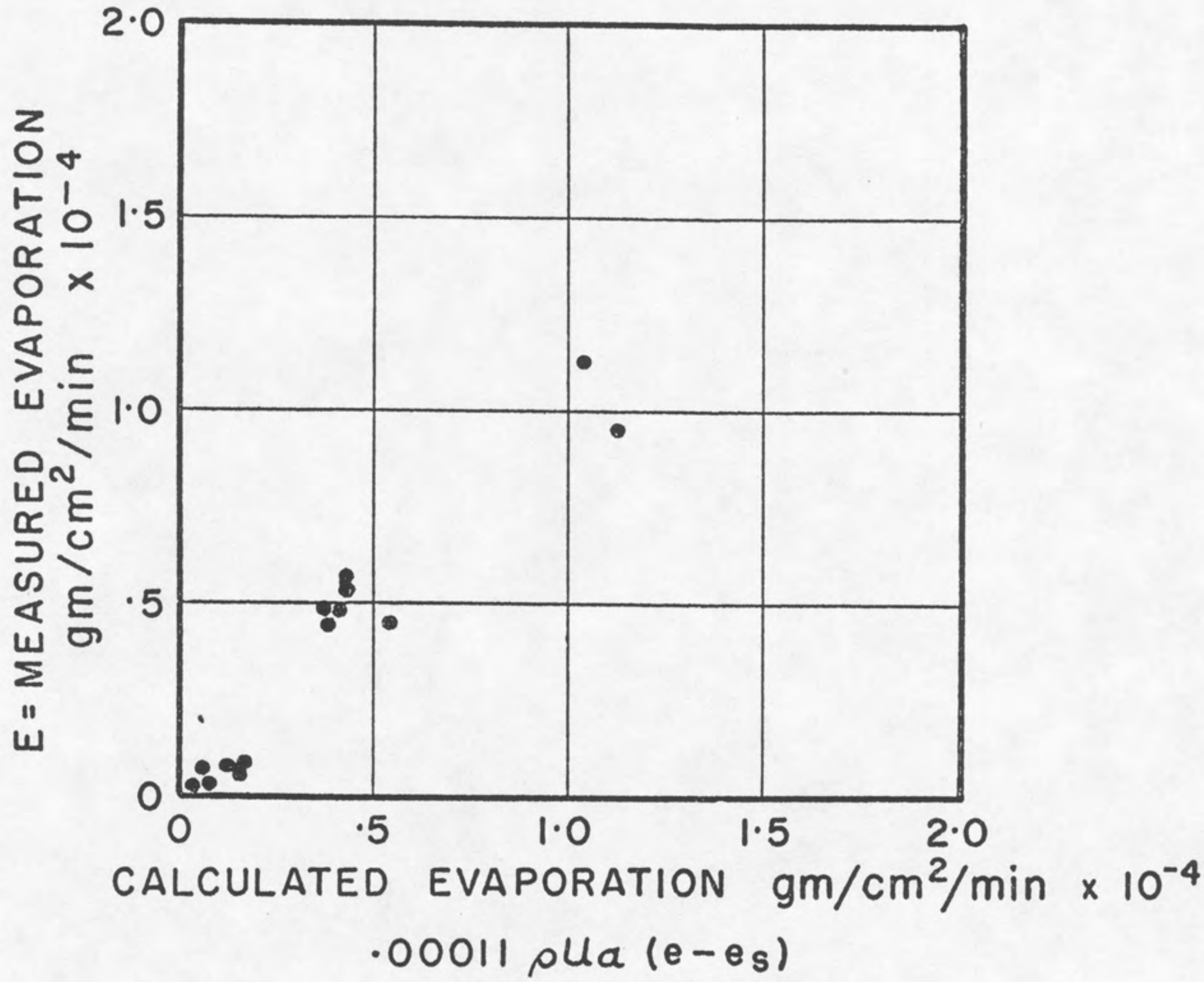


FIGURE I

RELATIONSHIP BETWEEN CALCULATED EVAPORATION RATE AND MEASURED EVAPORATION RATE. OTTAWA 1956-57.

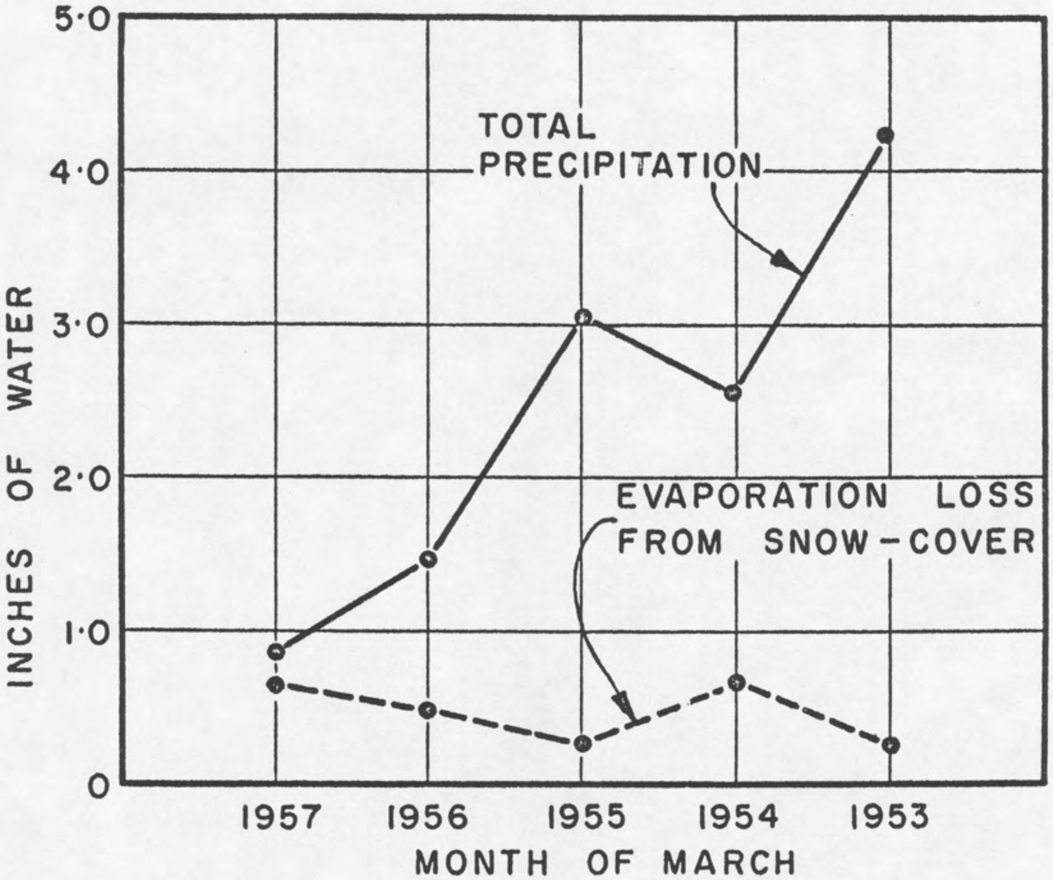


FIGURE 2

CALCULATED EVAPORATION RATES FROM SNOW-COVER. OTTAWA.