SNOWPACK WATER LOSSES DURING MELT IN A DECIDUOUS FOREST:
A COMPARISON OF LYSIMETRIC AND SNOW COURSE ESTIMATES

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INTRODUCTION

Accurate estimates of water losses from snowpacks are required for a number of purposes, including the development and calibration of snowmelt algorithms used in flood forecasting models, and in studies of the chemical dynamics of snow cover. Two commonly used approaches to obtaining such estimates are snowmelt lysimeters and snow survey measurements.

Snowmelt lysimeters record the rate at which water leaves the snowpack by intercepting vertically-percolating meltwater and channelling it to a flow recording device. Such lysimeters also facilitate the sampling of meltwater for chemical analyses. However, all lysimeters face the constraint that the initial water equivalent of the snowpack inside the lysimeter is usually not known, since sampling may disturb the snow cover and distort meltwater pathways. Therefore the initial water equivalent must be estimated using measurements taken outside the plot boundaries.

In addition, lysimeter design can introduce errors to the measured water loss rates. Those lysimeters consisting of an impermeable lining at the snowpack base may experience a time lag between meltwater leaving the snowpack and measured flow from the plot, since a saturated layer must build up above this lining before water can move laterally off the plot. Structural elements such as ice lenses can lead to lateral diversion of meltwater within the pack (Marsh and Woo 1984), and if the lysimeter does not have vertical boundaries extending through the snow cover, its surface area may not correspond to the snowpack area that contributes melt or rainwater (Greenan and Anderson 1984). Conversely, vertical plot boundaries can introduce edge effects (increases or decreases in melt at the snowpack's edges in the plot as a result of reflection of incoming solar radiation or shading, respectively) that become particularly pronounced late in the melt period.

Snow survey measurements estimate the water equivalent present in the snowpack (S) at the time of sampling. Water loss from the snowpack between successive snow surveys must be determined using the continuity equation:

$$I = O \,^{+}/_{-}\, dS/dt$$

This necessitates the measurement of inputs (I) to the snowpack (snowfall, rainfall and condensation), while the output term (O) represents the sum of snowmelt and/or rainwater, evaporation and sublimation. However, for most practical purposes condensation, evaporation and sublimation are considered negligible over short time intervals, or are assumed to cancel each other. Thus most studies employing snow survey estimates of water losses only record precipitation inputs and assume that snowmelt and/or rainwater dominate outputs.

While such measurements may provide adequate estimates of snowpack water losses over periods of days or weeks, their reliability is questionable when short-term (e.g. daily, hourly) loss rates are required, since the systematic and random errors associated with two successive water equivalent measurements may exceed the difference between them (Greenan and Anderson 1984). This problem is exacerbated by spatial variability in both the snow cover's water equivalent and melt rates, since one cannot sample successively at the same point.

Since the true depth of water loss from a snowpack is rarely, if ever, known, the absolute accuracy of these two techniques cannot be determined. Nevertheless it may be instructive to compare estimates of snowpack water losses obtained from both methods, particularly in light of the numerous hydrological and hydrochemical studies that have used one or the other approach.

STUDY AREA AND METHODS

Field observations were conducted during the spring of 1987 within a 3.12 ha forested headwater catchment in the Ottawa River valley. The site is located on the Canadian Shield about 200 km WNW of

Ottawa, Ontario (46°02'N, 77°20'W) and drains to Perch Lake on the property of Atomic Energy of Canada Ltd. (A.E.C.L.). Snowpack development usually begins in mid-December, and the peak water equivalent may range from 10-15 cm (Barry and Price 1987). The snowpack generally contains several ice lenses as a result of rain-on-snow and mid-winter melts followed by freezing temperatures. Snowmelt may extend over several weeks and is often accompanied by rain-on-snow events (Barry and Price 1987).

Snow course measurements

A 30 point snow survey was conducted in the catchment on March 3, prior to the initiation of melt. A 15 point snow survey was performed throughout the snowmelt, generally on a one or two day basis (Fig. 1). Snow samples were taken using a MSC snow tube. All samples were placed in pre-weighed plastic bags, and were weighed to obtain density and water equivalent depth.

Snowmelt lysimeter

A 5 X 5 m plot lined with polyethylene was used to measure water losses from the snowpack. The plot is located 500 m north of the catchment and was installed and operated by Dr. A.G. Price of the University of Toronto. The lysimeter is surrounded by plywood walls extending 32 cm above the ground surface. Since the snowpack typically reaches a depth of 41 cm during January and February (Barry 1975), all but the uppermost portion of the snowpack is separated from the surrounding snow cover prior to melt. The plot drains to two 200 L drums, and the water level within them was continuously recorded throughout the 1987 melt.

Precipitation (rain and snow) during the 1987 melt was measured daily using a Nipher snow gauge at an open station about 2 km from the experimental site.

RESULTS AND DISCUSSION

The 1987 snowmelt consisted of three distinct melt periods, separated by intervals of freezing temperatures (Fig. 2). During the first two periods melt was mainly radiation-induced, although rain-on-snow events also occurred (Fig. 3). There was a large input of snow between March 31 and April 1, followed by the final melt period which experienced a rain-on-snow event on April 4-5. The snow course water equivalent measurements tended to be normally distributed throughout the melt (Fig. 3); therefore the mean water equivalent depths obtained from the snow surveys have been used to estimate snowpack water losses.

Fig. 4 presents the snowpack water losses estimated by the snow survey vs those measured by the snowmelt lysimeter. Each estimate is for the period between successive snow surveys, which ranged from one to four days. The snow survey measurements produced reasonable estimates of water losses from the snowpack determined using the lined melt plot. 42% of the snow survey estimates were within 10% of the corresponding lined plot values, 53% were within 20%, and 63% were within 50%. There is no apparent systematic bias in short-term estimates of water losses using the two methods, although the snow survey measurements substantially overestimate the lined plot values during the initial part of the second melt interval (March 17-23).

Difference between losses obtained by the snow survey and the lined plot are reflected in the estimated cumulative water output (Fig. 5). The snowpack in the catchment began to lose water before the lined plot responded at the start of the first melt. A more pronounced divergence between the estimated cumulative losses occurred during the period of March 17-23. Both periods followed intervals of freezing air temperatures (Fig. 2) during which snow temperatures fell below 0°C, and the difference between the two methods may reflect the need to build up a saturated conducting layer at the snowpack base in the lined plot before runoff can be generated.

Fig. 5 indicates that the lysimeter had a lower total water loss than the nearby snowpack, which is also apparent in the results of English et al. (1987). This may be due to "real" differences in the initial snowpack water equivalent between the lined plot and the catchment and/or in the input of precipitation during the melt period. It may also be partly due to the influence of the plot itself upon processes occurring within the snow cover. The plot's polyethylene lining prevents water vapour from leaving the underlying soil and entering the snowpack, which generally results in the formation of depth hoar and an increase in the snowpack water equivalent. The lined plot retained snow longer than surrounding areas, which may also be attributed to the plot itself. The presence of the polyethylene sheet increases the albedo of the surface underlying the snowpack. Thus shortwave radiation penetrating through the snow would be increasingly reflected as the snow cover thins, instead of heating the darker soil surface and contributing to increased energy inputs to the snowpack base. The polyethylene may also provide a barrier to energy transfer from the soil to the snow.

These discrepancies between the lysimeter and snow survey results are particularly apparent when differences between the water equivalent storages measured by the snow survey and calculated from the water budget of lined plot are considered throughout the melt (Fig. 6). The initial water equivalent for the lined plot has been assumed to equal that of the snow course. The larger water equivalent in the catchment snowpack, relative to that in the lined plot during the early part of the 1987 melt, may partially result from the exclusion of vapour flux from the soil into the lysimeter snow cover. However, storage in the lined plot generally exceeded that in the catchment snowpack following the start of more intense melts on March 21. This may reflect the influence of the plot lining and boundaries in reducing snowmelt within the lysimeter. A similar transition in differences between water storage depths obtained from the lined plot and adjacent snow cores has been noted at this site (Barry and Price 1987), suggesting that the contrasts in lysimetric and snow survey results reported here occur during snowmelt periods observed in other years at Perch Lake.

IMPLICATIONS FOR HYDROLOGICAL AND HYDROCHEMICAL STUDIES

There was little difference in estimates of total water input to the catchment using either method, and the lysimeter underestimated the total water loss from the snowpack by less than 5%. This suggests that water losses and ionic loads determined for the lysimeter for the entire snowmelt period would be representative of those for the catchment snow cover. The use of vertical boundaries ensured that the area of snow cover that contributed flow to the plot was essentially identical to the lysimeter's surface area. This avoided the necessity of correcting flow volumes and ionic loads when using unbounded lysimeters in order to compensate for the influence of ice lenses and other structural elements upon meltwater flow paths within the pack (e.g. Jones 1987).

Snow course measurements in forested areas can provide reasonable approximations of water losses from lined plots over intervals of a day or more. However, there may be significant contrasts between estimated water losses using the two methods at the initiation of melt following a period of freezing temperatures. These discrepancies may be an artifact of the plot design. While these differences appear to persist only for a few days, they may be important in studies of preferential elution and fractionation of ions from snow cover at the start of melt, and in investigations of acid loading to surface waters during snowmelt.

ACKNOWLEDGEMENTS

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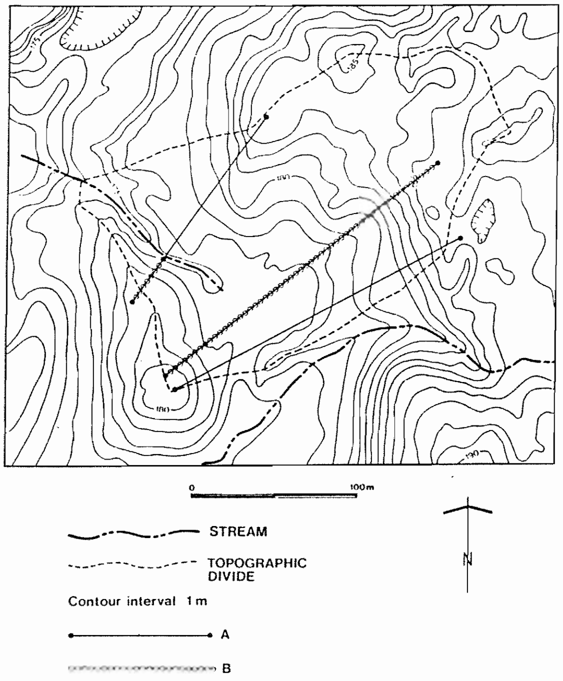


FIGURE 1:
Map of the experimental catchment, indicating the position of the 30 point (A) and 15 point (B) snow survey transects. The lined snowmelt lysimeter is located 500 m to the north of the catchment.

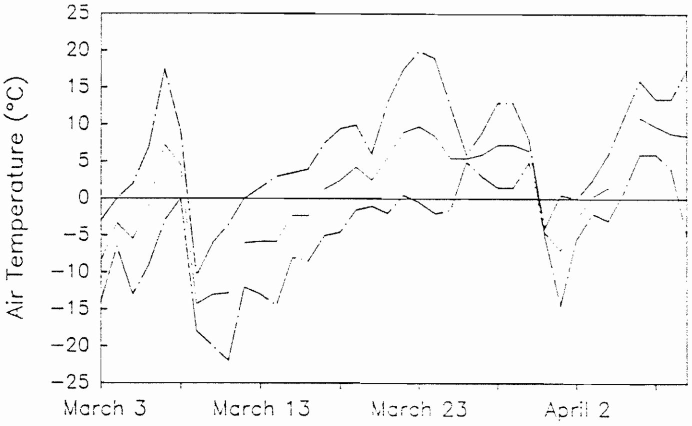


FIGURE 2:
Maximum, minimum and mean daily air temperatures at Perch Lake during the 1987 snowmelt.

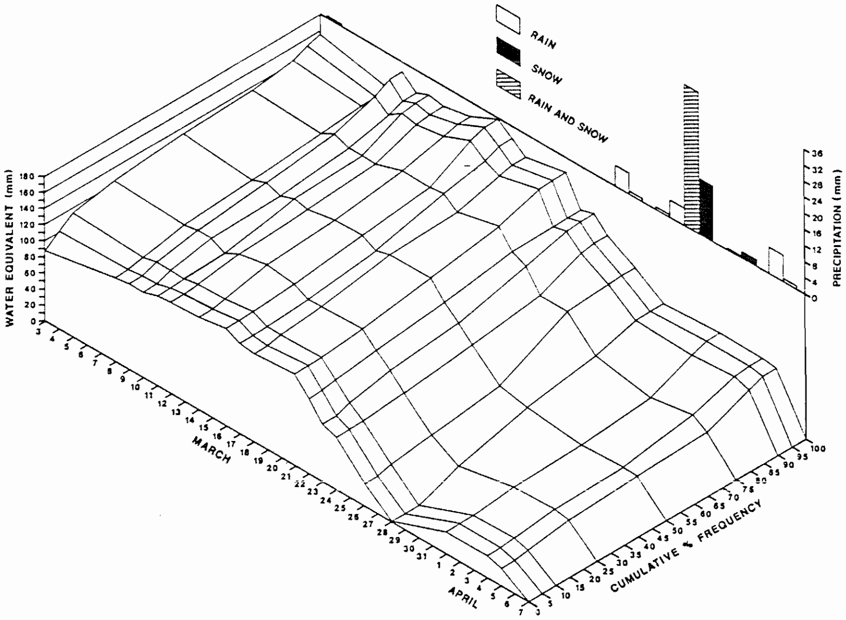


FIGURE 3:
Cumulative frequency distributions of snowpack water equivalent depths obtained from the snow surveys. Type and amount of daily precipitation during the 1987 melt is also indicated.

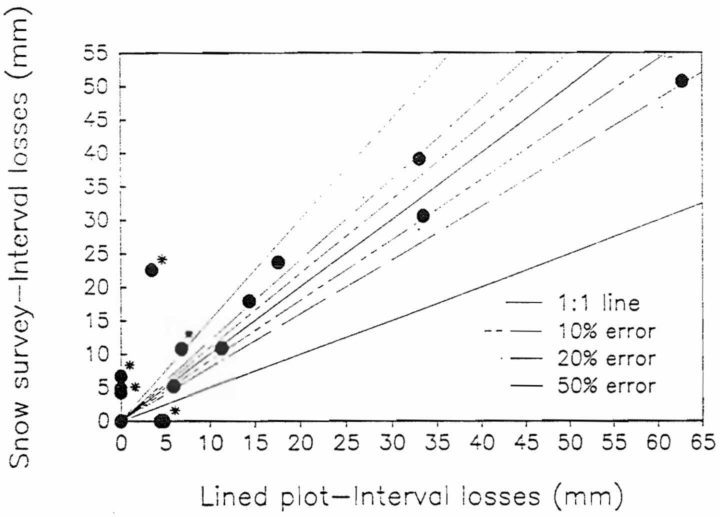
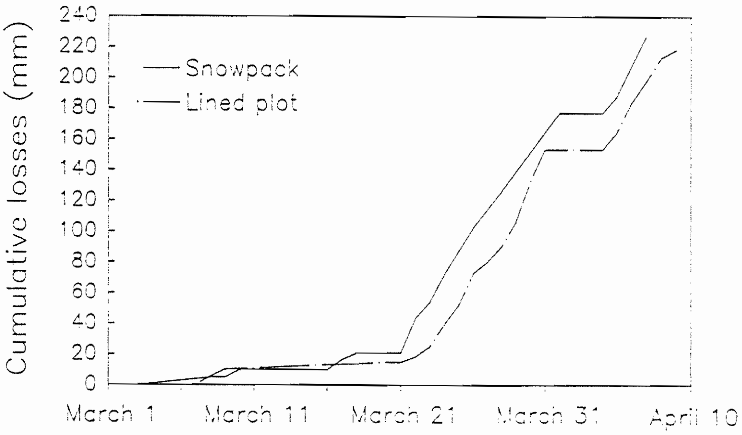


FIGURE 4:
Short term estimates of snowpack water losses based on snow survey and lined snowmelt lysimeter measurements. Estimated melt depths for the early part of the second melt period are indicated by *.

FIGURE 5:
Cumulative water losses based on snow survey measurements of the snowpack and output from the lined snowmelt lysimeter, 1987 snowmelt.



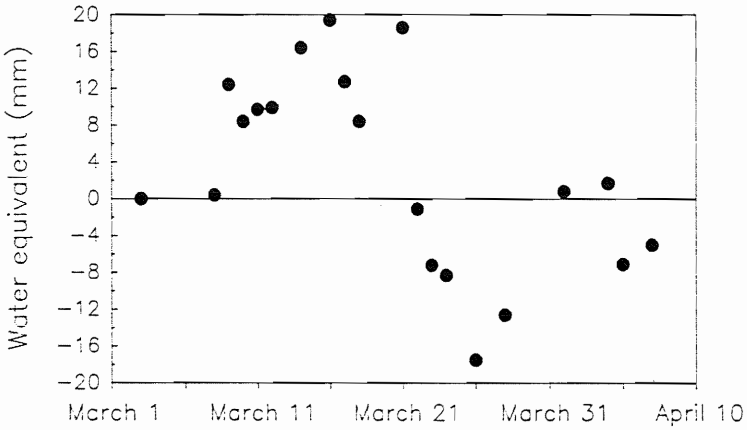


FIGURE 6:
Storage of water equivalent in the catchment snowpack minus estimated storage in the lined snowmelt lysimeter, 1987 snowmelt.