

# WATER EQUIVALENT MEASUREMENTS WITH SNOW PILLOWS IN THE LAURENTIANS

by

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## INTRODUCTION

In the fall of 1967, the Québec Department of Natural Resources has installed two snow pillows at partially forested sites on the St. Anne River Basin to the northwest of Québec City for a tentative evaluation of snowpack water-equivalent in that mountainous area. These circular pillows, made up of butyl rubber, are covered with nylon-reinforced rubber envelopes. They are 12-foot in diameter and are filled with a 50% methyl-alcohol solution.

In the winter of 1967-68, the pillows were laid flat on top of the ground at two sites about eight miles apart and at approximate elevations of 1,000 feet and 2,000 feet respectively. They were filled up with 315 gallons of methyl-alcohol solution. Their measuring system consisted of stilling wells, six inches in diameter, in which the anti-freeze level was sensed with water-level recorders. The pillows were connected to the stilling wells by means of copper tubing.

In the winter of 1968-69, the two pillows were installed side by side at the 1,000 foot altitude site. Their set-up was somewhat different: they were placed flush with the ground in shallow depressions and circular plywood boards were laid on top of them. With this system, continuous records were obtained throughout the season. The measuring system consisted again of stilling wells, six inches in diameter, and water-level recorders of the electro-mechanical type, recording at 15-minute intervals. The pillows were filled to capacity (315 gallons).

## DETERMINATION OF THE SNOWPACK WATER-EQUIVALENT

Suppose  $H_1$  is the rise of the water level in the stilling well with snow over the pillow relative to the level without snow. Thus, knowing that the weight of the liquid column in the stilling well is equal to the weight of snow over the pillow, one can write

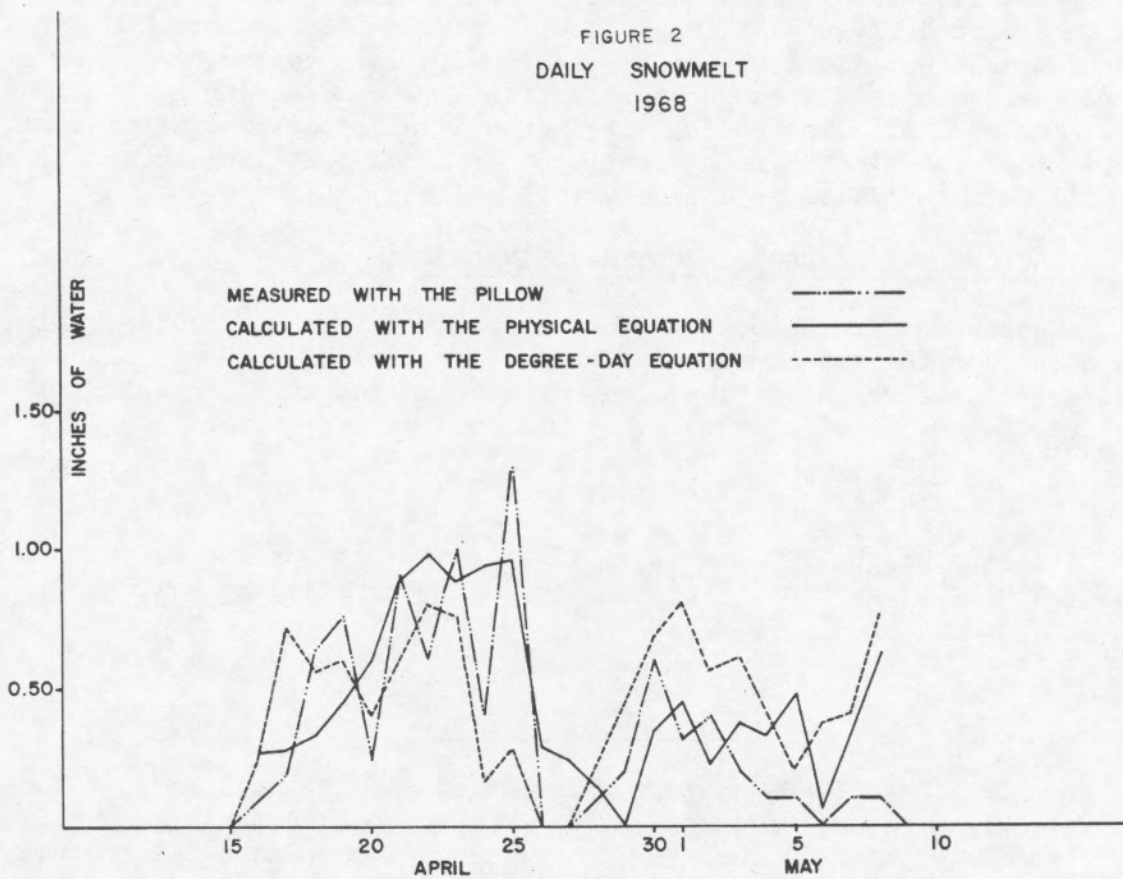
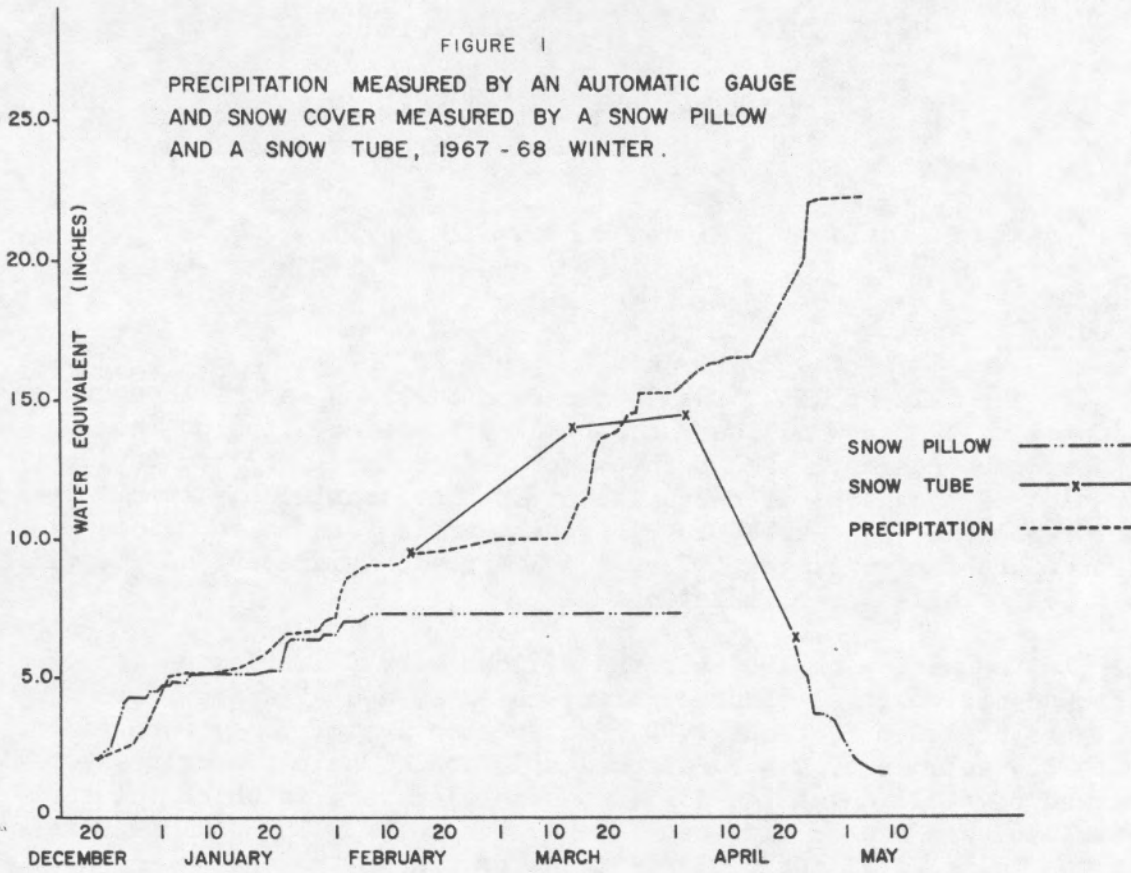
$$Y = D_1 H_1$$

where  $Y$  is the height of water equivalent of the snowpack over the pillow and  $D_1$ , the relative density of the liquid in the stilling well.

## RESULTS

### SNOW ACCUMULATION PERIOD 1967-68

During the 1967-68 winter, only one of the two pillows gave some results. Right after its installation, on December 20, daily snowfalls were recorded on the pillow. For comparison, we have used the recording snowgauge data, which are plotted on Figure 1. The discrete values obtained at the same site with a snow sampler are also plotted. From



December 20 to December 30, the recording snowgauge recorded 1.2 inches of water equivalent, while the snow pillow showed an increase of 2.5 inches of water. Afterwards, the snow pillow seemed to work well until the beginning of February, showing then a difference of 0.5 inch of water with the snowgauge.

From February 10 until April 3, no variation of the antifreeze level was recorded because an "ice bridge" formed in the neighbouring snowpack, which supported the newly-fallen snow. On April 3, the snowpack collapsed under the combined effect of rain and melt and the pillow began to function again.

SNOWMELT PERIOD 1968

It seems interesting to compare the snowmelt values as indicated by the pillow with values calculated by means of well-known snowmelt equations (1). Since temperature measurements are available at the St. Anne River Basin stations, a degree-day correlation equation of the following type is applied:

$$M = K (T_{\max} - T_0) \dots \dots \dots (1)$$

where M is the daily snowmelt in inches of water;

K is the point melt rate in inches per degree-day;

$T_{\max}$  is the daily maximum temperature in degrees F.;

$T_0$  is the reference temperature for the degree-day calculation.

This equation yields point snowmelt values. The daily snowmelt has also been determined by means of the U.S. Army Corps of Engineers' physical equations based on energy budget. These equations take into account the melt caused by radiation (short- and long-wave), by rain and by heat transfer due to convection and condensation.

The physical equations used are:

a) for periods with rain:

$$M = (0.029 + 0.0084 k v + 0.007 Pr) (T_a - 32) + 0.09 \dots \dots \dots (2)$$

b) for periods without rain:

$$M = k (0.0084 v) (0.22 (T_a - 32) - 0.78 (T_d - 32)) - 0.029 (T_a - 32) \dots (3)$$

where K is a coefficient for condensation and convection melt (k varies between 0.3 and 1.0 depending on the forest cover);

v is the mean wind speed at a height of 50 feet in miles per hour;

Ta is the air temperature in degrees F.;

Td is the dewpoint temperature in degrees F.;

Pr is the precipitation rate in inches per day.

These equations have been applied to daily temperature and precipitation values measured at the stations equipped with snow pillows. The wind values are taken from Québec Airport, located about 20 miles east of the pillow site.

In the analysis of the data from the 1967-68 season, the reference temperature value and the parameters have been taken as:

$$K = 0.04$$

in the degree-day equation (equation 1)

$$T_0 = 42$$

and  $k = 0.4$  in the physical equations (equations 2 and 3)

Figure 2 and Figure 3 show the daily and cumulative snowmelt as measured by the pillow and as calculated by the degree-day and by the physical equations. The graph for the daily melt features an approximate coincidence of the days with maximum and minimum melt and a similar general trend for the three curves, but point values are in general quite different.

In the cumulative graph (Figure 3), the measured and calculated values agree reasonably well for the first half of the melt season, until about April 25. From there on, the three curves are divergent. For a few days, the degree-day method yields smaller values than the other two (the observed one and the one calculated by the physical equations), perhaps because it does not take into account the heat released from the rain or because the value of K undergoes seasonal variations. At the end of the melt period, the cumulative values calculated by both methods are larger than the measured ones by 25%.

#### SNOW ACCUMULATION PERIOD 1968-69

Figure 4 shows the graphs for the water equivalent of the snowpack weighed by the two pillows and the graphs of the water equivalent measured with the recording snowgauge and with a snow sampler for the 1968-69 winter. The first snowfall occurred on November 16, 1968. Snowfalls were heavy during the last two months of 1968, with a high water equivalent. By mid-January, the total snowfall was up to about 180 inches, with a water equivalent of about 10 inches on the ground. The two pillows indicate a difference of 1.5 inches of water, the snow sampler giving an intermediate value and the precipitation gage weighing about two inches less.

Toward the end of January, a short period of thaw occurred, accompanied by rain. Meanwhile, the weight of the snowpack over the pillows decreased by an equivalent of half an inch of water, while the maximum temperature exceeded 32 degrees F. for four days. The physical melt equations yield a possible melt of 0.54 inches of water. During the whole season, there has been no ice bridging effect as it occurred on the preceding year. The snow sampler measured a maximum water equivalent of 16.5 inches for the snowpack which compares fairly well with the maximum value of 16.0 inches measured by Pillow A and the accumulated precipitation from the recording gage at that time. Pillow B gives only 13.5 inches as the maximum water equivalent, i.e. 15 percent lower.

As a general remark, we notice that Pillow B records values that are consistently lower than those recorded by Pillow A. That could be explained by a systematic error in the measurement of the density of the antifreeze in that pillow.

Both pillows have a relatively fast response and seem to have good sensitivity. Any precipitation was recorded on the day it fell. Both pillows always began recording fresh precipitation about two hours before the recording snowgage did. On the other hand, they exhibit a mean lag of four hours in recording the end of precipitation when compared to the snowgage. The values of precipitation measured by the pillows and by the snowgage are in good agreement, which shows the relatively good sensitivity of the pillows.

#### SNOWMELT PERIOD 1969

Figure 5 shows the cumulative daily melt as estimated from the snow pillows. The effective melt period began on April 11 and lasted until May 10.

Figure 6 compares the estimated melt from Snow Pillow A and the two curves obtained from the Army Corps of Engineers' equations, the parameters of which have been adjusted by "trial and error" so that the total measured and calculated snowmelts for the season are equal. The parameters thus obtained are:

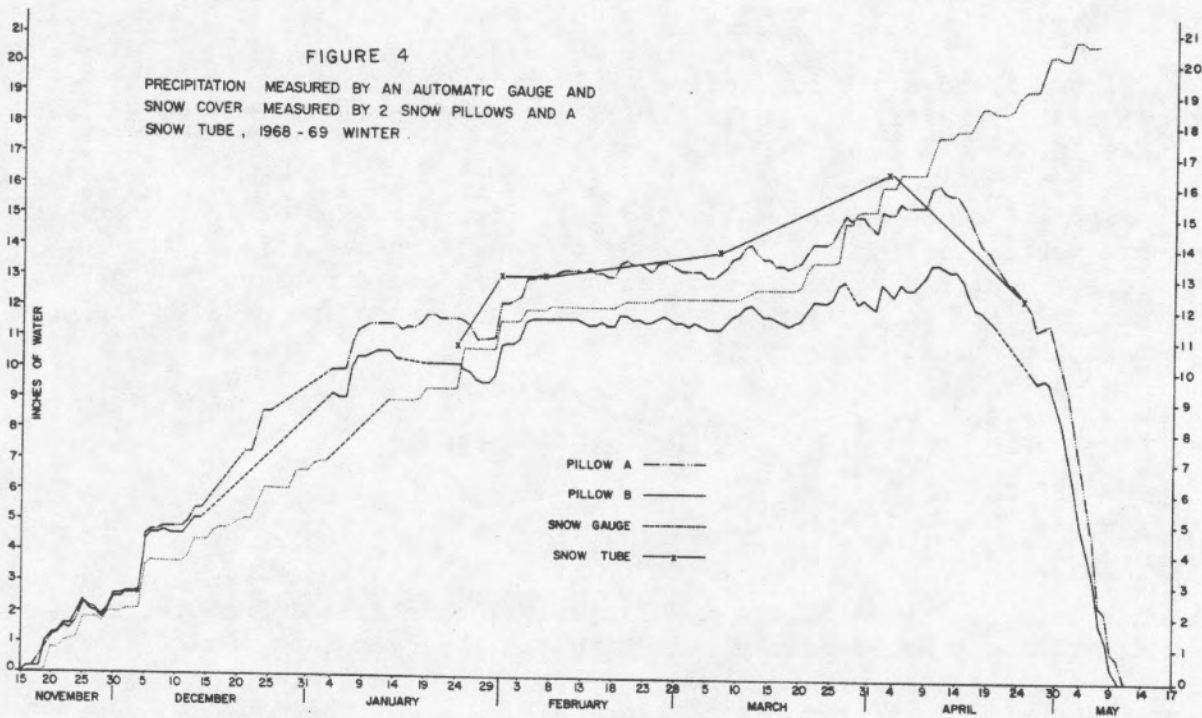
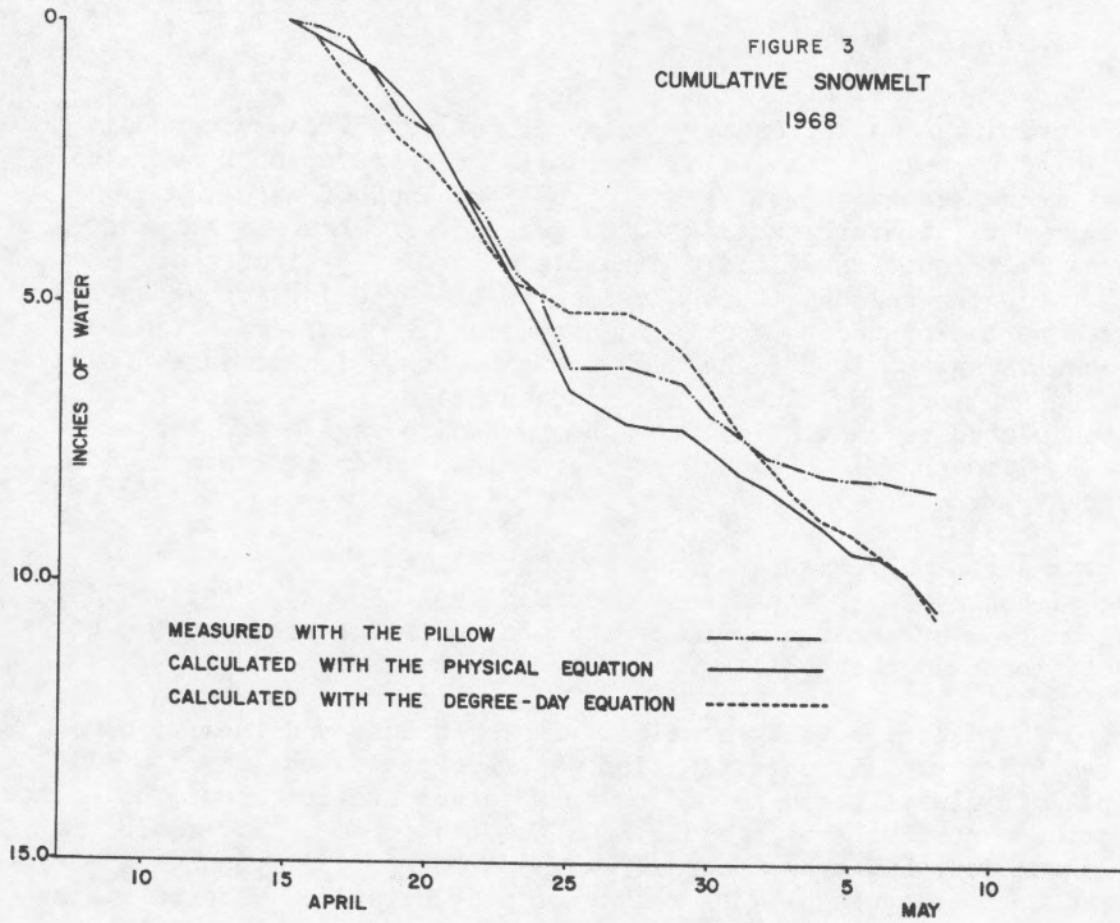
$$K = 0.03$$

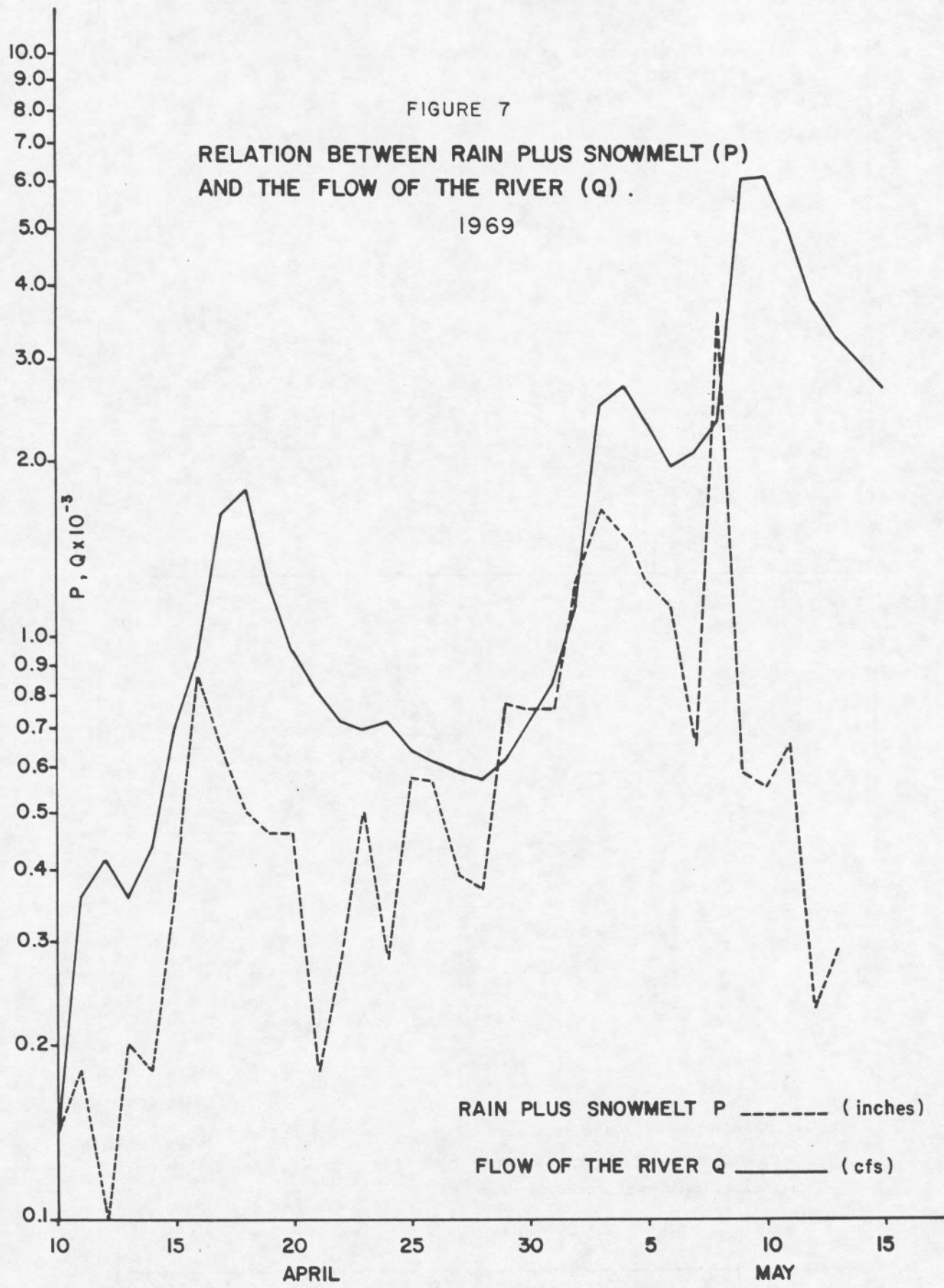
in the degree-day equation

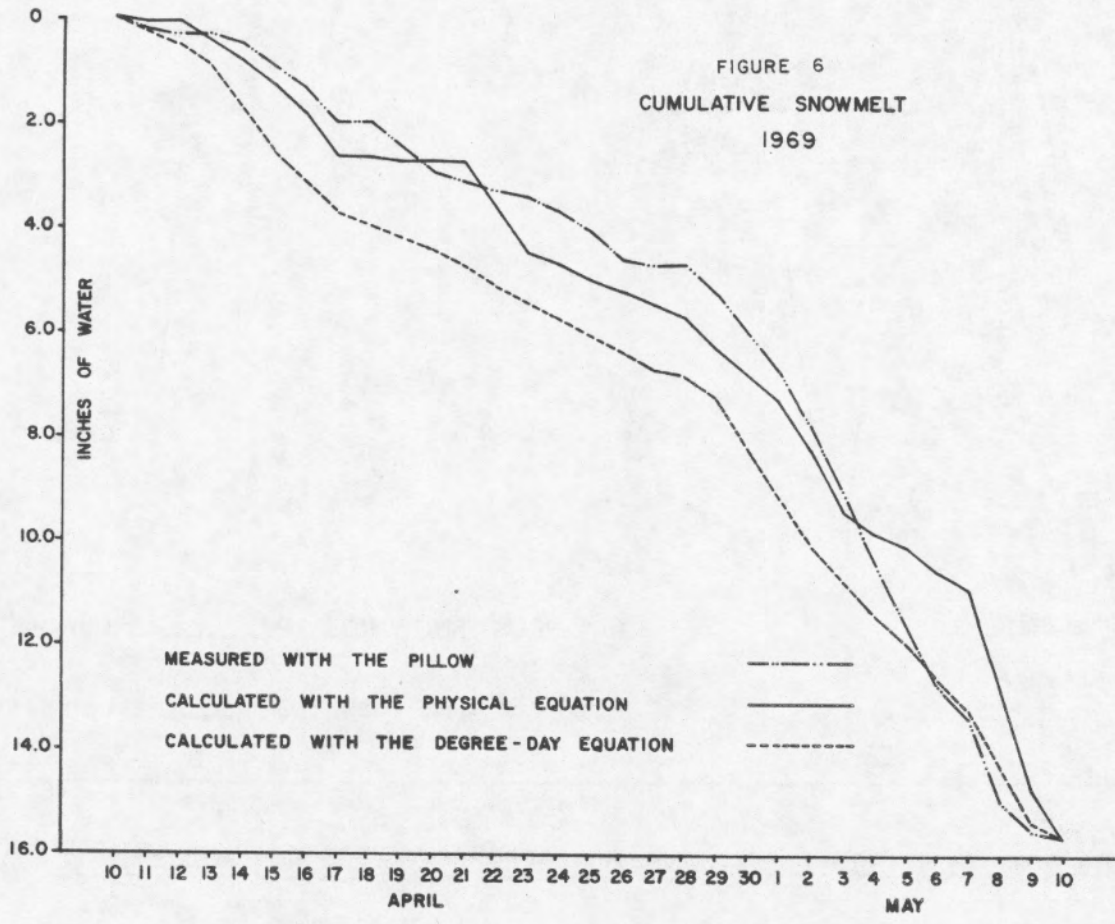
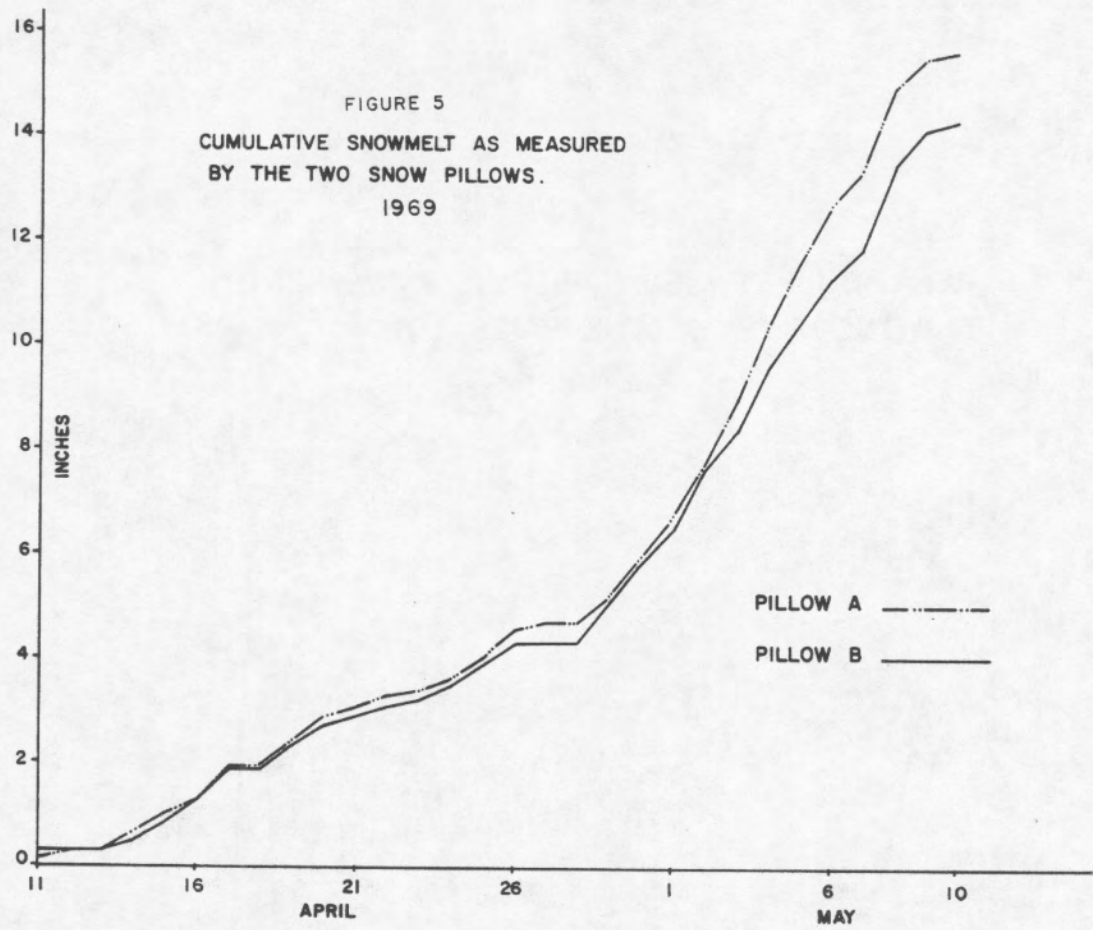
$$T_0 = 32$$

and  $k = 0.6$  in the physical equations.

As seen on Figure 6, the cumulative values obtained from the two snowmelt equations agree fairly well with the observed snow depletion curves, the degree-day equation melting the snow at a faster rate than either the physical equation or the snow pillow. But the physical equation and the snow pillow catch up with the degree-day equation toward the end of the melt season.









Since the site of the pillows during the 1968-69 season was close to a streamflow-gaging station on the same sub-basin, we have tried to correlate the river flow with the snowmelt added to the precipitation. The results are shown on Figure 7. At first glance, we notice that the peaks in streamflow occur about two days after the peaks in the curve representing the total of precipitation and snow depletion. Also, there seems to be a rather constant relationship between the amplitudes of the peaks of both curves. The ratios for the three main peaks are 2.0, 1.6 and  $1.7 \times 10^3$  cfs/in. These last figures might be useful in forecasting flow peaks or flood occurrences and their relative values on that basin.

### CONCLUSION

This experimentation with snow pillows has pointed out some operating problems due to the climatic conditions which prevail over the Laurentians, where they have been tested for two winter seasons. The main problem, as mentioned before, has been the formation of what is usually termed an "ice bridge" in the snowpack. This occurred during the 1967-68 winter season and, as a consequence, it stalled the snow pillows for quite a while. The 1967-68 winter was colder than normal with snowfalls below normal. The "ice bridge" was probably caused by freezing rain that occurred at the beginning of February.

On the contrary, the 1968-69 winter was mild with snowfalls much heavier than normal. Under these conditions, we did not encounter any operating problem with the pillows. Of course, the set-up was probably better and the experience gained during the first year may have helped us to overcome the difficulties. Nevertheless, it seems that the climatic conditions do have an influence on the functioning of snow pillows: the absence of rain or freezing rain and a deep snowpack would favour a better efficiency.

To sum up, it seems that the pressure pillow may come out as being an apparatus useful to indicate both the snow accumulation and ablation. The snow accumulation has been checked against the discrete values obtained with a snow sampling tube and the precipitation accumulated in a weighing-type gage. The snow ablation has been checked against the values obtained from a snow tube and from snowmelt equations. One must not expect that the melt equations agree closely with the measured values, since they are used only as indices of point or basin melt, but on a seasonal basis the agreement is satisfactory.

### REFERENCE

- 1 - "Runoff from Snowmelt", U.S. Army Corps of Engineers, Engineering and Design Manuals, EM 1110-2-1406, 1960.