# SNOWMELT MEASUREMENTS

# AND THEIR

# USE IN SYNTHESIZING SNOWMELT HYDROGRAPHS

by

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## I INTRODUCTION

Basin snowmelt forms an important input in the synthesis of spring season streamflow. Generally, basin snowmelt is estimated by Temperature Index Methods when only temperature data are available, or by Generalized Basin Snowmelt Equations (1, 2) when meteorological data are available concerning air temperature, dew point temperature, wind speed, insolation, snow surface albedo, forest canopy cover, cloud cover, and extent of snow cover. In either case only guestimates are obtained of this important source information on the basis of which basin routing and channel hydrograph synthesis proceed.

In 1965 it appeared feasible to the writer to install in a basin a network of snowmelt plots, with a network density compatible to that of automatic raingauges, and actually measure at such sites the total amount and rate of snowmelt. Support was obtained from the National Research Council of Canada for setting up an experimental snowmelt plot in the North Nashwaaksis Stream Basin (drainage area = 10.4 sq. miles), one of Canada's Representative Basins for the International Hydrologic Decade. An experimental snowmelt plot has been operational there since 1966.

This paper presents the Functional Role of Snowmelt Plots, a Report on Some Experimental Results, and indications for future work.

## II FUNCTIONAL ROLE OF SNOWMELT PLOTS

Snowmelt plots are being proposed by the author to serve three main functions:

1. A basin network of snowmelt plots to provide continuous measurements of actual snowmelt amounts and rates at selected sites in a basin.

2. At a few sites where instruments can be installed for measuring associated meteorological parameters, to derive empirical equations for predicting point snowmelt rates.

3. To analyze and obtain an insight into the basic physics of regional snowmelt, which would eventually lead to refinement of empirically derived snowmelt equations.

(Refer Figs. 1 and 2).

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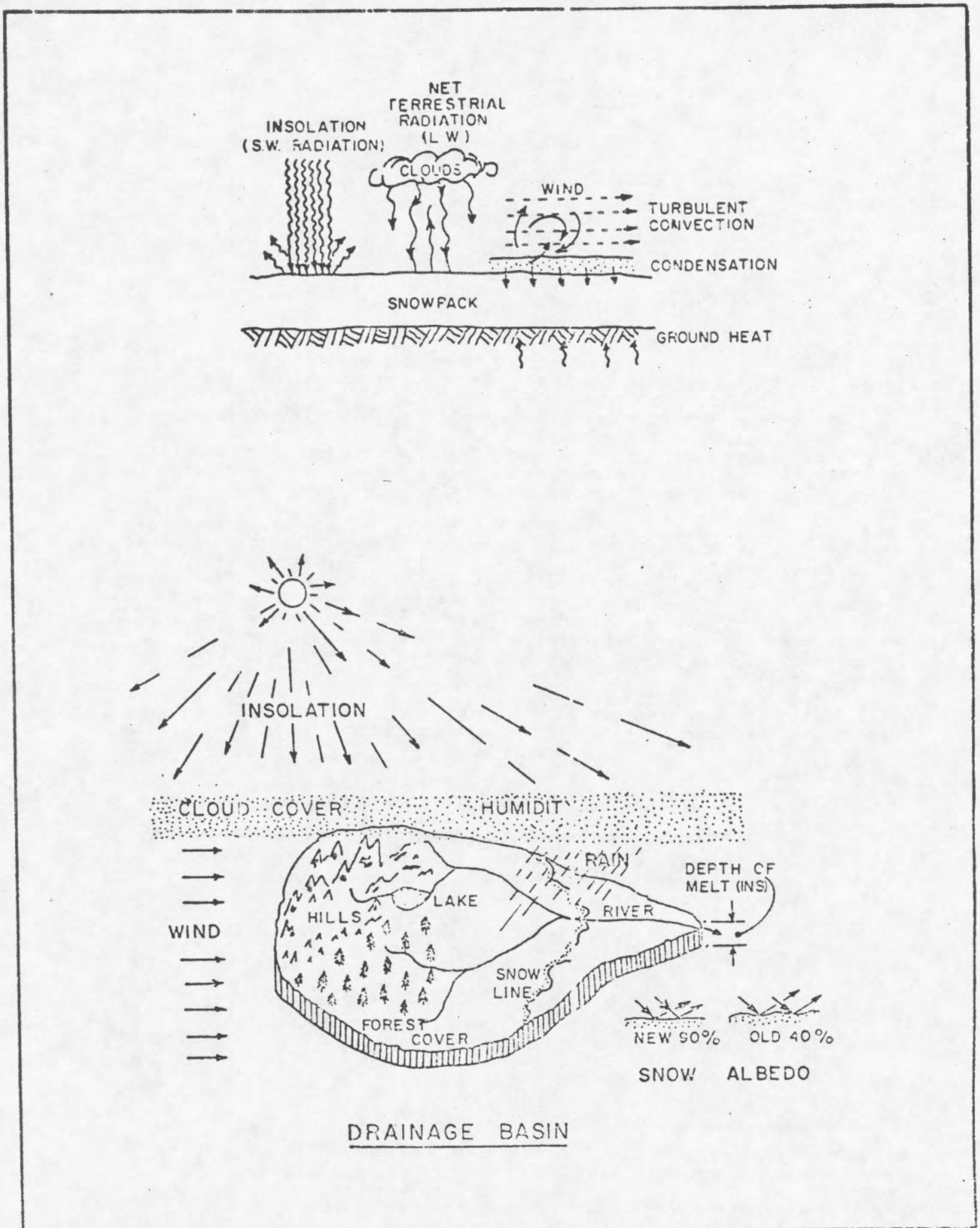


FIG. 1 SOURCES OF HEAT WHICH GENERATE SNOWMELT

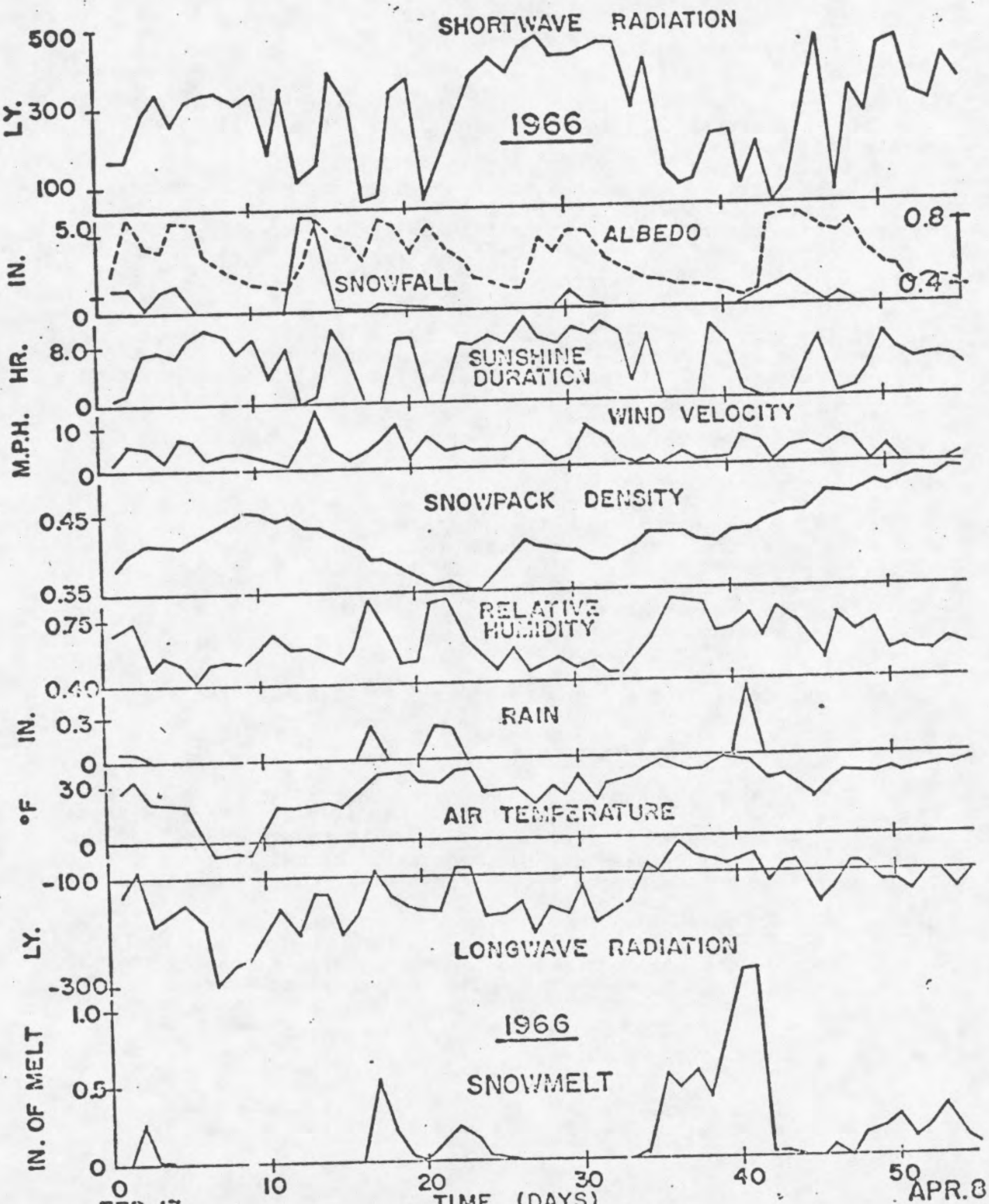


FIG. 2 MEAN DAILY PARAMETERS

In the North Nashwaaksis Stream Basin, only one experimental snowmelt plot has been operational and functions 2 and 3, as above, have been receiving attention.

The original snowmelt plot is shown in Fig. 3. An improved version installed in 1968 is shown in Figs. 4 and 5. In 1969 a vertical array of temperature probes has been installed outside the snowmelt plot to measure temperatures in the ground, in the snowpack, and in the air. Hopefully, a snow-pillow will be installed in 1970 to measure snow-density variations.

The snowmelt plot is located at the Royal Road Climatological Station which is in a clear area; however about 85 per cent of the basin is covered by forest. Meteorological instrumentation at this site now includes the following:

- Incoming solar radiometer (Kipp)
- Reflected solar radiometer (Kipp)
- Net radiometer (CSIRO)
- Campbell-Stokes sunshine recorder
- Maximum and minimum thermometers
- Recording hygrothermograph
- Anemometer
- Snow-gauge with nipher shield
- Tipping bucket raingauge
- Standard raingauge
- Class-A evaporation pan

The meteorological data are abstracted and plotted for each year as shown in Fig. 2.

## III REPORT ON SOME EXPERIMENTAL RESULTS

The data collected at the snowmelt plot in 1966 were analyzed and results reported by Pysklywec, Davar and Bray (3). Three types of prediction equations were tested: Degree-day Method, Generalized Snowmelt Equations, and Regression Equations with Thermal Budget Indices. These equations and their predictive capacities will now be discussed.

### a. Degree-day Method

This is the simplest and most commonly used method of snowmelt estimation. In this approach the following equations were used:

$$SM = 0.1742 + 0.0397(T-32) \qquad \text{------------------(1)}$$

$$SM_n = 0.0397 \left[0.6(T_n - 27.6) + 0.3(T_{n-1} - 27.6) + 0.1(T_{n-2} - 27.6\right] \qquad \text{------------------(2)}$$

where:

$T$ = mean daily air temperature at a height of 4.5 ft. ($^{o}F$).

$T_n$ = mean daily air temperature as above on day n ($^{o}F$).

$SM_n$ = snowmelt on day n (ins/day).

The results of predictions obtained by these equations are shown plotted in Fig. 6 and compared with other methods in Fig. 9.

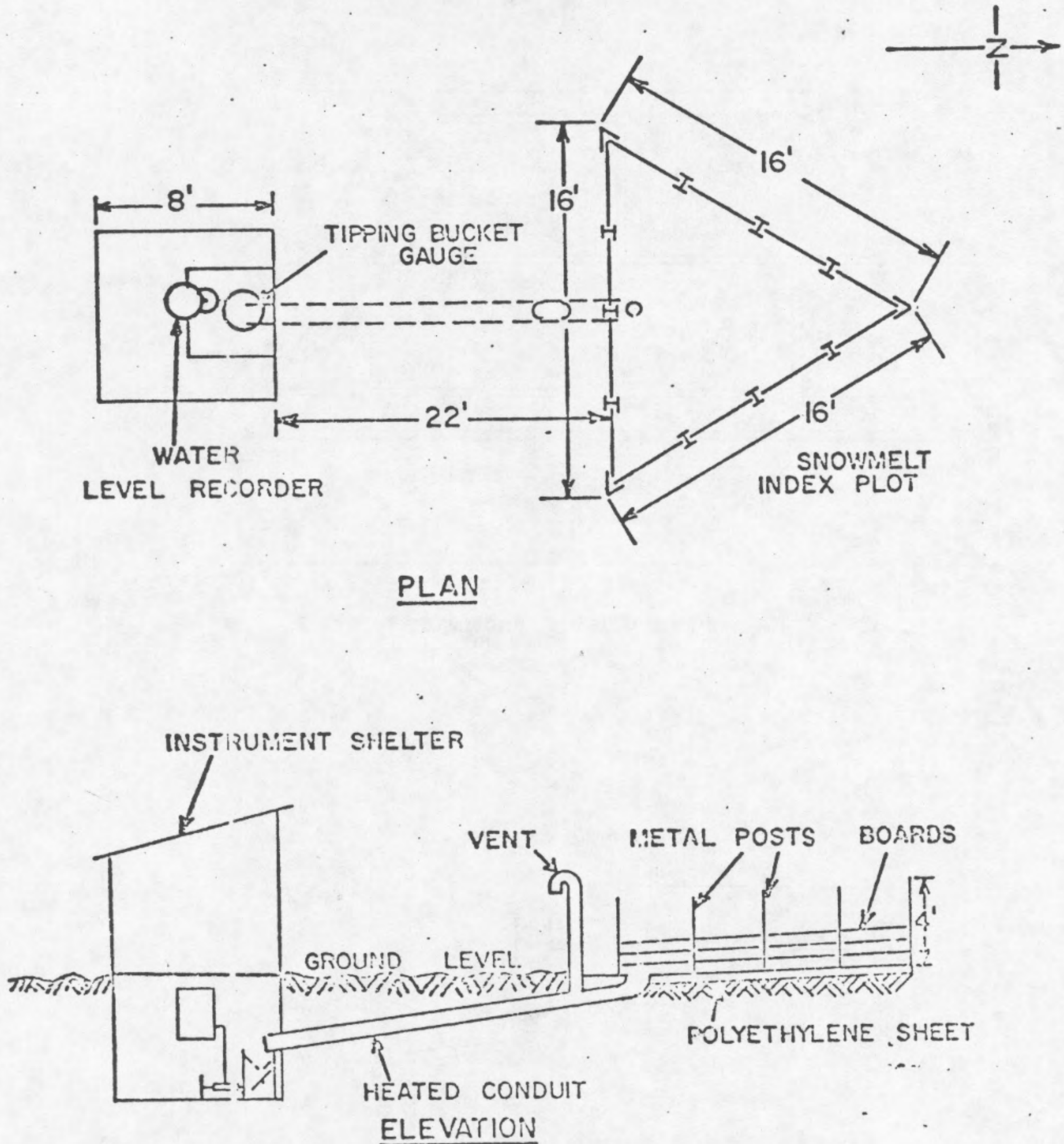


FIG. 3 EXPERIMENTAL SNOWMELT PLOT — I

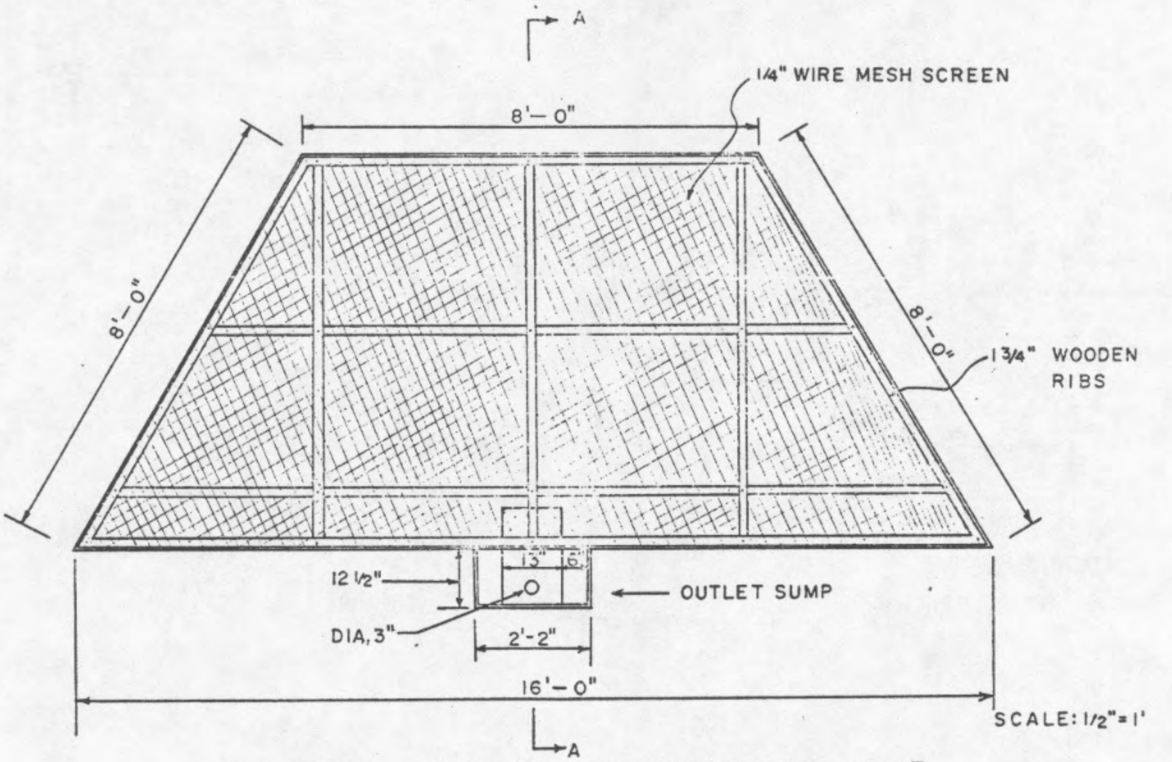


FIG. 4. PLAN VIEW OF SNOWMELT PLOT II.

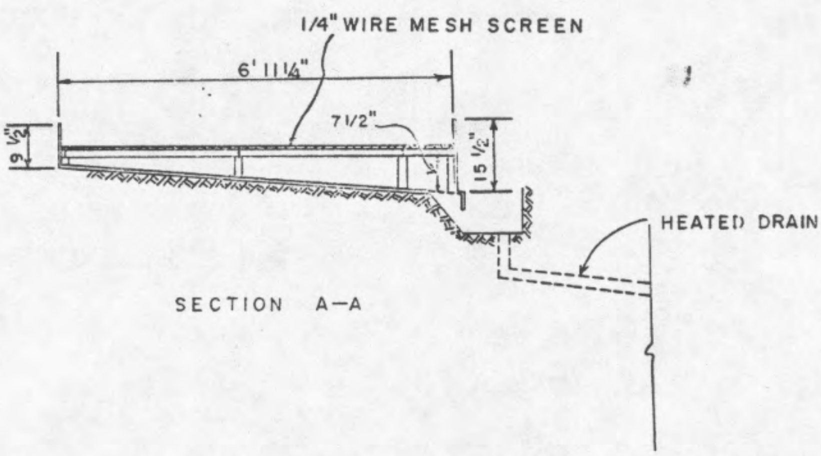


FIG. 5. SECTIONAL VIEW OF SNOWMELT PLOT II

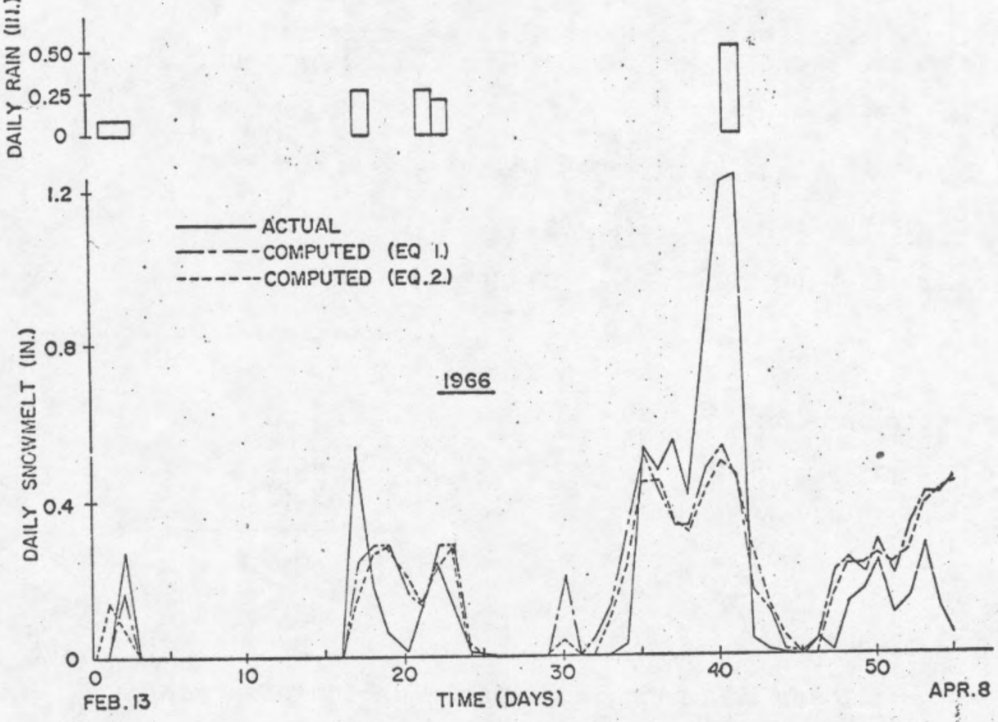


FIG. 6 SNOWMELT BY DEGREE-DAY METHOD

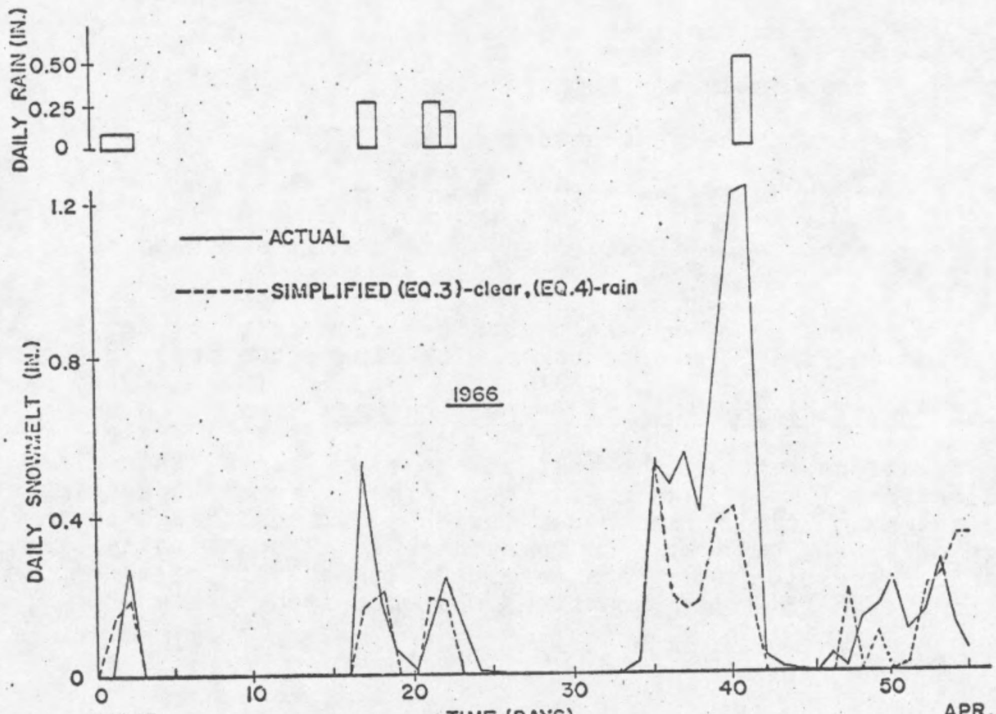


FIG. 7. SNOWMELT BY U.S.C.E. EQUATIONS

b. Generalized Snowmelt Equations

These equations based on research performed by the U.S. Corps of Engineers (1) are widely used. The following equations were tested:

During rain-free periods:

$$
\begin{aligned}
SM &= 0.00508\,(1-a)R_S + 0.029\,N\,(T_C-32) \\
&+ \left[0.0212\,(T-32) - 0.84\right]\,(1-N) \\
&+ \left[0.0084\,V\,(0.22\,(T-32) + 0.78(T_d-32))\right]
\end{aligned}
\qquad (3)
$$

During Rainy periods:

$$
SM = (0.029 + 0.0084V + 0.007P_r)\,(T-32) + 0.09 \qquad (4)
$$

where:

- $Sm$ = snowmelt (ins/day)
- $a$ = albedo of the snow surface (decimal fraction)
- $R_S$ = solar radiation (langleys/day)
- $N$ = estimated cloud cover (decimal fraction)
- $P_r$ = mean rainfall (ins/day)
- $T$ = mean daily air temperature at 10 ft. ($^oF$)
- $T_c$ = cloud base temperature ($^oF$)
- $T_d$ = mean daily dew point temperature ($^oF$)
- $V$ = wind velocity at 50 ft. height (miles per hour)

The estimates of snowmelt obtained from Eqs. (3) and (4) are shown plotted on Fig. 7, and compared with other equations in Fig. 9.

c. Regression Equations for Thermal Budget Indices

Relations between snowmelt at the experimental snowmelt plot and combination of melt causing factors termed thermal budget indices were derived as multiple linear regression equations, based on the principle of least squares. The relations were statistically examined and optimal regression equations obtained with the aid of a computer sub-routine. The following equations were obtained:

$$
\begin{aligned}
SM &= 0.534 + 0.00407R_L + 0.00309\,V\,(T-36) \\
&+ 0.0343\,V\,(RH) + 0.000772\,R_s\,(1-a) \\
&+ 0.007\,P_r\,(T-32)
\end{aligned}
\qquad (5)
$$

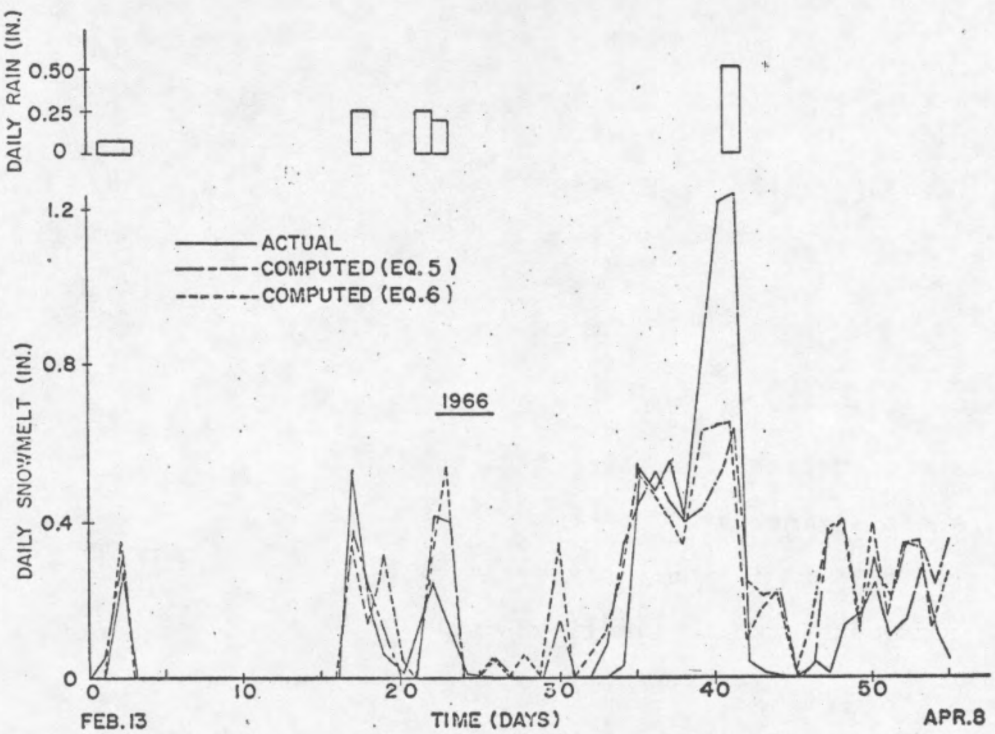


FIG. 8 SNOWMELT BY REGRESSION EQUATIONS

TABLE 1 Comparison of the three methods of snowmelt estimation. 1966

| Method | Mean (in.) | Max. Daily Difference (in) | R.M.S.D.* (in) | % Dev. Seasonal Total |
|---|---|---|---|---|
| Degree-day Eq. (1) | 0.172 | 0.74 | 0.19 | -11.5 |
| Degree-day (modified) Eq. (2) | 0.159 | 0.69 | 0.19 | - 2.6 |
| U.S.C.E. (Simplified) Eq. (3,4) | 0.070 | 0.68 | 0.22 | 54.5 |
| Regression Eq. (5) | 0.172 | 0.71 | 0.17 | -11.5 |
| Regression Eq. (6) | 0.178 | 0.61 | 0.18 | -15.6 |
| Data | 0.154 | 0.00 | 0.00 | 0.00 |

* Root mean squared deviation

$$\text{R.M.S.D.} = \sqrt{\frac{\Sigma(\text{Snow-melt estimated} - \text{snowmelt measured})^2}{N}}$$

FIG. 9 COMPARISON OF THE THREE METHODS (1966) or

$$SM = 0.615 + 0.0373\ SOL\ ..\ 0.00607\ R_L + 0.00201\ (T-36)V + 0.0437\ (RH)V + 0.007\ P_r\ (T-32) \qquad (6)$$

where:

SM = snowmelt (ins/day)

a = albedo (decimal fraction)

$P_r$ = rainfall (ins/day)

$R_s$ = shortwave radiation (langleys/day)

$R_L$ = longwave radiation (langleys/day)*

SOL = sunshine duration (hours/day)

T = mean daily temperature at 4.5 ft. ($^{o}F$)

V = wind speed at 33 ft. height (miles per hour)

The predictions obtained from Eqs. (5) and (6) are shown plotted with actual melt on Fig. 8, and compared with other methods in Fig. 9.

The results summarized in Fig. 9 show that for the observed data all three methods are of comparable acceptance levels; as prediction techniques they need to be considerably refined. Refinement of these techniques will require data of better quality, improvement in understanding the physics of snowmelt generation and transmission through the snowpack, and additional information on snowpack characteristics such as density and effects of rain. For the observed data, largest deviations were associated with rain events. This phenomenon has been isolated also for subsequent data for 1967, 1968, and 1969 but the precise reasons are not understood clearly. Data for these subsequent years are being currently analyzed, and general trends appear to be similar to those indicated for 1966.

## IV FUTURE WORK

As 85 per cent of the North Nashwaaksis Stream Basin is forested, and the present experimental snowmelt plot is located in a clear area, one of the first steps in extending the research program will be setting up a similar installation in a forest environment.

Also, it is to be realized that even completely accurate determinations of basin snowmelt form only the initial input. There remains the further steps of drainage basin hydrograph synthesis and channel routing; for the former, antecedent and prevailing soil-moisture, and extent of frost are likely to be significant influences. A network of 11 soil-moisture stations has already been established for this basin; hopefully,

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*$R_L$ was indirectly estimated from a procedure described in the U.S.C.E. Publication on Snow Hydrology (p. 160)

temperature profiles will also be available for determining frost influences.

## V CONCLUDING REMARKS

In view of the rather significant deviations, as of now, between observed and predicted snowmelt, even at point locations, it appears advisable to install and maintain snowmelt plots in a basin to obtain reliable estimates of this important source information for the synthesis of snowmelt hydrographs. Further, the accumulated data would eventually permit deviation of regional snowmelt prediction equations and improvement in understanding the local physics of snowmelt.

Of course, it is realized that there remains the difficult steps of basin hydrograph synthesis and channel routing under a variety of conditions in the spring season.

## REFERENCES:


1. U.S. Army, Corps of Engineers, Runoff from Snowmelt, Manual EM 1110-2-1406, January 1960

2. U.S. Army, Corps of Engineers, Snow Hydrology, North Pacific Division Office, June 1956

3. Pysklywec, D.W., Davar, K.S., and Bray, D.I. Snowmelt at an index plot. Water Resources Research, Vol. 4, No. 5, October 1968, p. 937-946.