

EFFECTS OF WATERSHED ENVIRONMENT ON SNOWMELT

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Introduction

In the upland watersheds of northern New England winter snows account for about one-fourth of the annual precipitation, and snowmelt produces nearly one-half of the annual runoff. Thus, by its very volume, snowmelt must be considered as representing a potential for flooding, and indeed every spring southern New Englanders keep a nervous eye on those ominous snowpacks up north. But most spring seasons the snow seems to spread its melt over several weeks keeping the rivers full but seldom pushing them over their banks. The rarity of serious spring snowmelt flooding in northern New England is due to a natural snowmelt flood control mechanism inherent in the environmental characteristics of the region. This environment-snowmelt mechanism can be expressed rather elaborately in terms of energy budgets which account for every calorie of heat and every gram of ice and water but the most casual observation can give us these essentials:

- (1) snow melts faster and earlier in the sun than in the shade,
- (2) snow melts faster and earlier on the south side of a hill than it does on the north side,
- (3) snow melts earlier in the valleys than on the mountains.

Thus, the greater the diversity of forest cover, slope-aspect ("the sunniness of slopes"), and elevation over a watershed the greater the areal differentiation of melt rates and the greater the time staggering of melt over the spring season.

The effectiveness of this natural snowmelt control mechanism depends on the type of melting weather. Melt from solar radiation is most subject to such environmental differentiation while melt from high air temperatures and high dew-points is less influenced by forests, slopes and elevation.

The idea of this study is to find a reasonably accurate expression of the relationships between the snowpack, its physical setting and the melting weather factors to permit an evaluation of watershed environment as a regulator of snowmelt. An environment-snowmelt model is adapted to the upper New England area and used to show:

- (1) differences in melt rates within a watershed,
- (2) differences in average melt between watersheds of sharply contrasting environments,
- (3) and differences between watershed melt for selected types of melting weather.

The environment-snowmelt model

A number of investigators have modeled the energy exchange processes involved

in snowmelt and this work is now becoming quite sophisticated. But our purposes require only a reasonably accurate representation of melt rates based on ordinarily available weather data and information on the areal distributions of forest, slopes and elevations over a watershed. The snowmelt equations developed by the U. S. Army Corps of Engineers (1956) were suited to this use and were modified to fit available weather and environmental conditions in northern New England. The following equation was used to estimate daily snowmelt for any environment for any type of melt day:

$$M = K (1 - F) (1 - 0.7 N) (0.0025 I_c) (0.2 T'_x + 1) - 0.84(1 - N) \\ (1 - F) + 0.0084 v (1 - 0.8 F) (0.1 T'_x + 0.78 T'_d) + T'_a (0.025 \\ + 0.007 R)$$

where:

M is snowmelt in inches per day
 K is exposure to short wave solar radiation relative to an open horizontal surface and is a function of slope-aspect
 F is the decimal fraction of forest canopy closure
 N is the decimal fraction of daily average cloud cover
 I_c is the clear sky solar radiation, in langley's per day, for the particular date and latitude
 T'_x is the maximum daily surface air temperature minus 32 degrees F.
 v is the mean daily surface wind speed in miles per hour
 T'_d is the mean daily surface air dewpoint minus 32 degrees F.
 T'_a is the average daily surface air temperature minus 32 degrees F.
 R is the inches of daily rainfall

The part of the first term, $(0.2 T'_x + 1)$, is included only when T'_x has values from -1.0 degrees to -4.0 degrees. This quantity is dropped when T'_x is zero and above and no melt is assumed when this quantity is -5 degrees or below.

A number of assumptions were made in adapting for eastern conditions this melt equation from the original U. S. Corps of Engineers equations which were based on empirical observations in western United States. These will not be discussed here but some comparisons between daily melt predictions based on the melt equation and actual field observations will be made. Figures 1, 2, and 3 show predicted and observed melt during the 1969 melt season for selected forest and slope-aspect settings in the Sleepers River Watershed in Danville, Vermont. Similar comparisons for the 1967 and 1968 seasons showed similar correspondence. The general agreement between prediction and observation is not perfect but quite good and is entirely adequate for our purposes of showing environmental effects.

Applications of the model

A. Variations and average melt over a watershed.

Our melt equation predicts daily melt for a specific forest, slope-aspect and elevation environment. To analyse melt over an entire watershed it was necessary to divide the watershed into a number of discreet melt environments. The 43 square mile Sleepers River watershed was analyzed for the distributions of forest cover, slope-aspect and elevation as follows:

<u>forest zones</u>	<u>slope-aspect (K) zones</u>	<u>elevation zones</u>
open (F = 0)	K = 1.2	660-1000 ft.
hardwoods (F = 0.3)	1.1	1000-1500 ft.
mixed hardwoods	1.0	
and conifers (F = 0.5)	0.9	1500-2000 ft.
conifers (F = 0.7)	0.8	>2000 ft.
	0.7	

FIGURE 1

Observed and predicted 1969 snowmelt
Sleepers River Watershed

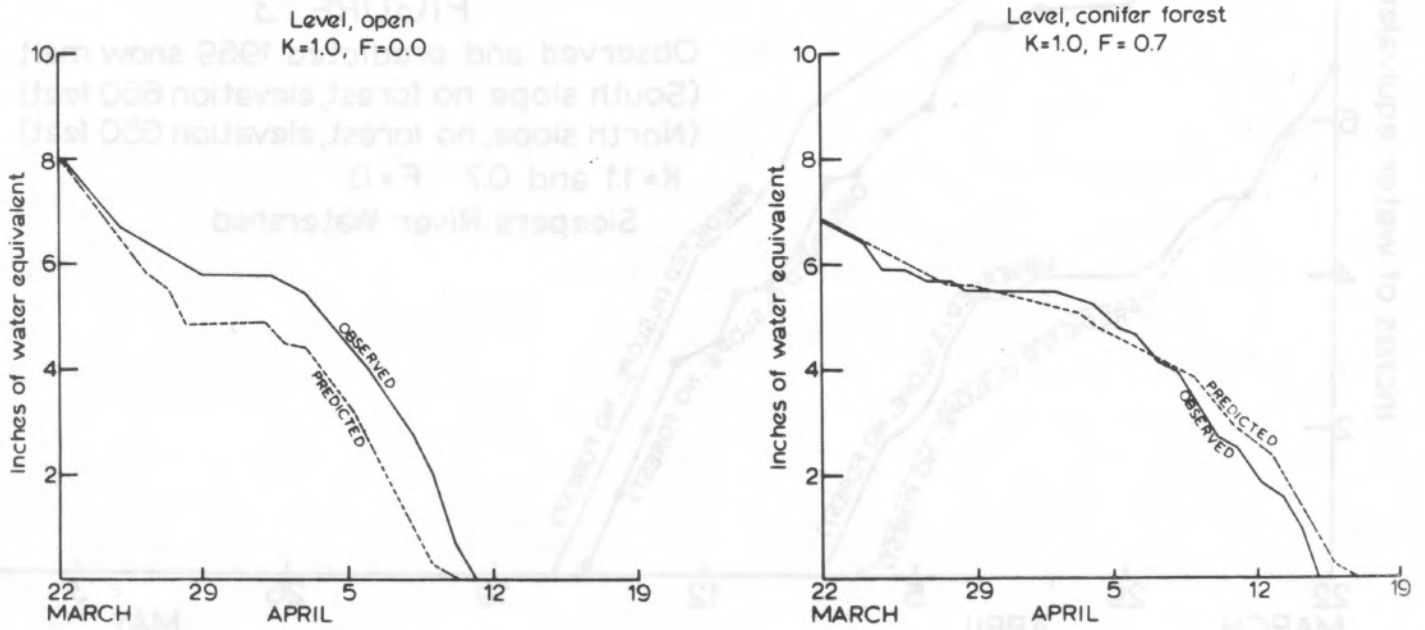
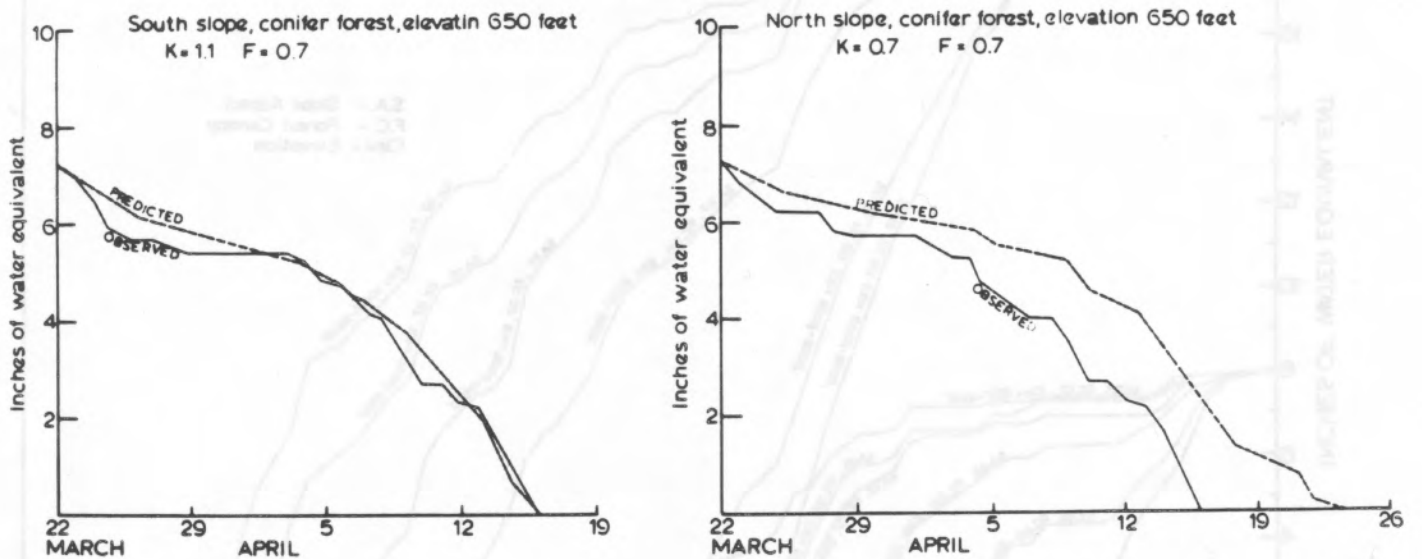


FIGURE 2

Observed and predicted 1969 snowmelt
Sleepers River Watershed



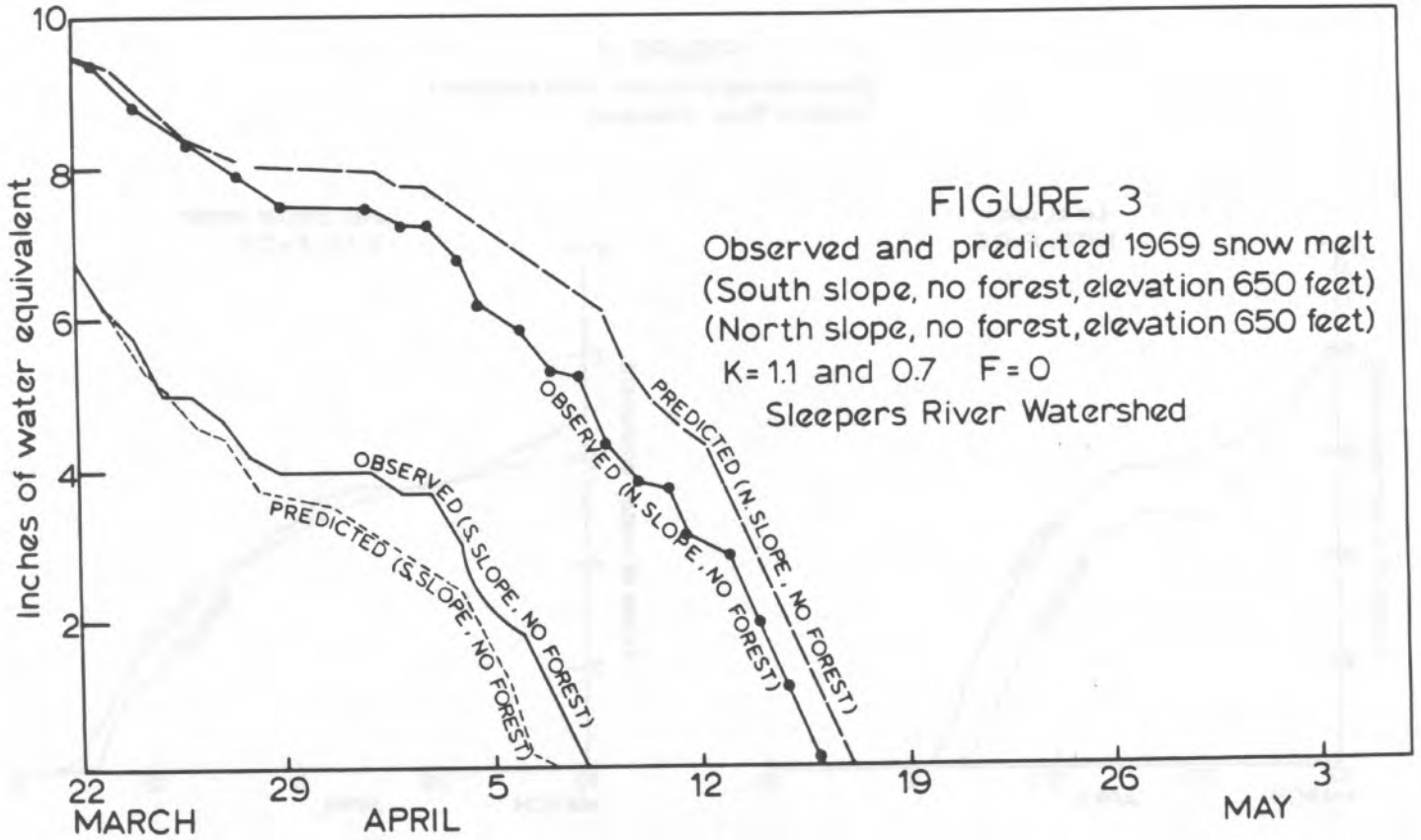
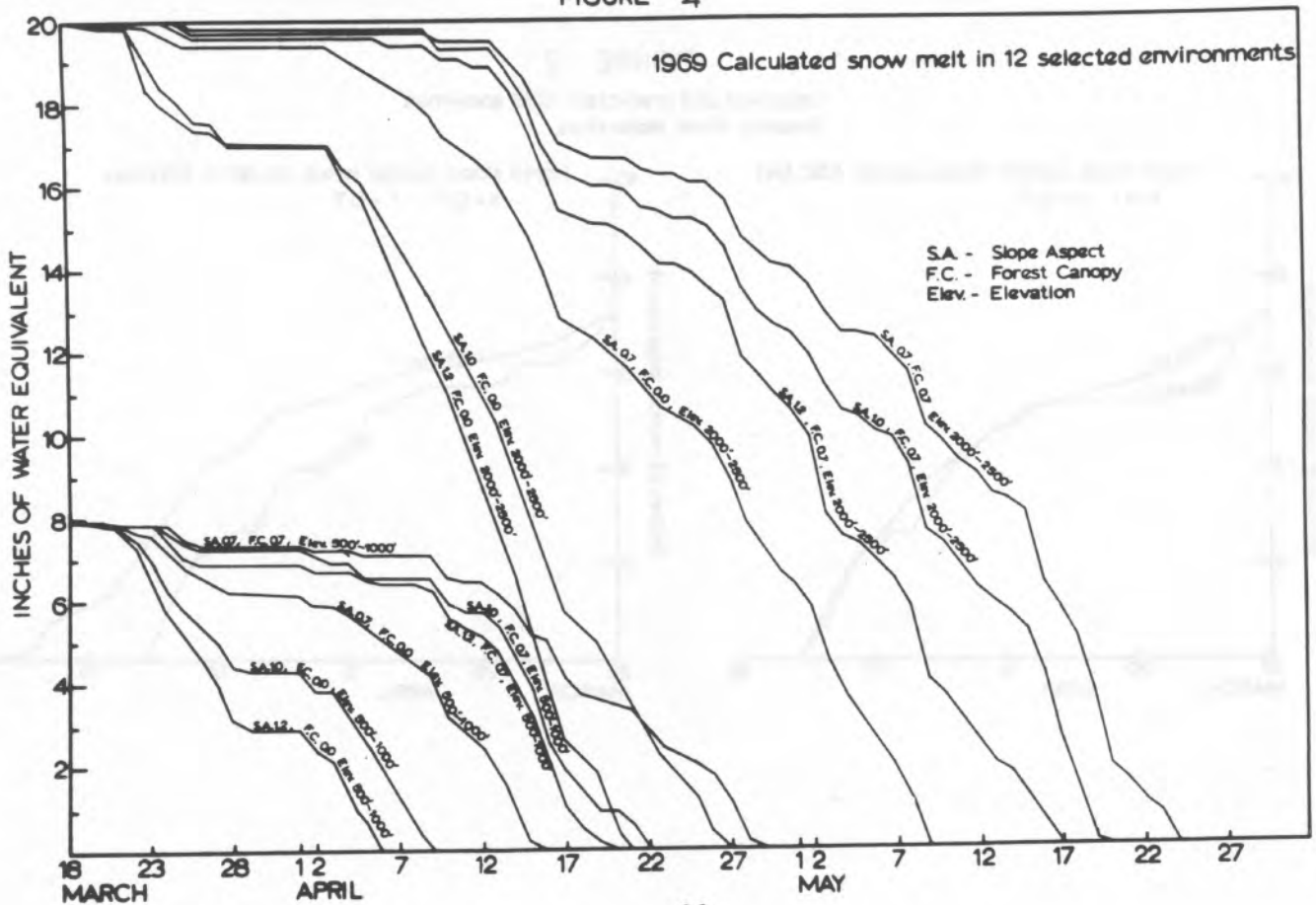


FIGURE 4



The percentage of the watershed area in each of the 96 melt zones represented by all combinations of the above environment factors was computed. A program was then written for application of the melt equation to each of the 96 environments based on weather data from a single station in the center of the watershed. Appropriate temperature-elevation and dewpoint-elevation functions were applied. The program computed the daily melt and kept a running account of the remaining snow cover at each of the 96 environments and also computed the average snowmelt and the percentage of bare ground over the watershed.

The diversity of watershed melt rates over the 1969 melt season is illustrated by the twelve selected melt environments in Figure 4. This figure graphically displays the operation of this watershed's natural snowmelt flood control mechanism during the 1969 melt season. This was the heaviest snowpack on record and melt weather was about normal. The 8 to 20 inches of snowpack water eased down the streams with no difficulty. The 1967 and 1968 seasons showed similar spreading of the melt within the watershed.

B. Variations between watersheds

The Sleepers River is a rather typical watershed in northern New England but other drainage areas may be much more or much less diverse. The most diverse environment is probably the Presidential range area of the White Mountains in New Hampshire. This area was analyzed and divided into 100 specific melt environments. In contrast, a Champlain Valley area was considered to comprise only 9 melting environments. The average daily watershed melt for these two areas was computed for the 1969 melt season and compared with the average daily melt in the Sleepers River watershed. Figure 5 shows the results. The Champlain melt reaches a peak of nearly 1.2 inches per day and the snow cover is totally melted in 15 days. The White Mountain area is still 41 percent snow covered after 48 days and never reaches an average melt of 1 inch per day. The Sleepers River falls in between.

Another way of looking at this difference in snowmelt between contrasting areas is to compute the daily melt ratio between the areas. This is shown in Figure 6. The White Mountain area melts at about one-fifth the Champlain area until April 12 when the rapidly increasing area of bare ground reduces the average melt rate in the Champlain area and brings the ratio sharply upward.

Similar contrasts were found for the 1967 and 1968 melt seasons. If the snowmelt equation is approximately correct, and this is indicated by our observations, then an analysis of the forest and topography over watersheds will tell us a great deal about their differences in snowmelt.

C. Variations during simulated extreme melt situations

The environment-snowmelt model can be used not only to tell us what kind of environment produces the most rapid or the slowest melt but also what kind of weather is most effective in melting snow. Before we become too smug about our immunity to snowmelt flooding perhaps we should look at some possible weather situations that haven't occurred in recent years. We hypothesized a series of 10 days of full sunshine and daily temperatures in the range from 52 to 82 degrees. This was labeled 1997. The computed daily melt for our three watersheds is shown in Figure 7. The differences between watersheds is pronounced and daily melt rates are all below 2 inches.

The simulated sequence which we labeled 1998 was based on an assumption of moist tropical air with strong southerly winds overspreading the region for 6 days. These 6 days had no sunshine, temperatures in the fifties, but dewpoints also in the fifties with winds 10 to 15 miles per hour after the second day. Rainfall was negligible. The more rapid melt in all watersheds, shown in Figure 8, reveals the

FIGURE 5

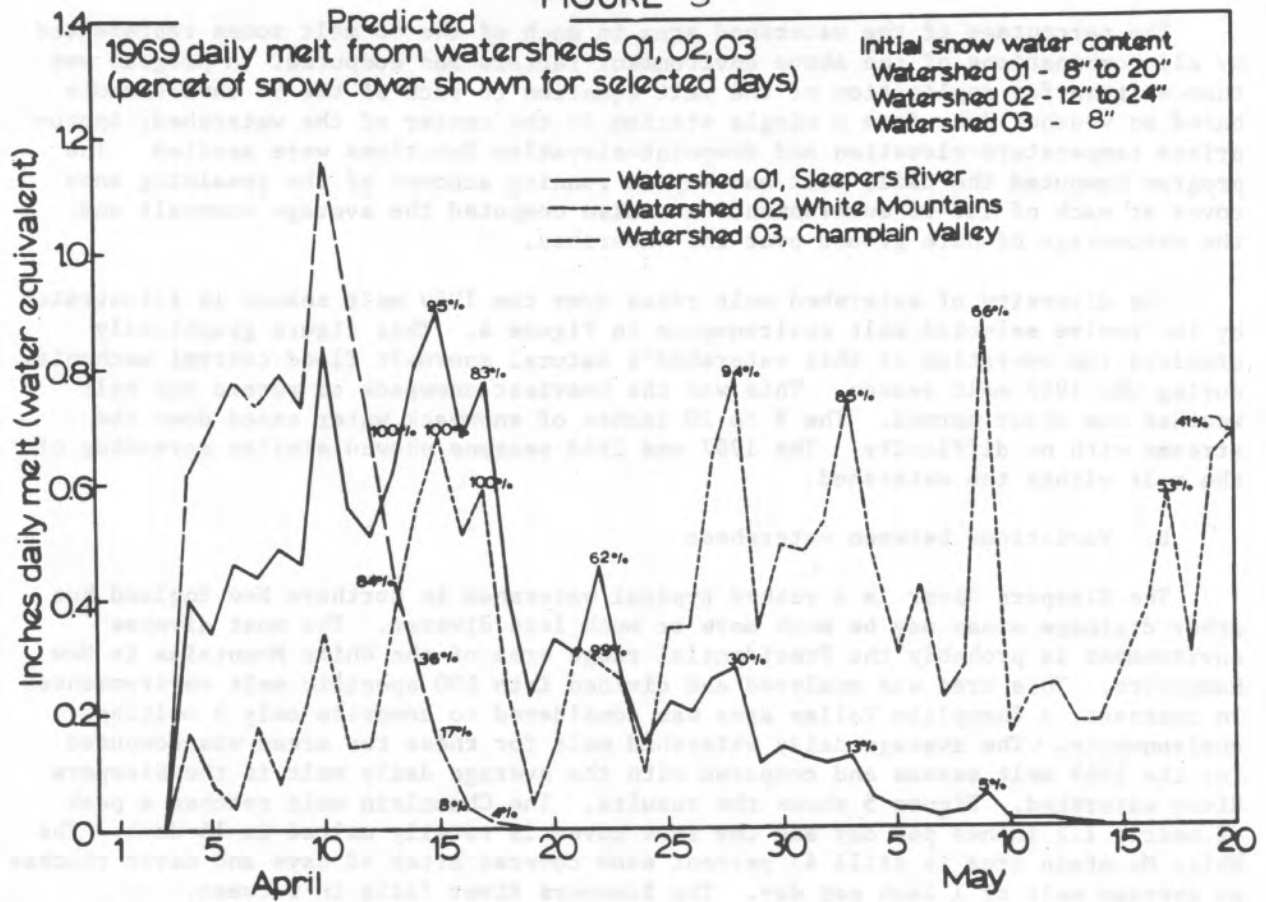


FIGURE 6

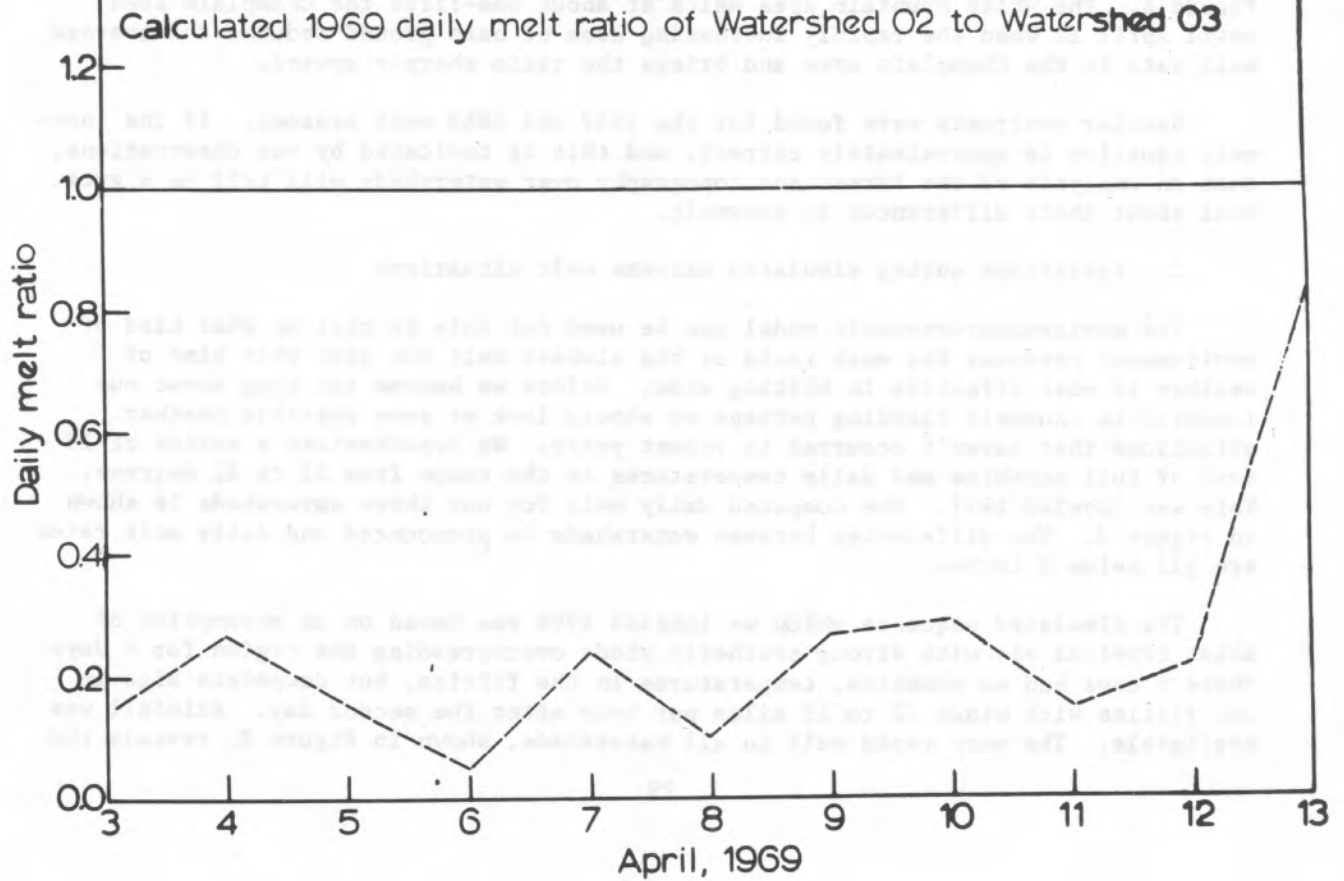


FIGURE 7

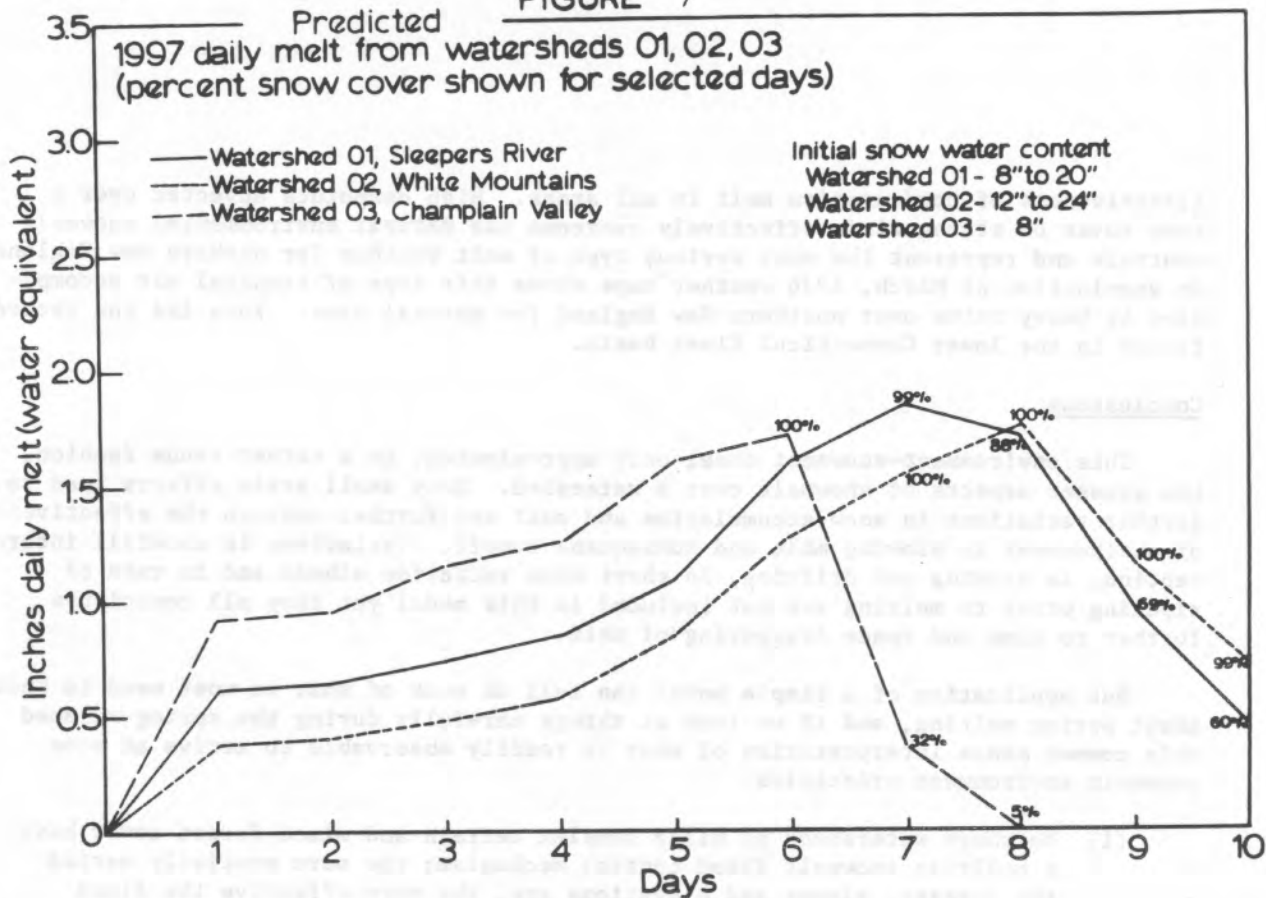
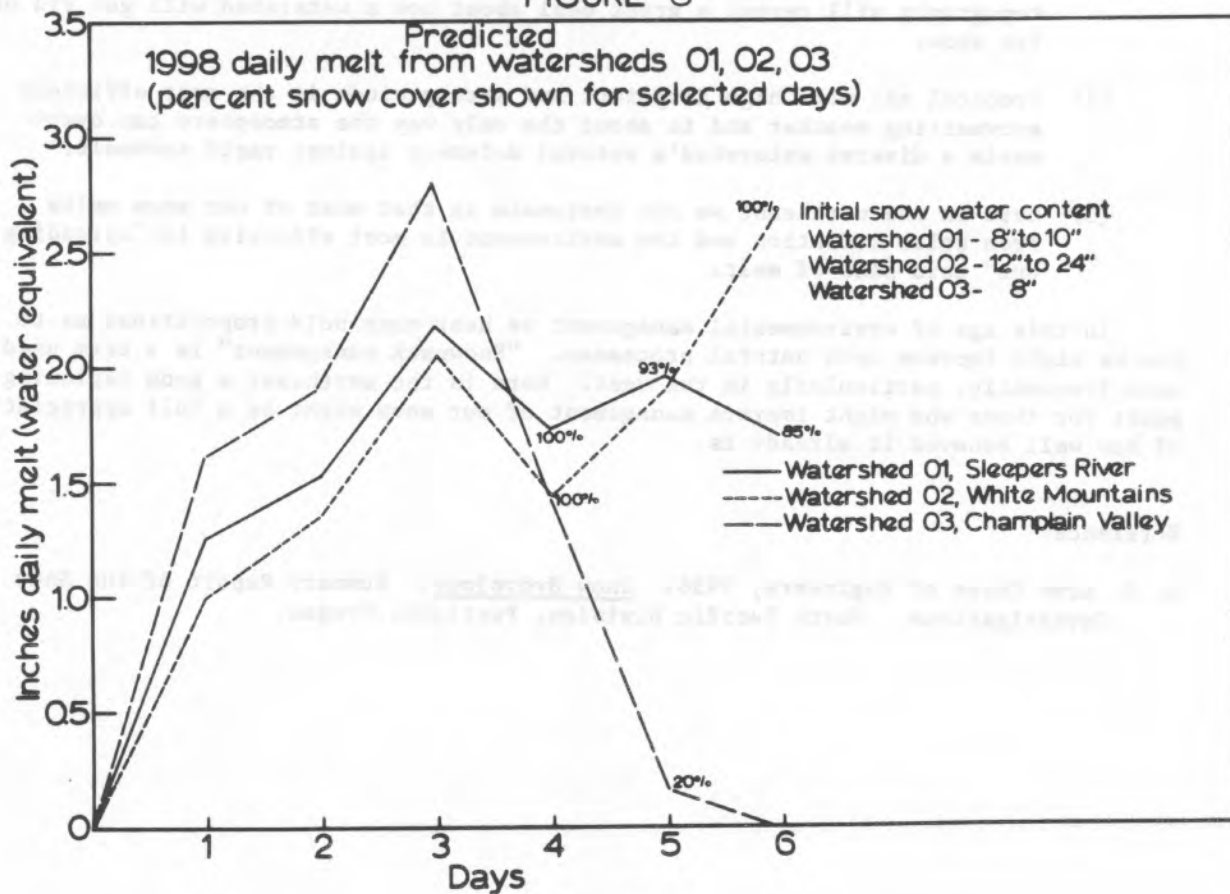


FIGURE 8



effectiveness of condensation melt in all areas. High dewpoints advected over a snow cover on strong winds effectively overcome the natural environmental snowmelt controls and represent the most serious type of melt weather for northern New England. An examination of March, 1936 weather maps shows this type of tropical air accompanied by heavy rains over northern New England for several days. This led the record floods in the lower Connecticut River basin.

Conclusions

This environment-snowmelt model only approximates, in a rather crude fashion, the grosser aspects of snowmelt over a watershed. Many small scale effects lead to further variations in snow accumulation and melt and further enhance the effectiveness of environment in slowing melt and subsequent runoff. Variations in snowfall interception, in blowing and drifting, in short wave radiation albedo and in rate of ripening prior to melting are not included in this model yet they all contribute further to time and space staggering of melt.

But application of a simple model can tell us much of what we most need to know about spring melting, and if we look at things carefully during the spring we need only common sense interpretation of what is readily observable to arrive at some snowmelt environment principles:

- (1) Northern watersheds of hilly complex terrain and mixed forest cover have a built in snowmelt flood control mechanism; the more spatially varied the forests, slopes and elevations are, the more effective the flood control mechanism is apt to be. Appropriate analysis of forest cover and topography will reveal a great deal about how a watershed will get rid of its snow.
- (2) Tropical air with high dewpoints and strong winds is the most efficient snowmelting weather and is about the only way the atmosphere can overwhelm a diverse watershed's natural defenses against rapid snowmelt.
- (3) Here in the northeast we are fortunate in that most of our snow melts from solar radiation and the environment is most effective in "spreading out" this kind of melt.

In this age of environmental management we hear many bold propositions as to how we might improve upon natural processes. "Snowpack management" is a term used more frequently, particularly in the west. Here in the northeast a good beginning point for those who might improve management of our snow might be a full appreciation of how well behaved it already is.

Reference:

U. S. Army Corps of Engineers, 1956: Snow Hydrology. Summary Report of the Snow Investigations. North Pacific Division, Portland, Oregon.