Chapter 6
Snowmelt—Temperature Index Solutions

6-1. Overview—Basic Assumptions

This chapter covers the second basic method for computing snowmelt, that of using air temperature as an index to melt. This method recognizes the basic problem in applied snow hydrology, particularly in river forecasting, that many of the energy budget variables are not conveniently available for use. It also fully employs the concept of an "index," where a known variable is used to explain a phenomenon in a statistical rather than in a physical sense. As noted in Chapter 5, the snow investigations studies used the index concept for some of the energy budget equations by employing multiple regression and by simply accepting the fact that the physics involved were not explicitly explained in the parameters so derived. These statistical studies went further to explore the possibility of removing many of the "difficult" variables from the equations to make them as practical as possible. Since air temperature was already a predominant variable used in the energy budget equations, it is logically connected with many of the energy exchanges involved in snowmelt. And since it is commonly available to hydrologists in historical and real-time databases, the studies concluded that air temperature is a useful index to snowmelt, particular in forest-covered basins. Since that time, the temperature index method has been used extensively and almost exclusively in snowmelt modeling and river forecasting. This chapter will present the basic temperature index equation and technique, concentrating on the melt-rate coefficient, which is the key to using this approach successfully. The method will be compared with results achieved with the energy budget equations to illustrate the problems in applying the equation using nominal melt-rate factor values to situations beyond the boundaries of ideal application. Since this is a solution that needs to be applied with considerable judgment, summary guidance on the approach will conclude the chapter.

6-2. Basic Equation

The basic equation for the temperature index solution is

$$M_s = C_m(T_a - T_b) \qquad (6\text{-}1)$$

where

M_s = snowmelt, in. per period

C_m = melt-rate coefficient that is often variable, in./(degree/period)

T_a = air temperature, °F

T_b = base temperature, °F

a. In the above equation the melt-rate factor C_m typically varies between 1.8 and 3.7 mm/°C (0.04 and 0.08 in./°F) as discussed in detail below. The temperature variable used would depend upon the method of application and the size of the river basin involved. For large snowmelt basins simulated with a daily time increment, it is typical to use daily maximum and minimum air temperatures as the index variables for this equation, weighting each as desired based upon model calibration. Sometimes the maximum daily temperature only is used as the index because it is an indicator of cloud cover in the basin. If the computation interval needs to be shorter than 1 day, then representative average temperatures for the computation period would be used.

b. The base temperature is typically a value near 0 °C (32 °F), particularly for shorter computation periods using representative period temperatures as input. If, however, maximum daily temperatures were used as the index, the base temperature would be higher, perhaps as high as 4.44 °C (40 °F).

c. Investigators have over the years offered variations to Equation 6-1, primarily in the manner of specifying the melt-rate factor. Gray and Prowse (1992) contains a good summary of these alternative expressions.

6-3. Melt-Rate Coefficient—Sensitivity, Range of Magnitude

a. *General*. Proper use of the melt-rate coefficient (sometimes called the degree-day factor) is an important key to successfully applying the temperature index equation. Review of the discussion in Chapters 2 and 5 of the physical principles involved in snowmelt shows intuitively that temperature is not directly related at all to shortwave or condensation energy sources, and it only partially explains the other components of total energy flux. In the derivation of the generalized energy budget equations, however, it was demonstrated that, for forested areas, shortwave radiation and wind effects become less important, thereby allowing temperature to become a more definitive index of snowmelt. In general, then, it can be said that temperature is a reasonably good index of energy flux in heavily forested areas, while it is less so in open areas where shortwave radiation or wind velocity plays a more important role in the melt process. It follows that for those situations where the factor is not a good index, the melt-rate factor must be treated less as a constant and more as a variable to make the application work with reasonable success. This is accomplished by having the melt-rate factor vary according to independent relationships in a simulation model or by simply applying careful judgment in choosing the appropriate value, say in a river-forecasting situation.

b. Range of variation. The range of the melt-rate factor is typically 1.8 to 3.7 mm/°C (0.04 to 0.08 in./°F) for rain-free conditions. Higher values can be expected in extreme cases, as will be demonstrated. These factors would be lower if the temperature index used is the maximum daily temperature. The possible range of the melt-rate factor can be illustrated by the hypothetical cases presented in Table 5-4. By use of the daily melt quantity calculated by the energy budget equations and the temperatures assumed, the melt-rate coefficients calculated through Equation 6-1 would be as shown on Table 6-1. This table demonstrates that one case where the nominal values of melt-rate coefficient would underestimate snowmelt is when heavy winds in a rain-on-snow situation with a saturated air mass cause condensation melt to be high. Additionally, Figures 5-6, 5-7, and 5-8 and overlying lines representing the temperature index equation with varying melt-rate factors illustrate the melt-rate factor range. These are shown in Figures 6-1, 6-2, and 6-3. In general, these suggest that a melt-rate factor for rain-on-snow should be on the high side of the nominal range, and, for situations where wind is import, even higher values should be used.

Table 6-1
Relative Magnitude of Melt-Rate Factors (Refer to Table 5-4)

Case	T_a, °F	T_b, °F	Melt, in.	C_m, in./°F	Comment
1	70	32	2.57	0.068	Clear, low albedo
2	70	32	2.40	0.073	Case 1, 40% forest
3	65	32	1.51	0.040	Case 1, cloud cover
4	70	32	1.73	0.046	Case 1, fresh snow
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5	50	32	3.24	0.180	Heavy rain, windy
6	50	32	2.92	0.163	Light rain, windy
7	50	32	1.11	0.062	Light rain, light wind

c. Determination and application. In modeling for engineering and forecasting practice, the melt-rate factors are verified through the process of calibrating a hydrologic model. The energy budget equations can be a useful guide in establishing initial estimates for the model. Once established for known historical conditions, the factor can be modified by judgment. Again, the energy budget principles should be applied in assisting in this process. Additional discussion of the magnitude of the temperature index melt-rate factor can be found in USACE (1956), Anderson (1973), and Male and Gray (1981).

(1) Real-time flood forecasting in some rain-on-snow situations may present challenges in using the temperature index method since, as shown above, the melt-rate coefficient can vary widely in magnitude because of wind effects. In major storms, the variation could be abrupt and have quite a significant effect on snowmelt rates. If this is a potential problem, real-time wind data should be used. If not factored directly into a simulation model, the wind data could be used with a relationship, such as that shown in Figure 6-2, as guidance to a forecaster who is making on-the-spot-judgment calls in setting up a forecast model. The relationship should be verified with known historical storm data, if possible.

(2) In clear-weather and partly forested snowmelt situations, the melt-rate factor varies seasonally, typically increasing as the snowmelt season progresses owing to factors such as the decrease in albedo and

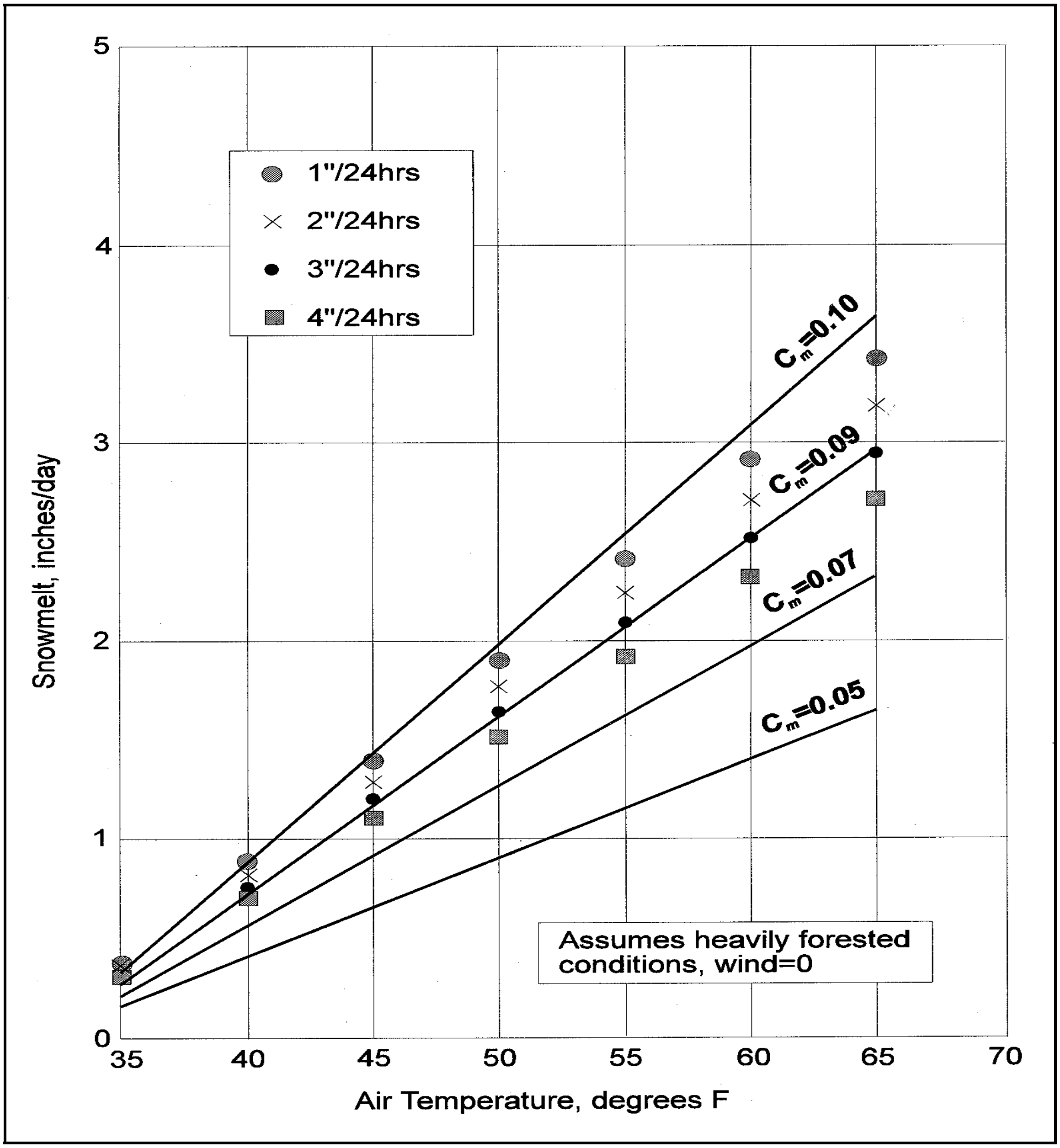

Figure 6-1. Melt rates in a heavily forested area, rain-on-snow

increased daily insolation. Because of this, simulation models usually calculate C_m as a variable. This can be done by making C_m a function of accumulated runoff or accumulated degree-days of air temperature. Such a relationship would need to be verified by simulation of historical records.

(3) For hydrological engineering analyses, the melt-rate factor must be used with considerable caution, if at all. In a well-calibrated and verified model, the factor is not a concern unless the design application extrapolates beyond the range of historical calibration. In such cases, reference to the energy budget equations may help in judging the magnitude of the melt-rate factor. For derivations of extreme floods, such as a PMF, the temperature index approach is of little or no value in computing snowmelt-rates, since there is no way to quantify a maximum snowmelt. In such applications, the energy budget method should be used.

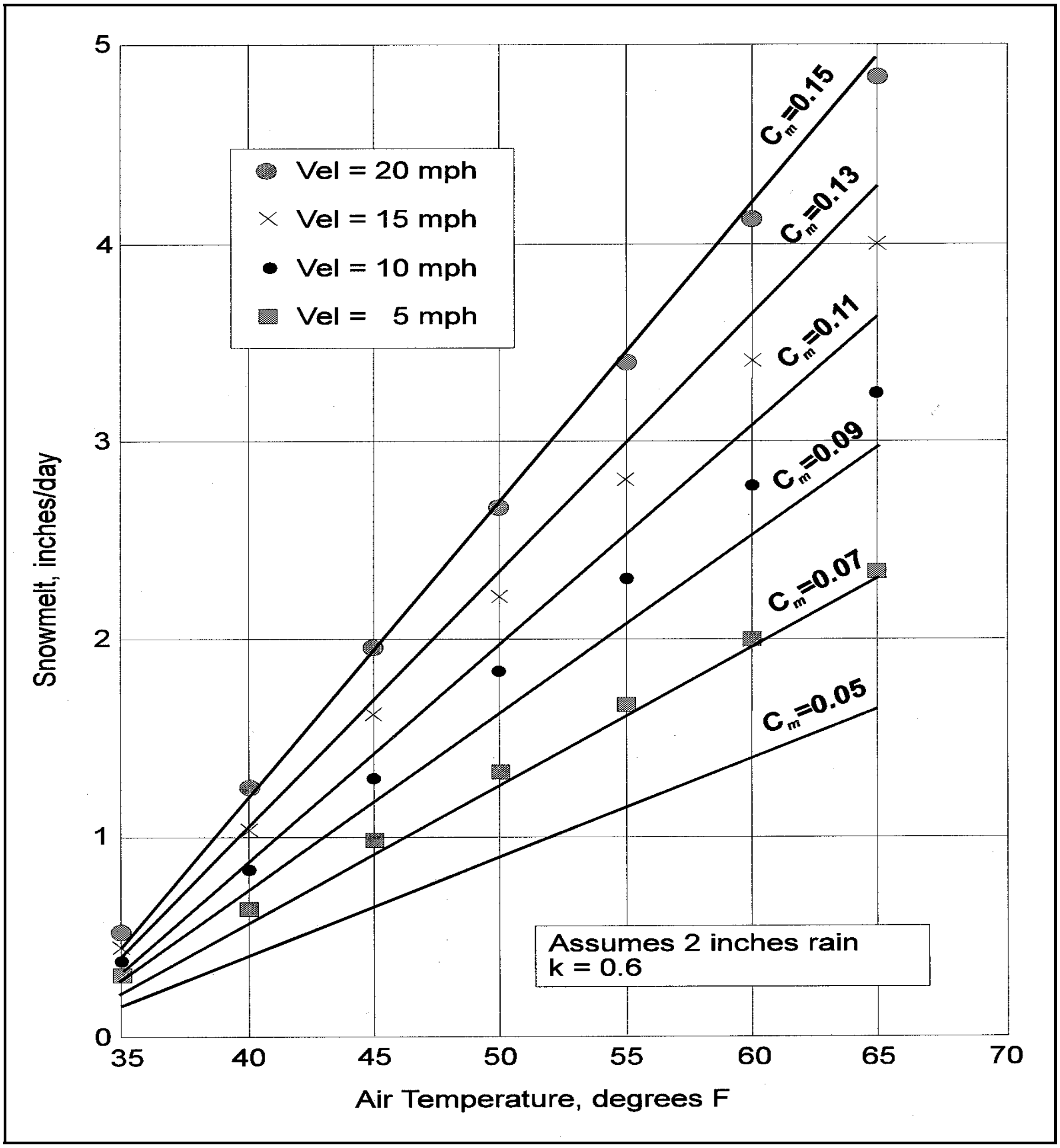

Figure 6-2. Melt rates in a partly forested area with wind effects, rain-on-snow

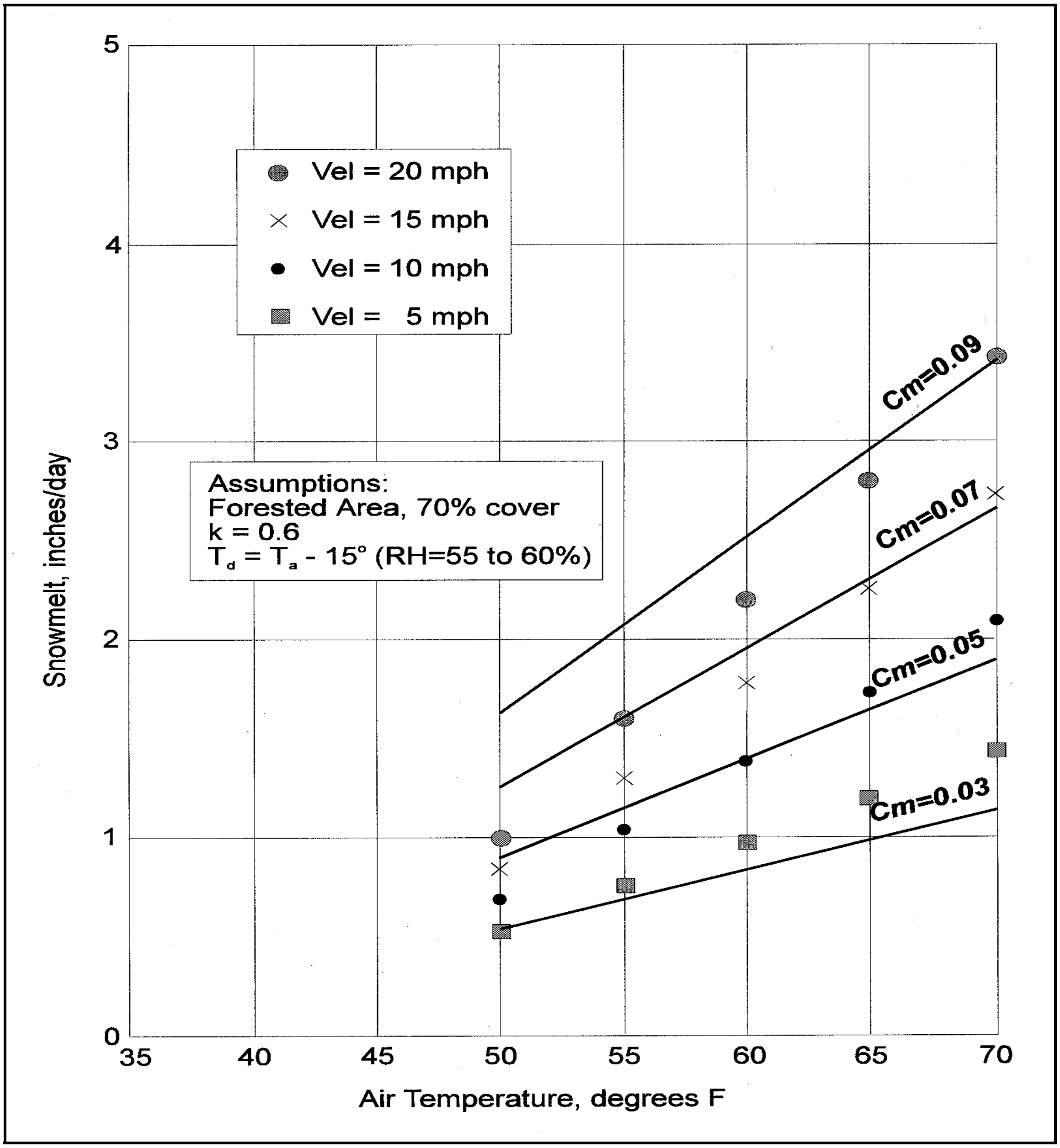

Figure 6-3. Melt rates in a forested area, rain-free conditions