How Similar Are Snow Depletion Curves from Year to Year? Case Study in the Upper Rio Grande Watershed

MICHAEL C. MENOES[1] AND KAYE L. BRUBAKER[1]

EXTENDED ABSTRACT

Many models of snowmelt runoff require snow depletion curves for the purpose of simulation or forecasting. These curves describe the seasonal decline of snow-covered fraction *(S)* as a function of time *(t)* or cumulative melt energy *(M)*. Under simplifying assumptions, the end-of-winter spatial distribution of snow water equivalent (SWE) can be estimated from the *S(M)* depletion curve. The use of *S(t)* and/or *S(M)* curves in forecasting assumes some uniformity of basin response from year to year. The objective of this study is to assess basin response uniformity for the Upper Rio Grande Watershed (Del Norte) by analyzing a time series of snow depletion curves. Curves are constructed for the Upper Rio Grande Basin for several years. *S(t)* are determined using the National Operational Hydrological Remote Sensing Center (NOHRSC) snow/no-snow products, and *M(t)* curves are derived by means of a simplified energy balance. The end-of-winter SWE distribution is assumed to follow a Beta distribution and its parameters are estimated using numerical methods. The end-of-winter SWE distributions are compared and analyzed.

S(t) is defined as the fraction of the plan-view area that remains snow-covered as the snowpack melts from a basin or a defined region of that basin. *M(t)* is defined as the cumulative melt energy received by a specific zone or region since the end-of-winter, expressed as the equivalent depth of snow, usually in terms of centimeters of water. *S(M)* is described as a modified depletion curve that defines the relationship between fractional snow-covered area and cumulative melt energy.

Martinec (1972) noted the relationship between the spatial frequency distribution of snow water depth and the temporal pattern of snow-cover decline. Liston (1999) presented a theoretical formalization of the relationship between *S - M - t*, and showed that, under certain simplifying assumptions, knowledge of any two of these variables could lead to the derivation of the third, unknown variable. Formalizing these ideas will make it possible to obtain additional information on the desired quantity (snow water volume), which is not easily observed, from a more easily observed quantity, snow cover.

Using *S(M)* in forecasting and other model applications is ultimately aimed at developing techniques to apply to data-poor regions, and to demonstrate the value of the theory for short term and extended hydrologic forecasting. A consequence of using *S(M)* curves in forecasting is that an assumption is made regarding some uniformity in snowmelt basin response from year to year.

The watershed utilized for this research was the Upper Rio Grande watershed at Del Norte. This watershed is centered at approximately 107^0 E, 37^0 7' N, and has an area of approximately 3,450 square kilometers. The range in elevation is from 2432 m to 4215 m. The terrain is fairly rugged, with an average slope of approximately 15%. Annual precipitation ranges from 25 cm in the

[1] Dept. of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742

foothills to 130 cm in the high mountains, over 60% of which occurs as snowfall. Roughly 60% of the region is forested. For this study, the watershed was subdivided into six zones based on elevation and aspect. Using “snow/no snow” NOHRSC satellite imagery, snow-covered fraction, *S(t)*, for each zone was determined. Cumulative melt, *M(t)*, was estimated by a degree-day equation (which is based upon daily average temperature), and nonlinear regression was used to fit the complement of the cumulative Beta distribution to the *(M, S)* points.

The probability density functions derived from the Beta distribution were first compared to distributions generated from NOHRSC SWE maps. NOHRSC develops estimated SWE maps based upon SWE data gathered at Natural Resources Conservation Service (NRCS) sites augmented with satellite imagery, and these maps were used to estimate the SWE distributions. The non-parametric Kolmogorov-Smirnov one-sample test was utilized to determine if the distributions derived from the NOHRSC SWE maps represented Beta distributions with a particular set of parameters as determined by the nonlinear regression analysis. The K-S one-sample test determined that the regression-derived Beta distributions tend to fit the lower elevation zones better than the higher elevation zones.

It is hypothesized that the regression-derived Beta distribution fits better for the lower elevation zones because the lower elevation zones have a greater percentage of snow-free area at the end-of-winter. The snow free surface absorbs a greater amount of solar radiation than a snow covered surface. The absorbed solar radiation warms the near surface air, thus making the average daily temperature a reasonable indicator of received energy. Conversely, the higher elevation zones have a small or zero percentage of snow-free area at the end-of-winter. The snow’s albedo initially reflects most of the solar radiation, preventing a warming of the near surface air, thus making average daily temperature a less suitable indicator of received energy.

Families of curves were created for each of the zones by grouping curves created for each year studied. Figure 1 shows examples of these families for the high elevation zones.

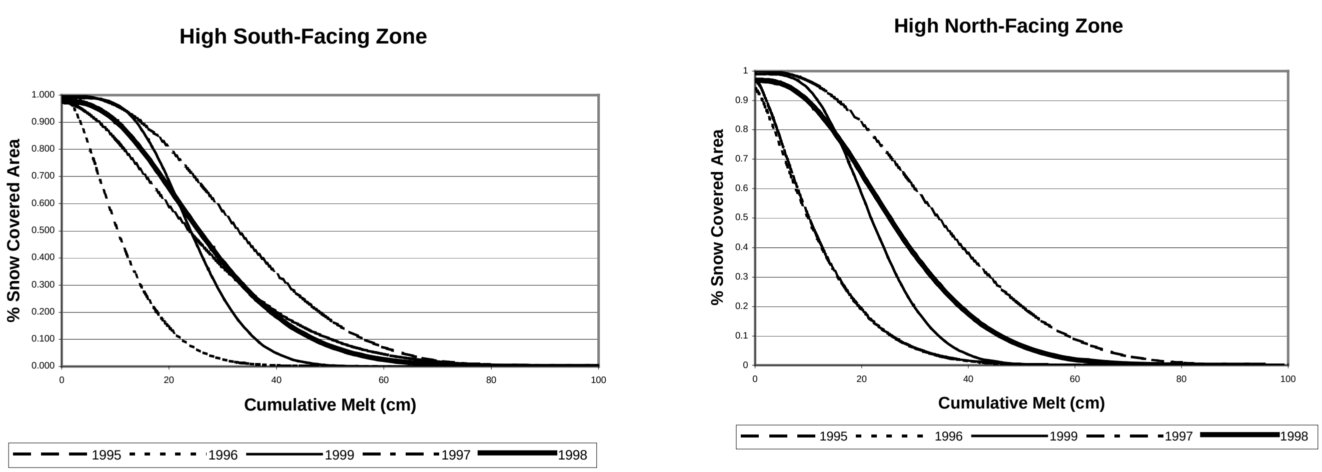

Figure 1. Families of depletion curves derived by fitting the Beta cumulative distribution to time-series data. Examples are shown for the high elevation zones in the Upper Rio Grande watershed.

The plots of the depletion curves are encouraging despite the uncertainties involved in the methodology. Theoretically, the intercept represents end-of-winter snow cover *(S)*, and the area under the curve is proportional to average SWE in the zone. We expect lower average SWE to be associated with lower end-of-winter *(S)*; therefore, the curves should not cross or intersect. The basic shapes in Figure 1 follow the pattern for a family of curves, but the intersections of curves indicate that they do not represent a true family of depletion curves. Several explanations can be offered: the nonlinear regression yields a non-unique solution; end-of-winter was visually determined from NOHRSC satellite images; the initial assumption that the disappearance of snow from a zone is due entirely to melt; and the use of the degree-day equation for determining cumulative potential melt energy.

Further research will concentrate on improving the methodology to include other physical processes, such as wind transport and avalanching, in the analysis of the depletion of snow-covered area. Additionally efforts will be made to minimize the uncertainties associated with the process, such as including additional factors like solar radiation in determining potential melt, and utilizing the concept of the snowpack cold content in determining "end-of-winter."

References

Liston, G. E., 1999: "Interrelationships Among Snow Distribution, Snowmelt, and Snow Cover Depletion: Implications for Atmospheric, Hydrologic, and Ecologic Modeling." *Journal of Applied Meteorology*, **38**, 1474 - 1487.

Martinec, J., 1972: "Evaluation of Air Photos for Snowmelt-Runoff Forecasts." *Proc. International Symposium on the Role of Snow and Ice in Hydrology*, UNESCO-WMO-IAHS, Banff, 915 - 926.