Comparison of Temperature-Index Snowmelt Models for Use within an Operational Water Quality Model

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The accurate prediction of snowmelt runoff is a critical component of integrated hydrological and water quality models in regions where snowfall constitutes a significant portion of the annual precipitation. In cold regions, the accumulation of a snowpack and the subsequent spring snowmelt generally constitutes a major proportion of the annual water yield. Furthermore, the snowmelt runoff transports significant quantities of sediment and nutrients to receiving streams and strongly influences downstream water quality. Temperature-index models are commonly used in operational hydrological and water quality models to predict snowmelt runoff. Due to their simplicity, computational efficiency, low data requirements, and ability to consistently achieve good results, numerous temperature-index models of varying complexity have been developed in the past few decades. The objective of this study was to determine how temperature-index models of varying complexity would affect the performance of the water quality model SWAT$_{\text{bf}}$ (a modified version of SWAT that was developed for watersheds dominated by boreal forest) for predicting runoff. Temperature-index models used by several operational hydrological models were incorporated into SWAT$_{\text{bf}}$. Model performance was tested on five watersheds on the Canadian Boreal Plain whose hydrologic response is dominated by snowmelt runoff. The results of this study indicate that simpler temperature-index models can perform as well as more complex temperature-index models for predicting runoff from the study watersheds. The outcome of this study has important implications because the incorporation of simpler temperature-index snowmelt models into hydrological and water quality models can lead to a reduction in the number of parameters that need to be optimized without sacrificing predictive accuracy.

Cold-region watersheds are characterized by long, cold winters that are brought about by extended periods of subzero temperatures (Pomeroy et al., 2007). Over the winter months, substantial quantities of water are held in storage within the accumulating snowpack. In the spring, when the air temperature begins to exceed 0°C, the stored water is released to the stream network. For most cold regions watersheds, runoff generated from the spring snowmelt produces the annual maximum flow and a large proportion of the annual water yield (Davison and Pietroniro, 2005).

Numerous studies have shown that large quantities of sediments and nutrients are mobilized and transported in snowmelt runoff (Harms et al., 1974; Timmons and Holt, 1977; Timmons et al., 1977; Martz, 1978; Culley et al., 1983). In these studies, large proportions of the annual sediment and nutrient export from the watershed were produced during the brief spring snowmelt period. Consequently, Oberts (1994) pointed out that “potential water pollution associated with melting snow are a concern to watershed managers in northern climates.”

More recent studies confirm the strong connection between spring snowmelt and the export of sediments and nutrients from watersheds in cold regions. For example, Braun et al. (2000) measured the suspended sediment yield from the Sophia River watershed on Cornwallis Island, Nunavut, Canada. They found that snowmelt runoff accounted for 88% of the annual suspended sediment load, whereas 6 and 9% was transported in response to a slushflow event and summer rainfall, respectively. Roberson et al. (2007) reported that two snowmelt runoff events contributed 68% of the annual cumulative dissolved reactive phosphorus load from a site covered in alfalfa in Wisconsin. Jamieson et al. (2003) found that snowmelt represented 89.7% of the total suspended solids lost from an agricultural field in Quebec for the 2000/2001 water year.

The mass load of sediment and nutrients carried by a stream is generally more important than the absolute concentration when it comes to assessing the long-term adverse effects on downstream aquatic ecosystems and water users. The study conducted by Jamieson et al. (2003) is illustrative in this respect. They found that snowmelt represented 89.7% of the annual total...