Chapter 11
Guidelines for Snowmelt Model Selection

11-1. General Introduction

The aim of the hydrologist in the choice of a particular mathematical modeling scheme depends on a clear definition of the problem to be solved and upon the database that is available to describe the physical system (Anderson and Burt 1985). The preceding chapters have discussed the fundamental physical and engineering processes that need to be addressed and the database requirements in snowmelt modeling. The key points in the selection of the appropriate modeling methodology are as follows.

- Operation and calibration data availability.

- Expected physiographic and climatic conditions.

- Detail and type of results required.

- Probability of extreme events.

a. The availability of operation and calibration data is a key constraint to the choice of methodology. If an ungauged catchment is the area of interest, any model involving optimization procedures based on historical discharge record or a complex conceptual energy budget would be ruled out because of the absence of data. The accuracy, representativeness, and validity of the collected data are as important as their availability in model selection. Models based on physical parameters require physically meaningful data inputs to correctly characterize the snowmelt process. Even with simple empirically derived index methods, the issues related to data reliability are of major importance. The versatility of a model in characterizing varying physiographic and climatic conditions is an important factor. This is called model mobility and is critical to applying a model to a new site. Most calibrated snowmelt models tend to be site-specific, and their applicability to differing conditions is a function of their deterministic quality. The purpose of the analysis is probably the most exact requirement of snowmelt analysis. Whether or not the model is used for real-time forecasting is also a consideration. The detail and type of results required, e.g., peak flow, event volume, event hydrograph, or a long-term sequence of flows, weigh greatly on the choice of the appropriate modeling scheme.

b. The probability of extreme events leads the hydrologist to consider a physically based approach versus empirically derived indexes. As mentioned previously, index methods are most accurate under normal conditions, whereas energy budget approaches, owing to their physical basis, are more accurate at forecasting extreme events.

c. For the operational hydrologist, the availability of resources and time to carry out a snowmelt-forecasting analysis is of extreme importance. Some techniques, such as a complete energy budget approach to snowmelt analysis, require extensive commitments of personnel, computer resources, and expertise to become operational. These management applications or operational constraints need to be fully considered in selecting methodology. In general, two main issues emerge in model selection: the need for widely applicable models and the requirement for suitable databases to support the snowmelt modeling.

11-2. Specifics of Snowmelt Model Selection

As mentioned previously in Chapter 10 (the analysis alternatives are summarized in Table 10-1), numerous alternatives are available for approaching computing snowmelt in hydrological engineering analysis and forecasting. Table 11-1 lists the characteristics of six operational snowmelt models that have been chosen because they are applied by USACE, generally in North America. These models are used by Federal, State, and private institutions. The USACE hydrologist should be aware of the framework of other agencies' models as they pertain to operation of USACE projects.

a. The USACE models, SSARR and HEC-1, are typically used for snowmelt. The choice between the two models, for example, might be based on the need for short- or long-term forecasts. The SSARR model is a continuous simulation model that does continuous accounting of snowpack conditions, whereas HEC-1 is an event-based model that does not have snowmelt accounting. Therefore, if the engineering applications

Table 11-1
Comparison of Operational Snowmelt Models (After Schroeter 1988; Ontario Ministry of Natural Resources 1989)

	Model Name / Type					
	SSARR C*	HEC-1 E*	NWSRFS C	PRMS C	SRM E	GAWSER E
Energy budget	o	o	•	•		•
			(rain on snow)			
Modeled components						
Temp. index	•	•	•		•	
Elev. correction	•	•	o	•	•	
Areal snow cover	•	•	•	•	•	•
Forest/open	o	o		•		•
Heat deficit	•		•	•		•
Water storage	•		•	•		•
Density depth		o				•
Frozen ground		o	o			
Input data requirements						
P	•	•	•	•	•	•
T_a	•	•	•	•	•	•
T_d	o	o				•
u_z	o	o				•
Q_{sin}	o			•		•

Note: • = standard; o = optional; C = continuous-simulation capacity; E = single-event model; P = precipitation; T_a = air temperature; T_d = dew point; u_z = wind speed; and Q_{sin} = incoming solar radiation.

require a short-term forecast, the hydrologist might choose HEC-1, and for long-term forecasts, SSARR.

b. The other models listed are for other agencies and institutions. The National Weather Service, as the primary U.S. river forecast agency, uses the National Weather Service River Forecast System (NWSRFS), which is an offspring of the Stanford Watershed Model (Anderson 1973). PRMS is supported by the U.S. Geological Survey and employs new technologies for distributing runoff based on hydrological response units (Leavesley et al. 1983). The Agricultural Research Service (Martinec, Rango, and Major 1983) supports the model SRM. It has been applied worldwide and consists of a simple, rational-form-based runoff model. The use of satellites to remotely sense snow-covered area to derive snow cover depletion curves is an important feature of this model. The last model listed in Table 11-1 is Guelph All-Weather Storm-Event Runoff (GAWSER) (Schroeter 1989). It is a Canadian model that has been applied operationally. The features that might affect its applicability are its distributed nature and its use in prairie, agricultural regions. In the following (Paragraph 11-3), summary fact sheets for each model are provided for quick reference to the models, and in Appendix F, a more complete description of each model is detailed. By using Table 11-1 and these fact sheets, the general capabilities of these models can be seen, and an appropriate snowmelt model can be selected.

11-3. Summary Fact Sheets for Selected Snowmelt Models

a. Model name, Streamflow Synthesis and Reservoir Regulation Model (SSARR).

(1) Description. Continuous streamflow simulation model using either a lumped parameter or distributed (elevation band) representation. SSARR contains a watershed model and a river system and reservoir regulation model. Originally developed in 1956, it has been successfully implemented for numerous diverse river basins worldwide. Model routing in the watershed and river system is accomplished by cascading linear reservoirs. Evapotranspiration is computed as a function of air temperature or from input-evaporation data. The model has been used for both short-term and long-term forecasting, including ESP-type forecasts.

(2) Snowmelt routine description. Two options:

(a) Temperature-index method with lapse-rate correction.

(b) Generalized energy budget snowmelt equation (USACE 1956). Daily melt is calculated and distributed throughout the day using distributions based on the diurnal fluctuations of heat supply for melting snow. Areal distribution of snow is by means of a snow cover depletion function or by elevation bands. Ground melt is available.

(3) Suitability and restrictions. Suitable to a wide range of basins; flexible in time step and basin size. Does not deal directly with occurrence of frozen ground; limited successful application to permafrost conditions. Lumped snowmelt relationships only allow for elevation-affected snow distribution and melt.

(4) Source.

U.S. Army Corps of Engineers
North Pacific Division, CENPDEN-WM
PO Box 2870
Portland, OR 97208

(5) Documentation. U.S. Army Corps of Engineers, User Manual, SSARR Model, Streamflow Synthesis and Reservoir, North Pacific Division, January 1991.

b. Model name, HEC-1, HEC-1f.

(1) Description. Event-based simulation model. Flexible component package to simulate surface runoff response to precipitation or snowmelt for complex, multisubbasin, and multichannel river basins. HEC-1f is a version used for real-time flood forecasting. Runoff transformation is done by unit hydrograph, with several options being available.

(2) Snowmelt routine description. Two options:

(a) Temperature-index method. Snow distribution specified by elevation bands.

(b) Energy budget snowmelt equation (USACE 1956) available for design analysis.

(3) Suitability and restrictions. Fully supported for use with HEC Data Storage System. Flexible in choice of watershed routing functions. Restricted by lack of soil and snow-moisture accounting routings. No accounting for frozen ground.

(4) Source.

Hydrologic Engineering Center
U.S. Army Corps of Engineers
609 Second Street
Davis, CA 95616

(5) Documentation. U.S. Army Corps of Engineers, HEC-1, Flood Hydrograph Package, User's Manual, Hydrologic Engineering Center, Davis, California, September 1990.

c. Model name, National Weather Service Snow Accumulation and Ablation System (NWSRFS)

(1) Description. Incorporating the Sacramento Watershed Model and other hydrology computation

modules, NWSRFS was developed in 1972 at the Hydrologic Research Laboratory of the NWS Office of Hydrology. It can continuously simulate watershed response for flood forecasting. Accounts for soil moisture among five reservoirs, differentiating between free and capillary water. Runoff transformation done by unit hydrograph.

(2) Snowmelt routine description. Snowmelt routine consists of two general sectors: a meltwater production unit and a meltwater storage and transmission component. During rainless periods, temperature index using a seasonally adjusted melt factor is used. During rain or snow events, a simplified energy budget approach is used, which requires only air temperature and precipitation data. Heat deficit of the snowpack is also continuously monitored.

(3) Suitability and restrictions. Has been applied to more than 20 basins in the United States over a wide range of climatic and snow cover conditions. Developers have designed and tested a snow energy budget model (Anderson 1979) and frozen ground routine (Anderson and Neuman 1984), which are being implemented.

(4) Source.

Office of Hydrology, W23
National Weather Service, NOAA
8060 13th Street
Silver Spring, MD 20910

(5) Documentation. Anderson, Eric A., National Weather Service River Forecast System—Snow Accumulation and Ablation Model, NOAA Technical Memorandum NWS 17, U.S. Dept. of Commerce, Silver Spring, Maryland, 1973.

d. Model name, Precipitation-Runoff Modeling System (PRMS).

(1) Description. Multipurpose model for short- and long-term forecasting of daily streamflow from snowmelt. Originally developed for mountainous areas, it has been recently and successfully applied throughout the U.S. Basin and is divided into HRUs. Used primarily for watershed analysis.

(2) Snowmelt routine description. Two-layered snowpack energy budget for each HRU (lumped processes within). Heat transfer by conduction within layers.

(3) Suitability and restrictions. Well suited for short-term forecasts (3 to 5 days) of mean daily discharge. Use of HRUs well founded in physical process modeling. No soil-moisture or frozen-ground accounting.

(4) Source.

U.S. Geological Survey
Water Resources Division
MS 412 Box 25046
Denver Federal Center
Denver, CO 80225

(5) Documentation. Leavesley, G. H., Lichty, R. W., Troutman, B.M. and Saindou, L. G., Precipitation-runoff Modeling System, User's Manual, U.S. Geological Survey Water Resources Investigators Report B3-4238, 1983.

e. Model name, Snowmelt Runoff Model (SRM).

(1) Description. First developed by Dr. J. Martinec, Federal Institute for Snow and Avalanche Research, Davos, Switzerland, and first used in 1973. Originally developed to make use of remotely sensed snow cover data, SRM has been applied to a wide range of basins.

(2) Snowmelt routine description. Snowmelt is calculated using the temperature-index method, employing precipitation, air temperature, and depletion curves of snow cover derived from ground-based data or Landsat. No accounting for snow properties and uses rational form for transforming snowmelt to discharge. Spatial distribution accounted for using elevation bands.

(3) Suitability and restrictions. Suitable for mountainous basins less than 4000 km^2. Limited to daily discharge calculations and no soil moisture accounting. Well suited for modeling when only data source is remotely sensed snow cover information.

(4) Source.

Dr. A. Rango
Hydrology Laboratory
Agricultural Research Service
Building 007, Rm. 139
Beltsville, MD 20705

(5) Documentation. Martinec, J., Rango, A., and Major, E. The Snowmelt Runoff Model (SRM) User's Manual, NASA Reference Publication 1100, Washington, DC, 1983.

f. Model name, Guelph All-Weather Storm-Event Runoff Model (GAWSER).

(1) Description. Modified version of HYMO and is a deterministic event-based model. Originally designed for agricultural areas, has been recently interfaced to a distributed snow model (Areal Snow Accumulation-Ablation Model, see description). Has options that deal with distributed soil characteristics. Has been used for operational forecasting in Canada.

(2) Snowmelt routine description. Temperature-index approach to determine snowmelt. Refreeze, compaction, new snow deposition, rain deposition, snowmelt, and release of liquid water are considered. Recently added cell-based detailed energy balance to account for areal variability of snow cover within subwatershed.

(3) Suitability and restrictions. Model originally designed for agricultural areas and has data requirements that restrict usefulness to areas with high data availability.

(4) Source.

School of Engineering
University of Guelph
Schroeter and Associates
Grand River Conservation Authority

(5) Documentation: Schroeter, H., GAWSER Training Guide and Reference Manual, Grand River Conservation Authority (GRCA), October 1989.