COMPARATIVE EVALUATIONS OF FOUR SNOW MODELS [1]

By

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Reliable predictions of resource outputs, along with information on ecological and environmental impacts of forest and range management alternatives, are important for effective land management planning. The Multiresource Management Analysis and Evaluation Project in Flagstaff, Arizona is responsible for developing, testing, and facilitating the application of mathematical models that can provide this information for major southwestern vegetative types.

Testing is a necessary step in the evolution of a model from initial prototype to a version suitable for widespread operational use. It provides data needed for determining requirements for using the model, and for evaluating performance under operational conditions. Evaluations also surface possible refinements to make the model more suitable for operational use. Comparative tests of potentially suitable response models should provide the kinds of information that will be of use to managers in judging which models, if any, are most suitable to their own particular situation. This same information should be of help to persons directing model development work in deciding which models most urgently merit further development or refinement.

This paper deals with a comparative evaluation of four models now available for predicting snow accumulation and melt on a given data set. The snow regime simulations presented comprise the initial results of a much broader comparative model testing study now being performed. Results from this broader study will include evaluations of all model components, and provide such information as ease of use, availability of required data, applicability of outputs to forest management activities, accuracy of predictions, and cost to run models.

Models Evaluated

BURP was developed by the U.S. Forest Service, Watershed Systems and Development Unit (USES 1968). It is basically a conceptual model of the water balance on a unit of land. BURP predicts total water yield from that unit of land, but does not differentiate between surface runoff, streamflow, or groundwater recharge. The model is a method of obtaining relative water yields for different land units.

BURP divides precipitation into either rain or snow on the basis of average daily air temperature. This dividing point can be varied by changing an input parameter, SNOT. All precipitation which is determined as snowfall is stored as water equivalent. Snowmelt is calculated as a function of a threshold temperature, degree-day factor, and mean daily air temperature. The degree-day factor is used to integrate the effects of aspect and vegetation density on snowmelt. Snowmelt, as the result of rain on snow, is also determined. BURP allows adjustments of both air temperature and precipitation to account for differences in slope, aspect, and elevation between a watershed and the climatic stations used.

ECOWAT1 is a revised combination of the water models developed by Rogers (1973) and Simons, Li, and Stevens (1975). Although the basic structure remains the same, algorithms were modified to incorporate recent work and to operate on either a daily or a varying time interval determined by precipitation slope breaks. The snowpack component used is based primarily on the work of Anderson (1968), with some modification to allow for pack settlement, density changes, albedo changes, and water-holding capacities. The albedo model used in ECOWAT is the same as that in SNOWMELT, which is discussed next. This snow component considers the energy balance of the thin surface layer of a snowpack. Heat

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supplied to this layer produces melt which, together with any rain, percolates into the pack. If the pack has a heat deficit, this water will freeze and release heat which warms the pack. When the pack becomes isothermal, additional water will satisfy the water-holding capacity of the snow and any excess water will run out through the bottom of the pack. A heat loss from the snow surface layer will cool the pack, and excess water will freeze to satisfy the heat deficit until all excess water is frozen and the pack develops a heat deficit.

ECOWAT can represent effects of vegetation manipulation. It also allows adjustment of air temperature and precipitation to account for location differences between a watershed and climatic stations.

SNOWMELT is a modification of the LEAF snowmelt model developed for Colorado subalpine watersheds (Leaf and Brink 1973). The original model assumed a continuous snowpack, which is a major constraint when applied in areas, such as Arizona, where the snowpack is often intermittent. The LEAF model was intended to be used with input variables that are sensitive to vegetation manipulation. The model simulates winter snow accumulation, the snow energy balance, snowpack condition, and resulting snowmelt. The LEAF model is sensitive to slope, aspect, elevation, and forest composition and density. It allows adjustment of air temperature due to differences in watershed and climatic station locations.

SNOWMELT allows the LEAF model to be used in areas with intermittent snowpacks (Solomon et al. 1976). SNOWMELT is intended to overcome three shortcomings of the LEAF snowmelt model: its inability to respond quickly to alternate freezing and thawing patterns during the accumulation and melt phases; its tendency to keep the snowpack excessively "cold" during the accumulation phase; and its need for some input variables, particularly daily solar radiation, which are not always available.

The USDAHL-70 model was developed to assist in the design of engineering structures. It emphasizes procedures that control the times, routes, and amounts of water flow (Holtan and Lopez 1971). It allows simulation of watershed behavior at a fairly detailed level, and allows a watershed to be stratified into three units plus the channel system. Snow accumulation and melt processes are accounted for in the revised USDAHL-74 and 75 versions (Holtan et al. 1975).

In USDAHL-75, the user must define snow events by labeling the precipitation that falls as snow on the input cards. Daily snowmelt is calculated as a function of average weekly temperature, vegetation density, and precipitation falling as rain. An input variable, THAW, is used to indicate the temperature at which snowmelt begins. This variable allows adjustments for aspect, elevation, or other factors relating snowmelt to a temperature index.

Methods

Snow data for water years 1966 through 1969 from the Soil Conservation Service (U.S. Dep. Agric. 1966-69) snow course at Hannagan Meadows in the White Mountains of eastern Arizona were used to test the snow models. The snow course at Hannagan Meadows is at an elevation of 9090 feet (2772 m). Temperature data used are from Castle Creek at an elevation of 7500 feet (2286 m); precipitation data are from South Thomas Creek at an elevation of 8400 feet (2561 m).

Table 1 lists the input parameters that can be manipulated in each snow model. Table 2 lists the driving variables required by each model or that can be supplied as an option.

Results

The following results are presented to indicate the sensitivity of various input parameters in each model. We will also point out advantages and disadvantages discovered while running the models on a common data set. The solid lines in the following figures are the simulated snow water equivalents. The asterisks indicate the observed snow water equivalents on days of measurement.

Snow Component of BURP

The snow component in BURP has the most input parameters (table 1). Increasing the degree-day factor from .04 in/°F (.056 cm/°C) to .07 in/°F (.098 cm/°C) decreases snowmelt duration 1 to 2 weeks.

Increasing the snowmelt threshold temperature parameter only 2°F (1.1°C) increases peak snow accumulation up to 60 percent. It has little effect on duration of melt.

Increasing the precipitation adjustment factor from 1 to 1.5 increases the peak water equivalent approximately 30 inches in 3 out of 4 years. Increasing the precipitation factor also lengthens snowmelt duration 1 to 2 weeks.

The snowfall temperature parameter has the biggest effect on both peak accumulation and snowmelt duration. Increasing snowfall temperature from 26°F (-3.3°C) to 32°F (0°C) increases peak accumulation 35 to over 200 percent and extends snowmelt duration 2 to 3 weeks.

Of the BURP simulation runs evaluated; the one in figure 1 appears to have the best graphical fit. This run was made using a melt threshold and snowfall temperature of 32°F (0°C); degree-day factor of 0.07 in 1°F (.098 cm/°C) and a precipitation factor of 1.5. Because the snow course is in an open meadow at a 600-foot (183 m) elevation difference from the precipitation gage, a precipitation factor of 1.5 does not seem unrealistic.

All of the BURP simulations have periodic sharp increases in snowpack accumulation. This model phenomenon is not entirely understood, but is unique to BURP since the same driving variables are used in SNOWMELT. We believe that, on days of precipitation when mean daily temperatures are less than the threshold melt temperature, BURP is unable to melt snow quickly enough. This may be because the model does not use an energy balance in the determination of melt.

Snow Component of ECOWAT

The two most sensitive parameters in ECOWAT, which affect the open meadow snow regime, are the temperature and precipitation adjustment factors. Reducing air temperature -5.4°F (-3°C) extends snowmelt duration about 6 weeks and has a variable effect on peak accumulation.

Increasing the precipitation factor from 1 to 1.5 while holding the temperature factor at -2.7°F (-1.5°C) results in a 75 percent increase in peak snow accumulation but essentially no change in duration of melt. The simulation shown in figure 1 has the best graphical fit of the ECOWAT runs.

SNOWMELT Component of LEAF

The temperature adjustment factor is the only input parameter that has a major influence in SNOWMELT. The albedo threshold temperature has no significant influence on the snow regime. Decreasing the temperature factor from 0 to -3°F (1.7°C) increases peak snow accumulation 67 percent in water year 1966, about 30 percent in 1969, and has little effect in the other 2 years. The melt period is extended 1 to 2 weeks.

Snow Component of USDAHL-75

The only adjustable parameter in USDAHL-75 is the melt threshold temperature. Raising this parameter from 28 to 34°F (-2.2 to 1.1°C) extends duration of melt 21/2 to 3 months and increases peak snow accumulation 40 to 200 percent.

Figure 1 presents the best simulation runs achieved with ECOWAT and BURP - those that graphically best predict the actual snow data. These two models both contain temperature and precipitation adjustment factors.

Figure 2 presents the best simulation runs achieved with SNOWMELT and USDAHL-75. The poorer simulations in these runs illustrate the need for a precipitation adjustment factor in both models, as well as a more sensitive temperature input parameter in USDAHL75.

Table 1 - Input parameters for the snow models tested.

Parameter	Model BURP*	ECOWAT*	SNOWMELT	USDAHL-75*
Threshold Temperature				
albedo		X	X	
melt	X			X
Temperature Factor	X	X	X	
Precipitation Factor	X	X		
Degree-Day Factor	X			
Snowfall Temperature	X			

*Snow component only

Table 2 - Driving variables for the snow models tested.

Driving Variables	Model BURP*	ECOWAT*	SNOWMELT	USDAHL-75*
Daily Precipitation	X	X	X	X
Type of Precipitation				X
Daily max-min air Temperature	X	X	X	
Weekly average air Temperature				X
Radiation		Optional*	X	
Dew point		Optional*		
Wind Run		Optional*		

*Snow component only

**Not used in these tests

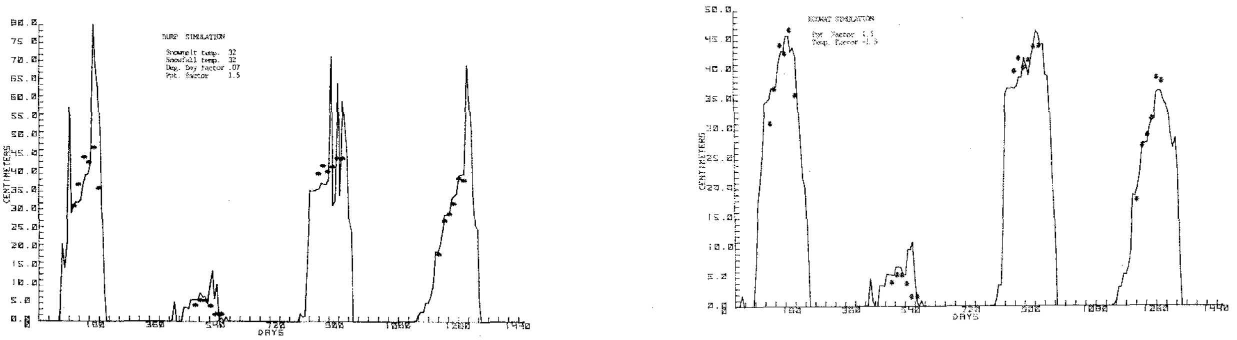

Figure 1 - Comparison of best ECOWAT simulation (above) with best BURP simulation (below).

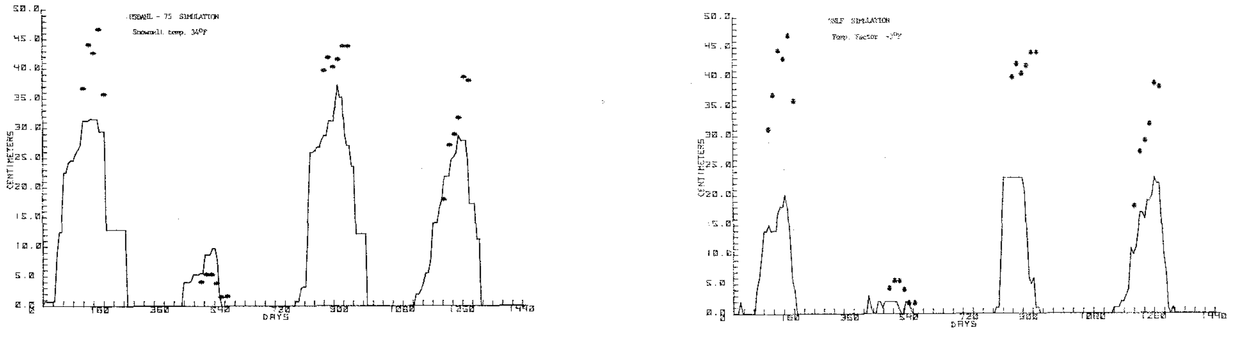

Figure 2 - Comparison of best SNOWMELT simulation (above) with best USDAHL-75 simulation (below).

Discussion

The outputs of all models are quite sensitive to small adjustments in air temperature and precipitation. This indicates the need for accurate daily air temperature and precipitation records if the models are to be used to simulate the snow regime on a particular site. The addition of a precipitation adjustment factor would benefit snowmelt and USDAHL75. The USDAHL-75 snow component would also be strengthened by a temperature adjustment factor

The number of input parameters in BURP does not improve its simulation capabilities enough to justify the extra effort needed to calibrate it.

The ECOWAT snow component appears to require little or no calibration. Where off-site weather records must be used, proper adjustments in temperature and precipitation factors produce reasonable simulations.

SNOWMELT and the USDAHL-75 snow component are at a disadvantage since they do not have a precipitation adjustment factor. Potential accuracy of the USDAHL-75 snow model is also questionable since it only uses mean weekly air temperature as the major energy input parameter.

Parameters needed to run these four snow components are readily available or easily determined. Therefore, use of none of these four models is restricted by need for inputs that are difficult to obtain.

LITERATURE CITED

Anderson, E. A. 1968. Development and testing of snowpack energy balance equations. Water Resource Res. 4:19-37.

Holtan, H. N. and N. C. Lopez. 1971. USDAHL-70 model of watershed hydrology. U.S. Dept. Agr. Tech. Bull. 1435.

Holtan, H. N., *G.* J. Stiltner, W. H. Henson and N. C. Lopez. 1975. USDAHL-74 revised model of watershed hydrology. U.S. Dep. Agric. Tech. Bull. 1518.

Leaf, C. F. and G. E. Brink. 1973. Computer simulation of snowmelt within a Colorado subalpine watershed. USDA For. Serv. Res. Pap. RM-99, 22p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

Rogers, J. J. 1973. Design of a system for predicting the effects of vegetation manipulation on water yield in the Salt-Verde Basin. Ph.D. Diss., 444 p. Univ. of Arizona, Tucson.

Simons, D. B., R. M. Li, and M. A. Stevens. 1975. Development of models for predicting water and sediment routing and yields from storms on small watersheds. Civil Eng. Dept., CSU Prog. Rep. CER74-75 DBS-RML-MAS 24, 130 p.

Solomon, Rhey M., Peter F. Ffolliott, Malchus B. Baker, Jr. and J. R. Thompson. 1976. Computer simulation of snowmelt. USDA For. Serv. Res. Pap. RM-174, 8 pp., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

U.S. Department of Agriculture. 1966-69. Water supply outlook for Arizona. Soil Conservation Service, Phoenix, Arizona.

U.S. Forest Service. 1968. BURP: A water balance program. Watershed Systems Devlop. Unit, Berkeley, Calif.

FOOTNOTES

[1] Rogers, J. J. 1977. Documentation of ECOWAT. Manuscript in preparation. USDA For. Serv. Res. Pap. RM-__________, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.