SIMULATION OF SNOWMELT IN A SMALL RANGELAND WATERSHED

by

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INTRODUCTION

Snow accumulation and melt on western rangelands are often extremely variable even within small watersheds because of the role wind and topography play in creating a spatially variable snow cover. Most hydrologic models assume uniform snow conditions over a watershed and do not account for variability. Distributed or grid-based models can account for this spatial distribution by dividing the basin into grids or areas with similar characteristics and simulating the energy and water balance of each sub-area.

The purpose of this paper is to test the ability of the Simultaneous Heat And Water (SHAW) model to predict snowmelt on areas within a watershed having extreme ranges of snow cover characteristics. The model's ability to simulate heat and water movement through plant cover, snow, residue and soil has been demonstrated for predicting climate and management effects on soil freezing, soil temperature and water, evaporation and transpiration (Flerchinger and Hanson, 1989; Flerchinger et al., 1990; and Flerchinger and Pierson, 1991). However, the accuracy of the model in predicting snowmelt and outflow from a snowpack has never been tested. Extensive data collected at the Upper Sheep Creek Watershed in the Reynolds Creek Experimental Watershed affords the opportunity for testing the snowmelt routines in the SHAW model.

DESCRIPTION OF THE STUDY SITE

The Upper Sheep Creek Watershed, located in the Reynolds Creek Experimental Watershed in southwestern Idaho, is a small, upstream, intermittent, first-order tributary of Reynolds Creek. The watershed, shown in Figure 1, is 26 ha in size and varies in elevation from 1840 to 2036 m. Locations on the watershed are referenced by a grid system as illustrated in Figure 1. Annual precipitation is approximately 508 mm, most of which is snow. The spatial variability of snow cover on the watershed varies from transient snow cover with large areas bare of snow for much of the winter to large drifts which typically remain into June. Snowpack variability within the watershed is discussed in detail by Cooley (1988).

Vegetation is primarily sagebrush, grasses and forbs. Shrubs and aspen thickets are found on the upper portion of the northeast-facing slopes where large snow drifts are formed annually by prevailing southwesterly winter winds. The drift within the study area at Upper Sheep typically extends from I4, to L7, and over to K17 following the break in slope near the crest of the ridge.

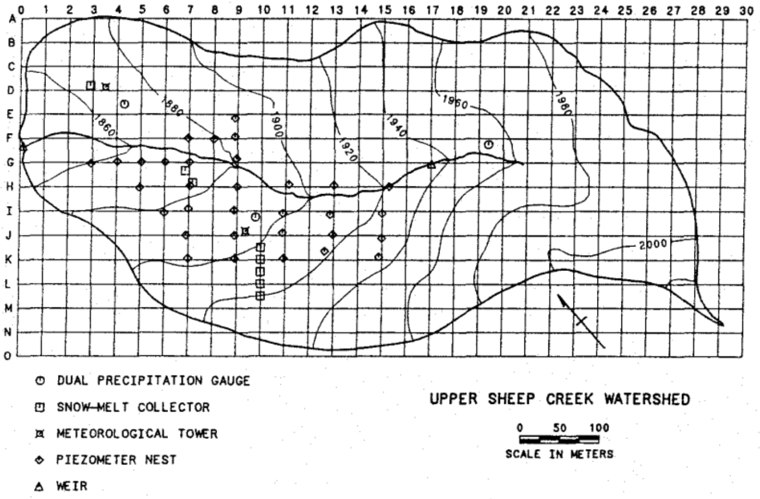

Figure 1. Topography and instrument locations in the Upper Sheep Creek Watershed

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Poster paper presented at the Western Snow Conference, Jackson, Wyoming

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"Reprinted Western Snow Conference 1992"

FIELD INSTRUMENTATION AND DATA COLLECTION

The instrumentation network in the Upper Sheep Creek basin was constructed in 1984 and consists of piezometers, snowmelt collectors, weirs, precipitation gages and meteorological instrumentation towers. Hourly meteorological information are collected at two sites on the watershed. Measurements on the north-facing site near J9 (Figure 1) include air temperature, wind speed and direction, relative humidity, and incoming solar radiation, while those on the west-facing slope near D4 include only air temperature and wind speed. Precipitation is measured at three sites on the watershed (Figure 1) using the dual gauge system, which consists of a shielded and an unshielded gauge (Hamon, 1973).

Three sets of melt collectors are used to monitor the rate of snowmelt from different snow accumulation areas. Melt collectors are located beneath the large drift (located between J10 and M10, Figure 2), downslope of the drift (located near H7), and on the windswept slope north of the stream channel (located near D3). Melt collectors vary in shape and size, but most consist of a standard precipitation gauge receptacle (203-mm diameter) installed about 25 mm above the ground surface. Meltwater entering a collector is drained downslope in a plastic pipe to a tipping-bucket mechanism within a heated instrument shelter. Additional field data collected throughout the winter season include snow sampling of depth and water content near the snowmelt collectors and on a 30-m grid with a snow tube.

THE SHAW MODEL

The SHAW model simulates a one-dimensional vertical profile extending from the snow, residue or soil surface to a specified depth within the soil. The system is represented by integrating detailed physics of snow, vegetative cover, residue and soil into one simultaneous solution. The model is sufficiently flexible to represent a broad range of conditions and the system may or may not include a vegetative canopy, snow, or a residue layer. Interrelated heat, water and solute fluxes are computed throughout the system and include the effects of soil freezing and thawing. Hourly predictions include evaporation, transpiration, soil frost depth, snow depth, runoff and soil profiles of temperature, water, ice and solutes. Further description of the model may be found in Flerchinger and Saxton (1989) and Flerchinger and Pierson (1991).

Energy and mass transfer calculations for snow within the SHAW model are patterned after the point energy and mass balance model developed by Anderson (1976) and applied by Barry et al. (1990). Anderson's energy balance model includes solar and long-wave radiation exchange, sensible and latent heat transfer at the surface, and heat vapor transfer within the snowpack. The SHAW model additionally includes the effect of vegetative cover and detailed energy balance of residue and soil beneath the snow cover. Liquid water is routed through the snowpack using attenuation and lag coefficients, and the influence of metamorphic changes of compaction, settling and grain size on density and albedo are considered.

Input to the SHAW model includes initial soil temperature and water content profiles, hourly weather conditions, general site description, and parameters describing the snow, residue and soil. General site information includes slope, aspect, latitude, and surface roughness parameters. Parameters necessary for simulating energy and water transfer for a snowpack include coefficients for the functional relation between snow depth and percent snowcover (Flerchinger and Saxton, 1989). Residue or litter properties include residue loading, thickness of the residue layer, percent cover and albedo. Input soil parameters are bulk density, saturated conductivity, and coefficients for the matric potential-water content relation, albedo-water content relation, and the thermal conductivity relation.

PROCEDURE

The snowpack at each of the three snowmelt collector sites on the Upper Sheep Creek Watershed was modeled for two winters (1986 and 1987) having quite different amounts of snow accumulation. The specific sites included: transient snow cover on the west-facing site near D3; the general snow cover area on the northeast-facing site near H7; and the uppermost snowmelt collector (number 5) located under the drift above J10. The model was initialized for sites D3 and H7 (where drifting is not substantial) using the first observations of snow depth and density for each year. To minimize errors in estimating snow deposited by drifting at the J10 collector, snow measurements near peak snow accumulation just prior to melt were used for this site. Nevertheless, significant drifting occurred during 1987 after the initial melt. Precipitation input to the model for 1987 were therefore adjusted to correct the discrepancies between melt collector measurements, measured snow-water equivalent, and measured precipitation. Hourly weather measurements collected at sites J9 and D4 were used for input to the model. Energy and mass transfer was simulated to a soil depth of four meters, at which soil moisture and temperature were assumed constant at 0.20 cm^3/cm^3 and 7.°C, respectively. The model was run without prior calibration; parameter values for albedo, conductivity, water transmission, and metamorphosis of the snow were taken from Anderson (1976). Hourly and daily simulated snow depth and snow cover outflow were compared with measured data.

MODEL RESULTS

Daily simulated melt and snow depth are plotted with measured values for sites D3, H7 and J10 in Figures 2, 3, and 4, respectively. Measured snowmelt plotted for site D3

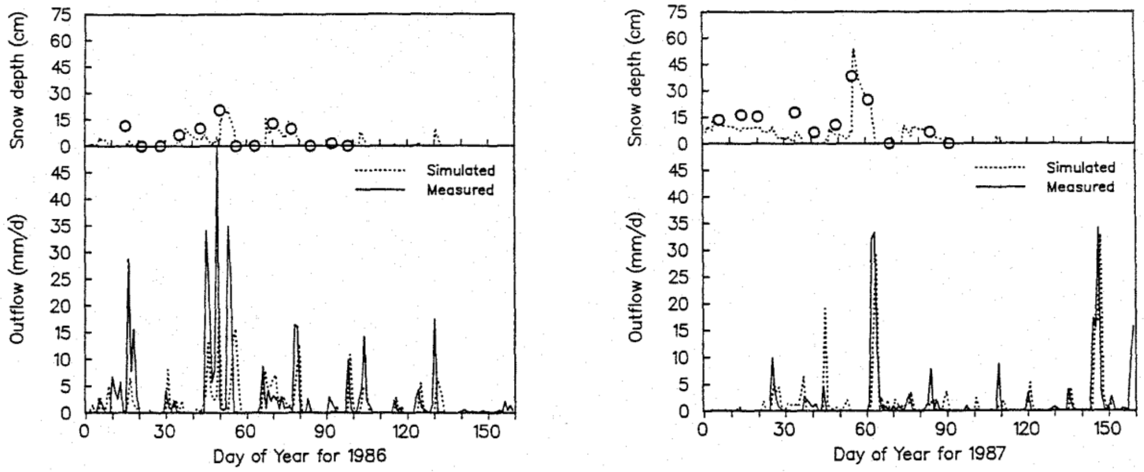

Figure 2. Measured and simulated snow depth and snow cover outflow at site D3 for 1986 and 1987.

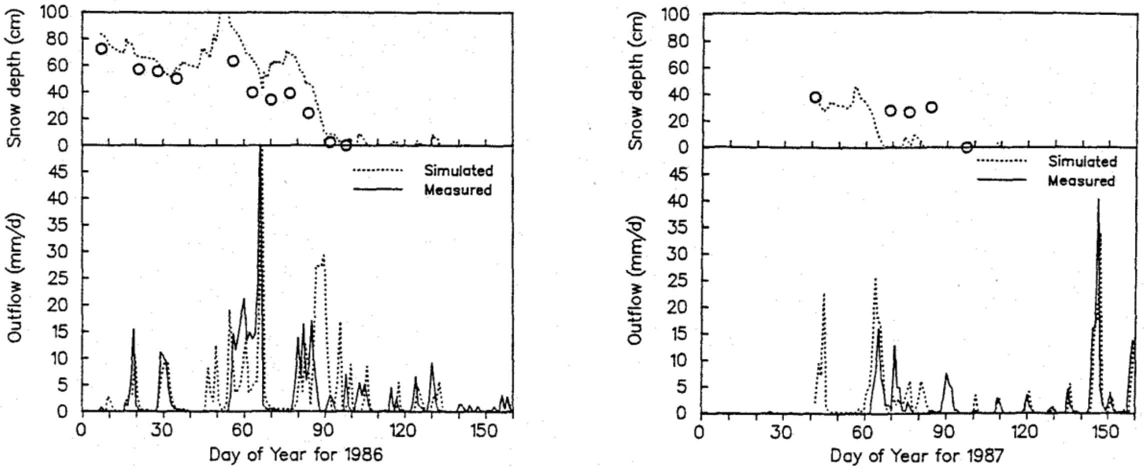

Figure 3. Measured and simulated snow depth and snow cover outflow at site H7 for 1986 and 1987.

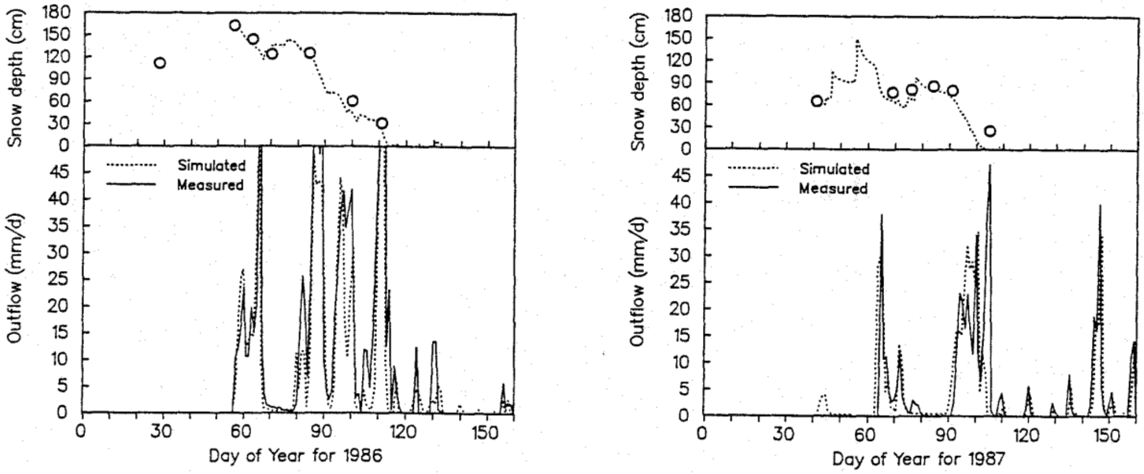

Figure 4. Measured and simulated snow depth and snow cover outflow at site J10 for 1986 and 1987.

represents an average of two collectors at the site, and that plotted for H7 is an average of three collectors at the site. The average departure of simulated daily snowmelt outflow from measured values ranges from 0.9 to 2.4 mm for sites D3 and H7 for the two years. The average departure between simulated and measured snowmelt for J10, which has considerably more snow, was 4.3 mm for 1986 and 3.0 mm for 1987. Correlation coefficients between measured and simulated snowmelt range from 0.39 to 0.80. Low correlations can generally be attributed to the model simulating large melt rates on days after snow had melted from the collectors. Timing and magnitude of simulated hourly snowmelt also compares well with measured values. Average departure between simulated and measured hourly melt ranged from 0.07 mm for site D3 during 1987 to 0.29 mm for site J10 during 1986. Hourly simulated and measured melt rate are plotted in Figure 5 for the period of peak melt rate at site J10.

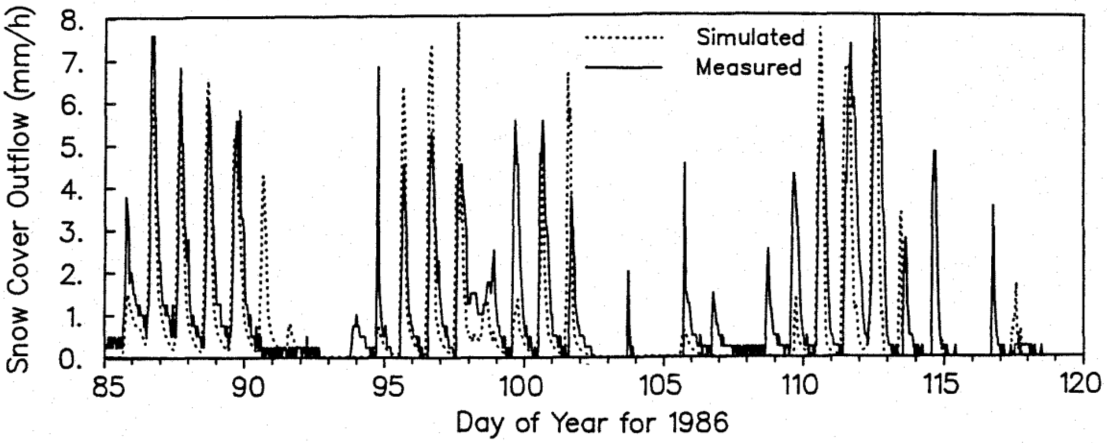

Figure 5. Measured and simulated hourly snow cover outflow at site J10 during peak melt rate of 1986.

SUMMARY AND CONCLUSIONS

Snowmelt simulation of the SHAW model was tested by applying the model to two years at three sites ranging from transient snow cover on a west-facing slope to a deep snow drift on a northeast-facing slope. Snow depth and the magnitude and timing of snow cover outflow were simulated well for all sites. Although this study is not a comprehensive test of the SHAW snowmelt routines, results suggest that the SHAW model can be applied successfully to predict snowmelt from diverse rangeland sites.

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