SECTION 4.4

REPRESENTATION OF HYDROLOGICAL PROCESSES IN THE SHE

SNOWMELT

By

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1 SNOWMELT

1.1 Processes of Snowmelt and Snowpack Evolution

The density of new snow (ie the depth of water obtained by melting a unit depth of snow) varies from about 0.05, if the air temperature during the storm is around -10^0C, to 0.20 at 0^0C to 1^0C. Soon after the snow falls, however, its density begins to increase as a result of gravitational settling, wind packing, melting and recrystallization. Midwinter melts and rainstorms form ice crusts on the snow surface, while the process of melting and recrystallization raises the snowpack temperature and converts the snow to ice crystals. By springtime the snowpack density increases to around 0.3-0.5 and the snowpack itself has water-holding and transmitting properties very much like those of coarse sand. Percolating meltwater brings the liquid water content of the snowpack up to the field capacity (usually between 2 and 8% by volume) and further additions of meltwater then generate runoff.

The moisture content of the pack at a site will not necessarily equal the cumulative amount of moisture which has fallen as snow at that site, since redistribution of the snow on the ground may occur in strong winds. Drifting is especially likely in lee areas and hollows, including water courses.

No runoff can be generated until sufficient heat has been transmitted to the snowpack to raise its temperature to 0^0C and then to melt 2 to 8% by weight of the pack, producing field capacity conditions. The necessary energy is supplied by several hydrometeorological processes. Snowpack depth and temperature, rainfall and melt rates vary across a catchment so the onset of runoff will vary accordingly and the area contributing runoff will change through time.

Once runoff begins, the meltwater can reach the stream system by a variety of surface and subsurface pathways, depending on the relative magnitudes of the meltwater supply and the soil infiltration capacity. A complicating factor can be freezing of the ground, which reduces the soil infiltration capacity and may promote overland flow.

Interception and sublimation of snow on trees has yet to be satisfactorily treated. However, field measurements indicate that these processes can significantly affect moisture transfer in certain circumstances.

1.2 Factors Affecting Snowmelt

The principal hydrometeorological factors important in the supply of energy to the snowpack are as follows.

a) Net radiation, the proportion of the incoming solar radiation which is not reflected off the snowpack or lost as net longwave radiation. This varies with vegetation cover, surface albedo, latitude, season, time of day and cloud cover.

b) Sensible heat transfer and latent fluxes into the snowpack occur when turbulent eddies in the windstream carry warm or moist air down to the surface and cooler, slow moving air away from the surface. This turbulent exchange between the atmosphere and the snowpack is thus particularly affected by the wind velocity profile. It also depends on the stability of the atmosphere. In stable conditions, the snowpack is colder than the atmosphere, so the air near the surface is cooled, becomes denser and resists being lifted away from the snowpack surface and therefore cannot be replaced quickly by warmer or moist air. For unstable conditions, the snowpack is warmer than the atmosphere and a reverse process occurs.

c) Condensation of moist air on the snowpack releases heat, while sublimation from the snow surface takes heat from the snowpack.

d) Heat advected by precipitation depends on whether the precipitation is rain or snow and on the relative temperatures of the precipitation and snowpack. Although the heat supplied from this source is not negligible in a large, warm rainstorm, the water contributed directly by rainfall far outweighs the amount of meltwater generated by the process, since even low rainfall intensities are much higher than extreme rates of snowmelt.

e) Heat entering the snowpack by solid conduction from the ground is very small compared with the energy fluxes at the snowpack surface. Generally it is of the order of 0-5 W/m^2.

The relative magnitudes of the three major energy contributions (net radiation, sensible heat transfer and latent heat transfer from condensation) vary through the day and between days with changes of weather. Net radiation is usually negative at night, whereas the other two components can be large and positive.

During sunny weather, radiant energy is usually the dominant control of snowmelt. However, local variations in hillslope gradient, orientation and vegetation mean that melting due to radiation in different parts of the catchment will be out of phase and the average rate of melting will usually be less than that expected on a uniform surface. The sensible and latent heat contributions are not subject to such modifications by topography and vegetation, except that local windspeed varies according to forest cover and topographic exposure. These energy inputs are much the same on all parts of the landscape, producing uniform melting, and are generally responsible for the highest melt rates.

Finally, snowmelt will also depend on the state of the snowpack, including such aspects as density and degree of recrystallization.

1.3 SHE Snowmelt Model

The component uses snowpack and vegetation parameters, along with meteorological input data, to predict the transfer of moisture resulting from processes of:

1) snowfall addition to the snowpack;
2) snowmelt (including percolating rain) from the snowpack;
3) spatial variations in snowpack conditions;
4) interception and evapotranspiration in the presence of a snowpack and at temperatures below freezing.

Its aim is to model the snowpack thickness as it is affected by precipitation and melting and to model the rate of delivery of meltwater from the snowpack to the soil surface.

Depending on data availability or general requirements, two different calculation modes can be used to determine the total heat flux to the snowpack. The first is an adaptation of the degree-day method, based on the observation that, of all meteorological variables, air temperature is usually the most highly correlated with snowmelt rate, especially when there is no rainfall. This approach gives the heat flux as

$$H = K T_a S \rho_w L_i \tag{1}$$

where H = heat flux; K= degree-day factor; T_a = air temperature; S = specific gravity of snow; ρ_w = density of water; and L_i = latent heat of fusion of ice. This is an empirical method, depending in particular upon calibration of the degree-day factor, and it should therefore be used only when available data are limited to air temperature. However, it does have the advantage of simplicity and rapid applicability.

At a more sophisticated level, the heat flux is determined from a budget of the energy inputs and outputs. Contributions from all the fluxes are calculated for the pack as a whole, giving,

$$H = C + P + E + G + R_n \tag{2}$$

where C = heat gained by convection from the air; P = heat gained from precipitation; E = heat gained from condensed vapour; G = heat conducted from the underlying rock or soil; and R_n = net radiation. Vertical variations in snowpack parameters are neglected and conditions are assumed to be uniform with depth.

The snowmelt resulting from the total heat flux is calculated from an energy balance equation and is then routed through the snowpack.

<u>1.4 Limitations of the Snowmelt Model</u>

a) An extensive data base of meteorological variables is needed for long-term simulations with the energy budget approach.

b) There is no allowance for recrystallization, change of density and similar effects in the snowpack. There is similarly no allowance for vertical variations in snowpack properties.

c) Absorption of rainfall and meltwater by the snowpack is not simulated. Any liquid is routed directly to the soil surface, with the time of travel dependent only on snowpack depth.

d) Spatial variations in snowpack depth arising from drifting during the simulation period are not simulated.

2. DATA ASSEMBLY

The snowmelt model has not been used in connection with the Narmada basin applications. However, experience elsewhere suggests that provision of the net radiation and wind gradient data present the greatest difficulty. Net radiation is not often available as a direct measurement and may instead have to be obtained from solar radiation and estimates of net back radiation and albedo. The wind gradient depends on snowpack surface roughness and topography and may vary considerably from the anemometer site. Some measure of the spatial variation of snowpack thickness at the start of the simulation period is also required.