

## ***Environmental Hydrology Chapter 10 Equations:***

### **Characteristics of Snow, Interception-Rain, Snow, and Fog, Energy Balance in Forests, Snowmelt, Subsurface Flow (Interflow)**

#### **Characteristics of Snow**

Hydrologists are concerned with snow pack depth and its water equivalent, the snow water equivalent, which is the depth of water after melting the snow. In most practical applications the actual depth of the snow pack is not as important as the snow water equivalent. The calculation of the snow water equivalent (SWE) requires knowledge of the depth of snow pack, density of snow, and density of water.

$$\text{SWE} = \frac{\rho_s}{\rho_w} d_s \quad (10.1)$$

where  $d_s$  = depth of snow pack  
 $\rho_s$  = density of snow pack  
 $\rho_w$  = density of water

The depth of cold content can be determined using a simple energy balance where the absorbed amount of sensible heat in a snow pack equals the release in latent heat due to the freezing of the added liquid water (assuming the added water has a temperature of 0°C).

$$\rho_s c_s d_s T_{\text{diff}} = L_f \rho_w d_{\text{cc}} \quad (10.2)$$

solving Equation 10.2 for  $d_{\text{cc}}$

$$d_{\text{cc}} = \frac{\rho_s \cdot c_s \cdot d_s \cdot T_{\text{diff}}}{\rho_w \cdot L_f} = \frac{\rho_s \cdot 0.5 \cdot d_s \cdot T_{\text{diff}}}{1 \cdot 80} = \frac{\text{SWE} \cdot T_{\text{diff}}}{160} \quad (10.3)$$

where  $c_s$  = snow pack specific heat (assumed 0.5 cal/g °C)  
 $L_f$  = latent heat of fusion (assumed 80 cal/g)  
 $T_{\text{diff}}$  = 0°C -  $T_s$   
 $T_s$  = temperature of snow pack (°C)

## Interception-Rain, Snow, and Fog

Interception is measured as a comparison of rain gages placed above the forest canopy, or in a nearby open area, to gages placed under the canopy, and gages collecting stemflow. While one or two standard precipitation gages are sufficient to measure the gross precipitation above the canopy or in a nearby opening, many randomly placed gages are necessary to estimate throughfall. Stemflow is caught on collars placed around tree trunks and directed to collection cans. It is necessary to have several trees in a plot to reliably estimate throughfall and stemflow.

The volume of stemflow is divided by the total area of the plot to estimate the depth of precipitation abstracted by stemflow. Interception,  $I$ , is then calculated as the difference between gross precipitation,  $P$ , and the sum of stemflow and throughfall,  $S + T$ .

$$I = P - (S + T) \quad (10.4)$$

Note that when using Equation 10.4 in a water balance, all intercepted water is considered to evaporate after or during a storm.

## Energy Balance in Forests

An energy balance considers the fluxes of all of these forms of energy to find the net energy flux (Figure 10.4). The equation of conservation of energy is

$$Q_{sw} + Q_{lw} + Q_{le} + Q_h - \frac{\Delta S}{\Delta t} = 0 \quad (10.5)$$

where,  $Q_{sw}$ , is the short-wave energy flux,  $Q_{lw}$  is the long-wave energy flux,  $Q_{le}$  is the latent heat flux,  $Q_h$  is the sensible heat flux (all flux units are energy per unit time, e.g., watts), and  $\Delta S/\Delta t$  is the change in stored energy per unit time. This equation must hold for any defined volume. When calculating evapotranspiration, it is easiest to consider the primary surfaces at the top of the canopy and under the soil, and when trying to calculate snow melt, it is easiest to consider the primary surfaces at the top of the snowpack and the bottom of the soil.

## Snowmelt

In many cases an energy balance approach is not justified due to time, input, or computational restrictions or due to desired accuracy. Temperature index snowmelt models have been the most popular for most basin modeling approaches. An example is the Degree-Day method (US Army Corps of Engineers, 1960), which is written as:

$$M = K(T_a - T_b) \quad (10.6)$$

where  $M$  is melt for the day (in units of depth of water, usually inches),  $K$  is the degree-day factor (units of depth divided by temperature),  $T_a$  is the average air temperature, taken as the average of the minimum and maximum temperature for the day, and  $T_b$  is the base temperature, usually taken as the melting temperature of snow, 0°C or 32°F. The idea is that there is no melt for temperatures below freezing, and that melt is directly proportional to the number of degrees above freezing. There are a variety of values for  $K$  and  $T_b$  that must be determined empirically for

each general area (Hathaway et al., 1956). For forested areas,  $K$  is on the order of 0.015 in/°F, while for clear areas,  $K$  varies from 0.04 – 0.11 in/°F. Typically, the degree-day method works best during overcast periods.

A more detailed degree-day approach which takes into account differences in solar radiation caused by slope-aspect and albedo ( $A$ ), and rain melt was presented by Riley et al. (1972)

$$M = k \frac{R_p}{R_h} (T_a - T_b)(1 - A) + 0.00125 P_r T_a \quad (10.7)$$

where  $R_p$  is the solar Radiation on a sloping surface,  $R_h$  is the solar Radiation on a horizontal surface, and  $P_r$  is the rainfall (cm). Albedo is a measure of the reflectance of a surface. Fresh snow typically has an albedo  $> 0.8$ . As the snow ages and becomes denser the albedo can fall to near 0.4.

### **Subsurface Flow (Interflow)**

In order to discuss lateral subsurface flow in forests it is easier to use the basic equation relating to water movement in soil, Darcy's Law,

$$V = -K \frac{\partial h}{\partial L} \quad (10.8)$$

where  $V$  is the average velocity over the cross section of soil considered,  $K$  is the hydraulic conductivity, and  $\partial h/\partial L$  is the change in head per unit distance in the direction of flow. The negative sign shows that water flows from places with high head to places with low head. Multiplying  $V$  by the depth of the soil gives the flow per unit width of hillslope being considered. Saturated flow responds mostly to slopes in the water table, whereas unsaturated flow can respond to differences in head caused by the soil being drier in one area than another. For shallow saturated subsurface flow, as may be found on steep mountain slopes,  $\partial h/\partial L$  is sometimes taken as the slope of the ground.