

SNOWMELT – STREAMFLOW FORECASTS

(eg. Anderson NWS 1973)

Models Have 3 Components –

1. Snow Accumulation | Ablation
2. Soil Moisture and Groundwater States
3. Streamflow Routing

Most modelling for forested mountains.

Watershed Efficiency – Alpine Basins in Rockies (Leaf 1975, Carroll 1976), Sierras (Kattelman & Elder 1991)

~ 90% of Input → Runoff | 75% Dry Years;
90% Wet Years

Alpine Main Source

10% of Utah (Uintah, Wasatch) → 60% of Streamflow
3.5% of Colorado ~ 20% of Streamflow

Water Movement in Snow Pack: Gray & Male: p.283 p.398-406

1. Pendular Regime (Wet Snow) – Continuous Air Pathways:
Gravity Drainage
2. Funicular Regime “Saturation – Above Ice Layer, Frozen Surface exceeds 14% of pore volume
Water Pathways Continuous Around Grains.

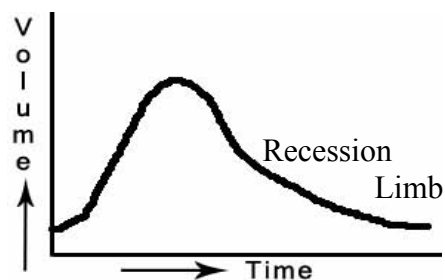
Homogeneous Snow – gravity flow (Darcian)

$$\text{Liquid Flux } q_z = \alpha k S_1^3$$

α = constant

k = Permeability (function of grain size, density)

S_1 = Effective Water Saturation (fraction draining by gravity)



Flux Rate: Proportional to $q_z^{2/3}$ (large vols faster)

Heterogeneous Snow: Multiple Pathways; Due to Ice Layers, Channels

LE: Condensation if $e_a > 6.1 \text{ mb}$

Importance: $-L_v/L_f = 2500/335 \text{ (kJkg}^{-1}\text{)} \sim 8$

Evap/Sublimation: Commonly assumed to be small and ~balanced by nocturnal condensation. Difficult to calculate LE reliably (Aerodyn. Method)

Best to use snow Lysimeter

Male and Granger: E-S ~ 15-20% of Snow Pack Loss on Prairies (Open Areas)

D. Cline / E. Hood: Niwot Ridge E-S ~ 15%

Meiman and Grant – Up to 45% of Winter Loss – Pingree Peak (Colorado)

H: Incursions of warm air important for $H \downarrow$

Also, small scale advection (e.g. Tundra)

$$H = -C_p \rho K_H \delta T / \delta Z \quad [K_H \sim K_M \text{ over melting snow}]$$

G: Minor term; $G \uparrow$ affects basal layer of snow when ground unfrozen.

SNOW MELT

2 Steps:

1. Remove "Cold Content" – ie. Warm snow to 0°C
Requires $(2.1 \text{ kJ kg}^{-1} \text{ K}^{-1})(273 - T_s)$ [$2.1 = C_p$ of Snow]
2. Satisfy the free-water capacity of snowpack (~3%)
"Thermal Quality" = Ice fraction in unit mass of wet snow
 $B \sim 0.97$

Example: 1kg of snow at 263K – Needs 21kJ to warm to 0°C and 10KJ ($0.03 \times 335 \text{ kJ kg}^{-1}$) to satisfy free water i.e. 31kJ to 'ripen'; contrast 335 kJ kg^{-1} for melting pack.

Melt Rate (cm d⁻¹)

$$M = \frac{Q}{\rho_w L_f B} = \frac{\overset{\nearrow}{\text{Avail. Energy}}}{3235 \cdot (\text{kJ m}^{-2})} \quad \text{Male + Gray}$$

Contribution of Energy Components – Examples

CEN. SIERRA (APRIL) – D. MILLER 1977 P. 176

2200 M

$$\text{Wm}^{-2} \quad \frac{R_n}{95} + \frac{H\downarrow}{37} + \frac{LE\downarrow}{7} + \frac{G\uparrow}{1} + \frac{Q_p}{15} = \frac{\Sigma Q}{155} \quad \left| \quad \frac{M(\text{cm})}{4} \right.$$

----- (13,300 $\text{kJm}^{-2}\text{mo}^{-1}$) -----

IN MAY, $100 \text{ Wm}^{-2} \Rightarrow 2.7 \text{ cm melt daily.}$

Michigan	R_n	$H\downarrow$	$LE\downarrow$	ΣQ	$M \text{ (cm/9hr)}$
Advection Event Jan. '96	15	80	60	165 Wm^{-2}	1.5
					TREIDL.1970.

Empirical Approaches

1. Linear Regression -using T or T.D.D.

J. MARTINEC – SPING MELT (cm d^{-1})

AT OPEN SITES: $0.27 (T + 4.4)$, for $1^\circ < T < 15^\circ\text{C}$

$1.1 \rho_s (\text{T.D.D.})$ T.D.D. $> 0^\circ\text{C}$

G. McKAY – PRAIRIES : $0.20 - 0.25 \text{ cm} / \text{T.D.D.}$

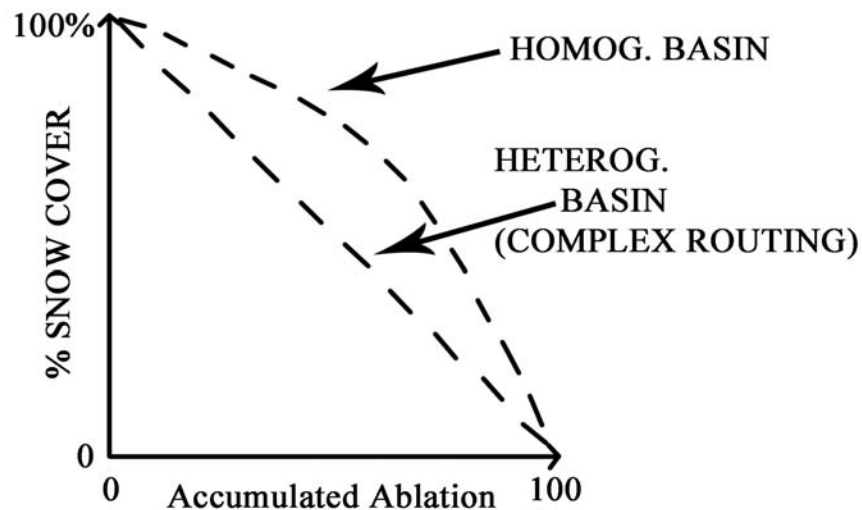
($T_{\text{MAX}} > 0^\circ\text{C}$) IN APRIL-MAY

OPEN/CLOSED FOREST : $\sim 0.12/0.05 \text{ cm} / \text{T.D.D.}$

2. MULTIPLE REGRESSION. – BASED ON MET. DATA (T,V etc)
AND TOPOG. FACTORS (ASPECT etc]

‘INDEX’ MODELS BEST FOR 1 SITE, RATHER THAN BASIN.

3. SNOW COVER DEPLETION CURVE



SNOW MELT FORECASTS (E. Morris)

Approaches: 1. Point-Site 2. Catchment. (Same Categories A-C)

A. Regression Models

Output: Melt rate, Water production (at base of pack)

Input: \bar{T}_A ; R_n , q , u (daily) Models highly site - specific

B. Lumped Conceptual Models – Treat Mean Properties of Snowpack.

Stages:

1. Warm Snow to $\bar{T} = 0^\circ\text{C}$ (Wet, Isothermal)
2. Melt of ‘Ripened’ Pack – (Flow begins when Free Water Content of pack reached: $\sim 2.5\text{-}5$ (mm water)/day K^{-1})

Melt Calculation:

1. Temp Index (T_A or Degree - Days $>0^\circ\text{C}$)

2. Energy Budget –

R_n – should allow for topog effects on direct and diffuse solar radiation, albedo, IR. Also penetration of radiation for shallow (prairie) snow.

$H + LE$ – especially advected $H\downarrow$

Warm rain – minor

C. Distributed Models

Consider processes within Pack – separated for Cold/Ripe Snow.
(but vary in time and space!)

Catchments

Main problem is representation of mean values for areas- eg.

Temperature, precipitation

Snow accumulation- affected by

1. topography, aspect, slope, elevation, relief.
2. land cover- Less snow cover under forest (up to 40-50%)

Interception by canopy→ evaporation

Reforestation→ reduced snow melt runoff

Clear-cutting→ increase (initially)

Energy budget

Need D.E.M. to model fluxes- slope, sky view, reflection from surroundings, (ef. Marks, Dozier)

Snow Pack: Ablation and Runoff

Energy budget approach (assumes no advection)

$$\Delta Q = R_n + H + LE + Q_p + G$$

↑
(change in
heat storage)

↙
(neglected in deep cover)

Mass balance approach

$$\Delta W = P - E - r / \pm \text{snow drifting}$$

↑
(change in
water storage)

Energy Terms

$$R_n = S(1-\alpha) + I\downarrow - I\uparrow$$

$$I\uparrow = \epsilon\sigma T_s^4$$

$$\epsilon \sim 1$$

$$I\downarrow = 0.642 (e_o / T_o)^{1/7} (\sigma T_o^4)$$

Brutsaert

In mountains:

$$I\downarrow = (\epsilon_a \sigma T_a^4) V_f + (\epsilon_s \sigma T_s^4) (1 - V_f)$$

“Thermal View Factor”

$$V_f = \cos^2 (90 - \bar{H})$$

\bar{H} = mean horizon angle

‘Warm’ Rain

(on melting snow)

$$Q_p \text{ (cals)} = (1.0) P_{\text{(cm)}} \frac{(T-273)}{1000}$$

T m °K

or Q_p (kJm⁻²) = 4.2P(mm)(T-273)

Minor role since Cp of rainwater – 4.2 kJ kg⁻¹ K⁻¹
(in melt) whereas L_f = 335 kJ kg⁻¹

In cold snow, rainwater freezes: 10mm of rain (273K) on 1m of snow, warms it 5°C