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P1.7 MODELLING DAILY SNOWMELT IN A FOREST AND CLEARCUT

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1. INTRODUCTION

The Upper Penticton Creek Watershed Experiment is a long-term paired-watershed study investigating the effects of forest harvesting on water quantity and quality. This work requires the determination of snowmelt at remote forested and clearcut sites using data acquired with standard weather stations. The research took place in the 240 Creek watershed, 22 km NE of Penticton, in the drier Engelmann Spruce – Subalpine Fir Zone. Permanent snow cover lasts from late October until mid to late May depending on the year. Maximum snow depth occurs between mid March and early April. The forests usually have less snow than the clearcuts and it takes up to 10 days longer for the pack to melt. Warming conditions in April result in the pack density increasing and ripening of the snow.

Energy balance and air temperature models will be evaluated for their ability to give reliable daily estimation of snowmelt in a forest and clearcut.

2. METHODS

Site description: The forest (49 39 30N, 119 24 10W, 1640 m) consists of 125-year-old lodgepole pine, 12 to 16 m tall. Stand density is 1000 stems ha^{-1} and canopy cover is 40%. The adjacent 50 ha clearcut has a sparse cover of 1-m-tall lodgepole pine. The weather station is at 49 39 20N, 119 24 10W, 1620 m.

Weather data: Hourly measurements of solar radiation, air temperature, air humidity, wind speed and precipitation were made in the clearcut. Air temperature and humidity were measured in the forest. Snow temperature and snow depth (Campbell Scientific Inc., UDG01) were measured in the forest and clearcut. Snow albedo was measured in the clearcut during spring 2001. Two snowmelt lysimeters were located at the at the clearcut weather station. They consist of a 1.2x2.4-m shallow open-topped box at the base of the pack draining into buried tipping bucket (Winkler 2001). Measurements of snow water equivalent (SWE) and snow density over a 80x80 m grid were made every two weeks during the melt period in the forest and clearcut (Winkler 2001). Conversion of the UDG01 depth data to snowmelt used daily snow density obtained by interpolation of the density data from the snow course.

Snowmelt modelling: The energy balance of a melting snow pack is $Q_M = Q_{Rn} + Q_H + Q_E + Q_G + Q_P + Q_S$ (MJ m^{-2} d^{-1}). Q_M is the total amount of energy available to melt the snow. The other subscripts indicate the source of energy used for snowmelt, i.e., energy from net radiation (Rn), sensible heat (H), latent heat (E), soil heat (G) and rain (P), and change in heat storage in the pack (S). Q_G is small (Adams *et al.* 1998) and during melt Q_S is negligible because the snow pack is close to 0°C (Male and Gray 1981). Q_P depends on the temperature difference between the rain and the snow. Daily net radiation (Rn, MJ m^{-2} d^{-1}) to the snow pack is calculated from measured solar radiation and albedo and calculated longwave radiation. Shading by the trees reduces the solar radiation to the snow pack below a canopy and downward longwave radiation is a combination of radiation from the sky and from the trunks and foliage assuming the canopy and trunks are at air temperature. The surface of a melting snow pack is assumed to be at 0°C and saturated.

Bulk transfer or exchange coefficients are used to calculate sensible and latent heat fluxes (Moore 1983). The exchange coefficients are assumed equal to that for momentum (D_m). There is disagreement on this in the literature particularly for stable conditions, but Moore (1983) shows that this does not create a significant error as long as D_m is corrected for stability.

Key coefficients used are roughness length = 0.004 m, solar radiation and wind below the forest canopy are 30% of the clearcut values, the view factor for longwave radiation from the canopy and trunks = 0.85. The forest albedo equals the clearcut albedo with allowance made for differences in the length of the melt season

The air temperature snowmelt model is based on the daily mean air temperature in the clearcut (T_C) or the forest (T_F). Lysimeter melt data for 1999 were used to calibrate the air temperature model in the clearcut. Depth gauge melt data for 1999 were used to calibrate the air temperature model in the forest. In the clearcut, daily melt (mm d^{-1}) = $0.28+0.28*T_C$, $T_C>-0.5°C$, se=0.5, $R^2=0.781$, n=34, In the forest, daily melt (mm d^{-1}) = $0.32+0.26*T_F$, $T_F>-0.5°C$, se=0.42, $R^2=0.710$, n=43.

3. RESULTS

3.1 *Depth gauge and lysimeter melt*

Snow density rapidly changes from 0.32 Mg m^{-3} prior to melt to 0.42 Mg m^{-3} at peak melt. There is a certain amount of judgment required in the interpolation of the snow density data. We assume that outflow from the pack as measured by the lysimeters is the true daily melt. The contribution of any rainfall to outflow is assumed small. Agreement between the depth gauge and lysimeters is good (Figure 1) with final melt totals from the start of the main melt period at day 105 of 41.3 cm for the lysimeters and 42.2 cm for the depth gauge.

3.2 *Snowmelt modelling*

Lysimeter outflow begins once the snow pack temperature becomes uniform at about 0°C. This 0°C

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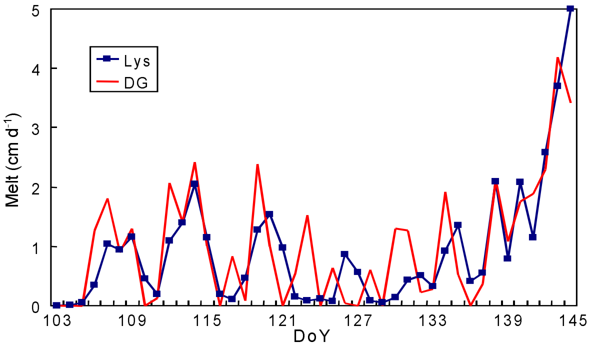

Figure 1. Daily snowmelt rate from lysimeter outflow (■) and the depth gauge (—) for 13 April to 25 May 1999.

threshold is used as the start date for the modelling and the 0.02 m soil temperature >0°C indicates that all the snow has melted. The albedo data for 2001 were used to estimate those for 2000 with allowance was made for differences in the length of the melt season.

Modelled snowmelt follows the course and magnitude of measured snowmelt reasonably well (Figures 2 and 3). The seasonal totals show some discrepancies (Table 1). In the energy balance model total melt, negative Q_M was neglected because Q_H and Q_E are too large. The model assumes the surface temperature is 0°C and the surface is saturated, which is not the case in this situation. The energy balance model underestimated seasonal melt in the forest in both years because it underestimated peak melt in the latter part of the season. This is probably due to the overestimate of the albedo. Net radiation provides almost all the energy for melt in the forest and about 70% of the energy in the clearcut (Table 1).

There is a tendency for the air temperature model to overestimate snowmelt early in the season and this biases the total melt. The coefficients are of similar magnitude to those obtained by Winkler (2001) at a site about 200 km north of our site. The air temperature based melt was a useful guide to interpolation of snow density data for the depth gauge estimates of snowmelt.

Table 1. Snowmelt (cm) for 2000 and 2001 melt seasons from the lysimeters (Lys), depth gauge (DG), energy balance model for $Q_M \geq 0$ (EB), $Q_{Rn} + Q_H$ all fluxes ($Q_{R,H}$), net radiation (Q_{Rn}), and air temperature model (Ta) in the clearcut and forest.

	Lys	DG	EB	$Q_{R,H}$	Q_{Rn}	Ta
Clearcut						
2000	33.0	33.1	35.8	37.2	25.9	42.6
2001	27.4	31.3	27.3	24.5	17.5	31.2
Forest						
2000	---	35.9	30.2	23.9	29.2	43.3
2001	---	28.1	22.4	21.8	21.4	30.2

4. CONCLUSIONS

It is necessary to measure soil surface and snow temperature to define the beginning and end of the melt season. The daily energy balance model can give acceptable estimates of daily and seasonal snowmelt. However, a measurement of albedo is required for accurate seasonal totals. Net radiation is adequate to model melt in the forest. An air temperature model can be used if early season overestimates are recognized.

5. ACKNOWLEDGMENTS

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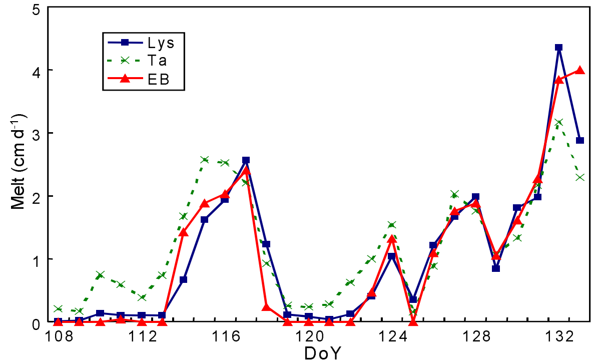

Figure 2. Daily melt for 18 April to 13 May 2001 in the clearcut for the lysimeters (■), air temperature model (X) and the energy balance (▲).

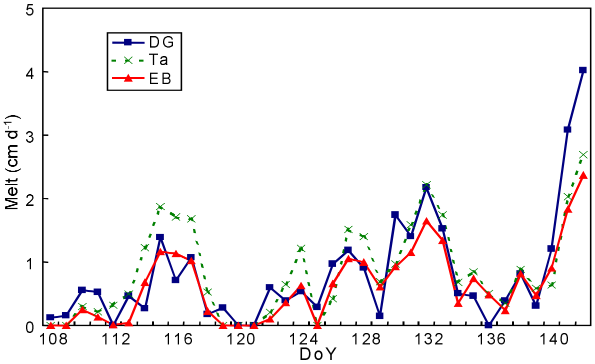

Figure 3. Daily melt for 18 April to 22 May 2001 in the forest for the depth gauge (■), air temperature model (X) and the energy balance (▲).

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