The Diminution of Snowmelt Rate with Forest Regrowth as an Index of Peak Flow Hydrologic Recovery, Montmorency Forest, Quebec

J. TALBOT[1] AND A.P. PLAMONDON[1]

ABSTRACT

Peak flows can be temporarily increased by forest harvesting. They usually go back to pre-harvest magnitudes with stand regrowth. The diminution of snowmelt rate with regeneration has been proposed as an index of hydrological recovery of peak flow. This index, expressed by a snowmelt augmentation coefficient (SAC = 100% - hydrological recovery), was calculated from snowmelt measured during three springs in twelve sites representing a range of stand structure and development of the balsam fir forest. The SAC were highly correlated with canopy height, square root of basal area, canopy density and light interception, the first two variables being readily available from standard forest inventories. For Montmorency Forest, the SAC indicates that 15 years after the cut, the effect of clearcutting on snowmelt is reduced by 50 %.

Keywords: Snowmelt, boreal forest, snowmelt augmentation coefficient, forest regeneration, forest hydrology, Québec.

INTRODUCTION

Rainfall and snowmelt peak flows can be increased by tree harvesting (Plamondon, 1993; MacDonald *et al.*, 1997). Previous knowledge (Ice, 1999; Washington Forest Practices Board, 1997) and a recent study (Faustini, 2000), indicated that peak flows 50 % higher than the bank-full discharge can significantly modify the streambed morphology and consequently affect aquatic habitat. Two paired watershed studies in Montmorency Forest north of Quebec City have shown that clearcutting more than 50-60 % of a basin area can increase rainfall (Guillemette *et al*. 2002, unpublished) and snowmelt peak flows (Plamondon 2002, unpublished) by 50 % or more. The observed changes of snowmelt peak flows in relation to the proportion of the basin area harvested correspond to the model proposed by Verry (1986) for Minnesota (Figure 1). Peak flow increases above 50 % for cutting less than 55 % of a basin area were observed in Alberta and the Rocky Mountains (Figure 1). Their large responses can be explained by the small size of the peak, the location on southerly exposed hillslope or the particular climatic conditions in comparison to the Minnesota and Quebec situation. More detailed explanations is beyond the scope of this paper. Regarding Minnesota and Quebec studies, it is therefore recommended to cut less than 50 % of a basin area to avoid unacceptable peak flow increases. However, this increase does not last beyond the first few years after cutting. Hydrologic recovery is defined as restoration of hydrological characteristics to pre-harvest conditions with stand regrowth. To take account of the effect of wood cutting on peak flows, local hydrologic recovery rates are needed by forest managers. Peak

---

[1] Centre de Recherche en Biologie Forestière, Université Laval, Québec, Canada, G1K 7P4

flow measurements during a few decades after harvesting would yield the needed information but, as suggested by Hudson (2000), snowmelt rates at various stages of stand development could be a good index of hydrologic recovery as it is a more rapid and cheaper approach than long term monitoring of stream flow. This index is expressed by a snowmelt augmentation coefficient (SAC = 100% - hydrologic recovery). The SAC enables the forester to calculate the equivalent clearcut area (ECA) of previous cuts and to set the maximum area (ECA < 50 %) for the next intervention. To our knowledge, the most comprehensive study to address snowmelt rates recovery in relation to vegetation was carried out by Hudson (2000) who established snowmelt recovery curves for regenerating stands in coastal British Columbia. The curves were related to canopy height and density since these characteristics are available from standard forest inventories. The recovery was about 80, 95 and 100 % (SAC of 20, 5 and 0 %) for the respective heights of 10, 20 and 32 m.

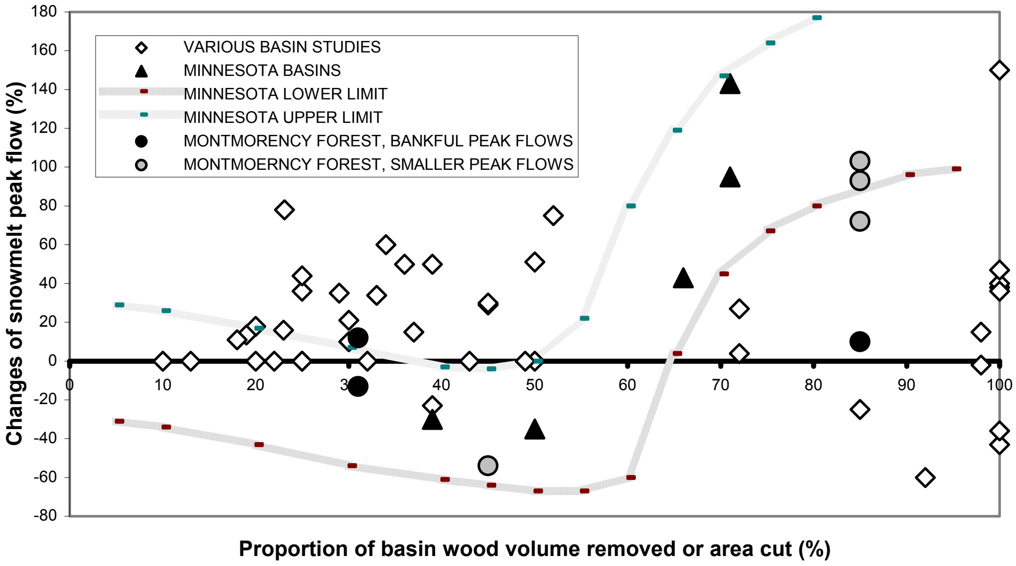

Figure 1. Changes of maximum snowmelt peak flow during the first or second spring after forest harvesting.

The purpose of this study was to determine snowmelt augmentation coefficients (SAC) for naturally regenerated balsam fir stands of Quebec's boreal forest . We hypothesized that the snowmelt rate recovery and consequently the SAC were correlated with stand characteristics and hillslope exposure.

EXPERIMENTAL AREA AND METHOD

The study was conducted at Montmorency Forest (47°N, 71°W), 80 km north of Quebec City in the Laurentian Uplands of the Canadian Shield. Land inclination is below 3 % for 30 % of the area and between 16 and 30 % on 45 % of the area. At an average altitude of 850 m, the climate is classified as cool microthermal with water surplus according to Thornthwaite (1948). The average annual temperature, precipitation and snowfall water equivalent are 0.3 °C, 1416 mm and 465 mm respectively. The snow cover persists from the beginning of November to the middle of May. Montmorency Forest is situated in the white birch balsam fir bio-climatic domain (Robitaille and Saucier, 1998). The average height of canopy ranged from 12 to 15 m in the 50 to 70 years old mature stands, with canopy density usually between 60 and 75 %. The mean stand density for all species typically ranged from 1000 to 1500 stems ha^{-1} for commercial-sized trees (diameter > 9.1 cm) to 4000-6000 stems ha^{-1} for all diameters (Bélanger et al. 1991).

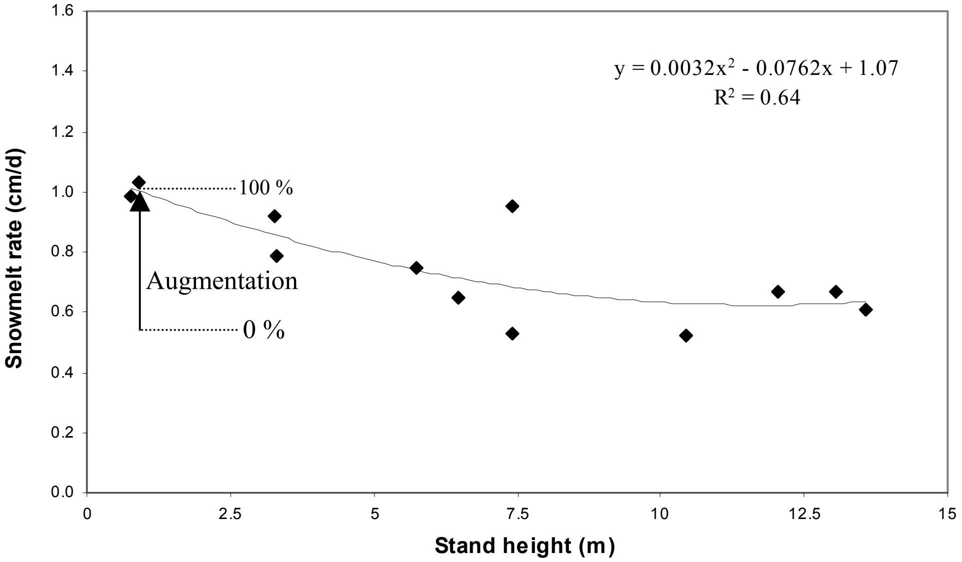

Figure 2. Calculation of the snowmelt augmentation coefficient
from the snowmelt rate expressed in relation to stand height, year 1998.

The study sites were selected to represent a range of stand structure (height, cover, density) and development (recent clearcut, sapling, pole, mature) representative of the balsam fir forest. To consider a possible interaction between aspects and cover, the sites were paired between the north and south exposures. Snowmelt was measured during the springs of 1998, 1999 and 2000. At each site, snow depth and mass were measured at 10 sampling points within four plots located at the corner of a 30 m x 30 m square randomly located over the stand area. The 10 points were distributed along a circle of 5 m radius at the beginning but decreasing at each visit in order to collect undisturbed samples. Snow depth and mass were obtained with a Federal snow sampler (*Carpenter Machine Works, Seattle*) and a field balance during days with negligible snow on the crowns in order to obtain the snow water equivalent (SWE). The measurements were taken every three to seven days for the whole melt period. The extent of snow cover near the end of the snowmelt period was evaluated by eye in each plot. The canopy density (C), defined as the relative amount of light cut off by specific areas of the forest overstory (Lemmon, 1956), was evaluated with a spherical densiometer (*Ben Meadows Equipment Inc.*). Light interception (Li) under the canopy was measured at each site with a radiometer (*LI-191sa Line Quantum Sensor, LI-COR inc.*) during clear sky periods. Standard forest inventories were made in order to obtain mean stand height of dominant and co-dominant trees (H) and basal area (BA).

The SWE and confidence limits of the mean (α = 0.05) for each sampling date were plotted against time for each site. Considering the confidence limits, a curve representing the SWE was drawn by hand and used to determine the annual maximum snow water equivalent (MSWE). The mean snowmelt rate (MSR) for the spring was obtained by adding snowfall to MSWE and dividing it by the number of days until complete melt. MSR was plotted against stand characteristics (C, Li, H and BA). As a significant interaction was found between year and site (α = 0.05), each annual snowmelt curve was used separately to determine the SAC for each site. No significant interaction was found between exposure and site, so north and south exposed sites were pooled. The SAC were calculated in reference to average snowmelt increase at both open sites fixed at 100 % (Figure 2, example for year 1998). The two sites with the lowest melt rates were used to set the SAC at 0 % (full recovery). The SAC (%) was then calculated for each site during each season as the ratio of (MSRsite – mean MSRlowest) over (mean MSRopen – mean MSRlowest) multiplied by 100. Since snowmelt rates were not the same at both open sites and at both forested sites, the values obtained for each site individually gives an indication of the variability between similar stands. Annual SAC curves were pooled as there was no significant interaction between year and site. The global SAC can be used to calculate the equivalent clearcut area (ECA), which is the actualized area of previous cuts considering the decreasing impact with time of these cuts on peak flows. The ECA of a former cut is obtained by multiplying the cut area by the appropriate SAC.

RESULTS AND DISCUSSION

For all snowmelt seasons, the lowest melt rates were generally measured in stands ranging from 7 to 11 m in height with a canopy density around 70 %. The corresponding light interception and basal areas were around 85 % and 45 m^2/ha respectively. The increase of melt rate under higher trees and more developed canopies is possibly due to gains in net long wave radiation as reported by the U.S.C.E. (1956) and Dunne and Leopold (1978).

The SAC were highly correlated with stand characteristics and decreased with an increase of canopy height, canopy density measured with a spherical densiometer, light interception measured with a radiometer and basal area. A square root transformation was performed on basal area in order to improve the relationship. The best regression was obtained with tree height ($R^2 = 0.76$). The data from site 53N in 1998 and 1999 were considered outliers and omitted in order to force the curve to approach zero for the stands having the lowest melt rates. The curve indicates that full recovery was reached at a height of 10 m or 2/3 of the mature height. It is very similar to the result obtained by Hudson (2000) reporting a 95 % recovery when the trees reached 20 m or about 2/3 of the 32 m high mature forest. Furthermore, in both study a mean SAC value of 50 % was obtained at a tree height of 4 m. As it is often the case in hydrology (Pilgrim 1975) the SAC remained at 100 % until a threshold value is reached. Due to the high variability of SAC relative to canopy height below 4 m, no attempt was made to fix a threshold height. A trial and error of least square fitting of the data above different heights was used by Hudson (2000) to obtain a threshold value of 0.6 m in British Columbia. The square root of basal area of stems above 1 cm in diameter was linearly related to the SAC with a coefficient of determination ($R^2 = 0.73$) similar to the one obtained using tree height (removing site 53N). The SAC approaches zero when the basal area exceeds 40 m^2/ha. In a South-Central BC study, the basal area was the best variable, explaining 73 % of the variation of forest to open mean melt rates ratio from stand to stand (Winkler 2001). Canopy densities, obtained from a densiometer and a radiometer, were linearly related to the SAC values with coefficients of determination (R^2) of 0.51 and 0.66 respectively. As also observed by Hudson (2000), our data indicate that the SAC can reach zero when the canopy density exceeds 70 %. However, in British Columbia the SAC value was found to decrease exponentially with canopy density reaching a value of 50 % at a density of 20 % while a density of 50-55 % was necessary to obtain the same mean recovery in our study. Tree height and clustering, species and climatic conditions can all account for differences between the two studies. Canopy height and basal area are the most practical relationships, as these data are readily available from standard forest inventories (MRNQ 1999). Forest cover based on the vertical projection of the crowns is also available on forest maps but is evaluated in classes of 20 %. This projection is also somewhat smaller than the canopy density measured with densiometer. Observations in balsam fir stands yielded spherical densities around 60 % for estimated vertical projection of 40 % in 4.5 m high stands (unpublished data).

The augmentation coefficients calculated from peak flow monitoring during the first 6 years after harvesting at Montmorency Forest (unpublished data) generally remain under the SAC curve as shown on Figure 4. Thus, the use of the SAC appears to be a conservative approach to control the augmentation of peak flows in forest management.

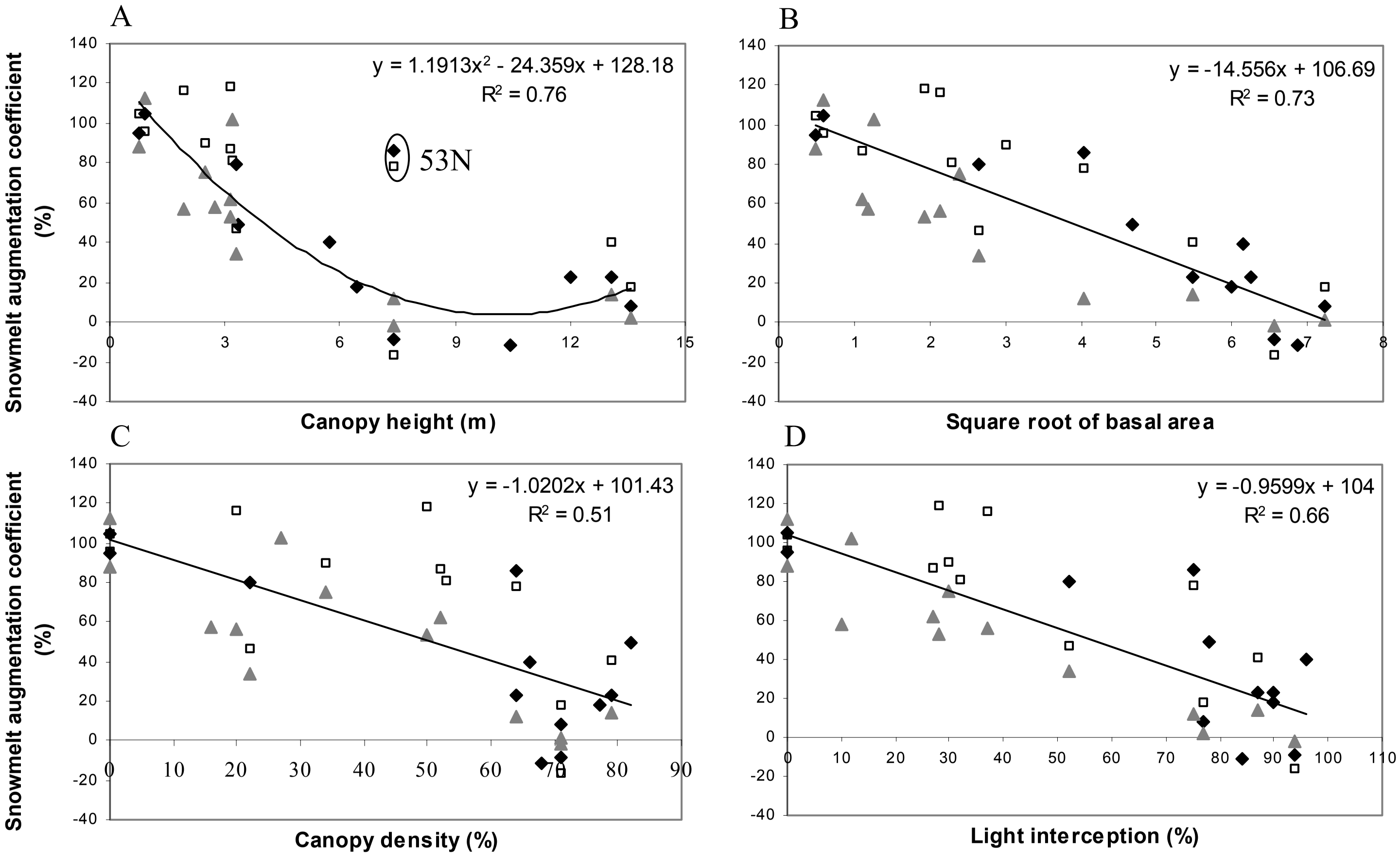

Figure 3 : Snowmelt augmentation coefficient in relation to (a) canopy height, (b) the square root of the basal area, (c) canopy density and (d) light interception at Montmorency forest

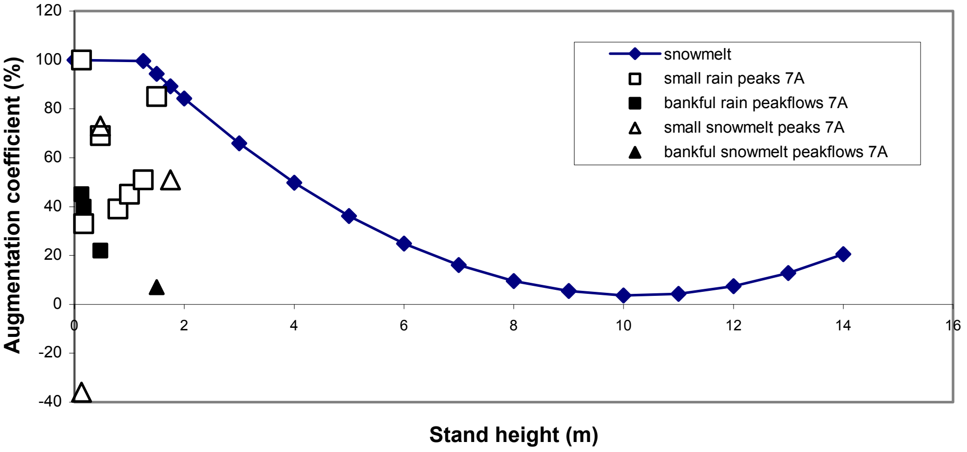

Figure 4. Snowmelt augmentation coefficients and peak flow at Montmorency Forest.

CONCLUSION

The SAC indicate that the effect of clearcutting on mean snowmelt rates is reduced by 50 % when H, C, Li and BA reached 4 m, 50 %, 55 % and 16 m^2/ha respectively. In Quebec's balsam fir forest, these stand characteristics are attained about 15 years after clearcutting. The best relations between the SAC and stand characteristics are obtained with H or BA, which are available from standard forest inventories. The ECA concept is consequently readily applicable to control peak flow augmentations in managed forested basins. However, the statement that the SAC is a good index of hydrologic recovery remains to be confirmed with stream flow measurements for up to 15 – 20 years after harvesting.

REFERENCES

Bélanger L, Bertrand L, Bouliane P, Lussier LJ and coll., 1991. *Plan général d'aménagement de la Forêt Montmorency*. Université Laval. 216 p.

Dunne T, Leopold LB. 1978. *Water in environmental planning*. W.E. Freeman and Company: San Francisco; 818 p.

Faustini JM. 2000. *Stream channel response to peak flows in a fifth-order mountain watershed*. PhD thesis, Oregon State University. 339 p.

Hudson R. 2000. Snowpack recovery in regenerating coastal British Columbia clearcuts. *Canadian Journal of Forest Research* 30: 548-556.

Ice G. 1999. *Streamflow and water quality: What does the science show about clearcutting in Western Oregon*. NCASI, Corvalis Oregon; 20 p.

Kuz'min PP. 1961. *Melting of snow cover*. Leningrad. Translated in 1972 by Israël Program for Scientific Translation. Jerusalem. 290 p.

Lemmon PE. 1956. A spherical densiometer for estimating overstory density. *Forest Science* 2(1): 314-320.

Macdonald LH, Wohl EE, Madsen S. 1997. *Validation of water yield thresholds on the Kootenai National Forest*. The Kootenai National Forest, Libby, M.T; 197 p.

MRNQ. 1999. Normes d'inventaire forestier. *Les placettes-échantillons temporaires (édition provisoire)*. Ministère des Ressources Naturelles. Québec ; 210 p.

Pilgrim DH. 1975. Model evaluation, testing and parameter estimation in hydrology In *Prediction in catchment hydrology. A national symposium on hydrology*, Australian Academy of Science; 305-333.

Plamondon AP. 1993. *Influence des coupes forestières sur le régime d'écoulement de l'eau et sa qualité.* Université Laval / Ministère des Forêts du Québec (C-47). Ste-Foy; 179 p.

Robitaille A, Saucier JP. 1998. *Paysages régionaux du Québec méridional*. Publications du Québec : Ste-Foy; 213 p.

Thornthwaite CW. 1948. An approach toward a rational classification of climate. *Amer. Georgr. Rev*. 38:55-94.

USCE. 1956. *Snow hydrology*. U.S. Army Corps of Engineers., North Pac. Div. 437 pages. Portland, Oregon and Office of Tech. Serv. PB151660. 437 p.

Verry ES. 1986. Forest harvesting and water: the Lake States experience. *Water Res. Bull*. 22(6):1039-1047.

Washington Forest Practices Board. 1997. *Board Manual : Standard Methodology for Conducting Watershed Analysis*, Washington State Department of Natural Ressources, Forest Practices Division. 112 p. 12 Appendices.

Winkler RD. 2001. *The effects of forest structure on snow accumulation and melt in south-central British Columbia.* PhD thesis, University of British Columbia, 163 p.