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Rainfall generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 world-wide basin studies

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Abstract

Increase in bankfull peak flows and a reduction of lag and base times of the storm hydrographs were the only change in stormflow characteristics observed after harvesting balsam fir stands over 85% of the area of basin 7A (122 ha) at Montmorency Forest (Quebec, Canada). The maximum peak flow increase by 63% and occurred when harvesting had reached 61% of the basin area. For the five-year period after harvesting 85% of the basin area, the maximum increase of bankfull flow was 57% while the average change derived from the regression between the treatment and control basin during the pre-harvest period was 54%. These peak flow changes were compared with results from harvesting effects on bankfull peak flow from 50 paired watershed studies. The maximum increase in peak flow of 63% (basin 7A) was at the upper end of published results for harvesting 45–70% of a basin area while a 54% peak flow increase corresponded to the average value (49%) of published results for the 70–100% harvesting intensity. The relatively high peak flow response of basin 7A was mainly attributed to the connections of skid trails and road ditches with two branches of the stream. Considered globally, the results from watershed studies indicate that logging should not cover more than 50% of a basin area to minimise the occurrence of peak flow increases above 50%, which are deemed to affect stream morphology significantly.

Keywords: Peak flow; Clearcutting; Boreal forest; Rainfall stormflow; Basin studies

1. Introduction

In Quebec, as elsewhere in North America, the fear of negative impacts of forest harvesting was mainly related to water quality during the 1970s (Plamondon et al., 1982) while it was considered that larger peak flows were not significantly affected (Hewlett, 1982). However, recent reviews of basin studies (Beschta et al., 2000; MacDonald and Hoffman, 1995; MacDonald et al., 1997; Plamondon, 1993, 2002) indicate that logging may increase peak flows large enough to affect stream morphology. MacDonald et al. (1997) reviewed the effects of forest harvesting on peak flows and concluded, irrespective of its cause as rainfall or snowmelt, that: (1) changes in the magnitude of peak flows tend to decline with

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increasing annual precipitation; (2) the percent change is usually less important in the dormant season than in the growing season; (3) about 10–15% of a basin area has to be cleared for a change in peak flows to be detectable; and (4) the percent change is generally decreasing with peak flow of increasing return period. However, results are very variable due to uncontrollable factors such as topography, soil characteristics and species harvested, as well as a function of other elements such as harvested area, road location, skid trails, magnitude of peak flow and method used in the data analysis. For example, small summer peak flows were increased by an average of 419% after clearcutting 20% of a basin area in Pennsylvania (Dietterick and Lynch, 1989), while several other studies indicated no significant changes in peak flows following clearcuts up to 100% of the basin area (Harr and McCorison, 1979; Harr et al., 1982; Harris, 1973; Miller, 1984; Nakano, 1967).

The tendency for peak flow changes, expressed in percentage, to decrease as the flow gets larger has long been recognized (Hewlett, 1982; Pearce et al., 1980) and confirmed by recent reviews (Beschta et al., 2000; MacDonald et al., 1997; Thomas and Megahan, 1998) although exceptions can be found (Verry et al., 1983; Clary et al., 1974). In practice, it is important to relate the increase of peak flows after logging to peak flow magnitude, because it is generally agreed that bankfull peak flows, corresponding to a return period of 1.5–2 years for alluvial streams (Dunne and Leopold, 1978; McCandless and Everett, 2002; Richards, 1982; Ryan and Emmett, 2002) to 11–100 years for mountainous streams (Nolan et al., 1987), are responsible for shaping the morphological characteristics of streams. A 50% increase of bankfull discharge, corresponding to a peak flow with a return period of approximately 5 years, was considered to significantly affect the aquatic ecosystem (WFPB, 1997) or stream morphology (Faustini, 2000; Ice, 1999). Bankfull discharge with a return period of 1.5 year was previously used by Van Haveren (1988) to evaluate peak flow changes after harvesting on the Wagon Wheel Gap watershed.

There is a need for guidelines to address large changes of bankfull peak flows following forest harvesting in the boreal forest of eastern North America. Patch cutting 31% of a 394 ha basin, at Montmorency forest, north of Quebec City, did not significantly modify rainfall generated peak flows and storm flows (Plamondon et al., 1998). The absence of knowledge on the effect of harvesting a large proportion of a basin on peak flow in the boreal forest, combined with the difficulty in extrapolating the results obtained elsewhere, has prompted the present study. The objectives of this study were firstly, to determine the effects of harvesting 85% of a basin in the boreal forest on rainfall bankfull peak flow and stormflow regime, and secondly, to relate the results of the present study with findings from the literature. Rainfall generated peak flows were used since flows with a close to a two-year return period are mostly generated by snowmelt while larger flows are usually generated by rainfall for watershed smaller than 500 km^2 in southern Quebec (Rousselle et al., 1990).

2. Site and methods

The study site was located at the Montmorency Experimental Forest, 80 km north of Quebec City (47°16′ 20″N, 71°09′ 40″W), Canada (Plamondon and Ouellet, 1980). The average annual temperature, precipitation and snowfall water equivalent are respectively, 0.3 °C, 1416 and 465 mm. The rainfall season, extending mainly from June to October, comprises about 50% of the annual precipitation. The depth of the unconsolidated material, mostly basal till, ranges from nothing on the summits to 18 m in the valleys. The top 30 cm of soil is highly permeable while the underlying till has a low permeability (Barry, 1984). The bio-climatic domain is white birch balsam fir (Robitaille and Saucier, 1998). It is dominated by balsam fir (*Abies balsamea* (L.) Mill), which accounts for more than 75% of the volume; white spruce (*Picea glauca* (Moench.) Voss) for 10%, black spruce (*Picea mariana* Mill) for 3% and white birch (*Betula papyrifera* Marsh) for 10% (Bélanger et al., 1991). The commercial volume (diameter at breast height > 9 cm) of balsam fir stands normally varies between 14 and 70 m^3 ha^{-1} at age 30 and between 75 and 200 m^3 ha^{-1} at age 60.

The impact of clearcutting 85% of basin 7A was analysed using both paired basin and the single basin approach (Reinhart, 1967). For the paired basin approach, streamflow from basins 6 (control) and