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Effects of pulpwood harvesting on the quality of stream waters of forest catchments representing a large area in Western Alberta, Canada

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Abstract. The effects of pulpwood harvesting on water quality are being studied by the Canadian Forestry Service. The present study was conducted from 11 May to 28 June 1973 on a pulp lease area (7770 km^2) in Western Alberta. Thirteen catchments in three working circles were selected, seven represented the undisturbed condition whereas the remaining six had been partially logged during the past ten years. Analysis of variance showed no significant difference in the concentration of cations between treated and untreated catchments. The long-term effects of pulpwood harvesting were not significantly different from the natural erosion of these nutrients from undisturbed forests.

Résumé. Les effets de la récolte de bois de pâte sur la qualité de l'eau ont été étudiés par le Service Forestier canadien. La présente recherche a été conduite du 11 mai au 28 juin 1973 sur une surface de 7770 km^2 consacrée à la production de bois de pâte dans l'Alberta de l'Ouest. Treize bassins versants groupés en trois zones de travail ont été sélectionnés; sept présentaient des conditions naturelles tandis que les six autres avaient été partiellement exploités au cours des dix dernières années. L'analyse de variance n'a montré aucune différence significative dans la concentration des cations entre les bassins traités et non traités. Les effets à long terme de la récolte de bois de pâte n'ont pas été significativement différents de ceux de l'érosion naturelle des éléments nutritifs dans des forêts non touchées.

INTRODUCTION

Reports on the effects of pulpwood harvesting on the nutrient outflow have been conflicting. Pierce *et al.* (1972) found substantial increases in the concentration of ions in the streams draining clearcut areas while Hall (1971) observed very small increases. It has also been reported that there was less loss of nutrients following strip-cutting than clearcutting (Hornbeck *et al.*, 1973).

In a preliminary study conducted on a small area, Singh and Kalra (1973) found that there were minor differences in the concentration of major cations in the streams draining undisturbed and partially-logged watersheds. The present investigation was conducted on a large area to evaluate the effects of pulpwood harvesting on the chemical quality of waters with respect to Ca, Mg, K and Na.

MATERIALS AND METHODS

Study area

The study was conducted on forest catchments representing the lease area (7770 km^2) of North Western Pulp and Power Ltd. (a major pulp producer in Alberta). The lease area extends from 52°56′ to 53°59′N and from 116°23′ to 118°27′W. It experiences a sub-humid, continental climate with long, cold winters and moderately mild summers. Mean annual precipitation is 533 mm, 75 per cent of which is rain.

Forest management practices

The company cuts 4450 ha, or about 0.912×10^6 m^3 of wood, per year consisting of 60 per cent lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), 30 per cent white spruce [*Picea glauca* (Moench) Voss] and 10 per cent black spruce [*Picea mariana*

TABLE 1. Study catchments on North Western Pulp and Power Company's leasehold

Physiographic region	Catchment (Station No.)	Dominant forest cover	Drainage area (km^2)	Percent clearcut Total	Percent clearcut 1972–73	Elevation (m above m.s.l.)	Dominant soils	Surficial deposits	Bedrock geology
Marlboro Working Circle	Pine Creek (MAO231D)*	Lodgepole pine	23.9	Undisturbed		1190–1450	Bisequa gray luvisols; orthic gray luvisols; mesisols common near stream channels	Continental till (Mayberne) Paleocene gravels	Tertiary (Paleocene): Paskapoo Fm:- sandstone, shale, minor conglomerate, and coal seams (non-marine)
	Pine Creek (MAO332D)	Lodgepole pine	22.1	44	2	1190–1370			
Alberta Plateau Benchlands	Edson River (MAO708D)	Lodgepole pine, white spruce	7.0	32	0	1140–1450			
	Edson River (MAO834D)	Lodgepole pine, white spruce	23.1	Undisturbed		1110–1400			
Berland Working Circle	Hendrickson Creek (BEO131D)	Lodgepole pine	22.0	Undisturbed		1420–1620		Till	Tertiary and Late Upper Cretaceous: Paleocene and Brazeau Fm. undivided:- sandstone, shale, conglomerate, coal seams (non-marine)
	Vogel Creek (BEO132D)	Lodgepole pine, white spruce	11.1	Undisturbed		1480–1650			
Rocky Mountain Foothills	Cabin Creek (BEO133D)	Lodgepole pine, white spruce	12.6	Undisturbed		1400–1770			
	Fox Creek (BEO334D)	Lodgepole pine	18.2	56	20	1370–1520			
	Fox Creek (BEO335D)	Lodgepole pine, white spruce	12.3	73	20	1370–1740			

(cont.)

TABLE 1 – cont.

Physiographic region	Catchment (Station No.)	Dominant forest cover	Drainage area (km²)	Percent clearcut Total	Percent clearcut 1972–73	Elevation (m above m.s.l.)	Dominant soils	Surficial deposits	Bedrock geology
McLeod Working Circle	Anderson Creek (MCO731D)	Lodgepole pine, white spruce	19.7	Undisturbed		1190–1680	Orthic gray luvisols; degraded eutric brunisols; mesisols common near stream channels	Cordilleran till (Robb); outwash gravels	Paleocene: sandstone, shale, minor conglomerate and coal seams (non-marine)
	(Creek not named) (MCO732D)	Lodgepole pine, white spruce	8.8	Undisturbed		1190–1460		Cordilleran tills: (Robb) and (Marlboro)	
Rocky Mountain Foothills	Anderson Creek (MCO933D)	Lodgepole pine, white spruce	10.7	38	21	1280–1620		Cordilleran till (Marlboro)	Brazeau Fm:- sandstone, shale conglomerate; minor coal seams and ash beds (non-marine)
	Quigley Creek (MCO934D)	Lodgepole pine, white spruce	16.8	38	14	1270–1430			

* MA = Marlboro Working Circle; BE = Berland Working Circle; MC = McLeod Working Circle.

(Mill.) BSP] and sub-alpine fir [*Abies lasiocarpa* (Hook.) Nutt.]. Growing stock averages 53 per cent lodgepole pine, 19 per cent white spruce, 8 per cent black spruce, 5 per cent sub-alpine fir, 9 per cent poplars, and the remainder is standing dead trees.

The lease area is divided into forest management units of various sizes called working circles (geographical regions), compartments and cutting units. Cutting units are made up of blocks 20 to 100 ha in area, the size depending on stand age, topography, silvicultural considerations, and the degree of erosion hazard. Provided adequate regeneration is obtained, each cutting unit is completely cutover in 20 years.

After the trees have been removed, scarification (exposing mineral soil by breaking up the heavy duff layer) operations are carried out to facilitate regeneration. About 3550 ha are scarified annually. Detailed accounts of the Company's woods operations and of the physical characteristics of the area are given by MacArthur (1968) and Dumanski *et al.* (1972), respectively.

The catchments

Thirteen catchments in three working circles were selected for study. Of these, seven were undisturbed (not logged) and the remaining six had been logged partially – mainly during the past ten years. A pairing system was adopted whereby catchments were selected so that an undisturbed catchment was located in the vicinity of a similar logged catchment, subject to the same geological and climatic conditions. Pertinent information regarding the catchments is shown in Table 1.

Methods

Water samples were collected from 11 May to 28 June 1973 on a weekly basis in the catchments situated in the Marlboro and McLeod working circles and on weekdays in the Berland working circle. Streamflow at the time of sampling was also measured in each case.

The samples were filtered using Whatman grade GF/A filter papers. The analyses were completed within a few days after collection. Calcium, Mg, K and Na were determined by atomic absorption spectrophotometry using Perkin-Elmer model 303. Instrument settings and other details were the same as given in the Analytical Methods manual (Perkin-Elmer Corp., 1973).

For each catchment and working circle the mean and the standard deviation of the concentration (mg/l.) and solute yield (kg km^{-2} day^{-1}) of the above-mentioned cations were calculated. Although care was taken to match catchments on similarities of vegetation, soil and geological conditions, not enough was known of their hydrological behaviour to permit paired comparisons. Analysis of variance, to test treatment differences for each cation, was therefore based on group comparisons within each working circle. In such comparisons the treated and undisturbed catchments were considered to be the samples representative of the working circle and the determinations on each catchment as sub-samples.

RESULTS

The mean concentration and mean solute yield of each cation in the studied catchments are presented in Table 2. The variability within each cation is shown by the standard deviation listed within parentheses. A summary for the three working circles is provided according to unlogged (*U*) and logged (*L*) catchments.

There is considerable variation in the mean concentration and mean solute yield of cations among catchments within the same working circle. Analysis of variance performed on the concentration data of each working circle did not show significant difference between the undisturbed and logged catchments at the 95 per cent confidence level. Similarly, there was no significant difference in the solute yield (kg day^{-1}) of the four cations on the basis of streamflow measured at the time of sampling.

TABLE 2. Concentration and yield of nutrients (main cations) in the stream waters of undisturbed and partially logged catchments

Catchment		Concentration (mg/l.)				Solute yield (kg km^{-2} day^{-1})			
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
Berland									
BE0131D		34.5	6.1	5.7	0.7	63.4	11.3	10.3	1.3
		(7.4)	(1.2)	(1.0)	(0.1)	(15.8)	(2.7)	(2.0)	(0.4)
BE0132D		12.8	1.8	4.4	0.4	33.3	4.6	10.4	1.2
		(7.8)	(1.3)	(1.3)	(0.1)	(28.6)	(4.4)	(3.4)	(1.0)
BE0133D		12.0	1.7	5.6	0.5	16.8	2.5	7.9	0.8
		(2.0)	(0.2)	(0.8)	(0.2)	(3.9)	(0.6)	(1.9)	(0.4)
BE0334D*		39.2	6.7	4.0	0.7	43.2	7.4	4.4	0.7
		(4.2)	(0.6)	(0.4)	(0.2)	(5.7)	(1.0)	(0.7)	(0.2)
BE0335D*		25.7	4.4	4.6	0.6	36.3	6.3	6.5	0.9
		(3.6)	(0.5)	(0.9)	(0.1)	(8.6)	(1.6)	(1.4)	(0.3)
Marlboro									
MA0231D		14.1	2.0	2.0	0.4	34.5	5.1	5.1	1.2
		(3.9)	(0.4)	(0.5)	(0.1)	(28.0)	(4.5)	(4.4)	(1.4)
MA0332D*		14.9	1.2	1.7	0.5	49.8	4.8	6.3	2.6
		(22.8)	(0.2)	(0.8)	(0.1)	(63.0)	(4.7)	(5.2)	(3.1)
MA0708RD*		35.0	5.5	4.1	0.7	70.2	11.3	8.4	1.5
		(6.9)	(0.9)	(0.8)	(0.1)	(26.1)	(4.5)	(11.7)	(0.9)
MA0834D		26.2	3.9	5.7	0.7	59.9	9.0	12.7	1.8
		(7.0)	(0.9)	(1.7)	(0.1)	(33.0)	(5.1)	(7.0)	(1.5)
McLeod									
MC0731D		40.5	7.0	4.1	0.7	46.7	8.1	4.7	0.8
		(5.5)	(0.8)	(0.3)	(0.1)	(8.2)	(0.9)	(0.7)	(0.2)
MC0732D		34.2	5.2	3.8	0.7	30.6	4.8	3.3	0.7
		(6.0)	(0.7)	(0.8)	(0.2)	(12.8)	(2.2)	(1.1)	(0.5)
MC0933D*		37.1	5.8	4.1	0.7	69.3	10.9	7.6	1.7
		(8.9)	(1.2)	(1.0)	(0.3)	(29.4)	(5.0)	(3.4)	(1.5)
MC0934D*		35.0	5.2	4.8	0.7	55.2	8.5	7.2	1.3
		(6.2)	(0.6)	(1.5)	(0.3)	(23.0)	(4.0)	(2.9)	(1.1)
Summary for working circles									
Berland:	*U*	20.2	3.3	5.2	0.5	39.2	6.3	9.6	1.1
		(12.4)	(2.4)	(1.2)	(0.2)	(27.3)	(4.9)	(2.8)	(0.7)
	L	31.8	5.5	4.3	0.6	39.4	6.8	5.5	0.8
		(7.8)	(1.3)	(0.8)	(0.1)	(8.1)	(1.4)	(1.6)	(0.3)
Marlboro:	*U*	20.2	2.9	3.8	0.5	47.2	7.0	8.9	1.5
		(8.3)	(1.2)	(2.2)	(0.2)	(32.2)	(5.0)	(6.9)	(1.4)
	L	25.0	3.3	2.9	0.6	60.0	8.0	7.3	2.1
		(19.3)	(2.3)	(1.5)	(0.2)	(47.8)	(5.6)	(4.4)	(2.2)
McLeod:	*U*	36.8	6.0	3.9	0.7	37.3	6.1	3.9	0.7
		(6.4)	(1.2)	(0.6)	(0.2)	(13.6)	(2.4)	(1.2)	(0.4)
	L	36.0	5.5	4.4	0.7	62.3	9.7	7.4	1.5
		(7.3)	(0.9)	(1.2)	(0.3)	(26.0)	(4.5)	(3.0)	(1.2)

* Indicates partially logged catchments.

The catchment solute yield was further expressed on an equal area basis as kg km^{-2} day^{-1}. Calcium, Mg and K did not show significant differences between disturbed and undisturbed catchments in any working circle. Sodium, however, showed a significant (95 per cent confidence level) increase in the logged catchments of McLeod working circle and a similar decrease for the logged catchments of Berland working circle. However, no change at this level of probability was detected in the stream waters of the Marlboro catchments.

On an equal area basis, the divalent ions (Ca, Mg) showed higher solute yields in the logged catchments than in the undisturbed catchments. The yields of Na and K, however, had no consistent pattern.

DISCUSSION

The study was conducted primarily during the snowmelt and high flow periods of May and June. Most of the streamflow occurs at this time and any significant loss of nutrients during these months could be detrimental to the site. Singh and Kalra (1974) have shown that nearly half of the total annual output of dissolved constituents from Marmot Creek experimental watershed (an Alberta IHD basin) occurred during the month of June. Although much of the solute yield in the present study should similarly occur during the May–June sampling period because of high flows, in most cases the differences between logged and unlogged catchments were not significant.

To some degree this result is to be expected since the period of snowmelt and early summer rains is also a period when dilution effects are at a maximum. The concentration of each cation is therefore likely to be low during this period as compared to late summer and early autumn when dilution effects are minimal. The increased temperatures during the latter seasons also accelerate the activity of micro-organisms which make nutrients readily available (Fredriksen, 1971). The difference in cation concentrations between the logged and undisturbed catchments is therefore likely to be the lowest during the period in which this study was done.

Loss of nutrients also occurs through the sediments removed by the erosion of soil. Chemical analysis of particulate matter, however, was not attempted. More erosion of nutrients therefore occurred from the site than suggested by the data presented in this study. Similarly, although data were collected on cations only, such losses are always balanced by equivalent loss of anions. An increased output of divalent ions as a result of logging therefore suggests further loss of nutrients in accompanying anions.

The data presented here represent only the quality of stream waters as sampled at the gauging sites. The nutrients in transit would be absorbed partly by the vegetation growing between the disturbed site and the stream. Some nutrients would also be deposited in depressions and may never reach the stream except through leaching. Moreover, dissolved nutrients are readily available to the aquatic vegetation growing in the stream reaches above the gauging sites. Nutrient status of the streams at the sampled sites thus represents only a portion of the total erosion of nutrients as a result of logging. Further research needs to be undertaken to provide answers in the light of above-mentioned considerations.

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