Alternate Strip Clearcutting in Upland Black Spruce The Nipigon Workshop, June 24 and 25, 1986

Eight of the nine presentations given at this workshop were revised following peer review. Four of these papers appeared in the December '87 issue of *The Forestry Chronicle* (Vol. 63: 435-456); the remaining four appear in this issue.

The workshop itself was sponsored by the Great Lakes Forestry Centre of the Canadian Forestry Service, the Ontario Ministry of Natural Resources and Domtar Forest Products.

The Editor

Alternate Strip Clearcutting in Upland Black Spruce V. The Impact of Harvesting on the Quality of Water Flowing from Small Basins in Shallow-soil Boreal Ecosystems

by

J.A. Nicolson¹

Abstract

Streams flowing from six small basins (100-450 ha), dominated or originally dominated by black spruce stands growing on sites with shallow soil over bedrock, were monitored for seven years (1978-1984) near Lake Nipigon, Ontario. Three basins were left uncut. Three basins were harvested, one by patch-cutting, one by clearcutting, and one by stripcutting (in a three-cut pattern, with cutting in 1977, 1979 and 1981). Comparison of streamwater from harvested and uncut basins indicated a greater water yield from the harvested basins, as well as differences in several chemical parameters. Specific conductance, alkalinity, Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and HCO_3^- concentration increases were statistically significant. Nitrate-nitrogen and total nitrogen (TN) levels generally decreased, the former significantly; pH, SO_4^{2-} , Cl^- , $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and total phosphorus (TP) changes were not significant.

Résumé

Les cours d'eau s'écoulant de 6 petits bassins (100 à 405 ha), dominés ou originellement dominés par des peuplements d'épinette noir sur des sites caractérisés par un sol mince sur la roche-mère, ont fait l'objet de surveillance pendant 7 ans (1978-1984), près du lac Nipigon, en Ontario. Aucune coupe n'a été faite dans trois bassins. Trois bassins ont été exploités, l'un par blocs, un autre par coupes rases, et le dernier, par bandes (coupes effectuées en 1977, 1979 et 1981). L'étude comparée des cours d'eau provenant des bassins exploités et non exploités a révélé que les apports d'eau des bassins exploités étaient plus grands et qu'il existait des différences entre plusieurs paramètres chimiques. On a relevé des hausses statistiquement significatives de la conductivité spécifique, de l'alcalinité, et des concentrations de Ca^{2+} , Mg^{2+} , K^+ , Na^+ , et HCO_3^- . On a généralement noté une baisse des teneurs en nitrate-azote et en azote total (AT), qui a été significative dans le premier cas; les écarts entre le pH et les concentrations de SO_4^{2-} , Cl^- , $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ et de phosphore total (PT) n'ont pas été significatifs.

¹Government of Canada, Canadian Forestry Service, Great Lakes Forestry Centre, P.O. Box 490, Sault Ste. Marie, Ontario P6A 5M7.

Introduction

Forested basins are generally recognized as primary sources of high-quality water in North America. Alteration of forest cover in such basins may influence streamwater quality and quantity. Results of research studies vary substantially, and depend on factors such as soil characteristics, vegetation type, climatic regime, and the degree, type, pattern, and timing of disturbance.

Research into the effects of forest harvesting on hydrologic parameters over the extensive area of the Canadian Shield has been minimal. Nicolson *et al.* (1982) reported on studies in the jack pine (*Pinus banksiana* Lamb.) cover type in northwestern Ontario. Plamondon *et al.* (1982) compared two sites in the boreal forest of Quebec. Powell (1983) and Krause (1982a) discussed the mixedwood cover type in the Nashwaak Experimental Watershed in New Brunswick. Publications from the Hubbard Brook Study and from other studies in New Hampshire have outlined harvesting effects in the northern hardwood forest (e.g., Bormann *et al.* 1968; Hornbeck *et al.* 1975; Pierce *et al.* 1970, 1972; Martin *et al.* 1986).

To date, no studies specific to the hydrology of black spruce (*Picea mariana* [Mill.] B.S.P.) forests on thin mineral and organic soils have been conducted. In northern Minnesota, work was done on black spruce bogs that covered less than 25% of most basins, while the other 75% was dominated by aspen (*Populus* spp.) and white birch (*Betula papyrifera* Marsh.) on deep mineral soil uplands (Verry 1981, 1986; Knighton and Steigler 1981). This study differs from earlier studies in that it looks at black spruce growing primarily on extensive areas of very shallow to nonexistent mineral soil over bedrock, with peat deposits restricted to local pockets

and drainageways. Aspen and birch are minor components of these basins.

One component of the alternate strip clearcutting project was to assess and compare the impacts of modified harvesting and clearcutting on water yield and quality. Since 1977, water quality has been measured from six basins in the Nipigon Working Circle of Domtar Forest Products, near Orient Bay. The purpose of this paper is to provide an interim look at water quality parameters by comparing the streamwater chemistry of three undisturbed and three disturbed basins over a seven-year period. Since these are time-trend studies, inferences drawn are weaker than those from paired-catchment experiments because there is no climatic control (a calibration period and a control basin) for separating the effects of disturbance from those of climate (Bosch and Hewlett 1982). Future results will include preharvest and postharvest comparisons, since some of the uncut basins have recently been harvested.

Study Area

The study area is located 35 km east of Lake Nipigon in the Central Plateau Section (B.8) of the Boreal Forest Region (Rowe 1972) of northern Ontario (Fig. 1). A detailed description of site conditions and forest types on the study area is found in Jeglum (1980).

Bedrock in the study basins is mainly composed of lava, slate, greywacke, and diabase layers, with some outcrops of acid igneous rock. Overburden is a shallow undulating till of fine sandy and silty texture, with high stone and boulder content (Zoltai 1967). Soils vary from slightly stony to stony

Figure 1. Geographical location of the study area within Ontario, and of the six experimental basins within the study area.

tills, with fine, sandy-silt or silty fine sand texture (Jeglum 1982), and are relatively nutrient-rich because of the local abundance of base-rich diabase bedrock. Brunisols and Luvisols occur beneath mixedwood and hardwood forests. Podzols and organic mats over bedrock with less than 10 cm of mineral soil occur under conifers. Gleysols and Organic soils are found in low, wet depressions along waterways.

Annual precipitation is 750 mm, with an annual runoff of 340 mm (Anon. 1978). Drainage is irregular, with numerous lakes, ponds and streams. Drainage blockages give rise to meandering, slow-flowing streams. The lack of strong topographic relief created problems in defining basin boundaries.

The study area was located in the headwaters region of the Blackwater River, which empties into Lake Nipigon (Fig. 1). In 1977, six small basins were selected, ranging from 100-450 ha in area (Table 1). At that time, all basins were undisturbed. Other than ground moraine, which was prevalent across each site, few glacial deposition features were evident in the study basins. Approximately 10% (a range of 0-20%) of each basin was classified as Brunisols, with deeper mineral soil supporting mixedwood forest; 20% (a range of 15-30%) was classified as Gleysols and Organic soils along drainageways that supported black spruce. The remaining 70% (a range of 60-75%) consisted of very shallow Podzols and organic mats over bedrock that supported black spruce. In the preharvest condition, more than 70% of each basin was covered by mature black spruce growing on the shallow-soil sites typical of the area.

Methods

Seven years of data (1978-1984) were collected for the six basins (Table 1). Two conditions were compared: i) uncut (basins 3, 5 and 6), and ii) harvested, which included a stripcut (basin 1), a patchcut (basin 2) and an operational clearcut (basin 4). Sample-period means of water quality parameters for these two conditions were compared statistically (by a two-sample t-test) on a yearly basis and as a total over the seven years.

Basins 3 and 6 were not disturbed throughout the period of data collection, but since road clearing began in basin 5 in the fall of 1983, this basin was excluded from the 1984 uncut category.

Table 1. Basin parameters for hydrology study installations in the Blackwater River watershed at Orient Bay.

Basin	Date established	Treatment	Area (ha)	Area cut (ha)	Buffer strip (m)
1	June, 1977	Stripcut: fall 1977, 79, 81	308	1977-128 1979-27	Partial 10-30 m
2	June, 1977	Patchcut: fall-winter 1977-1978	284	180	Yes 15-30 m
3	July, 1977	Undisturbed	102	none	Yes
4	July, 1977	Clearcut	136	136	No
5	Aug., 1977	Road right-of-way, fall 1983	438	130 ^a	Yes
6	Aug., 1977	Undisturbed	140	none	Yes

^aDisturbance occurred in the fall of 1983, so this basin was not included as part of the uncut condition for the 1984 summary.

Cutting in basin 2, the patchcut, was completed by early 1978, leaving 37% of the area with uncut unmerchantable forest. For the most part, harvesting occurred more than 30 m from the stream channel; at two minor locations, harvesting occurred approximately 15 m from the channel.

Basin 4, the operational clearcut, received the greatest disturbance. All merchantable trees were removed, including trees along the stream, and only a few scattered aspen were left in the basin. No roads were established, but skidding took place at right angles to the stream channel, crossing it at many points. No buffer strip of vegetation was left alongside the stream.

Basin 1 was an alternate strip clearcut. In 1977, a wide right-of-way was cleared for road building, and road construction began. Experimental strips were cut, and clearcutting of small, unmarked blocks of timber followed. About 40% of the area was clearcut. In 1979, a further 9% of the area was clearcut during the second cuts (the 2-year leaves), and in 1981, another 5% was clearcut during the third cut (the 4-year leaves). The area around and north of Bogus Lake (Fig. 1), and unmerchantable strips of trees 10-30 m wide along most drainageways, which totalled 45% of the basin area, were left undisturbed.

Water samples were collected at the same sampling point, in the centre of the stream, during each visit. One clean 500 mL polyethylene bottle and one 250 mL glass bottle were used to collect water samples. To remove particulate matter, all samples were passed through separate Whatman #41 filters that had been rinsed with distilled water. Half of the sample from the 500 mL bottle was transferred to a preservative-free polyethylene bottle that had been prepared by washing in HNO₃ and rinsing with distilled water. This bottle was then refrigerated. Analysis of pH, specific conductivity, and alkalinity, and levels of chloride (Cl⁻), sulphate (SO₄²⁻), calcium (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), and sodium (Na⁺), were completed within two weeks. Two 100 mL samples were removed from the glass collecting bottle. The first sample had 1 mL of 30% H₂SO₄ preservative added, and was stored in a refrigerator in a bottle prepared by acid (H₂SO₄) washing and distilled water rinsing; the second sample was passed through a 45 µm filter that had been washed with distilled water, then was stored similarly to the first sample (but without preservative). The preservative-treated water was analyzed for total phosphorus (TP) and total nitrogen (TN) within three months. The filtered water was analysed for ammonium-nitrogen (NH₄⁺), nitrite- (NO₂⁻-N) and nitrate-nitrogen (NO₃⁻-N), and phosphate-phosphorus (PO₄³⁻-P) within one week.

Streamwater was collected weekly (1978-1981) or biweekly (1982-1984) during a 28-week sample period from 15 April to 31 October each year. Water yield was continuously monitored at control structures (weirs) and weekly or biweekly totals were calculated using the mean daily discharge. Weighted-mean concentrations for the 28-week periods were calculated by multiplying the measured (weekly or biweekly) concentration by the total streamwater discharge over the corresponding time span, then dividing the sum of these by the total recorded discharge over the 28-week period. Weighted-average pH values were calculated by conversion of pH readings to H⁺ concentrations. In 1978 and 1979, samples were analyzed at the Ontario Ministry of the Environment regional laboratory in Thunder Bay. From 1980 to 1984, samples were analyzed at the Great Lakes Forestry Centre (GLFC).

In the GLFC laboratory, alkalinity was determined by potentiometric titration on a Metrohm E636 Titro-processor. Acidity (pH) was determined with a Ross Electrode on a Fisher-Accumet 750 Meter, and conductivity was measured on a Radiometer Type CDM2e Conductivity Meter and corrected to a standard 25°C. A Technicon AutoAnalyzer II-C⁺ was used to analyze NH₄-N (by sodium nitroprusside), NO₃-N (by cadmium reduction), TN (by micro-Kjeldahl), PO₄³⁻-P and TP (by molybdophosphoric blue), SO₄²⁻ (by methylthymol blue), and Cl⁻ (by mercuric thiocyanate). A Varian 1275 Spectrophotometer was used to analyze Ca²⁺ and Mg²⁺ by atomic absorption, and K⁺ and Na⁺ by flame emission.

Results and Discussion

Water Quantity

Natural annual variability, resulting primarily from differences in annual precipitation (610 to 863 mm), was demonstrated by the twofold variation in water yield from uncut basins that was recorded over the seven years during which measurements were taken. Discharge from the harvested basins (267 to 437 mm) was greater than that from the uncut basins (144 to 289 mm). During the seven years, average water yield from the three harvested basins was 338 mm (47% of annual precipitation) whereas the average yield from the uncut basins was 238 mm (33% of annual precipitation). Other studies of water yield and vegetative manipulation (Hibbert 1967, Bosch and Hewlett 1982) confirm the observation that reduction of forest cover results in increased water yield.

Since overland flow is rare on forested land and on clearcut land with the forest floor intact, the observed increase in water transmission must occur by seepage to groundwater or by shallow subsurface flow (15 to 45 cm deep) above the B horizons (Verry 1986). In the present case, soils are so shallow over bedrock that increased water transmission is invariably through the soil layers and over the bedrock surface to

drainageways. The sandy tills allow rapid infiltration and lateral (downslope) transmission of water. Greater discharge from harvested than from uncut basins was probably due mainly to the elimination of precipitation interception and to reduced evapotranspiration resulting from removal of the tree canopy (Verry 1986).

A portion of the differences in water yield from uncut and harvested basins may be attributed to natural variation; however, the differences are great enough to indicate strongly that a change in water yield occurred as a result of harvesting.

Water Quality

Probable changes in water quality resulting from timber and pulpwood harvesting have been a concern for several years. To compare streamwater chemistry in uncut and harvested basins, discharge-weighted mean concentrations for the 28-week sample periods were calculated for several chemical parameters (Tables 2 and 3).

In four of the seven years, there was a statistically significant difference in average pH values between the uncut and harvested areas (Table 2). The average pH of water taken from harvested basins was lower than that from undisturbed basins in 1978 and 1980, but was higher than in uncut basins in 1981 and 1982. The overall seven-year average pH of uncut basins was not significantly different from that of the harvested basins. There seemed to be a general increase in average pH of about 0.5 over the seven years in both the uncut and harvested basins. Hydrogen ion (H⁺) concentrations reported in Table 3 parallel the results for pH because H⁺ concentrations were used to calculate pH averages. Krause (1982b) reviewed the effects of forest harvesting on water quality across Canada and concluded that pH would decrease following harvesting of coniferous forests growing on the podzolic soils of the Canadian Shield. It is possible that the high base and carbonate content in the tills of this particular study area served to neutralize any trend toward acidification as a result of disturbance.

Table 2. Discharge-weighted averages of pH, conductivity, alkalinity and selected anions for streamwater during the 28-week sampling periods in 1978 to 1984 for Orient Bay basins.

Basin Conditions		pH	Cond. ^a µS/cm	Alk. ^b	HCO ₃	SO ₄ ²⁻	Cl ⁻ µeq/L	NO ₃ ⁻ -N	PO ₄ ³⁻ -P
1978	Uncut	6.29	48	—	—	71	—	5.7	0.15
	Harv.	6.19*	81*	—	—	84	—	1.3*	0.22*
1979	Uncut	6.28	40	—	—	68	41	4.3	0.25
	Harv.	6.46	63*	—	—	53*	51	1.8*	0.20
1980	Uncut	6.71	51	338	6.7	106	36	1.8	0.21
	Harv.	6.56*	62*	578*	11.6*	107	37	0.8*	0.25
1981	Uncut	6.38	44	275	5.6	126	27	7.9	0.31
	Harv.	6.56*	73*	546*	10.9*	110*	30	6.0*	0.29
1982	Uncut	6.85	43	273	5.4	85	26	3.2	0.25
	Harv.	6.96*	61*	574*	11.5*	72*	26	1.7*	0.27
1983	Uncut	6.53	39	225	4.4	77	25	6.8	0.36
	Harv.	6.73	59*	506*	10.1*	74	24	2.0*	0.30
1984	Uncut	6.78	41	284	5.7	82	30	3.0	0.19
	Harv.	6.84	63*	559*	11.1*	61*	31	2.6	0.19
Ave	Uncut	6.49	44	279	5.6	88	31	4.7	0.25
	Harv.	6.55	66*	553*	11.0*	80	33	2.3*	0.24

*Indicates that the average for harvested basins is significantly different from the unharvested basin average at the 95% level using a two-sampler t-test.

^aSpecific conductivity

^bAlkalinity

Table 3. Discharge-weighted averages of selected cations, total nitrogen and total phosphorus for streamwater during the 28-week sampling periods in 1978 to 1984 for Orient Bay basins.

Basin Conditions		H ⁺	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺ µeq/L	NH ₄ -N	TN	TP
1978	Uncut	0.51	376	167	12	24	1.0	36	0.34
	Harv.	0.65*	619*	263*	26*	29*	1.8*	33	0.42*
1979	Uncut	0.52	288	171	16	22	1.1	34	0.41
	Harv.	0.35	446*	221*	30*	27*	0.9	30	0.39
1980	Uncut	0.20	429	168	10	26	1.0	28	0.63
	Harv.	0.28*	513*	206*	28*	29	0.9	29	0.67
1981	Uncut	0.42	305	119	13	26	1.5	41	0.14
	Harv.	0.28*	549*	223*	27*	31	1.8	48	0.13
1982	Uncut	0.14	357	155	14	29	0.8	36	0.38
	Harv.	0.11*	497*	221*	34*	30	1.0	32	0.26
1983	Uncut	0.30	304	128	15	29	1.4	33	0.23
	Harv.	0.19	472*	204*	25*	32	1.6	31	0.22
1984	Uncut	0.17	332	132	8	36	2.6	40	0.30
	Harv.	0.14	471*	186*	14*	32	2.8	34*	0.24
Ave	Uncut	0.32	342	149	13	27	1.4	36	0.35
	Harv.	0.28	510*	218*	26*	30*	1.5	34	0.33

*indicates that the average for harvested basins is significantly different from the unharvested basin average at the 95% level using a two-sample t-test.

Average specific conductivity (overall, and for each individual year) of water from harvested basins was significantly greater than that of the uncut basins (Table 2). Except for a slightly higher value for the harvested basins in 1978, there was little variation over the following six years. Plamondon *et al.* (1982) reported a conductivity increase after conifer harvesting in Quebec, with the increase greater where no vegetation buffer was left along the stream. Similar results were found in the present study: the patchcut and stripcut had protective vegetation buffers along the stream, while the clearcut had none, and individual values indicated that water from the clearcut basin consistently had the highest specific conductivity of any of the harvested basins.

Alkalinity measures the ability of a system to buffer acid inputs, and is based on the amount of bicarbonate (HCO₃⁻) ion present. The t-test results indicated that the average alkalinity of the harvested basins was significantly higher than in the uncut basins, and this difference was consistent over the five years of measurement (Table 2). Bicarbonate ion values were calculated from alkalinity, and as a result, trends in HCO₃⁻ were the same as for alkalinity. The results indicate these streams have significant buffering from acidity because of the carbonate content in the glacial tills of the area. In a comparison of three areas on the Canadian Shield in Ontario, Nicolson (1987) found that HCO₃⁻ was the dominant anion in streamflow from uncut basins in this study area, comprising 54% of the total anion content of the water.

Sulphate concentrations were significantly lower in the harvested basins than in the uncut basins for four of the seven years, although the overall mean for the seven years was not significantly different (Table 2). Only in the first year did the mean SO₄²⁻ concentration of the harvested basins exceed that of the uncut basins. Chloride concentrations were not significantly different between treatments for any of the six years of measurement. Chloride is often considered to be a conservative anion that shows little change in concentration over time or in response to disturbance. The SO₄²⁻ and Cl⁻ results are consistent with findings from other studies (e.g., Nicolson *et al.* 1982, Powell 1983). Krause (1982b) discussed changes in the anion composition of the soil solution as a result of changes in climate at the soil surface after crop

removal, and reported an increase in SO₄²⁻ ion concentrations for a very acid forest floor (conifer forests) and for poorly buffered mineral soil. Since this increase was not indicated by streamwater concentrations in the present study (rather, a decrease was observed), it emphasizes the importance of the carbonate content of the tills, which provide HCO₃⁻ as a readily mobile anion in discharge waters.

Nitrate-nitrogen concentrations in the harvested basins were significantly lower than those in the uncut basins during the first six years of measurement (Table 2). Several factors may influence the production of NO₃⁻-N in disturbed ecosystems (Vitousek *et al.* 1982, Vitousek and Matson 1985). The most plausible factors inhibiting NO₃⁻-N production in these black spruce dominated basins are: 1) low initial NH₄⁺-N availability for conversion to NO₃⁻-N as indicated by the low concentrations of NH₄⁺-N in uncut basin streamwater (Table 3), 2) low initial populations of nitrifying bacteria, 3) slow growth of nitrifying bacteria because of acid soil conditions, and 4) low soil pH, which could itself inhibit the nitrification process.

Phosphate-phosphorus concentrations from the harvested basins were significantly higher than in the uncut basins only in the first year; thereafter, the concentrations from cut and uncut basins were essentially the same (Table 2).

Concentrations of all four major cations in streamwater from the harvested basins were significantly higher than those from uncut basins, on average, over the seven-year period (Table 3). Concentrations of Ca²⁺, Mg²⁺ and K⁺ were significantly higher in water from harvested basins in each of the seven years for Na⁺, concentrations were only significantly higher during the first two years. Increases in levels of these four cations were primarily responsible for the elevated specific conductivity values discussed earlier. Calcium concentrations from the harvested basins were significantly higher than from the uncut basins in all seven years. The increase varied between 16% and 45% in individual years, with an average increase of 33% during the seven years. Magnesium followed a pattern similar to that of Ca²⁺. Concentrations from the harvested basins on an individual year basis were 18% to 47% greater than from the

uncut basins, with a 34% average increase over the seven-year period.

Potassium is regulated directly by plant uptake, and as a result, large increases in streamwater K^+ concentrations from the harvested basins relative to those in the uncut basins were observed: 40% to 64% increases in individual years, and a mean increase of 50% over the seven years. There was some indication in harvested basins (in 1983 and 1984) of a change in K^+ concentrations towards the levels in uncut basins. Sodium concentrations showed some increase in the early years, but this became nonsignificant after three to four years.

Krause (1982b) indicated that increased water yield because of reduced evapotranspiration decreases the average depth of water penetration into the soil. Furthermore, since solubility of mineral constituents is probably highest in the upper soil layers and in the litter, water flowing laterally through these surface layers to the stream channel in harvested basins should exhibit higher specific conductivity and contain more dissolved solids than water from uncut basins. The differences reported in the present paper support these observations.

Ammonium-nitrogen, TN, and TP differences were not statistically significant on the seven-year average according to the t-test (Table 3). On a year-to-year basis, NH_4^+-N concentrations in streamwater from harvested basins showed little change from those in the uncut area: concentrations in water from harvested basins were significantly greater than those from uncut basins only in the first year. Total nitrogen concentrations were slightly reduced in the harvested basins in most years but were significantly lower only in 1984, seven years after disturbance. Total phosphorus concentrations were generally the same for water from harvested and uncut areas, with only the first year having a statistically greater concentration in the harvested than in the uncut basins. This differs from the findings of Knighton and Steigler (1981), who reported that clearcutting of black spruce on peatlands resulted in an increase in TP which could enrich downstream waters and become a cause for concern.

Conclusions

1. Water yield was greater from the harvested basins than from the uncut basins in all seven years.
2. Streamwater pH was generally not affected by harvesting; specific conductivity was approximately 35% greater in the harvested basin streams than in the uncut basins.
3. Alkalinity and HCO_3^- concentrations from the harvested basins were double those of the uncut basins.
4. Calcium and Mg^{2+} concentrations were 35% greater from the harvested than from the uncut basins, and the differences persisted even after seven years. Potassium concentrations approximately doubled in most years; however, five years after harvesting there was some indication of a decrease in values toward the K^+ levels in uncut basins. Sodium increases were minimal and disappeared after three to four years.
5. Sulphate concentrations tended to be lower in harvested than in uncut basins; Cl^- concentrations showed little change following harvesting.
6. Ammonium-nitrogen concentrations were unchanged, NO_3^- -N values were statistically lower in the harvested

basins, and TN values were slightly (but nonsignificantly) lower in the harvested basins in most years.

7. Phosphate-phosphorus and TP concentrations were generally not different between harvested and uncut basins.

These conclusions may apply only in areas where there is a similar Ca^{2+} and HCO_3^- rich till and bedrock in the shallow-soil black spruce type on the Canadian Shield of northern Ontario. However, this could include a considerable area north of Lake Superior, where diabase or other moderately basic materials comprise the dominant bedrock.

Recommendations

Past study and experience have demonstrated that the impact of harvesting and subsequent silvicultural operations in forest basins can be minimized by following a sound management plan. To meet the objectives of such a plan, the planner of harvesting operations should:

1. Minimize the number and areal extent of skidding routes.
2. Limit skid trails to low gradients.
3. Keep all machinery out of surface water pathways (even minor swampy drainageways).
4. Leave buffer strips (even strips 3-5 m wide will help) along water bodies.
5. Harvest fine-textured and organic soils when they are frozen or (at least) snow-covered.
6. Avoid harvesting steep slopes of fine-textured soil.
7. Keep vegetative residue out of lakes, streams, drainageways and ditches.
8. Promote rapid revegetation of cleared sites by tree planting or enhancing natural regeneration.

Acknowledgments

The author gratefully acknowledges the contributions of Mr. A.W. Johns, Forest Hydrology Technician, and his assistants (sample collection, data handling and analysis), as well as Mr. D.J. Kurylo, Mrs. L.M. Chartrand, and other laboratory staff.

References

- Anon. 1978. Hydrological atlas of Canada. Dep. Fish. Environ., Ottawa, Ont.
- Bormann, F.H., G.E. Likens, D.W. Fisher and R.S. Pierce. 1968. Nutrient loss accelerated by clearcutting in the forest ecosystem. *Sci.* 159: 882-884.
- Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *J. Hydrol.* 55: 3-23.
- Hibbert, A.R. 1967. Forest treatment effects on water yield. p. 527-543 *In* W.E. Sopper and H.W. Lull, Eds. *Proc. Internat. Symp. For. Hydrol.*, Penn. State Univ., Pergamon Press.
- Hornbeck, J.W., R.S. Pierce, G.E. Likens and C.W. Martin. 1975. Moderating the impact of contemporary forest cutting on hydrologic and nutrient cycles. p. 423-433 *In* *Proc. Internat. Symp. Hydrol. Char. River Basins*, IAHS Publ. 117.
- Jeglum, J.K. 1980. Strip cutting in shallow-soil upland black spruce near Nipigon, Ontario. I. Study establishment and site conditions. *Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-315*. 61 p.

- Jeglum, J.K. 1982.** Strip cutting in shallow-soil upland black spruce near Nipigon, Ontario. II. Regeneration in the first study area. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-337. 24 p.
- Knighton, M.D. and J.H. Steigler. 1981.** Phosphorus release following clearcutting of a black spruce fen and a black spruce bog. p. 577-583 in D.N. Grubich, R.S. Farnham, and B. Itkonen, Eds. Proc. Sixth Internat. Peat Congr., Duluth, Minn., Aug. 1980.
- Krause, H.H. 1982a.** Nitrate formation and movement before and after clearcutting of a monitored watershed in central New Brunswick, Canada. Can. J. For. Res. 12: 922-930.
- Krause, H.H. 1982b.** Effect of forest management practices on water quality: review of Canadian studies. Can. Hydrol. Symp. 82: 15-29.
- Martin, C.W., R.S. Pierce, G.E. Likens and F.H. Bormann. 1986.** Clearcutting affects stream chemistry in the White Mountains of New Hampshire. USDA For. Serv., Res. Pap. NE-579, 12 p.
- Nicolson, J.A. 1987.** Contributions of acid deposition to streamwater chemistry in three Precambrian Shield basins. p. 89-98 in R.H. Swanson, P.Y. Bernier, and P.D. Woodard Eds. Forest Hydrology and Watershed Management. Proc. of the Vancouver Symp., Aug., IAHS Publ. 167.
- Nicolson, J.A., N.W. Foster and I.K. Morrison. 1982.** Forest harvesting effects on water quality and nutrient status in the boreal forest. Can. Hydrol. Symp. 82: 71-89.
- Pierce, R.S., J.W. Hornbeck, G.E. Likens and F.H. Bormann. 1970.** Effects of elimination of vegetation on streamwater quantity and quality. p. 311-328 in Proc. Symp. on the Results of Research on Representative and Experimental Basins. IAHS Publ. 96.
- Pierce, R.S., C.W. Martin, C.C. Reeves, G.E. Likens and F.H. Bormann. 1972.** Nutrient loss from clearcuttings in New Hampshire. p. 285-295 in S.C. Csallany, T.G. McLaughlin, and W.D. Striffler, Eds. Proc. Symp. Watersheds in Transition, Colorado State Univ.
- Plamondon, A.P., A. Gonzalez and Y. Thomassin. 1982.** Effects of logging on water quality: comparison between two Quebec sites. Can. Hydrol. Symp. 82: 49-70.
- Powell, G.R., Ed. 1983.** Nashwaak experimental watershed project. Annual Report 1981-82. N.E.W.P. Tech. Comm. of New Brunswick For. Res. Advis. Comm., Univ. New Brunswick, Fredericton.
- Rowe, J.S. 1972.** Forest Regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont., Publ. No. 1300. 172 p.
- Verry, E.S. 1981.** Water table and streamflow changes after stripcutting an undrained black spruce bog. p. 493-498 in Proc. Sixth Internat. Peat Congr., Aug. 1980.
- Verry, E.S. 1986.** Forest harvesting and water: the Lake States experience. Water Resour. Bull. 22: 1039-1047.
- Vitousek, P.M., J.R. Gosz, C.G. Grier, J.M. Melillo and W.A. Reiners. 1982.** A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. Ecol. Monog. 52: 155-177.
- Vitousek, P.M. and P.A. Matson. 1985.** Causes of delayed nitrate production in two Indiana forests. For. Sci. 31: 122-131.
- Zoltai, S.C. 1967.** Glacial features of the north-central Lake Superior region, Ontario. Can. J. Earth Sci. 4: 515-528.

Retired Members

This note is to remind retired members and Section Councils about the provisions of By Law 4.4 which allows individuals who have been Institute members for 15 or more years and who retire "with a substantial reduction in income" to apply for retired status. If approved, retired status members are not required to pay any dues, but retain all rights and benefits except receipt of The Forestry Chronicle. The Chronicle for 1988 is available to retired members on payment of \$29.00, but dues are for the period July 1, 1987 to June 30, 1988.

The proper procedure for those interested in this provision is to apply to your Section Council. Councils will deal with these applications and notify National Office of the decision so that records can be adjusted.

Journal Bargains for Institute Members!

The Table of Contents of the Canadian Journal of Forest Research is carried every month in The Forestry Chronicle. Members are reminded that this prestigious forest research publication is available to them at a very special price of \$26.00 per year. The normal rate for Canadian individual subscribers for this Journal, direct from NRC is \$52.00. Here then is another advantage of membership — a saving of 50% on the price of a subscription to Canadian Journal of Forest Research. Indeed, all NRC Journals are available to CIF Members at greatly reduced prices. Not for all members to be sure but a real saving for some.

Send your order and cheque to National Office.