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WATER QUALITY AND QUANTITY IN BLACK SPRUCE STANDS FOLLOWING HARVESTING

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INTRODUCTION

Water from undisturbed forested basins is generally of good quality despite the presence of sediment and nutrients (Fig. 1). However, there is a great deal of variation in natural water quality from site to site. Alteration of forest cover in such basins may influence stream water quality and volume. Water quality depends on factors such as soil characteristics; vegetation type; climatic regime; and the degree, type, pattern, and timing of disturbance. Generally, after disturbance, the concentration of elements remains within human water quality consumption standards. However, short- or long-term nutrient losses from the site may result.

Figure 1. High flow drainage period in a northern Ontario watershed.

Public criticism of forestry operations has commonly focused on various aspects of forest management, including clear-cutting, scarification, and controlled burning. Aesthetic and environmental considerations undoubtedly provided the initial impetus for this criticism, but it was reinforced by the assumption that such practices were detrimental to the productive capacity of the land and to the quality of surface runoff from forested basins.

This note outlines how the concepts of forest hydrology can be used to mitigate the impact of harvesting operations. It is based principally on research conducted by the Canadian Forest Service–Ontario (Nicolson 1975, 1982, 1988).

APPROACH

For several years forest management practices have been examined from the standpoint of their potential and actual effects upon water quality and quantity. Changes in water runoff volume and chemistry have been related to modifications in the site itself. For many reasons, it is difficult to make generalizations about the impact of forest management practices on site nutrient status. Forested sites have an inherent natural variability, both in their basic makeup and in their productivity. For example, species vary in their growth rate and nutrient requirements; length of rotation age governs biological accumulation time; and recovery rates vary from site to site and from region to region.

Several small (35–450 ha) basins, representing undisturbed stands and cutovers of various ages, were monitored from 1973–76 in northwestern Ontario, and from 1978–84 in north central Ontario for water quality and quantity. Conditions included uncut stands, recent cuts, and up to

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10-year-old cutovers. Northwestern Ontario study basins were located at the Experimental Lakes Area (ELA), 55 km southeast of Kenora. Here, vegetation conforms to section B.11 (Upper English River) of the Boreal Forest Region and is a complex of V31 and V32 V-types of the Northwestern Ontario Forest Ecosystem Classification (Sims et al. 1989). Jack pine (*Pinus banksiana* Lamb.) dominates on dry upland sites, with black spruce (*Picea mariana* [Mill.] B.S.P.) growing in nearly pure stands on basin plains. ELA basins were commercially clear-cut, leaving scattered individuals and clumps on ridge tops, basin plains, and in lakeshore reserves on the larger lakes. Scarification with shark-fin barrels usually followed on the more level and drier areas.

In north central Ontario, the Orient Bay (OB) study was located in the Blackwater River headwaters, 35 km east of Lake Nipigon. This is the Central Plateau Section (B.8) of the Boreal Forest Region and is predominated by the V33 V-type. In preharvest condition, OB basins were more than 70% mature black spruce on shallow-soil sites typical of the area. Harvested areas included clear-cuts, patch cuts, and strip cuts.

By sampling basins at various times following disturbance, it was assumed that major changes after harvesting should be detectable by differences in water quality and quantity as compared to the undisturbed basins. Each year, stream water was collected weekly or biweekly for 28 weeks, from mid-April to early November, and analyzed for chemical constituents. Water yield was continuously measured at control structures (weirs) and weekly totals were calculated (Fig. 2).

WATER PRODUCTION

At the ELA, unit area flow increases (m^3/ha) were substantial following clear-cutting. On a monthly basis, increases from 44% to over 300% occurred in the first year. The overall 6-month average increase was 98%. By the fourth year following clear-cutting, increases had moderated, but still ranged from 40% to over 200%, with a 6-month average of 78%. Major increases came during high flow events in the spring and following major storms. Unit flows were essentially equal for the uncut and 4-year-old cuts during low flow periods. At the OB site, natural annual variability due mainly to annual precipitation differences (610–863 mm) demonstrated a twofold variation in water yield from uncut basins over a 7-year period. Discharge from harvested basins (267–437 mm) was greater than from uncut basins (144–289 mm). Average water yield from harvested basins was 338 mm (47% of annual precipitation); average yield from uncut basins was 238 mm (33% of annual precipitation). These flow increases have a major effect on element losses from a site even when concentrations return to normal levels.

Figure 2. Example of a weir used to measure surface water discharge from a terrestrial basin.

Since overland flow is rare on forested lands and on clear-cuts with an intact forest floor, the observed increase in water transmission must occur by seepage to groundwater or by shallow subsurface flow (15–45 cm deep) above the B horizons. At the OB site, soils were so shallow that increased water transmission was invariably through the soil and over the bedrock surface to drainageways. The sandy tills allowed rapid infiltration and lateral (downslope) transmission of water. Greater discharge from harvested than from uncut basins was probably due to the elimination of precipitation interception and to reduced evapotranspiration resulting from removal of the tree canopy.

WATER CHEMISTRY

Combining flow with concentration gives an estimate of losses from a site. At the ELA, ammonium, nitrate, total nitrogen, and total phosphorus rose sharply following clear-cutting and was still evident in 4-year-old cuts. Table 1 outlines increases in selected ion losses after clear-cutting.

For the OB area, Table 2 indicates that calcium and magnesium losses varied between 43 and 246% in individual years, with an average increase of 106% during the 7 years. Potassium, directly regulated by plant uptake, increased 107–300% in individual years, and had a mean increase of 190% over the 7 years. Five years after harvesting there was indication of a peak and then a decrease toward potassium levels from unharvested basins. Losses of sodium, with a 7-year average increase of 57%; sulfate, with a 7-year average increase of 30%; and chloride, with a 6-year average increase of 52%; were not as dramatic as the other three ions.

DISCUSSION

Many substances classified as water pollutants are natural products of the forest and result from geologic erosion, nutrient leakage, and decomposition. Disturbance caused by harvesting can disrupt nutrient and hydrologic cycles. Although element concentrations return to near normal within a few years following cutting, on a unit area (kg/ha) basis, substantial losses still persist after 7 years. Water yield increases are a major controlling factor in the continued elevated losses. Research suggests streamflow declines may require 12–35 years to stabilize.

Table 1. Unit area load averages (kg/ha per year) during 1975 for major ions in northwestern Ontario basins. These are the averages of two undisturbed, three 1-year-old clear-cut, and three 4-year-old clear-cut basins.

	Selected ions					
Conditions	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	SO_4^{2-}	Cl^{-}
Undisturbed	8.56	3.72	1.80	5.08	30.64	3.36
Clear-cut 1 yr	15.40	5.16	5.80	7.28	38.24	7.48
Clear-cut 4 yrs	17.52	7.20	11.52	13.92	70.72	14.80

Table 2. Unit area load averages (kg/ha per year) for selected ions in streamwater from 1978 to 1984 for three unharvested and three harvested basins in north central Ontario. Harvested basins included a clear-cut (1977), a patch cut (1977), and a strip cut (1977, 1979, and 1981).

		Selected ions					
Conditions		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	SO_4^{2-}	Cl^{-}
1978	Unharvested	22.51	6.06	1.46	1.61	10.18	--
	Harvested	44.33[a]	11.40[a]	3.68[a]	2.36[a]	14.47	--
1979	Unharvested	20.04	7.21	2.15	1.76	11.41	5.03
	Harvested	34.26	10.31[a]	4.44[a]	2.38[a]	9.70[a]	6.90
1980	Unharvested	26.28	6.24	1.25	1.80	15.52	3.95
	Harvested	37.61[a]	9.18[a]	3.98[a]	2.45	18.88	4.82
1981	Unharvested	10.56	2.51	0.88	1.02	10.44	1.64
	Harvested	35.21[a]	8.68[a]	3.36[a]	2.28	16.85[a]	3.46
1982	Unharvested	23.40	6.16	1.76	2.16	13.42	3.01
	Harvested	52.27[a]	14.11[a]	7.03[a]	3.62	18.16[a]	4.93
1983	Unharvested	16.18	4.14	1.60	1.75	9.85	2.34
	Harvested	35.27[a]	9.25[a]	3.66[a]	2.76	13.21	3.20
1984	Unharvested	18.86	4.54	0.91	2.35	11.23	3.04
	Harvested	48.71[a]	11.65[a]	2.89[a]	3.77	15.10	5.66
AVG	Unharvested	19.69	5.27	1.43	1.78	11.72	3.17
	Harvested	41.09[a]	10.65[a]	4.15[a]	2.80	15.20	4.83

[a] Indicates that the average for three harvested basins is significantly different from the average for three unharvested basins at the 95% confidence level using a two-sample t-test.

In undisturbed forest ecosystems, nutrient gains through precipitation, the addition of extraneous material, and mineral weathering are offset to some extent by that portion of the nutrient pool carried away in drainage water. This drainage occurs as leaching directly to groundwater or as stream runoff; a combination of surface runoff, subsurface flow, and groundwater. The contribution of each component depends upon surface configuration, soil depth and texture, and bedrock topography in the drainage basin.

Relatively high quality water flows from these basins and a two- to tenfold increase in ionic concentrations would not impair water quality. Ontario drinking water standards, based on ionic concentrations, were rarely approached and never exceeded in these studies.

The type of disturbance and its distance from a water body are critical factors when considering impact to a site. For example, scarification to regenerate jack pine and black spruce is a relatively common practice. However, most scarification occurs on flat or gently rolling terrain where surface runoff is negligible, infiltration is maintained, and revegetation is rapid. The harvesting system is also an important factor, since a clear-cut has more potential for disturbance than a strip cut or other type of partial cut.

Harvesting and related operations, such as road building, skidding, and scarification, are major disturbances that can be controlled by the forest manager. They are also major disruptive influences on both the nutrient and hydrologic cycles. Harvesting disrupts these cycles by reducing transpiration and interception and thus increases the amount of water passing through the system. As well, it creates a large volume of vegetative material for decomposition. Additional water passing through the soil, particularly in summer when nutrients are more mobile, increases the potential for nutrient removal. Also, the reduction of active root surface area severely limits nutrient removal from percolating water. The magnitude of these effects depends upon the proportion of the forest cut, the season of harvest, the degree of wood utilization, and the layout of the harvesting system in relation to the drainage patterns in the area.

MANAGEMENT IMPLICATIONS

Limiting the amount and areal extent of any disruption should be a priority. The forest should be managed with the aquatic environment in mind, and timber extraction must be balanced with the protection of other forest values. This checklist should provide guidance on protecting the aquatic environment during harvesting and regeneration operations. Application of these principles can also lead to improved economies in the operation. To meet objectives, the operations planner should:

1) minimize the number and areal extent of skid trails;
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 courses and small lakes;
5) harvest stands occurring on fine-textured and organic soils when they are frozen or at least snow covered;
6) avoid harvesting steep slopes if soils are fine-textured;
7) keep vegetation residue out of lakes, streams, drainage-ways, and ditches;
8) scarify lightly in higher risk areas so as to reduce massive disruption and minimize the time for revegetation; and
9) promote rapid revegetation of harvested sites by artificial or enhanced natural regeneration methods (e.g., direct seeding).

Adherence to the accepted tenets of responsible land management would control, and could dramatically reduce, element loss in surface runoff. It is especially important to control erosion that produces sediment, the major impact on surface runoff. The key to controlling the loss of elements lies in applying sound land management principles to those aspects of forestry operations that have the potential to create a disturbance or disruption of natural ecosystems.

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