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Post-Harvest Soil Disturbance and Permanent Structure Survey

Pockwock-Bowater Watershed Project

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ABSTRACT

A survey of soil disturbance and permanent structure features following clearcut harvesting was conducted as part of the Pockwock-Bowater Watershed Project in Nova Scotia. Following harvest, approximately half of all treated area was disturbed to varying levels. Machine traffic was the most common disturbance found, affecting between 18.8 and 39.4% of cutover area. Intact forest floor and light slash was the dominant surface condition, covering an average of 61.9% of harvested area (where assessed). Despite extensive disturbance levels, impacts were considered light on all treated areas, due largely to low hazard ratings associated with soil types found. With respect to permanent structures, several harvest areas have significant road coverage and water crossings which give rise to potential off-site impacts. These sites will need to be monitored to ensure these impacts are minimized over time.

INTRODUCTION

The Pockwock-Bowater Watershed Management Project is a multi-faceted project designed to study the impacts of forest harvesting and buffer zones on water quality in first and second order streams and lake catchments. Project partners include: Nova Forest Alliance Model Forest, Nova Scotia Department of Natural Resources, Environment Canada, Halifax Regional Water Commission, Bowater Mersey Ltd., Elmsdale Lumber Company, University of New Brunswick, Nova Scotia Department of Environment, and Natural Resources Canada.

As part of this project, a post-harvest soil disturbance and permanent structure survey was conducted in each of six study watersheds (Figure 1).

Soil disturbance resulting from forest harvesting can have significant impacts on regeneration (and subsequent forest growth), erosion potential, nutrient leaching, and water quality (Curran *et al.*, 2000; Martin, 1998). Harvest practices can impact water quality by altering stream chemistry, sediment loads, flow rate, water yield, and benthic invertebrate community structure (Swank *et al.*, 2001). Curran *et al.* (2000) noted that soil compaction, puddling, rutting, displacement of topsoil and organic layers, and interruption of soil drainage are some of the more important disturbance conditions affecting water storage and infiltration, erosion potential, and tree growth.

Soil compaction is the rearrangement of soil particles leading to an increase in bulk density that results from applied external forces (Curran, 1999). Krause (1998) reported that compaction from harvesting equipment can reduce water infiltration and permeability to air which is detrimental to the establishment and growth of regenerating species.

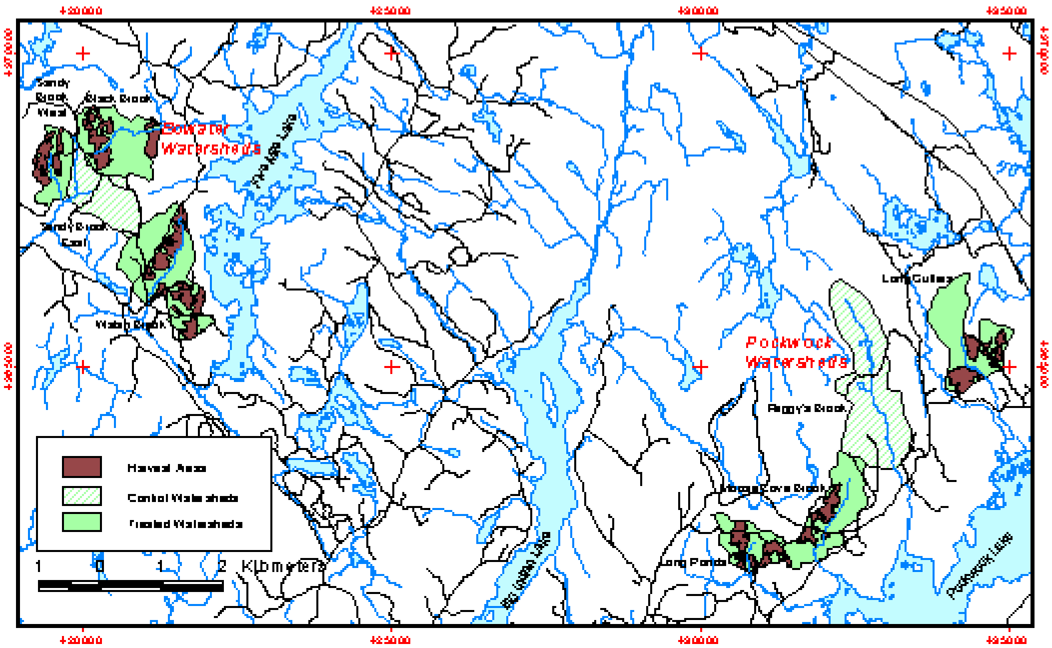

Figure 1: Harvest areas in the Pockwock and Bowater research watersheds.
Projection: Universal Transverse Mercator (UTM); Datum NAD83.

Soil disturbance from harvesting can also increase erosion potential. Erosion hazard increases with the amount of silt and very fine sand and decreases with higher amounts of clay, organic matter, coarse fragments, and increased permeability in a soil (Krause, 1998).

Curran (1999) and Swank *et al*. (2001) reported that on-site impacts of soil erosion from forest harvesting include soil loss, nutrient loss, and lower productivity. Off-site impacts can include changes in water quality attributed to altered chemistry and flow rates, sedimentation, and impacts on invertebrate habitat and community structure.

In addition to soil impacts, harvesting generally results in the production of slash on a site. Where slash loads are light, they can provide a protective mulch for soil and seedlings and return nutrients and organic matter to the soil (Krause *et al*., 2000). Deep, compacted slash, however, can destroy existing regeneration and prevent its re-establishment.

Finally, construction associated with forest harvesting (eg. roads, stream crossings, and landings) has been well documented as a leading source of off-site impacts including erosion, sedimentation, channeling, and decreased soil stability (Krause, 1998; Curran, 1999).

OBJECTIVES

The objectives of this study were:

1. To provide watershed level summaries on permanent structures (roads, landings, and water crossings) for use in analyzing off-site harvesting impacts on water quality.
2. To describe on-site soil disturbances resulting from harvest operations as they relate to soil hazard conditions.
3. To provide watershed level disturbance summaries for use in analyzing off-site harvesting impacts on water quality.

METHODS

Harvest Methods

Most harvesting was carried out using a variety of rubber tired and tracked mechanical harvesters, including single grip harvesters and some use of a feller buncher with on-site processing (Appendix I). A small amount of manual power saw work was also carried out. Most of the forwarding was completed with rubber tired porters, although tracked porters and a wheeled skidder were also used on some sites. Harvesting took place between June 28 and November 5, 2001.

Permanent Structure Assessment

Older, active roads were measured using existing GIS data with on-ground verification. New roads, landings, and water crossings (bridges and culverts) were measured with a GPS unit. Road widths were systematically measured (ditch to ditch) and an average used for calculating road surface area. The dimensions of each water crossing were measured directly.

Soil Disturbance and Surface Expression Assessment

Approximately 500 systematic sample points were established within harvest areas in each of six watersheds. At each sample point, the associated disturbance type and depth or height class of the disturbance (if applicable) were recorded. Disturbance types included: gouges or scalps, mounds, churned soil, and three levels of traffic: light (one to two passes), moderate (multiple passes, secondary harvest trails), and heavy traffic (primary forwarding trails). Undisturbed and natural non-forested (rock, wetland, or peat) categories were also recorded (See Appendix II for descriptions of disturbance types). At every 20th point, duff thickness and surface soil texture were assessed.

Following assessment of the Pockwock sites, survey methods were adjusted before assessment of the Bowater sites. Surface expression description was added to each sample point in addition to disturbance type (See Appendix III).

Pockwock watershed assessments took place in November, 2001. Bowater watershed assessments were carried out in June, 2002.

RESULTS

Harvest

A total of 16,139 metric tonnes of wood was removed from the 97 ha of area harvested in the Bowater watersheds for an average yield of 166 tonnes/ha. This ranged from 149 tonnes/ha at Sandy Brook West to 175 tonnes/ha at Walsh Brook. A total of 7,192 metric tonnes of wood was removed from the 66 ha harvested in the Pockwock watersheds for an average yield of 109 tonnes/ha. This ranged from 93 tonnes/ha at Long Gullies to 122 tonnes/ha at Long Ponds (Appendix 1).

Permanent Structures

The extent of new road construction, pre-existing roads, and landings for the study sites are reported in Table 1 along with the number and dimensions of water crossings (culverts and bridges).

Walsh Brook had the longest road surface of the Bowater watersheds (2.7 km), and Long Ponds the longest of the Pockwock watersheds (1.7 km). New road construction occurred at Moose Cove Brook and Long Gullies (which had no pre-existing roads). Long Gullies contained the only bridge inside any watershed boundary. The variety of culverts used included circular plastic and steel, as well as open bottomed wooden boxes. Culvert sizes ranged from a 30 cm diameter culvert to a 160 cm x 100 cm box culvert.

Soil Disturbance and Surface Expression

Disturbance Hazard Potential

Most harvest sites (Sandy Brook West, Black Brook, Walsh Brook, Long Ponds, and Long Gullies) are covered by well drained, coarse-textured soil (Appendix IV). These soils have low compaction and rutting hazards, but moderate to high forest floor loss hazard (Table 2).

In contrast, Moose Cove Brook (Pockwock) contains a higher percentage of loam and silt loam soil. These medium-textured soils have greater compaction, rutting, and erosion hazards, but a lower forest floor loss hazard.

Harvesting Disturbance

Disturbance levels and surface expression data from all watersheds are presented in Tables 3 to 5 and Figures 2 to 4.

Table 1: Road information for the treatment and control watersheds.

	Watershed	Total Area (ha)	Pre-Existing Road Surface		New Road Construction		Total Road Surface			Number and Dimensions of Water Crossings (cm)		
			Length (m)	Area[2] (ha)	Length (m)	Area[2] (ha)	Length (m)	Area[2] (ha)	% of Watershed Area[2]	Round Culverts (diam)	Box Culverts (l x h)	Bridges (l x h)
	Sandy Brook West	59.7	350	0.24	–	–	350	0.24	0.4	–	160x100 40x40	–
	Black Brook	119.7	700	0.54	–	–	700	0.54	0.5	–	60x30	–
	Walsh Brook	174.4	2 650	2.13	—	–	2 650	2.13	1.2	110 40 40 40 30	60x30 60x30 60x30 50x50	–
	Sandy Brook East[1]	94.3	1 770	1.19	–	–	1 770	1.19	1.3	–	80x80 70x40	–
POCKWOCK	*Long Ponds*	63.9	1 710	0.94	–	–	1 710	0.94	1.5	–	45x30 45x30 45x30 40x30 40x30	–
POCKWOCK	*Moose Cove Brook*	112.6	540	0.31	210	0.29	750	0.60	0.5	120	95x45 45x30 50x30	–
POCKWOCK	*Long Gullies*	129.9	–	–	780	1.42	780	1.42	1.1	–	55x35	420x120
POCKWOCK	*Peggy's Brook[1]*	226.4	–	–	–	–	0	0	0	–	–	–

[1]Control watersheds. [2]Includes road surface and landing area.

Table 2: Hazard ratings for each watershed based on soil type. Moose Cove Brook has medium-textured soil, therefore hazard potential differs (adapted from Keys *et al.*, 2003).

	Watershed	Soil Texture Range	Hazard Potential Ratings (Low - L; Moderate - M; High - H)					
			Compaction	Rutting	Erosion[1]	Frost Heave	Wind-Throw	Nutrient Depletion From Forest Floor Loss
BOWATER	*Sandy Brook West*	SL - LS	L	L	L - M	L	L	H
BOWATER	*Black Brook*	L - SL - LS	L	L	L - M	L	L	H
BOWATER	*Walsh Brook*	SL - LS	L	L	L - M	L	L	H
POCKWOCK	*Long Ponds*	SL - LS	L	L	L - M	L	L	H
POCKWOCK	*Moose Cove Brook*	SiL - SL - L	L - M	L	M - H	L	L	M
POCKWOCK	*Long Gullies*	SL - LS	L	L	L - M	L	L	H

[1] Erosion hazard is for slopes greater than 10%.

Table 3: Harvest induced disturbances and associated surface expression for clearcuts in the Bowater watersheds. Totals (%) for surface expression are weighted by the percent of clearcut.

			Surface Expression (%)										
			Forest Floor			Slash				Erosion		Unstockable	
Watershed	Disturbance	% of Clearcut	Forest Floor	Mineral	Forest Floor/ Mineral Mix	Moderate (16-30cm)	Heavy (>30cm)	Cribbed Wood	Stump or Tree	Eroded	Deposited	Rock/Stone	Wetland/ Organic
Sandy Brook West	Undisturbed	58.7	81.0	–	–	12.6	6.3	–	–	–	–	–	–
	Natural non-forest	2.6	–	–	–	–	–	–	16.7	–	–	75.0	8.3
	Wheel Traffic – Light	13.5	67.7	–	3.2	22.6	6.5	–	–	–	–	–	–
	Wheel Traffic – Moderate	13.3	39.3	1.6	4.9	27.9	6.6	14.8	1.6	–	–	3.3	–
	Wheel Traffic – Heavy	5.9	18.5	11.1	25.9	3.7	–	37.0	–	–	–	3.7	–
	Churned	2.6	8.3	–	83.3	–	8.3	–	–	–	–	–	–
	Gouge	2.2	40.0	30.0	–	–	–	–	–	–	–	30.0	–
	Mound	1.1	100	–	–	–	–	–	–	–	–	–	–
% of Clearcut	Total Disturbance	38.6											
	Watershed Total	100	65.3	1.5	4.8	14.4	5.7	4.1	.7	–	–	3.3	.2
Black Brook	Undisturbed	51.2	78.4	–	–	9.2	11.3	–	1.0	–	–	–	–
	Natural non-forest	5.4	–	–	–	–	–	–	22.6	–	–	54.8	22.6
	Wheel Traffic – Light	16.5	67.0	–	3.2	19.1	5.3	4.3	–	–	–	–	1.1
	Wheel Traffic – Moderate	14.4	36.6	–	3.7	20.7	13.4	23.2	–	–	–	2.4	–
	Wheel Traffic – Heavy	3.5	10.0	15.0	15.0	–	5.0	50.0	–	–	–	5.0	–
	Churned	4.4	60.0	–	40.0	–	–	–	–	–	–	–	–
	Gouge	2.6	33.3	6.7	40.0	–	–	–	–	–	–	13.3	6.7
	Mound	1.9	72.7	–	27.3	–	–	–	–	–	–	–	–
% of Clearcut	Total Disturbance	43.3											
	Watershed Total	100	61.8	.7	4.9	10.9	8.8	5.8	1.8	–	–	3.9	1.6
Walsh Brook	Undisturbed	44.3	76.2	–	–	12.7	9.9	–	1.1	–	–	–	–
	Natural non-forest	4.4	–	–	–	–	–	–	11.1	–	–	44.4	44.4
	Wheel Traffic – Light	9.3	76.3	–	7.9	13.2	–	2.6	–	–	–	–	–
	Wheel Traffic – Moderate	22.0	41.1	2.2	2.2	23.3	4.4	24.4	1.1	–	–	–	1.1
	Wheel Traffic – Heavy	8.1	24.2	15.2	27.3	–	–	24.2	–	6.1	3.0	–	–
	Churned	7.3	56.7	3.3	23.3	3.3	3.3	3.3	–	–	–	–	6.7
	Gouge	3.2	53.8	7.7	23.1	–	–	–	–	–	–	7.7	7.7
	Mound	1.5	66.7	16.7	16.7	–	–	–	–	–	–	–	–
% of Clearcut	Total Disturbance	51.4											
	Watershed Total	100	58.7	2.4	6.1	12.2	5.6	7.8	1.2	.5	.2	2.2	2.9

Table 4: Average harvest induced disturbances and associated surface expression for clearcuts in the Bowater watersheds. Totals (%) for surface expression are weighted by the percent of clearcut.

Watershed	Disturbance		% of Clearcut	Surface Expression (%)										
				Forest Floor			Slash				Erosion		Unstockable	
				Forest Floor	Mineral	Forest Floor/ Mineral Mix	Moderate (16-30cm)	Heavy (>30cm)	Cribbed Wood	Stump or Tree	Eroded	Deposited	Rock/Stone	Wetland/ Organic
All Three Bowater Sites	Undisturbed		51.4	78.5	–	–	1.5	9.2	–	.7	–	–	–	–
	Natural non-forest		4.1	–	–	–	–	–	–	16.8	–	–	58.1	25.1
	Wheel Traffic	Light	13.1	70.3	–	4.8	18.3	3.9	2.3	–	–	–	–	0.4
		Moderate	16.6	39.0	1.3	3.6	24.0	8.1	20.8	0.9	–	–	1.9	0.4
		Heavy	5.8	17.6	13.8	22.7	1.2	1.7	37.1	–	2.0	1.0	2.9	–
	Churned		4.8	41.7	1.1	48.9	1.1	3.9	1.1	–	–	–	–	2.2
	Gouge		2.7	42.4	14.8	21.0	–	–	–	–	–	–	17.0	4.8
	Mound		1.5	79.8	5.6	14.7	–	–	–	–	–	–	–	–
% of Clearcut	Total Disturbance		44.5											
	Watershed Total		100	61.9	1.5	5.3	12.5	6.7	5.9	1.2	0.2	0.1	3.1	1.6

Table 5: Harvest induced disturbances for the clearcuts in the Pockwock watersheds (%).

Disturbance Type		Watershed (% of Clearcut)			
		Long Ponds	*Moose Cove Brook*	*Long Gullies*	*All Three Pockwock Sites*
Undisturbed		41.5	43.2	45.7	43.5
Natural non-forest		3.5	4.0	4.4	4.0
Wheel Traffic	Light	14.8	5.1	5.0	8.3
	Moderate	8.0	8.9	6.5	7.8
	Heavy	4.8	8.2	7.3	6.8
Churned		3.7	9.7	6.8	6.7
Gouge		0.7	1.1	3.4	1.7
Mound		2.6	2.3	3.1	2.7
Slash	Moderate (16-30cm)	8.9	6.8	6.6	7.4
	Heavy (>30cm)	8.9	9.6	10.2	9.6
	Cribbed Wood	2.6	1.1	1.1	1.6
Total Disturbance (%)		**55.0**	**52.8**	**50.0**	**52.6**

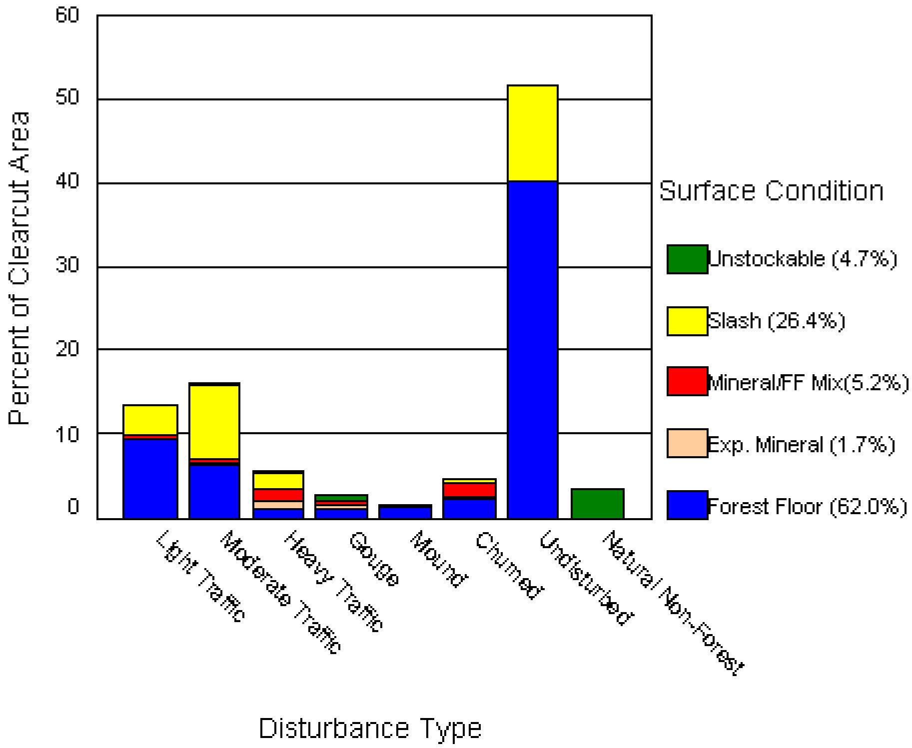

Figure 2: Percentage of each harvesting disturbance by associated surface condition at the Bowater watersheds. Total occurrence (%) of each surface condition is reported in parentheses in the legend.

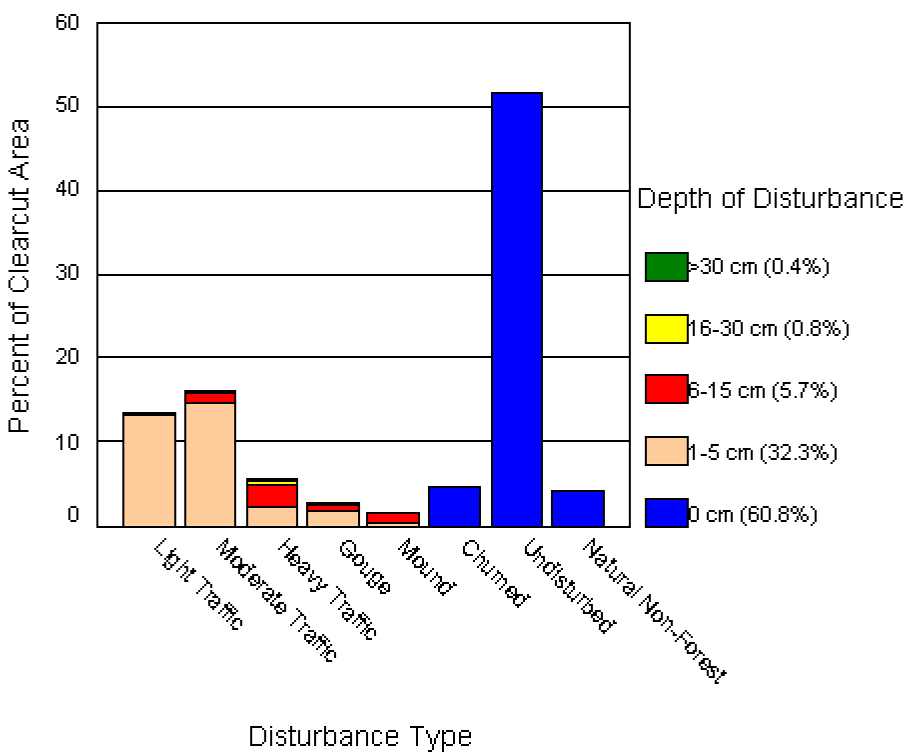

Figure 3: Percentage of harvesting disturbance type found at Bowater watersheds by severity of disturbance (depth). The total occurrence (%) of each depth class is reported in parentheses in the legend. The 0 cm class means no depth measurement was required or taken.

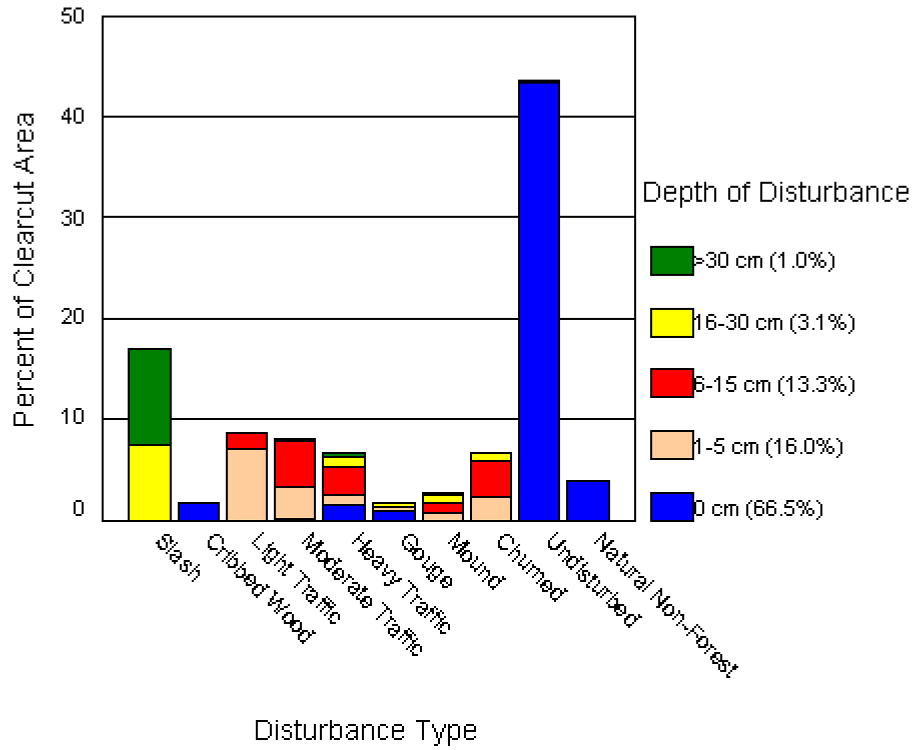

Figure 4: Percentage of harvesting disturbance type found at Pockwock watersheds by severity of disturbance (depth). The total occurrence (%) of each depth class is reported in parentheses in the legend (excluding slash). The 0 cm class means no depth measurement was required or taken.

1. <u>Bowater Sites</u>

An average of 44.5% of Bowater harvest areas showed signs of disturbance (Table 4). Sandy Brook West had the lowest disturbance levels (38.6%), followed by Black Brook (43.3%) and Walsh Brook (51.4%) (Table 3).

Wheel traffic created the most disturbance, totaling between 32.7% and 39.4% in all three watersheds (average 35.5%). Most of this traffic was light or moderate, with low disturbance depths (Figures 2 and 3). Heavy traffic levels ranged from 3.5% to 8.1% (average 5.8%) (Tables 3 and 4) and included a small percentage (1.2%) of disturbance depths greater than 16 cm (Figure 3).

Intact forest floor or light slash was the most common surface expression type (average 61.9%), followed by moderate slash (average 12.5%) (Table 4). All other surface expression types were less than 10%, including exposed mineral soil (<3%) and erosion channels/deposits (<1%) (Table 3).

2. <u>Pockwock Sites</u>

An average of 52.6% of Pockwock harvest areas showed signs of disturbance (Table 5). Long Gullies had the lowest disturbance levels (50.0%), followed by Moose Cove Brook (52.8%) and Long Ponds (55.0%).

Wheel traffic created the most disturbance, totaling between 18.8% and 27.6% in all three watersheds (average 22.9%). This percentage may be underestimated, however, because moderate and heavy slash was counted as a disturbance type rather than a surface expression on Pockwock sites (Figure 4) (see Methods section). As with the Bowater sites, slash mats were deliberately created on harvesting trails in the Pockwock harvest sites, therefore, some samples recorded as slash disturbance would have also experienced wheel traffic.

DISCUSSION

Disturbance Impacts

To assess the impact of disturbance levels found on harvest sites, results need to be looked at in relation to hazard levels.

Five of six study sites contained coarse-textured soil with low inherent hazards for compaction and rutting (Table 2). This, combined with low average moisture conditions during harvesting, suggest these soils were not damaged by light to moderate traffic levels (Keys, 2004). The main hazard for these sites is forest floor loss which can lead to nutrient and moisture deficiencies. Results showed, however, an average of only 1.5% mineral soil exposure (by area) on Bowater sites, with a likely similar level on Pockwock sites. In addition, evidence of erosion on these sites was negligible (where measured).

Soils at Moose Cove Brook (Pockwock) are mainly medium-textured with a higher compaction hazard rating (Table 2). Depending on moisture conditions during harvesting, compaction on this site may have been more damaging. The use of slash mats and the season of harvest suggest, however, that damage would have been mainly restricted to heavy traffic areas, which was less than 10% by area. With respect to forest floor loss, the low levels of gouging and mounding found (less than 5% total), together with the aforementioned use of slash mats, suggests mineral soil exposure was not significant at the Moose Cove Brook site.

As noted earlier, different equipment was used at the harvest sites (Appendix 1). The proportion of undisturbed versus disturbed area on treated watersheds were compared to see if any differences could be attributed to differences in harvesting system (Table 6). On the Bowater sites, Sandy Brook West and Black Brook had similar disturbance levels, while Walsh Brook had a significantly higher proportion of disturbed area. This difference may have been due to the use of tracked harvesters on 80% of the Walsh Brook harvest area. However, a range of equipment was also used on the Pockwock watersheds and no differences in disturbance levels were found on these sites.

Permanent Structures

For the Bowater sites, Walsh Brook has the most potential for off-site impacts due to roads and infrastructure. This site has the largest road area (2.1 ha), along with several water crossings (Table 1).

For the Pockwock sites, the potential for off-site impacts is (on average) greater than for the Bowater sites (Table 1). Long Ponds has several water crossings; Moose Cove Brook has new road construction and a more erodible soil than the other sites (Table 2); and Long Gullies has a sizeable road area (1.4 ha) and a bridge crossing.

Table 6: Critical values and levels of significance for the test H_o: $p_1 = p_2$ vs. H_a: $p_1 \neq p_2$ to test whether two proportions (undisturbed vs disturbed samples) are significantly different between two sample watersheds. [$Z_{0.05\,(2)} = t_{0.05\,(2),\,\infty} = 1.960$] from Zar, 1984.

Watersheds Tested		Z Value	Level of significance	Reject H
BOWATER	*Sandy Brook West vs Black Brook*	1.937	$0.05 < P < 0.10$	NO
	Sandy Brook West vs Walsh Brook	4.059	$P < 0.001$	YES
	Black Brook vs Walsh Brook	2.373	$0.01 < P < 0.02$	YES
POCKWOCK	*Long Ponds vs Moose Cove Brook*	0.606	$0.50 < P$	NO
	Long Ponds vs Long Gullies	1.363	$0.10 < P < 0.20$	NO
	Moose Cove Brook vs Long Gullies	0.793	$0.20 < P < 0.50$	NO

Conclusions

This report summarizes the extent of permanent structures and soil disturbance associated with harvesting operations on six watersheds within the Pockwock-Bowater Watershed Management Project area. Information can be used to aid in the assessment of water quality data collected as part of long-term monitoring.

Results of this study showed that approximately half of all treated area was disturbed to varying levels, but that overall disturbance impact was low, due mainly to low hazard ratings associated with soil types in the area. Also, mineral soil exposure was minimal (and erosion negligible) where assessed. Some differences were noted in disturbance levels based on machine type, but results were inconclusive.

With respect to permanent structures, several harvest areas have significant road coverage and water crossings which give rise to potential off-site impacts. These sites should be monitored to ensure impacts are minimized in the long-term.

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Appendix I: Harvesting data for the Bowater and Pockwock watersheds

Bowater watersheds.

Watershed	Watershed Area (ha)	Harvest Area (ha)	Harvested Log Weights (MT)	Machinery	Description
Sandy Brook West	59.7	21.0	3124	2-1270 Timberjack Harvesters 1-1210 8WD Timberjack Forwarder 1-1410 8WD Timberjack Forwarder	All Rubber Tired/Half Tracks
Black Brook	119.7	29.7	4885	2-1270 Timberjack Harvesters 1-1210 8WD Timberjack Forwarder 1-1410 8WD Timberjack Forwarder	All Rubber Tired/Half Tracks
Walsh Brook	174.4	9.2	1924	2-1270 Timberjack Harvesters 1-1210 8WD Timberjack Forwarder 1-1410 8WD Timberjack Forwarder	All Rubber Tired/Half Tracks
		15.0	3032	1-Keto Harvester 1-1010 6WD Timberjack Forwarder	Tracked Rubber Tired/Half Tracks
		22.3	3174	1-618 Harvester/762 Harvesting Head 1-230 Timberjack 4WD Forwarder	Tracked Rubber Tired - 44 in. High Flotation/No Chains

Pockwock watersheds.

Watershed	Watershed Area (ha)	Harvest Area (ha)	Harvested Log Weights (MT)	Machinery	Description
Long Ponds	63.9	13.6	1626	620 Prentice Harvester/750 Log Max Head 344 Fabtek 4WD Forwarder 2 Men/Power Saws	Tracked Rubber Tired Trail Cutting
		7.0	897	653 John Deere Feller Buncher 620 Prentice Harvester/750 Log Max Head 344 Fabtek 4WD Forwarder 2 Men/Power Saws	Tracked Tracked Rubber Tired Trail Cutting
Moose Cove Brook	112.6	17.0	1984	Rottne JD 2001 6WD Harvester Rottne 12 Tonne 8WD Forwarder	Rubber Tired/Half Tracks Rubber Tired/Half Tracks
		1.8	227	653 John Deere Feller Buncher 620 Prentice Harvester/750 Log Max Head 344 Fabtek 4WD Forwarder 2 Men/Power Saws	Tracked Tracked Rubber Tired Trail Cutting
Long Gullies	129.9	7.8	1020	620 Prentice Harvester/750 Log Max Head 344 Fabtek 4WD Forwarder 2 Men/Power Saws	Tracked Rubber Tired Trail Cutting
		13.1	844	590 John Deere Harvester/Fabtek Head 344 Fabtek 4WD Forwarder 1 Man/Power Saw	Tracked Rubber Tired Trail Cutting
		5.4	594	240 Timberjack 4WD Skidder 1 Man/Power Saw	Rubber Tired Tree Length

Appendix II: Description of disturbance classes.

Disturbance Type	Description	Depth/Height Class Measured?
Wheel Traffic - Light	One or two passes; wheels or tracks	Yes
Wheel Traffic - Moderate	Secondary haul trail	Yes
Wheel Traffic - Heavy	Main haul trail	Yes
Gouge	Gouges or scalps that removed soil material	Yes
Mound	Deposited mineral soil or forest floor	Yes
Churned Soil	Mixed forest floor and mineral soil (not gouged or mounded)	No
Undisturbed	Undisturbed growing area	No
Natural Non-Forested	Non-growing areas (rock, wetland, or organic)	No

Appendix III: Description of surface expression classes.

Surface Type	Description
Forest Floor	Intact Forest Floor with a slash load depth <15 cm
Mineral	Exposed mineral soil not associated with erosion
Forest Floor/Mineral Mix	Mixed soil and surface organic
Moderate Slash	Slash depth 15-30 cm
Heavy Slash	Slash depth >30 cm
Cribbed Wood	Tree boles packed into surface by traffic
Stump or Tree	A stump or tree that is not cribbed wood
Eroded Soil	Eroded mineral soil
Soil Deposit	Mineral soil deposit from erosion
Rock/Stone	Bedrock or stone (non-forested)
Wetland/Organic	Wetland or peat layers (non-forested)

Appendix IV: Mean duff thickness and soil texture at each of six watershed harvest areas.

Watershed		Mean Duff Thickness ± S.E. (cm)	Percent of Duff Thickness Classes	General Soil Texture Range[1]	Percent of Soil Texture Classes[2]
BOWATER	*Sandy Brook West*	14 ± 1.3	1-10 cm - 25.9% 11-20 cm - 60.7% 21-30 cm - 12.9% >30 cm - 0%	SL - LS	L - 8.7% SL - 52.2% LS - 34.8% O - 4.3%
	Black Brook	13 ± 1.5	1-10 cm - 40.7% 11-20 cm - 48.1% 21-30 cm - 7.4% >30 cm - 3.7%	L - SL - LS	L - 18.5% SL - 63.0% LS - 14.8% O - 3.7%
	Walsh Brook	14 ± 1.9	1-10 cm - 43.3% 11-20 cm - 39.1% 21-30 cm - 12.9% >30 cm - 4.3%	SL - LS	L - 8.7% SL - 52.2% LS - 21.7% S - 4.3% O - 8.7% B - 4.3%
POCKWOCK	*Long Ponds*	16 ± 1.4	1-10 cm - 22.6% 11-20 cm - 58.9% 21-30 cm - 13.5% >30 cm - 4.5%	SL - LS	SiL - 9.1% L - 9.1% SL - 59.1% LS - 22.7%
	Moose Cove Brook	18 ± 1.5	1-10 cm - 16.7% 11-20 cm - 45.8% 21-30 cm - 29.2% >30 cm - 8.4%	SL - L - SiL	SiL - 21.7% L - 30.4% SL - 43.5% LS - 4.3%
	Long Gullies	16 ± 1.1	1-10 cm - 12.6% 11-20 cm - 75.3% 21-30 cm - 12.5% >30 cm - 0%	SL - LS	SiL - 6.3% L - 12.5% SL - 43.8% LS - 31.3% S - 6.3%

[1] Based on field assessment only

[2] L=Loam, SL= Sandy Loam, LS=Loamy Sand, SiL=Silt Loam, S=Sand, O=Organic, B=Bedrock

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