FOREST ROAD EROSION IN NORTHERN ONTARIO: A PRELIMINARY ANALYSIS

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ABSTRACT

To determine if forest roads caused significant erosion problems in northern Ontario a preliminary study was conducted in 1972 and 1973. Areas that were potentially more erodible when disturbed were investigated. A crude measure of the severity of erosion was made, based on the accumulation of cross-sectional areas intersected by offset lines. These areas provided an index of the size and distribution of features in relation to slope position and road centerline.

The study suggests that most erosional effects are restricted to the road right-of-way. Problems encountered were due partly to a lack of proper management and partly to a lack of knowledge. There is probably a need to test and cost techniques which could reduce the incidence of unavoidable erosion.

RÉSUMÉ

En 1972 et 1973, dans le nord de l'Ontario, on a fait une étude préliminaire des problèmes que cause l'érosion, afin de déterminer si les chemins forestiers étaient responsables de ce phénomène dans une mesure significative. L'étude porta sur les lieux qui, lorsque détériorés, étaient probablement les plus vulnérables à l'érosion. On effectua un mesurage brut de la gravité de l'érosion, fondé sur une quantité de quadrats sectionnés par des transversales. Ces opérations permirent d'obtenir un indice de l'importance et de la répartition des anomalies par rapport à la position des pentes et à la ligne centrale des chemins.

Selon cette étude, la plupart des dégâts causés par l'érosion sont restreints à l'emprise des chemins. D'une part, les problèmes observés étaient dus à un pauvre aménagement et d'autre part, à un manque de connaissances. Il existe probablement un besoin de vérifier et évaluer certaines méthodes pouvant diminuer l'importance d'érosion inévitable.

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INTRODUCTION

During 1971 a program was developed at the Great Lakes Forest Research Centre to investigate the impact of forest management practices on boreal ecosystems. Although the principal effort initially was to evaluate the impact of clearcutting and scarification on vegetation, soil, and water, attention was also given to the impact of forest road construction. The study reported herein was developed to assess the impact of road design, location, and construction on boreal ecosystems, to determine whether or not a serious problem existed. Consequently, a low-intensity survey was initiated to pinpoint problematic road segments, to measure the magnitude of the impacts, and to identify some of the factors contributing to erosion.

Background Research

Both Wolman (1963) and Anderson (1967) reveal in their literature reviews that there has been considerable research into erosion and the erodibility of soils. Much of this research deals with the mechanics of soil erosion or erosion resulting from severe environmental manipulations or severe environments. For example, the long-term denudation of landscapes as a result of strip-mining or agriculture is not comparable to the removal of a portion of the vegetative cover once every 50 to 200 years such as occurs in forestry operations.

Research in forest areas has been conducted largely in very rugged terrain. The work of Frederiksen (1965) and Dyrness (1965) was undertaken in the Coast Ranges and Cascades of western Oregon, and that of Reinhart and Eschner (1962) in the Allegheny Mountains in western Virginia. The Zena Creek Logging Study (Craddock 1967) was located in the Idaho Batholith in south-central Idaho. The work of Dils (1957) took place at the Coweeta Hydrologic Laboratory in the Nantahala Mountains of North Carolina. Even the report of Rothwell (1971), which provides one of the few statements of impact in Canada, deals with the rugged terrain in the foothills of the Rocky Mountains in Alberta. Consequently, it is virtually impossible to use the results of the foregoing to predict the impacts in northern Ontario. Nevertheless, this research does reveal that, where a forest area has been harvested, road construction contributes a large percentage of whatever erosion and sedimentation do occur in disturbed natural environments.

Experimental Approach

In line with the decision to determine whether a serious erosion problem existed as a result of forest road construction, our initial efforts were concentrated on the more severe road environments. It was felt that if significant environmental deterioration was encountered in these instances, there would be justification for extending the survey to less severe situations.

Perhaps the first question requiring an answer was: "What kind of road should be studied?" The Northern Ontario Transportation Committee reported (Anon. 1970) that there were 12,375 miles (19,925 km) of non-status gravel roads in the north, 450 (725 km) of which had been incorporated in the provincial highway system. Of the total network, 11,100 miles (17,870 km) were developed since 1955, 7,700 (12,395 km) by the forest industry and 3,400 (5,475 km) by the Ontario Ministry of Natural Resources. In another survey[1], the Ontario Forest Industries Association reports that its member companies had built 6,805 miles (10,955 km) by 1971 and were constructing approximately 395 miles (635 km) of additional road each year. Therefore it is probably conservative to suggest that 500 miles (805 km) of this kind of road are being added each year. The figures further indicate that main roads constructed for logging and the implementation of subsequent silvicultural measures should receive major consideration. The very short-lived winter haul roads are not included in these figures.

Since there is considerable variation in construction standard of such roads (Fig. 1) it was necessary to classify them. Attempts to adopt an arbitrary classification based on primary, secondary and tertiary access, for example, failed because of the tremendous variability in construction standard within each class. Thus, roads were selected for study on the basis of such physical dimensions as right-of-way width, road surface width, and depth of fill/cut.

Another consideration in developing an experimental approach was the effect of road maintenance. The erosional consequences of poor road design or location would be masked by a recent resurfacing or grading of the road. It would still be possible to measure off-road erosion and deposition but an incomplete picture would be obtained. Since many forest roads are built for a short period of intensive use and are then abandoned or given minimal maintenance, the road survey was restricted to roads in this later stage of low use and low maintenance. Consequently, there was a large enough interval between the time of survey and the last maintenance operation to ensure that the roads had been subjected to a number of rainstorms and at least one spring runoff.

In keeping with our trouble-shooting approach, it was decided to select three road environments in which impacts were more apt to be significant. Since it was impossible to isolate factors of climate, topography, soil, and severity of manipulation, the selection of areas was based on the speculated net effect of a combination of factors. Each of the selected locations will be described in detail below.

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1 R. B. Loughlan, Manager, Ontario Forest Industries Association, Toronto, personal communication, March 1972.

Figure 1

Relatively long-lived and expensive all-weather road near Minaki.

Relatively short-lived all-weather road abandoned after several years' use near Kenora (ELA).

Seasonal haul road used for one winter, then abandoned near Kenora (ELA).

Finally, consideration was given to methods of measuring erosion and deposition. An accurate measure could be obtained only from an intensive survey. Since this would be both costly and time-consuming, an alternative approach was adopted to obtain a rough estimate of material movement in relation to road centerline and slope position. This will also be discussed in detail in a subsequent section.

Locations

The three locations described below have a basic similarity in that they are part of the Precambrian Shield which Chapman and Thomas (1972) aptly described as "rugged knobs and ridges of Precambrian rocks with their discontinuous drift". They are also similar in that they receive 25 to 35 in. (64 to 89 cm) of mean annual precipitation with approximately 15 in. (38 cm) falling between May and September. In analyzing data from 190 climatological stations across Canada, Bruce (1968) was able to produce a map of 24-hr rainfall intensity for various return periods. Using the pattern of isohyetal lines produced from these stations, he analyzed data from 54 climatological stations equipped with recording rain gauges to produce similar maps for rainfalls of shorter duration. Interpolating between these lines, one finds that the three areas are similar in terms of rainfall intensity and duration (Table 1).

Table 1. Range in rainfall intensities, in inches[a], for the three locations[b].

Event (maximum)	Return period in years			
	2	5	10	25
5-min. rainfall	0.30-0.35	0.45-0.50	0.50-0.60	0.60-0.70
10-min. rainfall	0.50	0.60-0.70	0.80	0.90-1.00
15-min. rainfall	0.04-0.60	0.80	0.90	1.10
30-min. rainfall	0.80	1.00	1.10	1.40
60-min. rainfall	0.80	1.20	1.40	1.50-1.70
24-hr rainfall	2.00	2.50	3.00	3.00-4.00

[a] 1 in. = 2.54 cm

[b] Data from Bruce (1968).

i) Experimental Lakes Area

In April, 1968 the Fisheries Research Board of Canada (FRBC) concluded an agreement with the Ontario Ministry of Natural Resources (OMNR) and the two licensees in the area--Ontario-Minnesota Paper Company and Dryden Paper Company--to restrict activity in 17 drainage basins in an area some 35 miles (56 km) southeast of Kenora, Ontario. FRBC then initiated a research program to investigate the effects of eutrophication on biological production in the 46 lakes included in these drainage basins. When OMNR asked the Great Lakes Forest Research Centre to study the environmental impacts of various forest management practices and FRBC asked the Centre to cooperate with them by studying the terrestrial components of the reserved watersheds in the Experimental Lakes Area (ELA), this area became a logical choice for impact studies.

Although Rowe (1972) has assigned this area to the Quetico Section of the Great Lakes Forest Region, the present forest cover would appear to be more typical of the adjacent English River Section of the Boreal Forest Region. ELA falls within Hills' (1955) Wabigoon Lake Site Region which he characterizes as 20% lacustrine and clay till plains, 50% sand and rock ridges, and 30% bedrock plains. Sand and rock ridges and bedrock plains typify this area, the former landform having gentle to moderate relief and the latter moderate to steep. Their respective magnitudes of relief are 5-100 ft (2-30 m) and 50-300 ft (15-92 m) (Hills 1955). Further detail about the geomorphology at ELA was provided by contract research undertaken by Lockwood Consultants Limited in 1972 (de Vries 1972). The soil is a podzol, discontinuous to shallow in depth over most of the area and coarse in texture. The shallow soil in conjunction with the magnitude of relief made it a prime candidate for impact research.

ii) Dog River Area

The second area is approximately 50 miles (80 km) northwest of Thunder Bay. It falls within the Upper English River Section of the Boreal Forest Region (Rowe 1972). As such it is typified by spruce-fir-aspen-birch (*Picea, Abies, Populus* and *Betula* spp.) stands with jack pine (*Pinus banksiana* Lamb.) on sand plains and shallow-soiled uplands. The license to harvest timber from the study area has been granted to the Great Lakes Paper Company. Consequently, large parts of the study area have been clear cut over the past 10 years. The Nipigon Site District which is a part of the Lake Abitibi—Nipigon Site Region encompasses the Dog River area. It is described by Hills (1955) as 50% bedrock plains with scarps and 50% river valleys and pockets. The former landform has a magnitude of relief of 50-100 ft (15-30 m) and the latter 5-100 ft (2-30 m). The area is similar to ELA in that it has been strongly glaciated, but ELA is largely ground moraine in genesis, whereas the Dog River study area is predominately aeolian deposit over ground moraine and outwash plain. Generally the soils are considerably deeper and the aeolian deposits finer textured than the ELA soils (Zoltai 1961). The fine texture of the soil in combination with the magnitude of the relief led to the investigation of this area.

iii) Wawa Area

Although the third area was not adequately researched, it is unique in Ontario and should be mentioned in this report. It extends along the eastern shore of Lake Superior and south of Wawa, and is a part of the Algoma Ecological Section of the Great Lakes—St. Lawrence Forest Region which is typified by a combination of communities of white pine (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) and communities of tolerant hardwoods, principally sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britt.) (Rowe 1972). Much of the mature forest crop has been selectively logged by a variety of firms manufacturing principally hardwood veneer and sawlog products. Hills (1955) has identified the general area as the Michipicoten Site District of the Lake Temiskaming—Quetico Site Region. The landform is described as "bedrock upland with narrow valleys" with a relief of 10-300 ft (3-92 m). Although the valleys are often filled with deep, sandy, glacio-fluvial deposits, the uplands are often shallow, sandy, dump tills. The drastic changes in elevation made this area one of special interest.

Methods of Measurement

In each of these three areas, a stretch of road which was relatively uniform in construction standard, age, and maintenance history was selected for study. The location of all the severe problem segments was first determined. Although the definition of "problem segment" was not based on a rigid set of criteria, the overriding consideration was whether the road would be rendered impassable and whether the effects might eventually extend beyond the boundary of the road right-of-way. The basis for delimiting the length of the problem segments was the size of the catchment which contributed either surface runoff or throughflow to the segment of road in which the erosion occurred. The upper end was the point at which the roadway entered this catchment, and the lower end was the lowest point the road reached in that catchment. This occurred either at or beyond the terminus of the deposition. In some instances it occurred at a stream crossing. The boundary of the catchment itself was determined from aerial photographs. For ELA, formline maps provided as a part of the geomorphic analysis (de Vries 1972) were also used.

Along each problem segment, azimuths, slope percentages and distances were measured. This enabled plotting of the segments on the formline maps for ELA and determination of horizontal distance, net direction, and average slope for each segment. At 2-chain (40-m) intervals along the segment the right-of-way width was determined. At half-chain (10-m) intervals the following road characteristics and erosional features were measured in terms of an offset distance to the left or right of the road centerline:

i) edge of travelled surface

ii) inside and outside edge of fillslope, cutslope, and backslope wherever they occurred

iii) depth of fillslope or cutslope

iv) inside and outside edge of the intersected erosional or depositional feature

v) average depth of erosional features

There were two basic reasons for making these measurements. The first was merely to obtain some objective measures of the class of road being investigated. The second was to develop a crude measure of the movement of material downslope and away from the centerline. Typical examples of the kinds of measurements made are provided for an upper, middle, and lower slope position in Figure 2. Figure 3 demonstrates the complex nature of some of the erosional features encountered.

Many of the engineering and erosional features do not have well-defined boundaries. For example, the edge of the right-of-way is generally characterized by sighting along the edge of the undisturbed forest, yet slash, stumps and other debris are often pushed beyond this tree-line into "push-outs". Gravel pits, turnouts, and landing areas located at intervals along the right-of-way are really part of the right-of-way and yet their inclusion in the calculation of a mean width for a short stretch of road biases that mean considerably. If the forest area adjacent to the road has been clear cut it becomes impossible to determine the width accurately. With most forest roads it is impossible to separate gravel surfacing, subgrade, and roadbed. Consequently, the depth of all three were measured as "fillslope". The distinction between cutslope and backslope was based on whether drainage was toward or away from the road. Cutslopes were defined as those scraped surfaces draining toward the road. Backslopes drained away from the road. There was no particular name given to that part of the right-of-way stripped of shrub and tree cover but otherwise undisturbed.

It was neither possible nor necessary to make accurate measurements of the amount of erosion. Accuracy was limited by the need to estimate the original ground surface by projecting the slope of the adjacent undisturbed surface. Litter and leaf-fall often confused the true depth of deposition. The most accurate measurement was undoubtedly the offset distance from the road centerline to the inner and outer edges of the features. The mean depth was estimated by taking several vertical measurements periodically across the intersected feature.

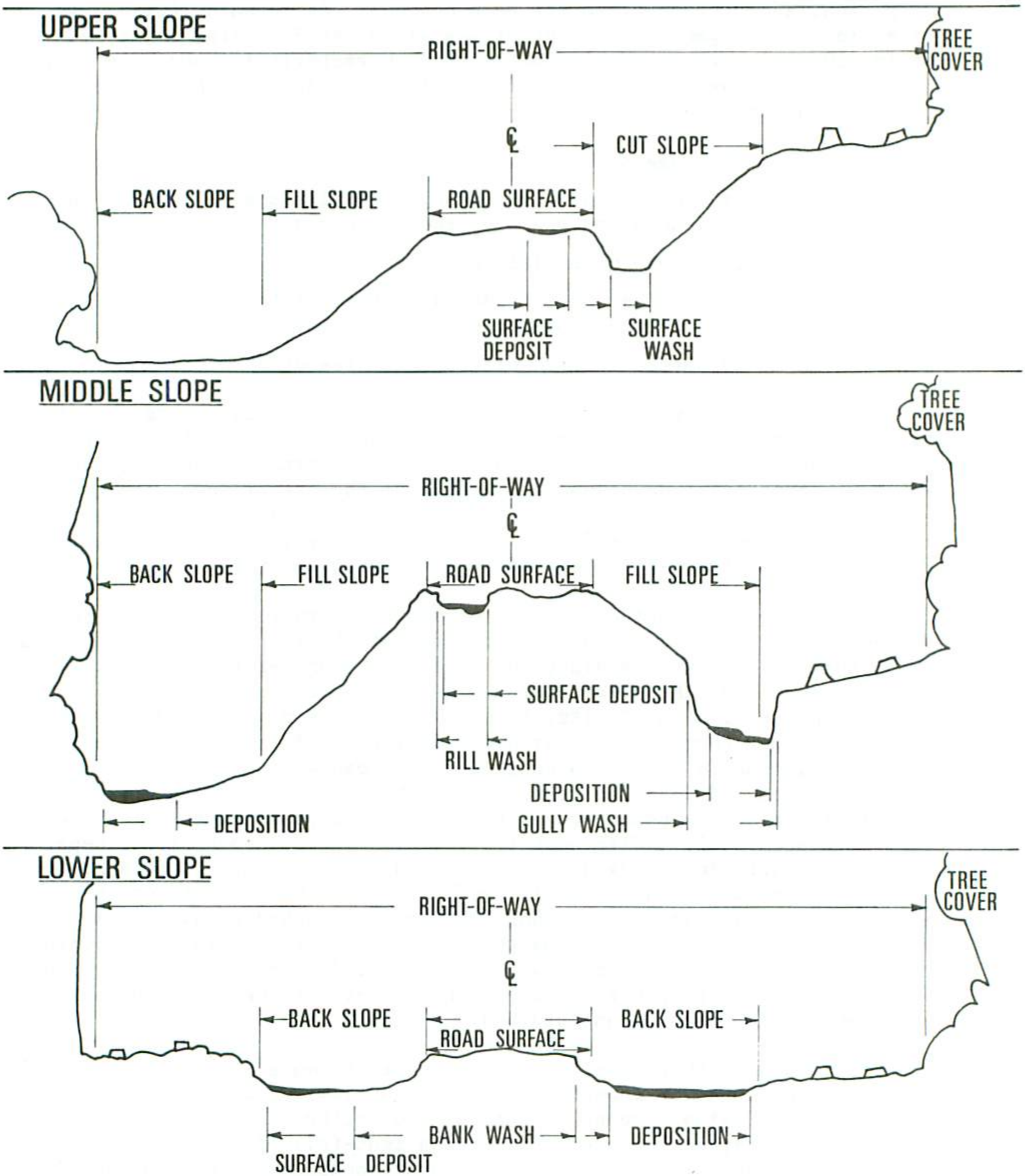

Figure 2. Measurements made for upper, middle and lower slope positions.

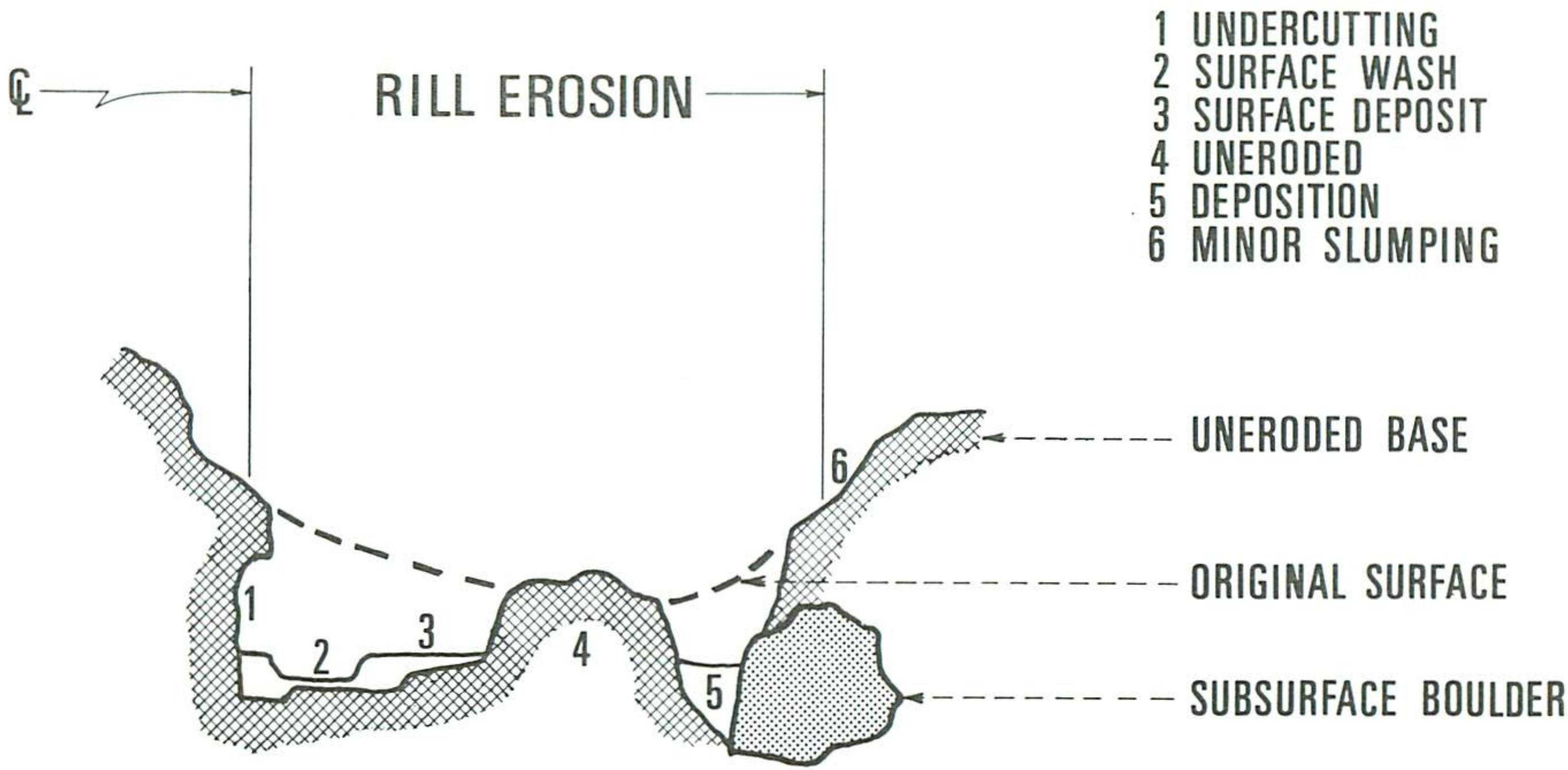

Figure 3. Erosional features encountered during measurement of problem segments.

The erosion-deposition index used to rank the problem segments according to severity of disturbance was a summation of all the cross-sectional areas of both the erosion and deposition features. By summing the cross-sectional areas by feature, distance class along each offset line, and each of the offset lines along the road surface it was possible to see how the disturbance was distributed areally.

To avoid giving a false impression of the precision of erosion determination, the various features were divided into two broad depositional classes and three erosion classes based on the mean depth. They are listed below and illustrated in Figure 4.

Erosion Classes

i) Surface wash	1 to 2 in.	(2.5 - 5.1 cm)
ii) Rill wash	2 to 12 in.	(5.1 - 30.5 cm)
iii) Gully wash	greater than 12 in.	(30.5 cm)

Deposition Classes

i) Surface deposit	1 to 2 in.	(2.5 - 5.1 cm)
ii) Deposition	greater than 2 in.	(5.1 cm)

The accuracy of this technique is probably strongly dependent upon the angle at which the various features intersect the right-angle offsets. Since most of them virtually parallel the direction of the road travelling down wheel ruts or ditch lines, this is a minimal bias. However, where the feature intersected the offset line at an angle, the width measurements were taken perpendicular to the long axis of the feature rather than to the offset line.

RESULTS

Table 2 shows the name and length of the road surveyed and the number of problem segments encountered in the three locations. With the exception of the Dog River Road which was not completely surveyed a problem segment averaging 0.20 miles (0.32 km) in length was encountered every 3.14 miles (5.05 km) along the surveyed length of road. This constitutes 6.4% of the length of road surveyed.

As the study developed, additional variables were measured in the expectation that they might provide a better understanding of what factors were contributing to the erosion. These included the width of the right-of-way and the intercepted lengths of cutslope, fillslope and backslope. Table 3 ranks all the problem segments measured in terms of the total erosion-deposition index for each of the three locations.

Figure 4

Surface erosion and deposition

Rill wash

Bank wash and gully erosion (ditch line)

Table 2. Number and length of problem segments for the roads sampled during the survey.

Location	Survey year	Road		Problem segment	
		Name	Length (miles)[a]	Number	Length (miles)[a]
Experimental Lakes	1972	South Loop	8.95	1	0.31
		Roddy Lake	4.16	4	0.93
Experimental Lakes	1973	Molar Lake	5.43	5	0.95
		South Loop	8.95	1	0.21
Dog River	1973	Sideen Lake	3.00	1	0.22
		Pakashkan	13.50	2	0.28
		Heaven Lake	12.00	2	0.28
		Sharp Lake	6.00	2	0.42
		Dog River	39.00[b]	1[b]	0.15[b]
Wawa		Sand River	0.83	2	0.39
		Total[b]	62.82	20	3.99

a 1 mile = 1.61 km.

b The survey was not completed for the entire length of the Dog River Road; consequently, the figures are excluded from the totals.

It also indicates the mean widths of the right-of-way and road surface, the mean and maximum slope length as well as the total slope length and total intercepted length of cutslope, fillslope, and backslope. Note the considerable variation in the range of variables for the road segments. This amount of variability is probably inherent in forest roads. However, only considerable additional sampling could substantiate this contention. On the assumption that the sample means do represent the real means the three locations are compared in Table 4. The means for all areas combined are also shown.

When these means are subjected to an analysis of variance and Duncan's new multiple range test, the differences among the means are significant for only some of the variables and usually between only two of the three areas (Table 5). With the exception of the erosion-deposition index, slope length, and the intercept for backslope and fillslope, the differences among the means are highly significant. Duncan's test indicates that the problem segments for Dog River and Wawa differ significantly only with respect to the width of right-of-way. The segments at ELA differ significantly from those at Wawa with respect to both mean and maximum slope percent and cutslope and total intercept. The significant differences between ELA and Dog River are in physical dimensions of the road and not measures of erosion.

These tables establish that there is considerable variation among the problem segments in terms of road design and road environment. In the next three tables the quantity and distribution of this erosion will be examined. Table 6 reveals the percentage of erosion and deposition in each of the various depth classes used.

With the apparent exception of ELA, a large part of the erosion is in the surface and rill classes. This indicates that the erosion has a mean cross-sectional depth of less than 4 in. (10 cm). At ELA, where 69% of the erosion is gully erosion with a mean depth in excess of 12 in. (30.5 cm), 87% of the total gully erosion was contributed by one of eight problem segments. Although the table does not indicate it, the deposition rarely exceeded 12 in. (30.5 cm) in depth. The fact that the relation of erosion to deposition is not uniform will be discussed later.

Tables 7 and 8 show the distribution of erosion and deposition in relation to the road and its right-of-way. Statistics indicating the variability of data among the various problem segments are not included in the tables for the sake of brevity.

Table 7 shows the distribution of erosion and deposition as the cumulative percentage of cross-sectional areas of erosion and deposition within 5 ft (1.5 m) classes of offset distance. The two classes within 10 ft (3 m) of the centerline indicate the approximate on-road disturbances. Since the mean erosion and deposition cross-sectional areas for all locations combined are approximately equal (Table 6), it is probably correct to conclude that there is three times as much on-road erosion as deposition (Table 7). Significantly larger percentages of the erosion were within 25 ft (8 m) of the road centerline than the deposition.

Table 8 indicates the distribution of erosion and deposition along the roadway downslope from the point where the road crosses the catchment divide. The distribution percentage is based on cumulative summation of erosion and deposition cross-sectional areas. More than 90% of both types of disturbance have occurred within 10 chains (201 m) of the divide. Since the average length of the road segments is 14.6 chains (294 m), this indicates that very few of the disturbance effects would be felt in streams draining these catchments. There is very little difference between the distribution of erosion and deposition for a particular location owing largely to the averaging process. The abrupt change in distribution over the 8-10 chain (161-201 m) interval for the ELA catchments is caused by the one very badly eroded catchment (Roddy Lake "C-3").

Table 3. Problem segment parameters ranked in decreasing order of erosion-deposition index by location.

Name of road and segment number		Erosion-deposition index	Right-of-way width (ft)[a]	Road surface width (ft)[a]	Slope percent		Length slope (ft)[a]	Intercepted length (ft)[a]			
					Mean	Maximum		Cutslope	Fillslope	Backslope	Total
Experimental Lakes Area											
Roddy Lake	C-3	754.27	--[b]	--	12.0	18.0	712.8	--	--	--	--
South Loop	S-2	187.81	65	24.4	6.9	17.0	1110.8	75.7	119.3	353.1	548.1
Molar Lake	M-1	135.81	57	15.7	7.9	22.5	2518.6[c]	10.1	0.0	0.0	10.1
Molar Lake	M-2	79.03	81	15.3	9.9	19.5	924.0	38.6	0.0	0.0	38.6
Roddy Lake	C-1	66.64	--	19.8	5.0	9.0	1056.0	--	--	--	--
Roddy Lake	C-2	52.39	--	19.2	8.6	12.0	924.0	--	--	--	--
Molar Lake	M-3	40.68	83	14.1	9.1	14.5	838.2	--	--	--	--
Molar Lake	M-5	32.84	59	15.5	5.6	11.5	744.5	0.0	194.3	470.5	664.8
Molar Lake	M-4	22.42	92	16.1	7.5	12.0	653.4	3.8	207.9	713.5	925.2
Dog River Area											
Heaven Lake Road	H-2	128.70	154	25.6	6.3	10.0	765.6	0.0	608.5	1217.5	1826.0
Heaven Lake Road	H-1	115.91	170	22.8	7.1	9.5	660.0	0.0	529.7	1435.6	1965.3
Sharp Lake Road	SH-0	104.19	106	22.1	4.6	10.0	1056.0	0.0	431.6	1109.5	1541.1
Pakashkan Lake Rd	P-2	103.71	98	26.1	3.4	10.0	1456.0	144.6	209.0	724.0	1077.6
Sharp Lake Road	SH-2	98.00	104	23.1	6.9	13.5	627.0	0.0	312.6	616.4	929.0
Sharp Lake Road	SH-1	52.13	129	23.9	5.8	12.0	528.0	0.0	365.5	725.0	1090.5
Pakashkan Lake Rd	P-1	47.29	123	27.0	5.6	8.5	660.0	0.0	216.0	395.6	611.6
Dog River Road	D-1	37.50	106	26.3	3.9	13.5	792.0	115.5	199.0	417.0	731.5
Sideen Lake Road	SID-1	25.45	88	17.9	4.3	8.5	1188.0	387.8	14.5	1133.7	1536.6
Wawa Area											
Sand River Road	SA-3	119.95	75	20.4	2.7	5.0	891.0	406.5	115.5	527.5	1049.5
Sand River Road	SA-2	99.83	73	23.2	3.4	6.0	1188.0	330.1	263.9	701.0	1295.0
Sand River Road	SA-1	84.22	60	18.9	5.9	12.0	792.0	133.0	117.5	667.7	918.2

[a] 1 ft = 0.30 m

[b] Whereas a dash indicates that no measurements were taken, a zero indicates that the measurement was negligible.

[c] Anomalous problem segment in that there are three branches contributing to the total length at the upslope end.

Table 4. Road character and severity of erosion for each area and for all areas combined

Location	Erosion-deposition index	Right-of-way width (ft)[a]	Road surface width (ft)[a]	Slope percent		Length slope (ft)[a]	Intercepted length (ft)[a]			
				Mean	Maximum		Cutslope	Fillslope	Backslope	Total
<u>Experimental Lakes Area</u>										
Mean	152.4	72.8	17.5	8.1	15.1	1053.6	25.6	104.3	307.4	437.3
Mean deviation	141.6	12.5	2.7	1.6	3.7	338.8	25.2	83.4	245.9	330.4
Range	731.8	35.0	10.3	7.0	13.5	653.4	75.7	207.9	713.5	915.1
<u>Dog River Area</u>										
Mean	79.2	119.8	23.9	5.3	10.6	859.2	72.0	320.7	863.8	1256.5
Mean deviation	34.3	21.5	2.1	1.1	1.6	249.4	96.0	145.0	320.2	409.4
Range	103.2	82.0	9.1	3.7	5.0	928.0	387.8	594.0	1040.0	1353.7
<u>Wawa Area</u>										
Mean	101.3	69.3	20.8	4.0	7.7	957.0	289.9	165.6	632.1	1087.6
Mean deviation	12.4	6.2	1.6	1.3	2.9	154.0	104.6	65.5	69.7	138.3
Range	35.7	15.0	4.3	3.2	7.0	396.0	273.5	148.4	173.5	376.8
<u>Areas combined</u>										
Mean	113.8	95.7	20.9	6.3	12.1	956.5	96.8	229.7	659.3	985.8
Mean deviation	72.4	24.9	3.6	1.8	3.2	274.1	110.2	133.4	293.4	411.2
Range	731.8	113.0	12.9	9.3	17.5	1990.6	406.5	608.5	1435.6	1955.2

[a] 1 ft = 0.30 m.

Table 5. Significance of differences in variable means for the three locations as determined by an analysis of variance and Duncan's new multiple range test

Parameter	Analysis of variance F-ratio	Duncan's new multiple range test		
		ELA	Dog River	Wawa
Erosion index	0.5	——	——	—— [a]
Right-of-way width	11.0*	——		——
Road surface width	9.4**	——	——	—— / ——
Mean slope percent	8.2**		——	——
Maximum slope percent	6.7*		——	——
Slope length	0.4	——	——	——
Cutslope intercept	5.0*	——	—— / ——	——
Fillslope intercept	1.7	——	——	——
Backslope intercept	1.7	——	——	——
Total intercept	6.0**	——	—— / ——	—— / ——

* significant at 5%

** significant at 1%

[a] There is no significant difference between areas through which the same line extends.

Table 6. Severity of erosion by class for each location, and all locations combined

	Erosion classes				Deposition classes			
Location	Surface	Rill	Gully	Total	Surface	Deposition	Total	Grand total
Experimental Lakes Area								
Index mean	6.7	22.6	65.6	95.0	4.5	55.0	59.5	154.5
average deviation	6.3	11.6	104.0	99.7	4.8	60.3	59.9	158.2
range	19.8	48.2	481.8	485.1	17.6	258.5	250.8	731.6
Percent	4.3	14.6	42.5	61.5	2.9	35.6	38.5	100.0
Dog River Area								
Index mean	4.3	19.6	1.3	25.2	2.7	51.2	53.9	79.1
average deviation	3.1	7.5	2.0	10.1	1.4	24.6	24.1	34.3
range	14.3	29.8	6.3	34.8	4.8	84.5	80.5	103.2
Percent	5.4	24.8	1.7	31.9	3.4	64.7	68.1	100.0
Wawa Area								
Index mean	5.0	31.8	16.3	53.2	6.3	41.9	48.2	101.3
average deviation	1.6	13.4	7.2	17.5	2.0	24.1	26.0	12.4
range	4.6	30.5	17.7	46.6	5.2	62.7	66.7	35.7
Percent	5.0	31.4	16.1	52.5	6.2	41.3	47.5	100.0
All areas combined								
Index mean	5.35	22.7	29.3	57.31	4.0	51.3	55.3	112.6
average deviation	4.18	9.4	45.7	49.25	3.0	38.7	38.2	74.3
range	19.84	49.3	481.9	488.23	17.6	488.2	252.3	731.6
Percent	4.75	20.1	26.0	50.90	3.5	45.6	49.1	100.0

Table 7. Cumulative percent distribution of erosion and deposition in terms of distance offset from road centerline

	Offset distance (ft)[a]				
	0-5	5-10	10-15	15-20	20-25
Erosion					
Experimental Lakes Area	10.6	19.3	29.6	36.0	40.4
Dog River Area	5.4	21.3	45.5	64.7	69.2
Wawa	16.3	40.5	68.6	83.8	90.6
Areas combined	10.4	22.6	38.2	48.3	53.1
Deposition					
Experimental Lakes Area	6.2	12.4	19.8	26.6	30.5
Dog River	0.4	1.6	4.0	11.8	26.0
Wawa	8.7	16.5	24.2	32.8	43.1
Areas combined	4.0	8.1	13.4	20.9	30.2

[a] 1 ft = 0.30 m.

Table 8. Cumulative percent distribution of erosion and deposition in terms of distance downslope from the catchment divide

	Distance classes (chains)[a]									Mean slope length
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	
Erosion										
Experimental Lakes Area	0.8	4.6	9.2	22.4	93.9	99.6	100.0			16.0
Dog River Area	5.0	28.6	65.6	91.5	99.2	99.8	100.0			13.0
Wawa Area	21.3	29.8	59.9	79.4	92.1	95.8	98.6	99.4	100.0	14.5
Areas combined	4.5	12.8	27.2	43.8	94.7	99.0	99.8	99.9	100.0	14.6
Deposition										
Experimental Lakes Area	3.4	7.2	13.3	22.7	92.3	93.6	93.6	93.6	100.0	16.0
Dog River Area	2.6	28.1	61.9	89.7	94.8	94.8	94.8	94.8	100.0	13.0
Wawa Area	1.2	3.4	81.4	89.2	91.6	92.0	93.5	94.7	100.0	14.5
Areas combined	2.8	15.9	43.1	60.4	93.3	93.9	94.1	94.3	100.0	14.6

[a] 1 chain = 20.1 m.

DISCUSSION

There are two aspects to any evaluation of the impact of human activity on the environment: how the environment has been changed by man in terms of its intrinsic character, and how the usefulness of that environment has been altered. The construction of forest roads of the caliber considered in this study does effect a drastic change in the intrinsic nature of forest environment. This change is, in effect, irreversible owing to the prohibitively high cost of recreating a forest environment in the right-of-way. Consequently, the decision to build a road along a particular route should not be made lightly. With respect to utility value the road allowance is being converted from tree growth to transportation. If it is a desirable and necessary change in land use, it is an acceptable impact. This discussion and the ensuing conclusion are based on the premise that the rightness or wrongness of changing the utility value of the resources contained within the road right-of-way and indeed the surrounding area is a separate issue.

The frequency, intensity, and duration of precipitation have the greatest effect on degree of erosion. Table 1 shows the variation in these precipitation characteristics for the three general areas studied. Relatively heavy rainfall can occur in any one of these areas. The more severe the storms, the less frequently they occur. The desired life of forest roads built for the express purpose of extracting wood products is determined by the volume of wood in the area accessed by the road and by the level of logging activity. In most instances this life expectancy is less then 5 years; consequently, the road planner is not concerned with the more severe, less frequent storms. Should a storm render a road currently in use impassable, the damaged sections are rebuilt. Of course, once the road is abandoned these stretches of road eventually become impassable. Our concern is with the prevalence and environmental consequences of this deterioration.

Tables 2-8 give the severity and distribution of erosion for each of the roads surveyed, and show that there is as much variability among problem segments as among locations. This is an unavoidable consequence of the large number of uncontrollable factors contributing to road erosion. Only through a much more extensive survey or intensive study of the problem can this variability be explained. Only three segments were measured on one road in the Wawa area, and this is grossly inadequate. In the Wawa area the terrain is far more rugged than in the ELA and Dog River areas and consequently roads are often built along the base of slopes or ridge tops. This means that many of the erosion features tend to be perpendicular to the road direction and, as a result, this measurement technique is inappropriate.

The road right-of-way at Dog River is considerably larger than that at either of the other locations. Consistent with this is the greater intersected length of cutslope, fillslope, and backslope. These roads were of a higher standard of construction than those at Wawa and ELA.

The fine-textured loess of the topsoil at Dog River was also scraped to the side of the right-of-way so that the coarser-textured morainic material underneath could be used for the roadbed. This practice tended to require a wider right-of-way and resulted in a relatively large measure of fillslope and backslope. The proportionately larger cutslope measurement at Wawa was the result of building roads at the base of steeply sloped hills. At ELA there was very little evidence of the three measures of off-road surface disturbance, owing to the shallow soil and the lower standard of road. In this instance roads hug the contours of the land more closely and a larger percentage of the roadbed material has to be hauled to the road site from gravel pits.

Table 3 shows that nearly all the problem segments have stretches of maximum slope exceeding 10%. Unfortunately, it was impossible to conduct a slope traverse along the entire length of sampled roads to see whether 10% road slopes result inevitably in the deterioration of roads to the point at which they are eventually impassable. However, on the basis of observations this appears to be a valid conclusion.

Maintenance of forest roads during the period over which they are used for wood extraction masks on-road erosion. As quickly as the erosion appears, roads are repaired so that wood can be moved over them. This may lead a casual observer to conclude that there is no problem. However, unless roads are regularly maintained, eroded material may still leave the travelled surface or even the right-of-way. This study was conducted on low-use or abandoned roads which had not been maintained recently, but the problem areas were restricted to 6% of the length of road sampled and generally occurred only where the maximum slope exceeded 10%.

In tables 6, 7 and 8 the severity of erosion and its lateral and longitudinal distribution are examined. Most of the erosion encountered was from 4 to 12 in. (10-30 cm) in average depth. Since the majority of these roads had been abandoned for several years the extent of their deterioration has probably stabilized. Only the less frequent and more severe storms would cause severe damage. The peak periods of runoff result in the maximum downcutting in the erosional features and in the maximum extension of the deposition. During periods of lesser flow these erosion features partially fill with deposition from sediment loads that cannot be transported to the furthest deposition fans and pondings.

A large part of the erosion is confined to the road right-of-way (Table 7). The maximum offset distance of deposition from the road centerline is 92 ft (28 m). This is 55 ft (17 m) beyond the average width of right-of-way. There is considerable variation among the locations in terms of how the erosion and deposition are distributed within the confines of the right-of-way. On-road erosion which includes all the disturbance in the first 10 ft (3 m) varies from 19 to 40% of the total. Erosion within 25 ft (8 m) of the centerline varies from 40% to 91%. This indicates that there is even considerable disturbance beyond the ditch line. Smaller percentages of the deposition occur on the travelled surface. Variation here is between 2 and 17%.

Most of the disturbance appears off the road because roadbed and surface material tend to be coarser and more compacted, and consequently less erodible than the surfaces of cut-, fill-, and backslopes. The road surface is also periodically repaired, whereas the remainder of the right-of-way remains largely untouched from the time of original construction. This part of the right-of-way does have a singular advantage in that it can and does revegetate quickly, preventing erosion on much of this portion of the right-of-way. Only ditches, and steep cutslopes, fillslopes and backslopes remain sources of erosion.

Much of the deposition was confined to the right-of-way. This is due not only to the character of the terrain and climate in northern Ontario, but also to road construction practices. Though not a planned impediment to deposition, the slash, stumps and debris piled along the edge of road right-of-ways, and periodically on the right-of-ways themselves (Fig. 5), impede the flow of runoff, thereby reducing its ability to transport material. The bulldozing of material from the sides of the right-of-way creates small depressions which act as sediment pools (Fig. 6), often preventing the flow of runoff to the base of the slope where the road might intersect a small stream or river.

Table 8 shows that very little of the eroded material reaches the lowest point in the catchment. Although the mean segment lengths vary from 13 to 16 chains (262-322 m), over 90% of the sediment has been deposited within 10 chains (201 m) of the catchment divide. Only one of the segments ended at a permanent stream where sedimentation of the stream bed was evident. Unmeasured instances of sedimentation were found where roads were built too close to lakes and where road approaches to streams were too steep.

To what extent have road erosion problems resulted from ignorance of the possible environmental consequences and to what extent have they resulted from unsatisfactory resource management? Was the road built too close to the lake because it was believed that environmental problems would not develop? Was it poor supervision by a roads superintendent, or was it the cheapest alternative? Were upslope alternative routes physically impossible because of steep terrain or bedrock outcropping, or was a rerouting feasible? Both research and management are involved. Where unavoidable problems arise, research must be conducted to find ways of building roads economically to prevent deterioration of the environment. Where problems <u>are</u> avoidable, management must be certain they are detected before the bulldozer becomes involved.

The survey documented in this report provided some insight into which road characteristics or environmental factors contributed most to the erosion problem. In Table 9 the erosion-deposition index is correlated with road characteristics. As none of the variables are highly correlated

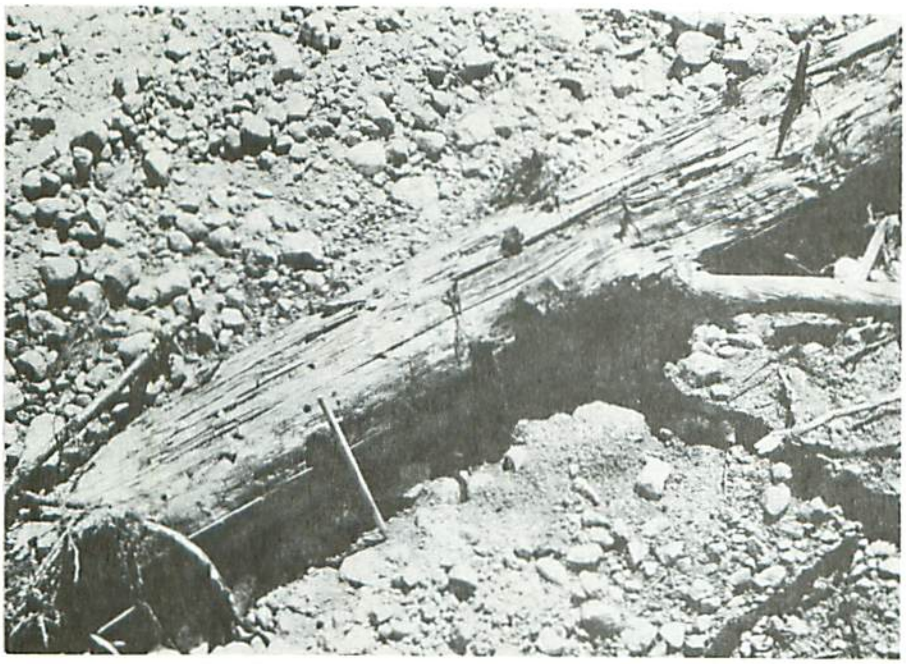

Figure 5. Deposition accumulation caused by slash left on right-of-way.

Figure 6. Small depression acts as a sediment pool.

Table 9. Correlation matrix of the road characteristics measured on each of the problem road segments

	Right-of-way width	Surface width	Mean slope	Maximum slope	Slope length	Cutslope intercept	Fillslope intercept	Backslope intercept	Total intercept	Erosion-deposition index
Rigth-of-way width	1.00	0.56	0.05	-0.31	-0.46	-0.36	0.81	0.65	0.64	-0.04
Surface width	0.56	1.00	-0.44	-0.38	-0.27	-0.42	0.54	0.30	0.38	0.24
Mean slope	0.45	-0.44	1.00	0.75	0.25	-0.66	-0.09	-0.30	-0.42	0.11
Maximum slope	-0.31	-0.38	0.75	1.00	0.46	-0.51	-0.40	-0.63	-0.72	0.23
Slope length	-0.46	-0.27	0.25	0.46	1.00	0.16	-0.46	-0.36	-0.37	0.39
Cutslope intercept	-0.36	-0.42	-0.66	-0.51	0.16	1.00	-0.40	0.08	0.19	-0.02
Fillslope intercept	0.81	0.54	-0.85	-0.40	-0.46	-0.40	1.00	0.73	0.74	0.15
Backslope intercept	0.65	0.30	-0.30	-0.63	-0.36	0.08	0.73	1.00	0.98	-0.03
Total intercept	0.64	0.38	-0.42	-0.72	-0.37	0.19	0.74	0.98	1.00	0.02
Erosion-deposition index	-0.38	0.24	0.11	0.23	0.39	0.19	0.15	-0.03	0.02	1.00

NOTE: The minus signs indicate an inverse relationship.

with this index, other, unmeasured factors must have contributed to erosion. However, a more extensive study would be necessary to identify and quantify these factors. Precipitation, history, revegetation, maintenance practices, and/or age of the road are probably major sources of variability in the results. In conducting a thorough survey of the forest road situation, one must isolate these factors either by stratifying the survey population so that each stratum is uniform with respect to the factors, or by treating the factors as variables to be evaluated.

In my view the impact of forest roads merits further evaluation. We have the expertise to predict the location of problem segments of road; what is needed now is an examination of current road construction practices to determine whether problems can be avoided. If they cannot, research should be undertaken to develop construction techniques to minimize deterioration of the environment and to ascertain the extra cost involved.

CONCLUSION AND RECOMMENDATIONS

It should be emphasized that this was a preliminary study to determine whether there was an environmental problem sufficiently serious to merit an intensive research program. It was recognized as a result of the literature review and our knowledge of the variability in road standards and in northern Ontario topography that a comprehensive impact statement would be a very expensive undertaking. It could be warranted only if a preliminary study indicated that a serious problem existed.

Our research shows that most erosion and deposition are restricted to the right-of-way, several hundred feet before the downslope terminus of problematic stretches of road. Eroded material found beyond the right-of-way and at the downslope terminus was the result of high runoff. This undoubtedly occurs during the spring breakup and during major storms, neither of which can be controlled by man.

In one sense the solution is obvious: we must learn to recognize problems before construction is begun. Thereafter, there are two alternatives: either we do not build the road in problem areas or, where road construction in such areas cannot be avoided, we must use special construction techniques to minimize erosion.

Perhaps it is timely to assert that erosion is an inevitable natural process, and as such is referred to as "geologic erosion". However, man's manipulation of the environment can increase the rate of erosion, which is then referred to as "accelerated erosion". The reasonable objective of forest managers must be to minimize erosion since it cannot be prevented entirely. Furthermore, the exposure of mineral soil, which is an inevitable part of road construction, accelerates erosion. The benefits of improved access must be weighed against the drawbacks of environmental deterioration.

Under current road construction and maintenance practices, 6% of the length of road surveyed showed appreciable erosion. On the average there was one problem segment every 3 miles (5 km). In nearly every instance these problem segments attained a maximum slope in excess of 10%. Given the amount of relief in northern Ontario it appears unlikely that significant reductions can be made in the incidence of problems by relocating roads.

The solution therefore becomes one of improving road construction practices. This involves spending more money on the problem portions of the road. Since most forest roads are initially single-purpose roads planned, built, and largely funded by the forest industry, the responsibility lies largely with them. Where a road will satisfy the needs of a number of users a sharing of the costs would permit the design, construction and maintenance of a better road, namely one which minimized environmental deterioration and considered the particular needs of each user.

The development and evaluation of techniques to reduce erosion could be a very useful research study. The present study suggested several possibilities worth examining. Small depressions in the off-road portion of the right-of-way could act as sediment pools. Berms of slash across the untravelled part of the right-of-way temporarily dam runoff, causing the deposition of transported material. Undulating the road surface on long slopes diverts runoff from the road. Material which is otherwise buried in pushouts, or burned, could be chipped and applied as a mulch on steep-sloped cutslopes, fillslopes, and backslopes. Techniques such as these may not dramatically increase road costs, yet may reduce erosion.

The final decision as to whether or not the impact of forest roads is unacceptable does not rest with the research manager or the resource manager but with all who collectively own the environment and wish to benefit from its use. The function of this report has been to point out what is happening and, to a lesser extent, why it is happening. Others must judge.

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