FOREST RESEARCH REPORT

NOVA SCOTIA DEPARTMENT OF LANDS AND FORESTS
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DRAINING FOREST LAND: A LITERATURE REVIEW

INTRODUCTION

Drainage of wetlands has long been recognized in many parts of the world as a relatively economical means of increasing forest productivity. For example, in Scandanavia, drainage has been a major forest improvement activity for over 60 years (Hirvonen 1984). Finland alone has increased the growth of their forests by 7 to 8 million m^3 per year by draining 5.5 million hectares (an area equivalent to Nova Scotia). Other countries where significant forest areas are drained include Sweden (30,000 hectares/year), Great Britain and Russia.

In Nova Scotia, there has been no large scale operational drainage of forest lands, yet approximately 25% of its soils are classified as imperfectly or poorly drained and a further 2.5% as peatlands (Soil Survey, Can. Dept. of Agric.). This report attempts, through a literature review, to identify the potential benefits of undertaking an intensive drainage program in Nova Scotia. To provide a more complete picture of what this program might involve, the report includes sections on drainage techniques, methods and equipment, experience in other countries and environmental impacts.

DRAINAGE METHODS

Drainage operations are designed to remove excess water from the site in two ways. On impeded soils (iron pan and indurated soils), cemented or compacted layers are broken up to allow more rapid movement of excess water down through and out of the soil profile. On impervious soils (non-indurated gley and deep peats) where downward movement of water is not possible, ditches ensure movement of water from the site and the upper layers of the soil.

Most drainage plans are based on utilizing the 'cross drainage principle'. This principle, as described by Rosen (1985a), involves three types of ditches.

1. *Side ditches,* oriented crossways to the main gradient, stop the lateral movement of water through the soil. This represents the most common type of ditch in the plan. The drop in the side ditches must be 2-3 m/km to allow water which has entered the ditch to properly flow. Also referred to as drainage, contour, feeder, or lateral ditches.
2. *Collector ditches* (main ditches) collect and remove the water from the side ditches to the existing stream or

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outlet channels, usually located where the greatest natural gradient exists.
3. *Surround ditches* collect and remove water that tries to invade the site by draining this water directly into a collector ditch and are normally dug so that their bottom is in mineral soil to facilitate good drainage. Also referred to as boundary or perimeter ditches.

In addition to ditches, *sedimentation ponds* are constructed to slow water flows, thereby facilitating sedimentation. Experience shows that a rush of sediment occurs after the initial digging of the ditches and during the first spring. After these two events, sedimentation is very limited (Rosen 1985b).

DITCH SPECIFICATIONS

On peatlands in Finland, early work established ditches 80-120 m apart, however, this was found to be too wide. Päivänen and Wells (1978) reported that studies on Newfoundland peatlands have shown that ditch depth affects the depth of soil drainage, but not as effectively as ditch spacing. Standard practice now is to space contour ditches 40 m apart with 200-300 m of ditch per hectare (Hirvonen 1984). The goal is to lower the water table to approximately 50 cm below the surface. Smissaert (1984) concludes that the spacing of ditches used for drainage of organic soils appears to be closer than what is required to achieve the same effects on mineral soils. Boelter (1965) reports that permeability is usually much lower in peat soils than, for instance, in soils derived from glacial till.

Open ditches are the most common type used in both peat and mineral soils. They are characterized by a bottom width of 24 cm, a ditch wall slope of 1.00:1.07 and a depth varying from 60-90 cm. Finnish studies indicate that main ditch depths of 120 cm and 90 cm for contour ditches will usually provide adequate water removal. At Goose River, Alberta where shallow peat overlies clay, Hillman (1987b) reported that lateral ditches could have been shallower, since most of the water released by ditching issued from the interface between the organic material and the mineral soils.

Ditch maintenance is required if long term drainage of the site is desired. Mikola (1967) stated that ditches require cleaning and repairing regularly, perhaps once in 20 years. Päivänen and Wells (1978) prepared a summary (Table 1) of ditch depth and spacing for different sites in Finland.

Table 1. Ditch depth and spacing recommendations in Finland (Päivänen and Wells 1978).

Sites	Spacing (m)	Density (m/ha)	Depth (m)	Size (m^3/m)
Tree-covered peatlands				
Shallow peat soils (and wet mineral soils)	50	200	0.65	0.55
Deep peat soils of good quality	40	250	0.75	0.70
Deep peat soils of poor quality	30	333	0.75	0.70
Open peatlands				
Fens[1]	30	333	0.80	0.75
Bog[2]	25	400	0.80	0.75

[1]fen: a peatland with the water table usually at or just above the surface. The waters are mainly nutrient-rich and minerotrophic from mineral soils.
[2]bog: a peatland, generally with the water table at or near the surface. The bog surface, which may be raised or level with the surrounding terrain, is virtually unaffected by the nutrient-rich groundwaters from the surrounding mineral soils and is thus generally acid and low in nutrients.
From National Wetlands Working Committee (1987)

DRAINAGE BENEFITS

Poor forest growth on wet sites is attributed to poor aeration, lack of oxygen, low temperatures and low levels of available nutrients in their soils (Mikola 1967). Further, these poor growing conditions result in significantly lower root and shoot development (Leiffers and Rockwell 1986) and microbial activity (Haavisto and Wearn 1987). But by draining these sites, the moisture content of the soil can be reduced. In fact, Smissaert (1984) reported that the water table was lowered by 5-15cm by draining a New Brunswick site. As well, numerous studies from various countries have shown increased growth as a result of draining.

According to Payandeh (1982), large scale application of drainage and fertilization has proven both practical and economical under the socio-economic conditions of Finland and Russia. In Finland, drainage is only undertaken on sites where an increase of 2 m^3/ha/yr can be expected (Mikola 1967). These sites are fairly fertile and can support good forest growth once the water table is lowered. However, some of these areas will require subsequent fertilization (Hirvonen 1984). Kusnierczyk (1987) reported increases in tree growth of 1.0 to 6.0 m^3/ha/yr respectively for northern and southern Finland. Smissaert (1984) in reviewing Finnish and Russian studies reported timber production increases of 4-8 m^3/ha/yr. In Sweden, Andreáson (1978) reported that forest production on peatlands can be increased to that of the surrounding mineral soil, providing proper ditching and fertilization is carried out.

Hillman (1987a) performed a comprehensive review of some of the major forest drainage experiments undertaken in Canada. In this review he concentrated on how drainage affects tree growth, seedling survival and site fertility. As a result of this study he concluded that tree growth can be increased five fold through draining.

Stanek (1977) compared differences in the growth of dominant and codominant trees from undrained and drained sites in Ontario. The comparisons, based on tree height at the age of 100 years, indicate that growth improves by about 6 m in bog types and by about 4 m in fen-marsh types.

On the water-logged, deep sands of the south-eastern coastal plain of the United States, Klawitter and Young (1965) reported a doubling of the rate of plantation growth following drainage. In Minnesota, Heikurainen (1964) summarized forest growth before and after drainage and found that volume growth of black spruce on good growing sites increased from 1.7 m^3/ha/yr to 4.6 m^3/ha/yr after drainage.

Nadeau and Parent (1982) created a drainage model based on data from the literature and a technical mission to Finland. The results of these model simulations showed that for coniferous stands in Quebec, drainage would increase increment between 2-5 times. They calculated the costs of drainage using a modified tractor digger at $237.86/ha without ditch maintenance and at $325.29/ha with ditch maintenance.

Trottier (1986) concludes that few silvicultural treatments can compete with drainage given costs of $300-$400 per ha, a treatment duration of 20 years, and an increase in productivity of 3-7 m^3/ha/year.

Misiak (1982) reported that a drainage program on a poorly drained 12,550 ha tract of forested land in Michigan increased trafficability from only the frozen winter months to 9-10 months of the year. As well, drainage increased diameter growth from 8-10 rings/cm to 2-3 rings/cm. Adequate regeneration was an additional benefit noted on many of the drained areas.

DRAINAGE EXPERIENCE IN CANADA

The following summaries briefly describe forest drainage projects across Canada. The reader is encouraged to reference Hillman (1987a) for a more complete review of these and other Canadian forest drainage projects.

NEWFOUNDLAND

Päivänen and Wells (1978) reported on early drainage trials in Newfoundland, however, they could not determine the potential for forestry from the limited amount of data available. Richardson (1981) reported that after draining a fen, annual height increment for natural black spruce and tamarack was significantly increased, especially in fertilized plots (Figures 1 and 2). He concluded that productive forest growth can at least be initiated through drainage on these [fens] sites.

NEW BRUNSWICK

In early investigations, explosives were used to drain treed peatlands (Wetmore 1972). On 6 hectares, 762 m of ditches were dug using 2 sticks per hole, 45cm apart at a depth of 60cm. The resulting drain was 30cm wide and 90-120cm deep.

Recent work by J.D. Irving Woodlands Ltd. has attempted to improve the drainage of imperfectly drained mineral soils by draining catchment areas such as swales and hollows. Machinery used included tracked excavators and backhoes. Drainage of these areas assists in the harvesting of stands and the subsequent establishment of natural regeneration.

King (1985) surveyed eastern Canadian companies within the forest industry and reported that forest drainage operations are still not applied to any

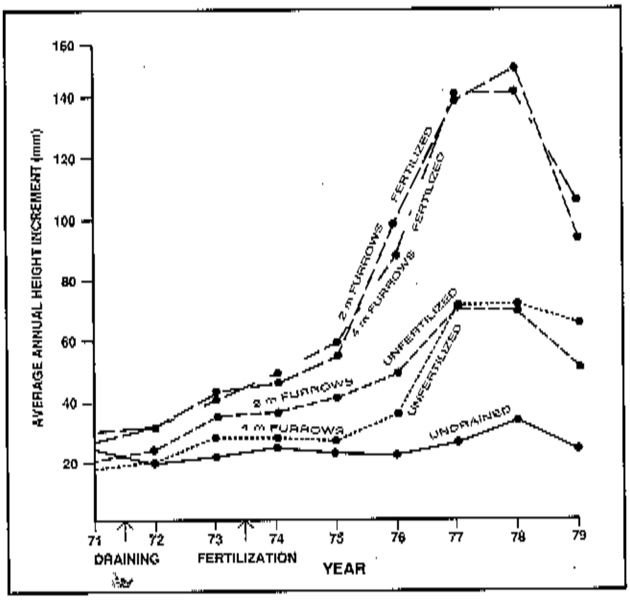

Figure 1. Average annual height increment for black spruce from Richardson (1981).

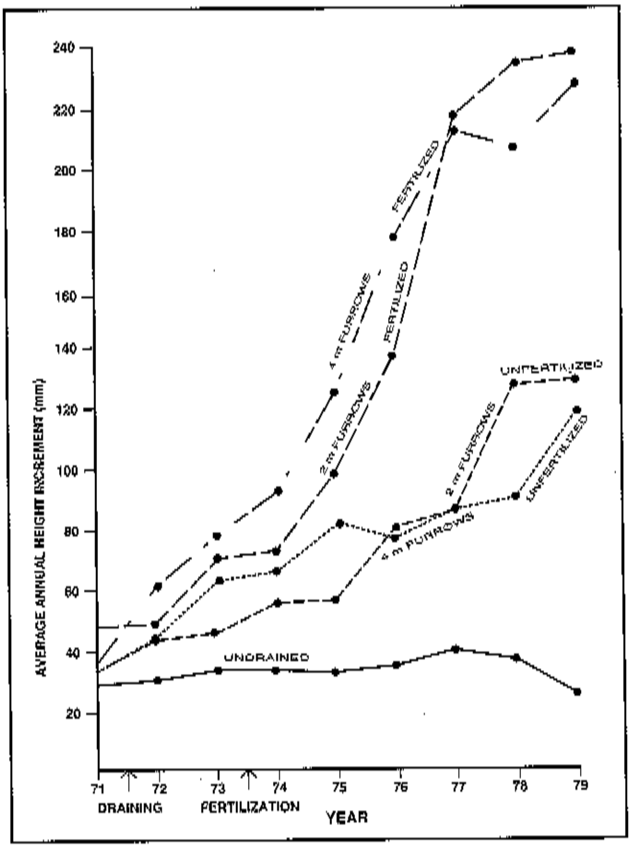

Figure 2. Average annual height increment for tamarack from Richardson (1981).

great extent. The most common reasons given for lack of drainage being performed were lack of funds and uncertainty of benefits.

QUÉBEC

Between 1982-86 over 5200 ha of forest land was drained in Québec, mostly to improve planting chance and repair sites damaged due to poor harvesting techniques (Table 2). The bulk of the drainage was done on private woodlots with financial assistance from a Canada-Québec forestry agreement. Drainage specifications in Québec were summarized by Trottier (1986) and are presented in Table 3.

ONTARIO

Drainage work in this province has centered on the improvement of poorly drained, semi-treed and clearcut peatlands. Haavisto and Wearn (1987) suggest that the best candidates for drainage in Ontario are (1) the extensive areas of the "two-storied mid-rotation" stands that have developed following previous cuttings and (2) stands in which an abundance of well established advance growth is present. A typical drainage operation (Table 4) involves the creation of approximately 280 m/ha of ditch using a Lännen excavator at a cost of $0.65/m (pers. comm. F. Haavisto, 1987). Line clearing and increased planning expenditures for two-storied stands increases total drainage costs to $290/ha. This cost would of course be lower for clearcuts and young stands.

Table 2. Forest drainage activities in Québec, 1980-1986, in hectares. (pers. comm. F.Trottier, Québec Min. de l'énergie et des ressources, Nov. 1987).

Tenure	1980-82	1983	1984	1985	1986	Total
Private woodlots	48	125	729	1,492	1,903	4,297
Crown lands	24	35	86	156	420	721
Company holdings	-	-	-	126	80	206
Total	72	160	815	1,774	2,403	5,224

Table 3. Drainage specifications in Québec (Trottier 1986).

Cover Type	Soil Type	Spacing (m)	Density (m/ha)	Ditch Depth (cm)
Poorly drained forest				
(Peat < 40 cm)				
-wooded	coarse texture	55	180	70
-non-regenerating	coarse texture	50	200	70
-wooded	fine texture	35	285	70
-non-regenerating	fine texture	30	333	70
Forested bogs (Peat > 40 cm)	organic layer slightly decomposed	40	250	90
	organic layer well decomposed	35	285	90
Non-regenerating bogs	organic layer slightly decomposed	35	285	90
	organic layer well decomposed	30	333	90

Table 4. Operational ditching recommendations for Ontario. From Rosen (1985a); Haavisto and Päivänen (1987).

	Ditch Spacing (m)	Ditch Depth (cm) Organic Matter Depth (cm)		
		30	30-80	80+
Sparsely-treed peatlands	30-40	60	70	80
Well-treed peatlands	40-50	60	70	80
Shallow peatland/water-logged mineral soils	50-60	60	70	80

ALBERTA

A noteworthy study conducted by Leiffers and Rothwell (1987), on a 50 ha fen with excavated ditches 80 cm deep and 40 m apart concluded that:

1) drainage lowered the water table 20-50 cm compared to the undrained site.
2) planted black spruce and tamarack reached 50% total shoot elongation earlier on the drained site.
3) the general pattern was for growth to start earlier and end earlier, notably for leader elongation, on the drained site.

MACHINERY

Early drainage in Finland was accomplished manually and by 1939 one million ha of peatlands with 150,000 km of ditch had been dug by hand. The use of machinery and explosives in the 1960's increased annual ditching to 50,000 km on 200,000 ha. Explosives now are only used on the more difficult sites where machinery transportation is restricted. A partial listing of machinery currently used worldwide includes:

1) backhoe
2) British forestry ploughs—commonly used on the blanket bogs of Great Britain
3) tracked excavators—Lännen S10
4) Marttiini plough—requires D6 crawler tractors
5) Kopo trencher—prepares a rectangular shaped ditch 100 cm deep and 35 cm wide

6) Mallett wheel ditcher—prepares a V-shaped ditch by means of a large wheel churning through peat at 400 rpm.
7) modified forestry equipment—skidders and forwarders.

A variety of bucket shapes are available for backhoes and tracked excavators. The "V" shaped bucket has been used to reduce side slumping in mineral soil excavations.

ENVIRONMENTAL IMPACT

One of the major concerns in peatland drainage is the impact on groundwater storage and runoff fluctuations. Jeglum (1985) concludes that for the first two or three years after drainage, runoff is higher because water storage is decreasing. However, long-term results indicate that drainage has a moderating effect, such that the maxima are lower and the minima higher than in the virgin peatland areas.

In Finland, studies have examined the effect of drainage on stream water quality and stream organisms. Ice (1984) and Jeglum (1985) in their review of the literature state:

1) Suspended sediment increases only for the period immediately following ditch construction (first peak flows in the spring) with suspended solids derived from the sides and bottoms of ditches.
2) pH values may increase because of contact of acidic surface runoff with mineral soil.
3) NH_4 may increase because of increased mobilization of N as NH_4 under acid conditions.
4) 3 years after drainage, annual runoff increased 10%, spring maxima decreased by 10% and summer and winter minima increased by 50%.

From his review of Finnish studies, some of which have been monitored for over 50 years, Ice (1984) concluded hydrologic and water quality changes appear to recover rapidly. Heikurainen *et al* (1978) concluded that forest drainage has a levelling influence on hydrologic fluctuations; in other words it reduces peak runoffs and increases low water runoffs. He also stated that water quality impacts were short term, particularly in regard to sediment.

In South Carolina, Williams (1984) concluded that the overall impact of drainage on pine plantation establishment on the Atlantic coastal plain results in a general and significant improvement in water quality.

Jeglum (1985) summarized the following measures necessary to minimize environmental impacts:

> ...making a break in the ditch where there is a steep gradient, thus letting the water run over the peat surface; creating sedimentation pools and sedimentation ponds; using only one collector ditch to the creek, as opposed to many side ditches; stopping the collector ditch just short of the creek bank so that water percolates through or over the bank; and avoiding direct drainage of collector or outlet into lakes.

DRAINAGE POTENTIAL FOR NOVA SCOTIA

Drainage of peatlands can increase productivity from a minimum of 1 m^3/ha/yr up to 8 m^3/ha/yr (Mikola 1967; Smissaert 1984; Kusnierczyk 1987). Andreáson (1978) reported that drainage of poorly (imperfectly) drained mineral soils and peatlands will raise the productivity of the site equal to that of surrounding well drained sites. Trottier (1986) expects an increase in productivity of 3-7 m^3/ha/yr by draining bogs and paludified (poorly drained) mineral soils in Quebec.

Assuming an average increase of 3 m^3/ha/yr, drainage could increase the potential yield from imperfectly and poorly drained soils in Nova Scotia by approximately 3.3 million m^3/yr (1.5 million cords/yr). While the potential gain will never be achieved for a variety of reasons, substantial gains are nevertheless possible.

DRAINAGE RESEARCH IN NOVA SCOTIA

Since 1986 several forest drainage studies have been established on imperfectly and poorly drained mineral soils in Nova Scotia using a variety of mechanical equipment including a tracked excavator (4000 m of ditches) and the Lännen ditching machine (5000 m of ditches). Sites drained included non-regenerating clearcuts, old fields, and forested stands.

Piezometers and permanent sample plots have been established at all sites to monitor water table fluctuations and the effect of drainage on tree growth. These trials will also provide an indication of the amount of ditch maintenance required.

Additional trials will be established to better determine the economics of drainage in relation to site and stand characteristics, type of equipment and drainage design and method.

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