IMPROVING WETLANDS FOR FORESTRY IN CANADA

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ABSTRACT

A review of the development of wetlands drainage for forestry in eastern Canada and Alberta is presented. Results from experiments relating drainage to tree growth, seedling survival, and fertilization indicate that tree growth can be increased fivefold through draining. Knowledge obtained from these earlier experiments provided a foundation for establishing in Alberta the Wetland Drainage and Improvement Program under the Canada-Alberta Forest Resource Development Agreement. The purpose of the program is to determine if operational drainage for forestry is economically feasible in Alberta and if it can be done without harming the environment.

RESUME

L'étude présente une revue des travaux de drainage des terres humides de l'est du Canada et de l'Alberta à des fins de foresterie. Les résultats d'expériences reliant le drainage à la croissance des arbres, à la survie des semis et à la fertilisation montrent que le drainage peut quintupler la croissance des arbres. C'est à la lumière de ces expériences préliminaires qu'on a établi le programme de drainage et de mise en valeur des terres humides dans le cadre de l'Entente Canada-Alberta sur la mise en valeur des ressources forestières. Ce programme doit permettre de déterminer si le drainage en grand pour la foresterie est économiquement et écologiquement possible en Alberta.

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NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service.

INTRODUCTION

Controlling groundwater table levels through drainage for the purpose of increasing wood production is a fairly new forest management technique in Canada. Practiced extensively on peatlands in Finland and the Soviet Union, and to a lesser extent in Scandinavia and Great Britain, the technique is designed to improve soil aeration conditions, thereby promoting tree root development and stem growth (Heikurainen 1964). Drainage can result in marked improvement in tree height growth; therefore, a major benefit from this treatment is effective increase in site index. In Alberta, improved growth of trees near roadside ditches (Fig. 1), and the contrast in tree response on opposite sides of roads constructed through peatlands (Fig. 2), provide evidence of the potential for forest drainage.

It is customary to associate forest land drainage with organic soils, but mineral soils can also benefit from measures to control water table levels. Timber harvesting reduces the draft on soil water. Harvesting conducted on flat terrain with a shallow water table in mineral soil can result in the water table rising close to or above the ground surface, a condition unsuitable for reforestation. It is important to resolve this particular problem in order to avoid loss of productive mineral soil sites.

Some information is available on the effects of drainage on forest growth in Canada. Drainage of Ontario clay belt peatlands (Stanek 1977) increased site indexes of all sites investigated. Height growth increased by 4 m at 100 years for swamps and fen-marsh types and by 6 m for bog types. Wood volume increases of over 116% were reported.

Compared to forest growth, the impact of forest drainage on the environment in Canada has received little attention. Changes in groundwater table levels were reported for studies in Newfoundland (Richardson et al. 1976), Quebec (Stanek 1970a; Trottier 1986), and Ontario (Stanek 1968), but, for Canada, there are no published data on the impact of forest drainage on runoff, stream sedimentation, chemical water quality, and wildlife habitat. These are factors that should be addressed in a comprehensive forest drainage study.

In assessing benefits resulting from forest land drainage, possible adverse effects that may accompany growth increases should also be considered. Studies on black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*Picea glauca* (Moench) Voss), and tamarack (*Larix laricina* (Du Roi) K. Koch) from two drained wetland sites in north-central Alberta (Wang et al. 1985) showed that increases in radial and volume growth were accompanied by reductions in wood relative density and tracheid length—changes that warrant investigating the wood's suitability for structural purposes. The effects were pronounced in white spruce and tamarack, particularly in younger trees.

The purpose of this paper is to review important forestry drainage operations and studies conducted in Canada, particularly in Alberta, and to highlight their results. A secondary objective is to outline the future direction of forest drainage research in Alberta.

WETLANDS DRAINAGE AND IMPROVEMENTS FOR FORESTRY IN EASTERN CANADA

Newfoundland

Wetlands cover 2.5 million ha of insular Newfoundland, about 22% of the land area. They consist of 1.4 million ha of reclaimable peatlands, 0.7 million of which are open peatlands, and 0.7 million are scrub-forested peatlands (Paivanen and Wells 1978). Research into the possibility of using these lands for forestry dates back to the mid-1960s (Heikurainen 1968; Pollett 1969; Paivanen and Wells 1978). Because half of the reclaimable peatlands are treeless, initial research efforts were directed at afforesting these open peatlands. Details of the drainage and afforestation studies conducted in Newfoundland are given in Table 1. In all cases, drainage was accomplished by ploughing furrows.

Results from the Stephenville trial (Paivanen and Wells 1978) showed very poor height growth for all species except Japanese larch (*Larix leptolepis* (Sleb. & Zucc.) Gord.). The average height of Japanese larch 11 years after planting was 2.65 m. Poor growth for all species at the Bottom Brook trial (Paivanen and Wells 1978) was attributed to severe exposure, poor site quality, and improper drainage techniques. Survival counts after one growing season on the Crooked Bog site (Paivanen and Wells 1978) indicated 91% survival for all species, 100% survival for tamarack and Norway spruce (*Picea abies* (L.) Karst.), and 80% survival (lowest) for lodgepole pine (*Pinus contorta* var. latifolia Engelm.).

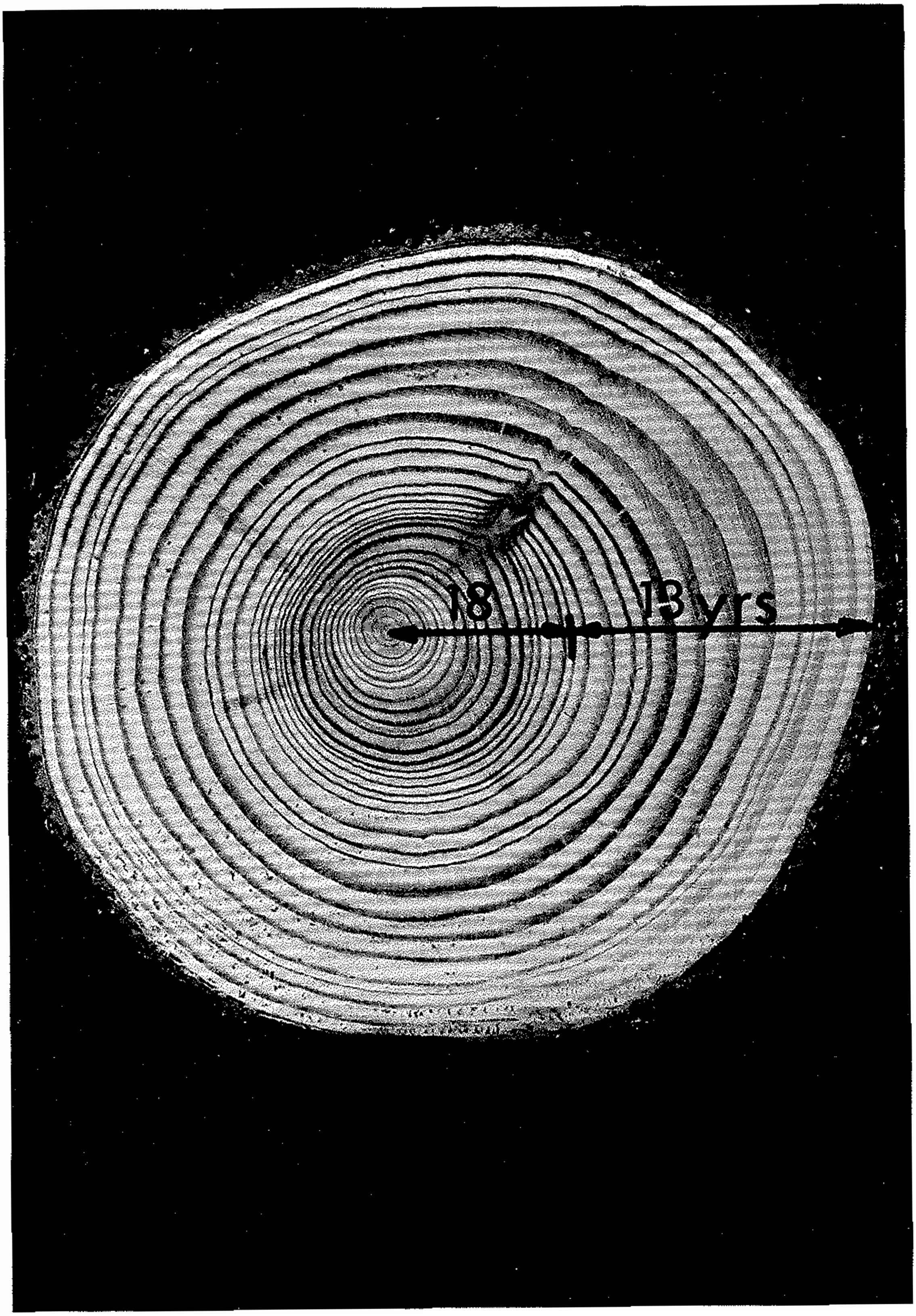

Figure 1. Black spruce disk showing diameter growth improvement due to ditching associated with road construction. (Disk courtesy of Alberta Forest Service.)

Table 1. Peatland drainage and afforestation trials, Newfoundland[a]

Location	Site description	Treatment	Species planted	Lead agencies
Near Stephenville Crossing	Nutrient-poor, blanket bog	Ploughed and planted 1966.	Black spruce, Sitka spruce, Norway spruce, Scots pine, Japanese birch, Japanese larch	Bowaters Newfoundland Limited
Bottom Brook — St. George area	Nutrient-poor, blanket bog	Ploughed 1967, planted 1968.	Scots pine, white birch, European larch, Sitka spruce, black spruce	Bowaters Newfoundland Limited
Crooked Bog, near Badger	Ombrotrophic raised bog	2-m drain spacing 1974–75. Trees spot-fertilized with compound fertilizer (N-40, P-2, K-2) spring 1976.	Black spruce, white spruce, Norway spruce, lodgepole pine, Japanese larch, hybrid larch, Siberian larch, eastern larch	Canadian Forestry Service
Near Millertown Junction	Moderately nutrient-rich fen (6.6 ha)	1. Furrow spacing trial: 2 and 4 m apart, 1972. 2. Planting spacing trial: 1.2, 1.8, 2.4 m apart along furrows, 1972. 3. Tree species trial, 1972. 4. Trees spot fertilized with compound fertilizer (N-16, P-14, K-10).	Black spruce, white spruce, Sitka spruce, white birch, lodgepole pine	Canadian Forestry Service
Buchan's Junction	Nutrient-rich fen	1. 4-m drain spacing (half area), 1974–75. 2. 2-m drain spacing (half area), 1974–75. 3. Planting position trial, 1974–75: a. on side of ridge closest to drain. b. on side of ridge farthest from drain. c. on undisturbed peat surface.	1. Black spruce, white spruce, Norway spruce, lodgepole pine, Japanese larch, eastern larch, hybrid larch, Siberian larch 2. Same as for 1, except European larch was planted instead of eastern larch 3. Japanese larch, black spruce	Canadian Forestry Service
Cochrane Pond, near St. John's	1. Open, nutrient-poor slope bog 2. Open, nutrient-poor slope bog	1. Ploughed at 2-m intervals, 1966. 2. Ploughed at 2-m intervals, 1966.	1. Scots pine, fertilized (1967) 2. Spruce—black, white, Serbian, Sitka, Norway; fertilized (1967)	Newfoundland and Labrador Department of Mines, Agriculture and Resources; Canadian Forestry Service

[a] After Paivanen and Wells (1978).

Figure 2a. Vigorous tree growth on north side of an oil well access road, Slave Lake, Alberta.

Figure 2b. Stagnant or drowned vegetation on south side of same road.

Table 2. Height (m) of naturally stocked black spruce and eastern larch seedlings on a fen near Millertown Junction, Newfoundland, before and after draining[a]

	Black spruce		Eastern larch	
	Before drainage (1971)	After drainage (1979)	Before drainage (1971)	After drainage (1979)
Drained area	0.169	0.691	0.212	1.125
Control area	0.471	0.689	0.404	0.695

[a] After Richardson (1981).

Measurements taken on the Millertown Junction fen (Richardson et al. 1976) showed that the predrainage water table was 0.025 m below the surface; 2 weeks after drainage it was as much as 0.56 m below the surface. Water table depths were similar for the 2- and 4-m ditch spacings, with the 2-m spacing being slightly lower. Beyond 5 m from the ditches, the water table was too high for afforestation. To shorten the period when these high water table conditions prevail, Richardson et al. (1976) proposed that large, main drainage ditches be constructed in future drainage-afforestation trials.

Other results from the Millertown Junction trials indicated an overall first year survival of about 97%, with lodgepole pine showing the highest survival rate (Paivanen and Wells 1978). After three growing seasons 73% of the seedlings had survived, with black spruce showing the highest survival rate. Five years after drainage lodgepole pine was growing well, but most of the black spruce seedlings were damaged by spruce budworm (*Choristoneura fumiferana* Clem.).

Richardson (1981) found drainage of the Millertown fen had a pronounced effect on seedling growth rates of naturally stocked black spruce and tamarack (Table 2). Height growth was always greater on the drained areas. There were no significant differences, however, in height growth between the 2-m and 4-m spacings. Superposition of fertilization on drainage treatment resulted in annual height increments 2-3 times greater on fertilized sites than on unfertilized sites, 4-7 years after drainage.

At Buchan's Junction (Paivanen and Wells 1978), survival counts in spring 1976 indicated survival rates for 2-m furrow spacings were greater than those for 4-m spacings (Table 3). They also showed that in the planting position trials, the survival rates of black spruce and Japanese larch on the side of the ridge closest to the ditch were 46% and 27%, respectively. On undisturbed peat, the survival rates were 42% and 6%.

Survival tallies on the two bogs at Cochrane Pond 4 years after planting showed a 50% survival rate for all spruce species and 86% for Scots pine (*Pinus sylvestris* L.) (Paivanen and Wells 1978). Total height growth was greatest for white spruce and Scots pine. Later observations (1971-76) showed poor height growth for all seedlings, due mainly to severe exposure and nutrient-poor soils.

The six drainage and afforestation trials described above constitute the extent of early peatlands forestry research in Newfoundland. In these studies, drainage systems were poorly designed, and tree growth, in most instances, was poor (Paivanen and Wells 1978). Tree growth response to drainage has also been observed near highways and railways. Measurements taken on transects perpendicular to a highway drainage ditch near Birchy Narrows in western Newfoundland showed that 15 years after construction, height growth of trees 50-70 m from the ditch was affected (Paivanen and Wells 1978).

Table 3. Survival rate of planted tree species 1-2 years after drainage of a fen near Buchan's Junction, Newfoundland[a]

Drain spacing (m)	All species (%)	Norway spruce (%)	Japanese larch (%)	Lodgepole pine (%)
2	79	99	70	45
4	64	98	32	27

[a] After Paivanen and Wells (1978).

Quebec

In Quebec, south of the 50th parallel, peatlands cover 2.7 million ha or 6.3% of the province's economically accessible and productive forest land (Bolghari 1986). Forest drainage is being practiced more and more in this part of Quebec, where foresters now find it necessary to increase wood production on poorly drained sites close to mills, especially in areas where wood shortages are acute. Private woodlot owners, in particular, are applying drainage techniques to improve their stands. The Quebec Wood Producers Federation was charged by its members, the Quebec woodlot owners, to investigate the value of forest drainage and, depending on the results, to oversee the implementation and development of this practice on privately owned forest land (Urgel Delisle and Associates 1983).

Between 1980 and 1986, 5 224 ha of forest land were drained in Quebec. Of this amount, 82% (4 297 ha) was completed on private woodlots, 14% (721 ha) on crown lands, and 4% (206 ha) on company holdings[1].

Some forest drainage research has been conducted in Quebec. In 1968, an ombrotrophic bog near Quebec City was drained and fertilized (Stanek 1970a, b). The area (about 70 ha), which supported young (44–70 years) and pole-sized black spruce, some tamarack, white birch (*Betula papyrifera* Marsh.), eastern white pine (*Pinus strobus* L.), and balsam fir (*Abies balsamea* (L.) Mill.), was considered to have poor to moderate forestry value.

About 1280 m of ditches were dug with an excavator and a further 427 m ditched with dynamite. Ditch depths ranged from 1.2 to 1.8 m, and ditch gradients were maintained between 0.007 and 0.01. Before ditching, the water table contour approximated the peat surface contour. After ditching, a general lowering of the water table was observed. The drop was most pronounced near ditches. After drainage, the water table remained for long periods at depths of 0.3–0.45 m and occasionally fell below 0.5 m. The highest levels were measured in the spring and after rainfall; the lowest levels were recorded during late summer and during periods of drought (Stanek 1970a).

On the same drained peatland, Stanek (1970b, 1975) also investigated the combined effects of drainage and fertilization on height growth, diameter at breast height (dbh), and chemical content of foliage of young, naturally established black spruce. Treatments, consisting of applications of P, N-P, P-K, N-P-K, N-P-K-Cu, and sewage sludge, were compared with the control on the drained site.

Measurements taken 5 years after application (Stanek 1975) showed that the N-P-K-Cu and N-P-K treatments had a significant effect on height, dbh, and volume increments (Table 4). The periodic annual increments for these treatments were 10.9 and 10.5 m^3 ha^{-1}, respectively, compared with 2.0 m^3 ha^{-1} for the control. Tree appearance was also improved by fertilization. The improvement was particularly noticeable on the N-P-K-Cu plot, where trees appeared healthier, greener, and more vigorous than those fertilized with N-P-K or any other combination of the three elements.

The incidence of mortality on the control plots and the lack of it on the fertilized plots support the conclusion drawn from other studies that fertilizing trees in the year following drainage may enable them to recover from postdrainage shock (Stanek 1975).

A more recent study was conducted on peatlands near Lemieux in the Nicolet region of Quebec (Trottier 1986). Seven sample plots 20 × 50 m in size were established adjacent to a drainage channel (with no lateral ditches) dug for agricultural purposes in 1953. The longitudinal axes of the plots were oriented perpendicular to the channel. To determine the effect of distance from ditch on stand growth, each plot was subdivided into five subplots 20 × 10 m, and tree growth data were collected from each. A drainage network with variable ditch spacing (20, 40, 60, and 80 m) was constructed nearby. During the 1984 growing season, depth to water table was measured weekly at the midpoints between ditches and for a control section.

Trottier (1986) found water table depths for the 20- and 40-m ditch spacings were significantly different from each other, from the 60- and 80-m spacings, and from the control (Table 5). There were no significant differences between the two widest spacings and the control. Thus, only the 20- and 40-m spacings had positive effects on water table drawdown.

The stand growth data (Table 6) reflect the change in depth to water table with distance from the ditch. In the first subplot (0-10 m), where the postdrainage wood

[1] Personal communication. Letter dated March 18, 1987, from F. Trottier, Forest Engineer, Silviculture Treatment Service, Quebec Ministry of Energy and Resources, Quebec, Quebec.

Table 4. Growth of black spruce on drained peatland in Quebec 5 years after fertilization[a]

Treatment	Age (1969)	Height (m) 1969	Height (m) 1974	Dbh[b] (mm) 1969	Dbh[b] (mm) 1974	S[c] 1969	S[c] 1974	S%[d]	V[e] 1969	V[e] 1974	Pai[f]
N-P	61	5.3	6.8	77	101	3.8	4.5	19	43.2	75.1	6.4
P	54	5.2	6.7	66	83	4.3	4.8	12	44.7	69.2	4.9
P-K	50	4.7	5.9	59	77	4.3	4.8	11	37.1	60.0	4.6
N-P-K	66	6.1	8.3	85	114	4.1	5.4	33	59.8	112.4	10.5
Manure	57	5.9	6.9	71	85	4.4	4.7	7	53.4	72.6	3.8
Control	44	4.2	4.6	51	62	4.2	4.2	0	24.0	34.8	2.0
N-P-K-Cu	70	6.4	8.6	91	116	3.9	5.2	35	64.2	119.1	10.9

[a] After Stanek (1975).
[b] Diameter at breast height.
[c] Site index (m) at age 50.
[d] Percent increase of S from 1969 to 1974.
[e] Gross total volume (m^3 ha^{-1}) of fully stocked stands.
[f] Periodic annual increment (m^3 ha^{-1}) of fully stocked stands from 1969 to 1974.

Table 5. Mean depth to water table at midpoint between ditches for different ditch spacings[a]

Spacings (m)	Depth to water table (m)
20	0.456
40	0.332
60	0.258
80	0.268
Control	0.238

[a] After Trottier (1986).

Table 6. Stand growth data for different distance classes and subplots[a]

Distance class (m)	Mean volume (m^3 ha^{-1})	Subplot	Mean ratio[b]	Volume (m^3 ha^{-1})
0-10	120.7	0-10	5.57	120.7
0-20	87.1	10-20	3.23	53.5
0-30	73.1	20-30	2.81	45.2
0-40	66.7	30-40	1.84	47.5
0-50	61.3	40-50	2.58	39.5
Control	15.0	—	—	15.0

[a] After Trottier (1986).
[b] Rate of increase in basal area after drainage to the rate of increase in basal area before drainage.

production rate was more than five times the predrainage rate, the volume of wood 30 years after drainage was 120.7 m^3 ha^{-1}. Growth elsewhere was much less (Trottier 1986), although all subplots produced greater volumes than the control.

Mean stand growth rates for the 0-10 m and 10-20 m subplots were significantly different from each other and from the other three subplots (20-30 m, 30-40 m, and 40-50 m). No significant differences were detected among the three subplots furthest from the ditch (Trottier 1986). These results suggest that drainage had a significant effect on growth up to 20 m from the ditch, and that the maximum ditch spacing, in this case, should be 40 m.

Ontario

What was probably the first forest drainage experiment in Canada was established just north of Iroquois Falls in 1929 by Abitibi Paper Company Limited and the Ontario Department of Lands and Forests (now Ontario Ministry of Natural Resources). The purpose of the study was to determine the effects of drainage on growth and yield and to assess the economic feasibility of draining marginal and submarginal peatland black spruce stands (Payandeh 1973).

A swamp drainage system consisting of 2600 m of hand-dug drainage ditches was installed on a 26.7-ha area supporting 79-year-old submarginal black spruce. Forty growth plots, each 25.3 m^2, were established at specified distances from the ditches, and three control plots were located in an adjacent undrained area. The trees were measured in 1929, 1956, 1965, and 1969.

Unsuccessful attempts to determine growth response to drainage using 1956 and 1965 data led Payandeh (1973) to conduct stand growth analyses as well as individual tree and increment core analyses using cores and disks. He found significant ($p = 0.01$) increases in tree diameter and height growth after drainage. Pronounced differences were exemplified by data presented for a single sectioned tree (Table 7). In this case, the average dbh growth rate had almost tripled, and the height growth increased nearly four times.

The analyses (Payandeh 1973) showed that response to drainage was more pronounced for individual trees than for stands, and that response was greater for younger trees with larger crowns growing on better sites. Also, younger stands with lower stocking tended to grow faster. It was also determined that trees nearest the ditches did not necessarily have the most improved diameter growth rates. Overdraining, compaction of spoil banks, and disturbance of tree roots were cited as reasons for this apparent anomaly.

Another forest drainage experiment was established (Stanek 1968) in the same region of northern Ontario in 1961. About 60 ha of waterlogged organic terrain near Cochrane were drained to evaluate the effects of ditching on the groundwater table and on the growth and foliar nutrient content of black spruce. The stand consisted mainly of black spruce with some tamarack, alder swamps, balsam fir, and white birch.

Dynamite was used to excavate about 2500 m of drainage ditches in a dendritic pattern with parallel lateral ditches spaced 45-60 m apart. It was probably the first time in Canada that both main ditches and parallel lateral

Table 7. Pre- and postdrainage growth data for sectioned tree 28 from the Abitibi drainage area[a]

Period	Age (yr)	Dbh[b] (mm)	Dbh[b] growth (mm yr^{-1})	Height (m)	Height growth (m yr^{-1})	Total volume (m^3)	Annual total volume growth (m^3 yr^{-1})	Merchantable volume (m^3)	Annual merchantable volume growth (m^3 yr^{-1})
Before drainage (up to 1929)	41	20.1	1.671	2.69	0.066	0.003	0.00006	—	—
After drainage (1929-1969)	81	213.4	4.831	12.5	0.245	0.1987	0.005	0.1843	0.00462

[a] After Payandeh (1973).
[b] Diameter at breast height.

ditches were constructed to drain forest land. The practice of using closely spaced (30-60 m) parallel lateral ditches to lower the water table, and using main ditches to carry water away from the area, is used extensively in Finnish forestry operations. The ditches were 1.22-1.83 m deep and 1.83-3.66 m wide. Slopes for the main drainage ditch were 0.003 on the upstream portion and ≥ 0.01 on the downstream portion. Lateral ditch slopes ranged between 0.003 and 0.006.

Slumping ditch sides and low gradients resulted in reduced water movement in some instances. Before ditching, the water table remained within 0.05 m of the surface during the growing season. After drainage, it was lowered to depths of 0.26-0.35 m during dry spells and raised to depths of 0.05-0.14 m after several days of rain. It did not reach predrainage levels.

The average annual dbh and height growth of black spruce increased following drainage. Five years after drainage, dbh had increased from 1 mm $yr.^{-1}$ to 5.1 mm yr^{-1}, and height growth had increased five times (Table 8). Foliar analyses before and 5 years after drainage indicated that nitrogen had almost doubled, potassium and phosphorus had increased slightly, and calcium and magnesium had decreased slightly. Improved tree vigor resulting from drainage was evident from the healthy green foliage that contrasted with the original yellow and yellowish green foliage evident before drainage. Younger trees and seedlings responded best to drainage. Older trees with short narrow crowns showed no positive response, and some died.

The most recent drainage project undertaken in Ontario was a cooperative effort between the Canadian Forestry Service and the Ontario Ministry of Natural Resources on the Wally Creek drainage basin near Cochrane (Haavisto 1984; Rosen 1985). The area, which is typical of that found in the boreal forest (waterlogged and supporting black spruce), was surveyed and mapped according to the Forest Ecosystem Classification (FEC) (Jones et al. 1983). The FEC, designed to provide a practical forest site classification system for forest management of both uplands and forested peatlands in the Ontario clay belt, enables the user to identify 14 different operational groups in the field (Jones et al. 1983; Jeglum 1985).

The drainage project drew extensively on Finnish experience. In 1984-85, 464 ha were drained by a 114.4-km network of collector, lateral, and surround ditches constructed with Lannen S10 ditching backhoes. The lateral ditches were spaced 30-40 m apart on sparsely treed peatland, 60 m apart on waterlogged mineral soil, and 40-50 m apart on the the most common site type—densely treed black spruce swamp. Ditch dimensions were uniform throughout at 1 m deep and 1.4 m wide. In this project, ditch spacings were directly related to FEC site types because each wetland area corresponded to a specific operational group. To minimize stream sedimentation, 32 sedimentation pools were constructed between the main ditches and the stream channels. An adjacent area, to be drained some years hence, was chosen for baseline data collection.

A number of treatments were imposed on contiguous 130-year-old and 55-year-old black spruce stands on the area. One part of the 130-year-old stand was full-tree harvested and the other subjected to conventional cut and skid harvest. The latter area was divided into two parts that were subjected to shearblading[2] and prescribed burn site preparation techniques, respectively. These replicated areas were further subdivided and planted with black spruce, jack pine (*Pinus banksiana* Lamb.), Scots pine, and larch. Further replications were made in the black spruce plots for fertilizer applications. The stand was drained at 40-m ditch spacings. The 55-year-old stand was subjected to drainage and fertilization. In both stands sufficient plots were established to compare control with drained and with drained plus fertilization[3].

The costs and benefits of the treatments will be examined. Predrainage tree growth and development patterns are being evaluated by destructive sampling and detailed biological stem analyses procedures that make extensive use of computers. Other areas of investigation include: changes in ground vegetation, water levels, and physical and chemical properties of peat; effects of drainage on flora and fauna; changes in peat and water chemistry; and the usefulness of intensive competition control.

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[2] Shearblading is a tree-planting site treatment carried out in winter when the ground is frozen. A Caterpillar with blade is used to shear off shrubs, grasses, and some duff. The debris, together with snow, is pushed into windrows.

[3] Personal communication. Letter dated November 28, 1984, from D. MacIver, Mensurational Specialist, Forest Resources Group, Ontario Ministry of Natural Resources, Toronto, Ontario.

Table 8. Average annual height and dbh[a] growth of black spruce before and after draining[b]

	Years before drainage					Years after drainage				
	5 (1956-57)	4 (1957-58)	3 (1958-59)	2 (1959-60)	1 (1960-61)	1 (1961-62)	2 (1962-63)	3 (1963-64)	4 (1964-65)	5 (1965-66)
Height (m)	0.028	0.028	0.028	0.043	0.028	0.043	0.079	0.091	0.117	0.145
Dbh (mm)	1.02	1.02	1.02	1.02	1.02	1.27	2.29	3.81	4.83	5.08

[a] Diameter at breast height.
[b] After Stanek (1968).

Table 9. Wetlands drainage for forestry projects in Alberta

Legal description	Drained area (ha)	Total length of ditches (km): Main	Total length of ditches (km): Lateral	Year started	Lead agencies
Athabasca Forest					
1. Sect. 23, 24, 25, and 26 Township 87, Range 9, W4M	76	2.12	—	1975	AFS[a]
Peace River Forest					
2. Kimiwan: Sect. 16, 17, 20, and 21 Township 80, Range 17, W5M	172	4.05	71	1984	AFS
3. Kimiwan II; Sect. 22, 26, and 27 Township 79, Range 19 W5M	456	4.45	115	1985	AFS
4. Manning: Sect. 12 Township 95, Range 1, W6M	105	3.77	40	1984	AFS
5. McLennan 28: Sect. 28 Township 79, Range 19, W5M	90	2.61	28	1985	CFS[b]/AFS
Slave Lake Forest					
6. Goose River: Sect. 14, 15, and 23 Township 68, Range 19, W5M	135	2.73	37	1985	CFS, AFS
7. Saulteaux River: Sect. 8, 9, 16, and 17 Township 71: Range 2, W5M	50	2.69	16	1981	AFS, U of A[c]
Whitecourt Forest					
8. Wolf Creek: Sect. 19 and 30 Township 51, Range 14, W5M	60	1.53	19	1985	CFS, AFS

[a] Alberta Forest Service.
[b] Canadian Forestry Service.
[c] University of Alberta.

WETLANDS DRAINAGE AND IMPROVEMENTS FOR FORESTRY IN ALBERTA

In Alberta, concern about the decreasing productive forest land base as more forest land was withdrawn for other uses led foresters to consider increasing the wood-growing capability of forested wetlands. Alberta contains nearly 13 million ha of peatlands, about 11% of the peatlands in Canada (Tarnocai 1984); about 4 million of these are considered suitable for drainage and conversion to productive forest. Several forestry drainage projects were initiated in Alberta (Table 9), all but one of which are less than 5 years old. Consequently, very little information is available on the long-term effects of forest drainage in Alberta on tree growth and the environment. Rothwell (1986) summarized recent progress in Alberta forest drainage and described the activities of Alberta agencies and individuals involved in this and related fields. It is believed that there is good potential in Alberta for increasing tree growth through peatland drainage (Paivanen 1980). The following discussion covers past and present forest drainage work in Alberta, as well as research needs.

Athabasca Forest

The first land drainage conducted as a forestry project in Alberta was implemented by the Alberta Forest Service in the Athabasca Forest in 1975 (Alberta Forest Service 1980). The project, located 11 km south of Fort McMurray (Fig. 3, Table 9), was established to test the suitability of existing scarification equipment for drainage work and to determine if drainage would improve tree growth rates. The operational trial was set up in a dense cover of black spruce that originated following a 1953 wildfire. The peat depth ranged from 0.6 to 1.2 m.

Initial treatments consisted of: 1) clearing and scarifying strips of two bulldozer blade widths (i.e., 2 × 3.5 m) with windrows on either side (25 ha); 2) clearing and scarifying strips of one blade width, alternating with unscarified strips also of one blade width (26 ha); and 3) clearing and scarifying strips of one blade width, bounded by leave (unscarified) strips 8–9 m wide (23 ha). Where water ponding occurred, lines were cut through windrows and unscarified strips to facilitate drainage (Alberta Forest Service 1980). A 305-m long main ditch, 2.1 m wide and 0.9–1.5 m deep, was dynamited between the control and Treatment Area 1 to carry water away from the site. No lateral ditches were constructed during this phase.

In spring 1976, transects were established on the control, on each treatment type, and adjacent to the main drainage channel. Leader growth for 1975, total tree height, age, and foliage color were recorded for each tree sampled (Table 10).

Further improvements were attempted in 1976 when a double moldboard ripper was used to make lateral ditches in Treatment Area 3. Results showed that scarification equipment and the double mouldboard ripper were unsuitable for constructing adequate drainage ditch systems (Alberta Forest Service 1980).

In 1979, ditches 0.76 m deep were dug on each bladed area with a Marttiini plough. Average ditch spacings were about 9 m on treatment areas 1 and 2, and 18 m on Treatment Area 3. The following year, an additional 1 817 m of main drainage ditches 1.07 m deep and from 1.06 to 1.22 m wide were dug with large tracked excavators (Alberta Forest Service 1981).

Four plots were established on each treated area and on the control area during 1980. In 1981, one plot was thinned to 1 730 stems ha^{-1}, one fertilized with nitrogen, and another with phosphorus; the fourth plot served as a control. The trees were measured in the springs of 1981 through 1985 (Alberta Forest Service 1982, 1984f, 1985b).

Because no comprehensive statistical analyses were undertaken, it is not possible to comment on the significance of the results (Table 11). It is evident from the mean values, however, that best tree leader growth occurs on the area where cleared and scarified strips are two dozer blades wide, i.e., where scarification and ditching were most intense. Growth for Treatment Area 1 is nearly four times that of the untreated area 9 years after draining.

Saulteaux River

The Saulteaux River experimental drainage study was initiated in 1981 and undertaken by the University of Alberta under contract to the Forest Research Branch, Alberta Forest Service (Toth and Gillard 1984). The 100-ha study area is located in a treed fen about 37 km southeast of the town of Slave Lake (Fig. 3, Table 9).

The study differs from other similar projects in Alberta in that considerable scientific effort went into the drainage system design, a primary objective of the study. Other primary objectives have been evaluation of the effects of drainage on the water balance and water quality of the area, and the development of local expertise on peatland drainage (Toth and Gillard 1984).

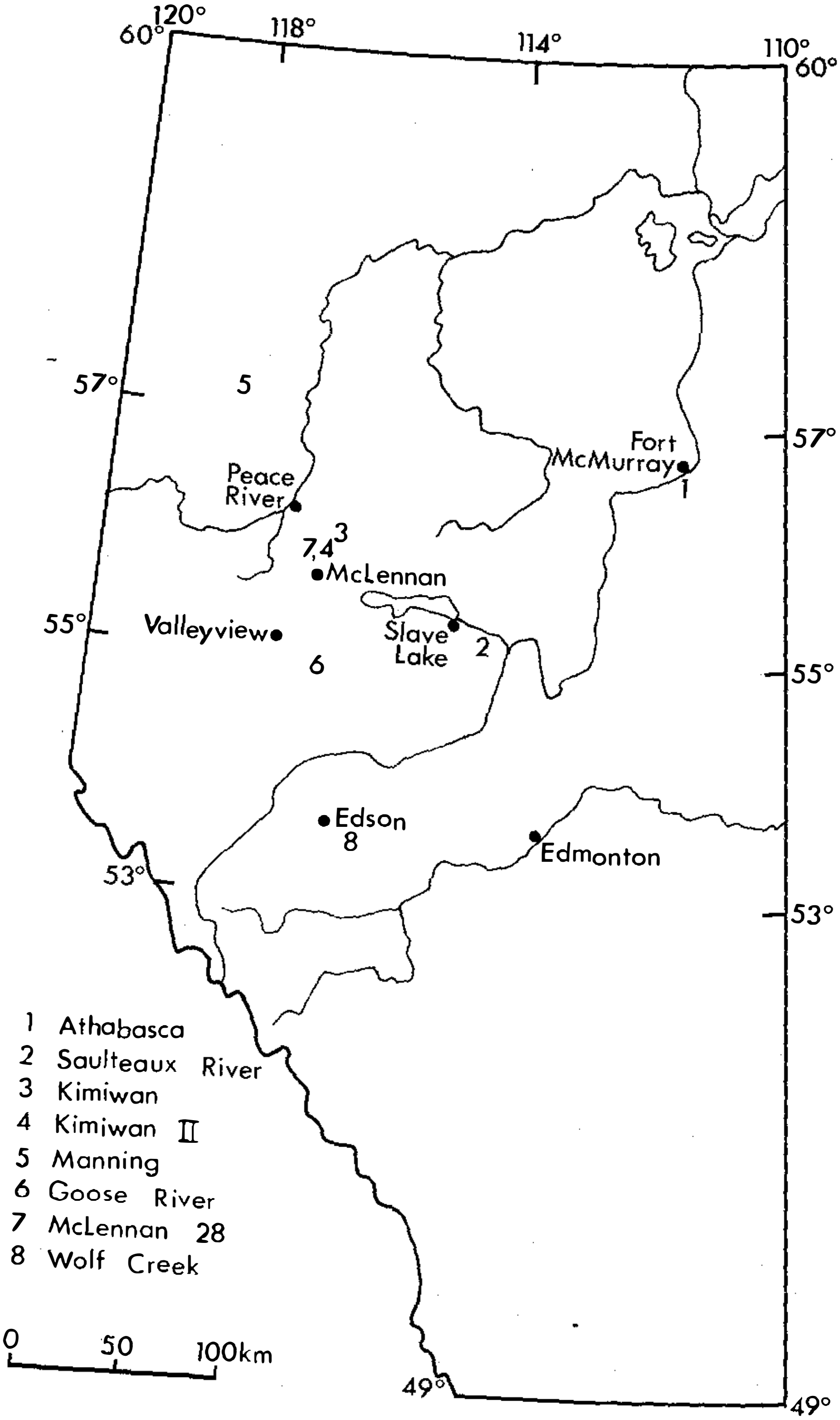

Figure 3. Locations of experimental drainage areas in Alberta.

Table 10. Mean annual height increment and 1975 height growth of trees on the Athabasca trial drainage area[a]

Treatment	Age (yr)	Mean annual height increment (mm yr $^{-1}$)	1975 leader growth (mm)
Clearing and scarifying —two blade widths	13	24.6	13.7
Clearing and scarifying —one blade width	12	18.0	24.4
Control	16	24.4	18.8

[a] Source: Alberta Forest Service. 1980. Wetland drainage for forest site improvement in the Athabasca Forest. Alberta Dep. Energy Nat. Resour., Fort McMurray, Alberta. Unpublished report.

Table 11. Average annual leader growth (m) (1981, 1982, 1984) of trees subjected to draining, fertilizing, and thinning on the Athabasca trial drainage area[a]

Fertilizing or thinning treatment	Drainage treatments			
	Treatment 1[b]	Treatment 2[c]	Treatment 3[d]	Untreated
Control[e]	0.374	0.146	0.125	0.053
Phosphorus	0.371	0.252	0.106	0.072
Nitrogen	0.318	0.275	0.137	0.164
Thinned	0.327	0.171	0.127	0.089
Mean	0.348	0.211	0.124	0.095

[a] Sources: Alberta Forest Service. 1982. A statistical analysis of the measurement results and compendium of observations of the muskeg improvement project—Athabasca Forest. Alberta Dep. Energy Nat. Resour., Fort McMurray, Alberta. Unpublished report.
Alberta Forest Service. 1984. Muskeg improvement project—1983 analysis. Alberta Dep. Energy Nat. Resour., Fort McMurray, Alberta. Unpublished report.
Alberta Forest Service. 1985. Muskeg drainage report 1985. Alberta Dep. Energy Nat. Resour., Fort McMurray, Alberta.

[b] Cleared and scarified, two blades wide; ditched with Marttiini plough, 9 m ditch spacing.

[c] Cleared and scarified, one blade wide; unscarified strips, one blade wide; ditched with Marttiini plough, 9 m ditch spacing.

[d] Cleared and scarified, one blade wide; unscarified strips 8-9 m wide; ditched with Marttiini plough, 18 m ditch spacing.

[e] No fertilizing or thinning.

A procedure that uses a mathematical model to generate synthetic groundwater hydrographs was developed to obtain ditch depths and spacings that take into account the variable site characteristics of the study area. The procedure entails the specification of design criteria, measurement of a number of environmental parameters, comparison of synthetic groundwater hydrographs with field hydrographs, and, eventually, the selection of appropriate ditch depths and spacings. The design criteria for the Saulteaux River study required that the water table not rise above the 0.4-m depth (below the ground surface) at the midpoint between ditches for a period of more than 14 consecutive days.

The synthetic hydrographs were obtained by solving a transient-flow drain spacing formula using methods recommended by the United States Bureau of Reclamation (U.S. Department of the Interior 1984). Inputs required to solve the equation include hydraulic conductivity, water table buildup coefficient of precipitation, depth to impermeable layer, rainfall distribution, ditch spacing, and ditch depth. After the synthetic hydrographs were derived, they were scrutinized to determine which of them best fit the design criteria. For Saulteaux River, drainage ditch spacings of 25 and 40 m were deemed the most suitable.

Drainage ditches with these spacings were incorporated into a network of drainage, trap, and collector ditches draining 50 ha. They were constructed from February to March of 1984 using D6, D7, and D8 bulldozers and Caterpillar 215 and 235 backhoes. (Toth and Gillard 1984).

Groundwater table observation wells equipped with water-level recorders were installed at midpoints between ditches. They provided field hydrographs to be compared with the synthetic hydrographs. If the actual hydrograph did not match the synthetic curve, adjustments were made to the input parameters until a good fit was obtained. The values of input parameters producing close fits were noted. The next step was to verify this set of parameters in the field through another monitoring period. If the synthetic hydrograph did not match the actual hydrograph, the input parameters for the model were adjusted until they did. The final set of input parameters could then be used together with specified design criteria to determine the ditch depth and ditch spacings for an operational drainage system.

Preliminary results from this study (Lieffers and Rothwell 1987) indicate that drainage lowered the water table 20–50 cm. In 1985 the maximum ground temperature (16°C) at 10-cm depth on the drained area was 4°C higher than on the undrained site. Temperatures were lower at depths 40 and 60 cm on the drained site, and there was some delay in thaw compared to the undrained site (Swanson and Rothwell 1986). Flowering and bud flush of tamarack, and flowering of black spruce, occurred earlier on the drained site, but black spruce buds flushed earlier on the undrained site (Lieffers and Rothwell 1987).

Kimiwan

The ultimate purpose of the Kimiwan drainage project is to convert nonproductive forested wetlands into productive forest areas (Alberta Forest Service 1984a). The drainage site, located 75 km southeast of Peace River town (Fig. 3, Table 9), is 172 ha in extent and supports black spruce with a ground cover dominated by sphagnum and Labrador tea (*Sphagnum* spp. and *Ledum groenlandicum*). Peat depth ranges from 0.05 m to several metres with an average of about 0.61 m. The peat is underlain by Gleysolic soils.

Work began in February 1984 with two D6 crawler tractors with blades used to clear lines two blades wide (i.e., 2 × 3.5 m) at a rate of 67.2 m h^{-1}. Two backhoes, a 215 Caterpillar and a 245 Caterpillar, were then used to excavate 2 787 m of main drainage ditches with depths ranging from 0.6 to 2.44 m. The 245 Caterpillar backhoe dug 62.6 m of ditch per hour. In September 1984, two D6C Caterpillars, operating in tandem and hooked to a Marttiini plough (Fig. 4), were used to dig 71 km of lateral ditches with an average spacing of 20 m at a rate of 1 014 m h^{-1}. (Alberta Forest Service 1984a, b).

Kimiwan II

A second Kimiwan drainage project was begun about 15 km north of McLennan (Fig. 3, Table 9) in January 1985 (Alberta Forest Service 1985a). The stated purpose was to increase growth of coniferous species through improved drainage. The area to be drained is 456 ha in extent and supports black spruce with crown density of 51–70%, and dominants and codominants in the 6.1–12 m height class.

The drainage system design provides for 4.45 km of main ditches, 2.15 km of boundary ditches, and 115 km of lateral ditches. The laterals will be spaced 50 m apart. All ditch lines have been marked and cleared for ditching, which is scheduled for 1987.

Manning

The purpose of the Manning project, the most northerly of the Alberta drainage projects, is to determine the feasibility of draining wetlands to increase the productive forest land base (Alberta Forest Service 1984c).

The area, which is 105 ha in extent and contains peat 1-3 m deep, is located about 50 km northwest of Manning (Fig. 3, Table 9) near the southern fringe of the discontinuous permafrost zone. It is an area where in September a frozen layer is encountered 60% of the time during soil sampling (Lindsay and Odynsky 1965). The site supports black spruce 3-40 years old.

In January 1984, a D6 crawler tractor with blade was used to clear ditch lines of trees, and a 235 Caterpillar backhoe was used to excavate 3 766 m of main drainage ditches 1.5 m deep, at a rate of 52 m h^{-1}. In the fall of 1984, three types of machines were used to construct 40 km of lateral ditches with spacings of 25-30 m: a Kopo trencher (Fig. 5), a Mallett wheel ditcher (Fig. 6), and a Marttiini plough. The Kopo and Mallett machines were pulled by a 70 hp Massey-Ferguson 275 tractor specially adapted for drainage work. The heavier Marttiini plough was pulled by two D6C crawler tractors hooked in tandem.

The Kopo trencher, which is a Finnish-designed auger, excavates a rectangular-shaped ditch about 1 m deep and 0.35 m wide. It was first tested in Alberta in June 1984 at the Manning site, where it completed 600 m of lateral ditches. The machine performed well in clay and frozen ground less than 0.3 m thick but encountered difficulties when thicknesses exceeded this amount (Alberta Forest Service 1984d).

The Mallett wheel ditcher is an Italian machine that digs a V-shaped ditch about 0.3 m deep and 1 m wide by means of a large wheel churning through the peat at approximately 400 rpm. Two passes are necessary to complete the ditch. It performed well in deep peat but could not penetrate clay or frozen peat or remove stumps and large logs (Alberta Forest Service 1984e).

The Marttiini plough constructed ditches from 0.38 to 1.07 m deep and about 2 m wide. It too encountered problems with frozen peat. Using the plough with crawler tractors in tandem generated problems not encountered with the other machines. Sometimes, the tractors had to drive through the trees to avoid wet areas. It was also very difficult to use the plough to link the main and lateral ditches properly (Alberta Forest Service 1984e).

Because of the presence of permafrost, none of the machines was able to construct ditches of uniform depth. Consequently, the efficiency of the drainage system was reduced because frost bumps impeded water flow through the ditches. For this reason, ground temperature studies should be conducted on drained and undrained areas before further drainage projects are undertaken this far north.

SUMMARY OF ALBERTA FOREST DRAINAGE PROJECTS AND RESEARCH NEEDS

The Alberta forest drainage projects have served as proving grounds for a variety of clearing and excavating equipment. In addition to helping evaluate the suitability of equipment for drainage purposes, they have provided estimates of machine production rates and drainage costs. In northern parts of the province, a tentative drainage site should be inspected for widespread, discontinuous permafrost before ditching because machines may be unable to construct ditches on permafrost with the required profiles and gradients.

With the exception of the Athabasca Forest drainage study, none of the Alberta drainage projects provides forest growth data—most of them have not been in existence long enough. This information is essential for measuring changes in forest productivity due to drainage. Collection of forest growth data on the Athabasca Forest trial drainage area should be continued because the project is the oldest forest drainage experiment in the province. Growth data have been collected from it on a regular basis since it was drained nearly 12 years ago. Existing data should be subjected to comprehensive statistical analyses and supplemented with core and stem analyses through destructive sampling. Information so obtained will provide foresters with an estimate of forest growth rates to be expected for other forest drainage projects in Alberta.

The impact of drainage on the environment was investigated in the Saulteaux River study only. In this case, ground temperature and chemical water quality were monitored. The impact of drainage on sediment concentrations, ground vegetation, peat subsidence, and wildlife habitat was not considered. These components should be included in future forest drainage studies.

The Saulteaux River project provided a method to determine ditch spacings that allow the groundwater table to rise above a specified depth below the surface for no more than 14 days. We have no scientific basis to determine what the specified depth should be to promote tree growth best, although optimum depths for some

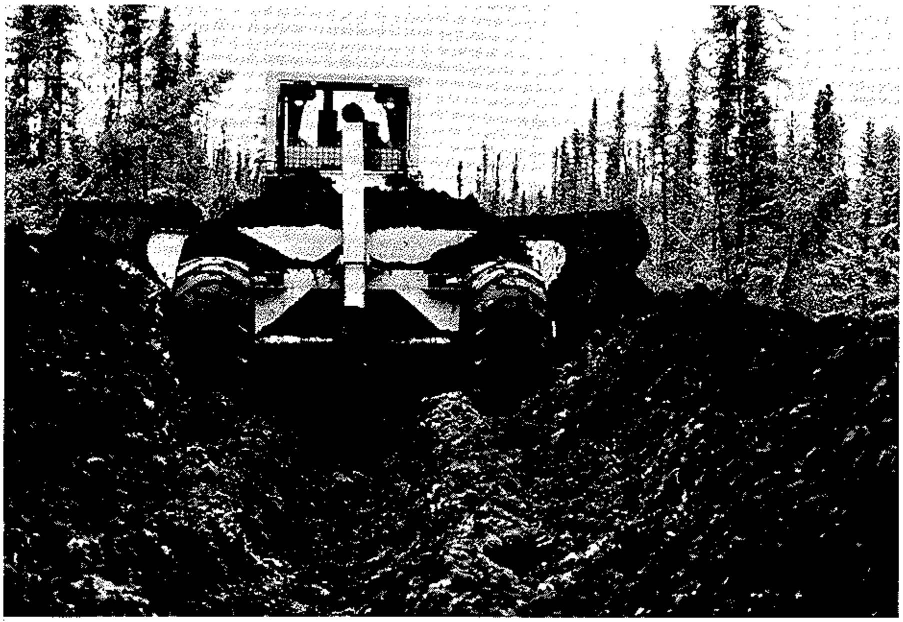

Figure 4. Marttiini plough (Kimiwan).

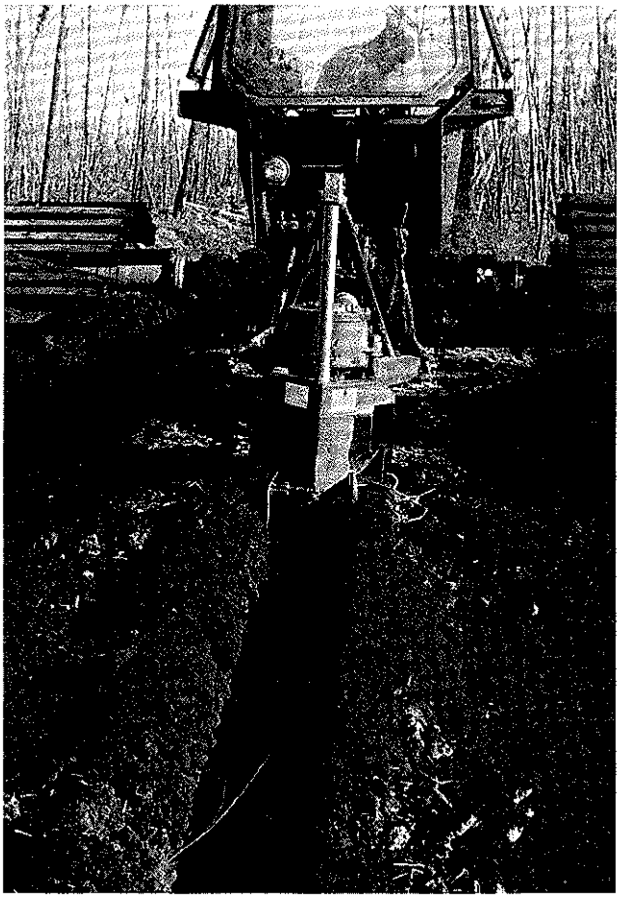

Figure 5. Kopo trencher (Manning). (Photo courtesy of Alberta Forest Service.)

European and southeastern U.S. conditions have been suggested (Table 12). Relationships among tree growth, depth to shallow water table, and water content in the unsaturated zone need considerably more research.

Beaver dams are a problem common to most forest drainage projects in Alberta. Plans for their removal should be integrated into ditch network maintenance programs, in consultation with wildlife authorities, to ensure efficient operation of the drainage systems.

Table 12. Optimum depths to groundwater table for different tree species or site types[a]

Location	Species or site types	Depth to water table (m)
Norway	—	0.30
Byelorussia	Best swamps	0.50
	Poor swamps	0.30[b]
Estonia	—	0.40-0.50
Latvia	Pine	0.18
	Spruce	0.29
	Birch	0.42
Southeastern USA	Slash and loblolly pines	0.45

[a] After Heikurainen (1964).
[b] Plus the thickness of loose humus.

A WETLANDS CLASSIFICATION SYSTEM FOR ALBERTA FOREST DRAINAGE

Although extensive wetlands occur in the boreal forest of both Alberta and northern Ontario, there are pronounced differences between the two regions. Annual precipitation in northern Alberta is about half that of northern Ontario, and Alberta summers are hotter and drier.

A consequence of these differences is that northern Alberta has experienced a greater incidence of forest fires in the past than has northern Ontario. Alberta's complex forest fire history makes it difficult to develop a classification system for Alberta such as the Forest Ecosystem Classification produced for the clay belt of northern Ontario, a system that can be used to determine the suitability of wetlands for drainage and serve as a basis for designing a drainage network. The Wetlands Classification System developed by the National Wetlands Working Group (Zoltai and Pollett 1983), the Johnson-Zoltai physiognomic classification for peatland vegetation, and Jeglum's guidelines for trophic states are considered to be the most useful systems for these purposes in Alberta (Rothwell 1986).

There have been attempts in Alberta (Harkonen 1985; Makitalo 1985) to establish relationships of water and peat properties of peatland to ground vegetation and tree growth, and between ground vegetation species and tree growth. Harkonen (1985) was able to separate ground vegetation into groups that had sufficient nutrients for sustained forest growth, and those that did not. Makitalo (1985), however, was unable to establish correlations between each of these groups and tree growth. He did find that on a richer and wetter peatland type, tamarack growth showed stronger correlation with site nutrients and ground vegetation than did black spruce. On a drier and poorer peatland area, black spruce growth correlated only with site nutrients. On both peatland types, black spruce basal area correlated well with individual ground vegetation species.

Before forest drainage is carried out on an operational scale in Alberta, a wetlands classification system must be developed to delineate areas suitable for drainage and capable of increased wood production. Some elements of such a classification, which would be applicable to Saskatchewan and Manitoba as well as Alberta, are already in place (Zoltai and Pollett 1983).

CANADA-ALBERTA FOREST RESOURCE DEVELOPMENT AGREEMENT WETLAND DRAINAGE AND IMPROVEMENT PROGRAM

In 1985, after the signing of the Canada-Alberta Forest Resource Development Agreement, the Canadian Forestry Service (CFS) and the Alberta Forest Service (AFS) prepared a research and development proposal to establish three experimental drainage areas in Alberta's boreal forest. The Wetland Drainage and Improvement Program arose in response to the concerns and research needs mentioned in the last two sections. It is aimed at developing cost-effective and environmentally sound forest drainage technology appropriate for Alberta. This technology could also be applied to Saskatchewan and Manitoba. Its major objectives are as follows:

1. to develop optimal silvicultural regimes for increasing the growth of commercial tree species on wetlands with lowered water tables; and

2. to assess the effects of drainage on soils, local hydrology, ground vegetation, and tree growth.

Although the CFS and AFS have distinct responsibilities within the program, close cooperation between the agencies has been maintained for all aspects since program inception. Therefore, no attempt will be made to identify separate responsibilities in the ensuing discussion.

The experimental design requires that portions of each study area be designated for ditching and the remainder preserved as control. This scheme is necessary when ditching is undertaken early in a study, and meaningful amounts of pretreatment data cannot be obtained. The main disadvantage of this approach is the difficulty in deciding if differences between control and treated sites are treatment effects or the result of differences in site characteristics.

The best method of evaluating drainage effects is by repeated measurements on the same sites before and after drainage (Heikurainen 1964). In this method, the uncertainty due to site differences is reduced. The disadvantage, of course, is the long waiting period before treatment is implemented and results are available. Fortunately, pretreatment data for only 1 or 2 years are required to evaluate the effects of ditching on some variables, such as groundwater table levels. Because the ditch network construction schedule for the Canada-Alberta Wetlands Improvement Program allows for the gathering of some pretreatment data, both methods outlined above will be applied.

In summer 1985, a CFS-AFS team selected three forested wetland areas as experimental drainage sites. The forest vegetation on each originated after a fire. All areas were surveyed, instrumented, and sampled in a similar manner. Weather stations consisting of a recording precipitation gauge and a recording hygrothermograph were installed. Survey lines were cut, topographic surveys conducted, and topographic maps produced with contour intervals of 0.5 m and scales of 1:2000 or 1:5000.

Preliminary peat, water, and vegetation surveys and sampling programs were completed to determine wetland, vegetation, and peat types, peat depths, nutrient status, and other site characteristics. Saturated hydraulic conductivity was measured in the top 1 m of soil using the piezometer method (U.S. Department of the Interior 1984).

Drainage ditch network designs were prepared for each area using field observations, topographic maps, and enlarged aerial photos[4]. Toth's synthetic hydraulic curve method (Toth and Gillard 1984) was used to find the optimum ditch spacings. Each network design allowed for evaluation of different ditch spacings on the same site.

In 1986 four transects were established on each experimental area, one on the control site and three at different ditch spacings, perpendicular to ditch lines, on the area to be drained. Each transect was instrumented, sampled, and surveyed to measure the effects of drainage on groundwater table levels, ground temperatures, ground vegetation composition, and peat subsidence. Peat, groundwater, and foliage samples were collected from all transects to determine the existing levels of nutrients important for tree growth.

EXPERIMENTAL DRAINAGE AREAS

Goose River

The Goose River experimental drainage area is a black spruce swamp situated about 35 km southeast of Valleyview (Fig. 3, Table 9). It is accessible from the Gulf Oil road and the Sweathouse Forestry Tower road, which run along the western and northern boundaries of the swamp, respectively. The swamp, which covers about 320 ha, is characterized by thin (less than 1 m) peat over clay. A small creek runs westward through the site. Near the western edge of the swamp, the creek cuts through a fairly steep ravine with slopes of about 40%. The swamp supports a black spruce stand 40–50 years old.

The drainage plan provides for drainage of 135 ha north of the creek using 30, 40, and 50 m ditch spacings (Fig. 7). The ditch network was marked out and 5-m rights-of-way were cleared with a D6 during winter when the ground was frozen. Ditch construction with a Lannen

[4] M. Rosen, Ontario Ministry of Natural Resources, assisted in this process. The project benefited from his experience in designing and constructing the Wally Creek drainage ditch network in Ontario.

Figure 6. Mallett wheel ditcher (Manning).

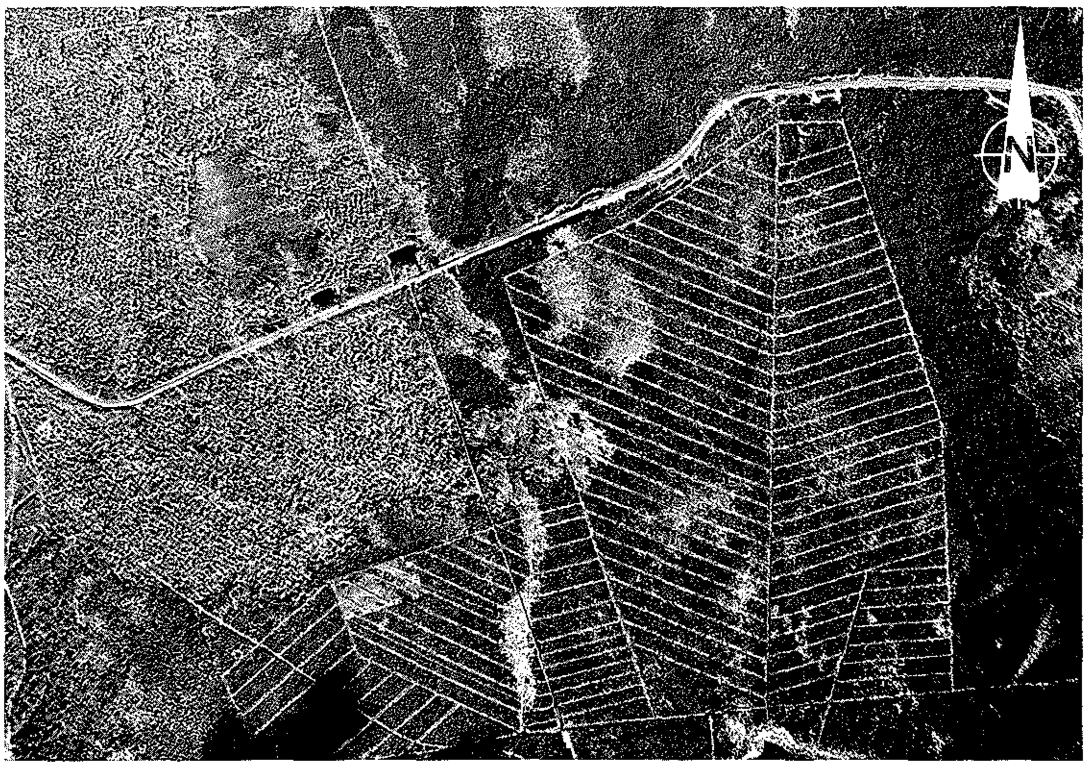

Figure 7. Aerial photo of Goose River experimental drainage area. Scale 1:16 830.

S10 excavator (Fig. 8) was completed in September 1986. The ditches are about 0.9 m deep and 1.4 m wide. Of the three experimental areas, the Goose River site has the most limited set of pretreatment data, from only the summer of 1986.

McLennan 28

McLennan 28 is a treed bog located in Section 28 immediately west of the Kimiwan II demonstration drainage project, about 15 km north of McLennan (Fig. 3, Table 9). Because the area is 6 km from the nearest road, access is difficult and requires the use of all-terrain vehicles.

A water track or fen is located along the western edge of the bog (Fig. 9). It feeds into a series of beaver ponds near the northwest corner of the experimental drainage area. The experimental area itself, which supports black spruce and slopes from the southeast toward the beaver ponds, contains only one small, well-defined stream channel.

About 90 ha in the southern part of the section have been marked and cleared for ditching with ditch spacings of 30, 40, 50, and 60 m. The remaining area to the north serves as a control. Ditching began in October 1986.

Wolf Creek

The smallest (132 ha) of the three experimental drainage areas set up under the agreement is located within a confluence of Wolf Creek about 30 km southeast of Edson (Fig. 3, Table 9). This wetland, a treed fen, is characterized by peat depths ranging from 0 to more than 3 m. The shallow peat occurs near the stream channels, and the deep peat is found at the center of the confluence area away from the creeks. Peat depth increases upslope and away from the confluence area. Black spruce (80 years old) and tamarack (70 years old) are the predominant species in the fen, but mineral islands within the fen support mature lodgepole pine and white spruce. A comprehensive pretreatment data base is forthcoming from the Wolf Creek site when it is drained in the fall of 1987. The drainage plan for Wolf Creek is shown in Figure 10.

RESEARCH PLAN FOR THE CANADA-ALBERTA AGREEMENT EXPERIMENTAL DRAINAGE AREAS

The division of each experimental area into drained and control sections is an essential feature of the research plan. The components of the plan are outlined below together with the progress to date for each.

1. Evaluation of the effects of drainage on tree growth

It is essential to establish and to measure tree growth permanent sample plots on both drained and control (undrained) areas. There must be a commitment to remeasure the plots periodically for at least another 20 years.

Permanent sample plots were laid out and measured on the Wolf Creek experimental area during fall 1986. Some plots will be established along the instrumented transects perpendicular to the ditches so that tree growth can be related to distance from the ditch. Pretreatment growth data will be gathered through destructive sampling and stem analyses.

2. Tree species evaluation

To determine which species adapt well to newly-drained conditions, the Alberta Forest Service has cleared a portion of the Goose River experimental area and will plant lodgepole pine, white spruce, and black spruce.

3. Fertilization trials

The Alberta Forest Service is investigating the effects of drainage plus fertilization on tree growth. Permanent sample plots for this purpose were installed in 1987.

4. Groundwater table profile investigations

Groundwater table investigations are essential to confirm if the desired water levels were attained and to determine the relationships between tree growth and water table depth.

Groundwater table configurations will be monitored through a system of groundwater wells installed along each transect. Ninety-seven 5-cm diameter wells, and six 15-cm diameter wells were installed in 1986. Pressure transducers connected to battery-operated data loggers were inserted in 24 of the 5-cm wells to provide continuous records of changes in water levels. Water level recorders will be mounted on the 15-cm diameter wells in the future.

Figure 8. Lannen S10 ditcher (Goose River).

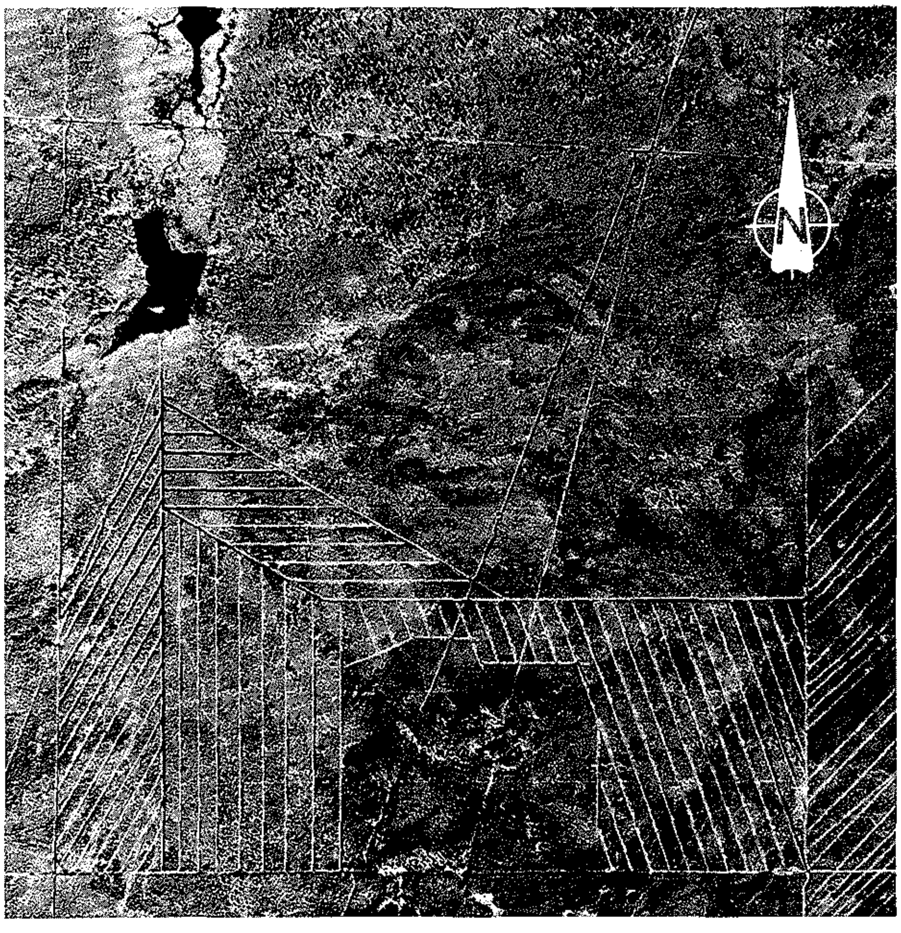

Figure 9. Aerial photo of McLennan 28 experimental drainage area. Scale 1:16440.

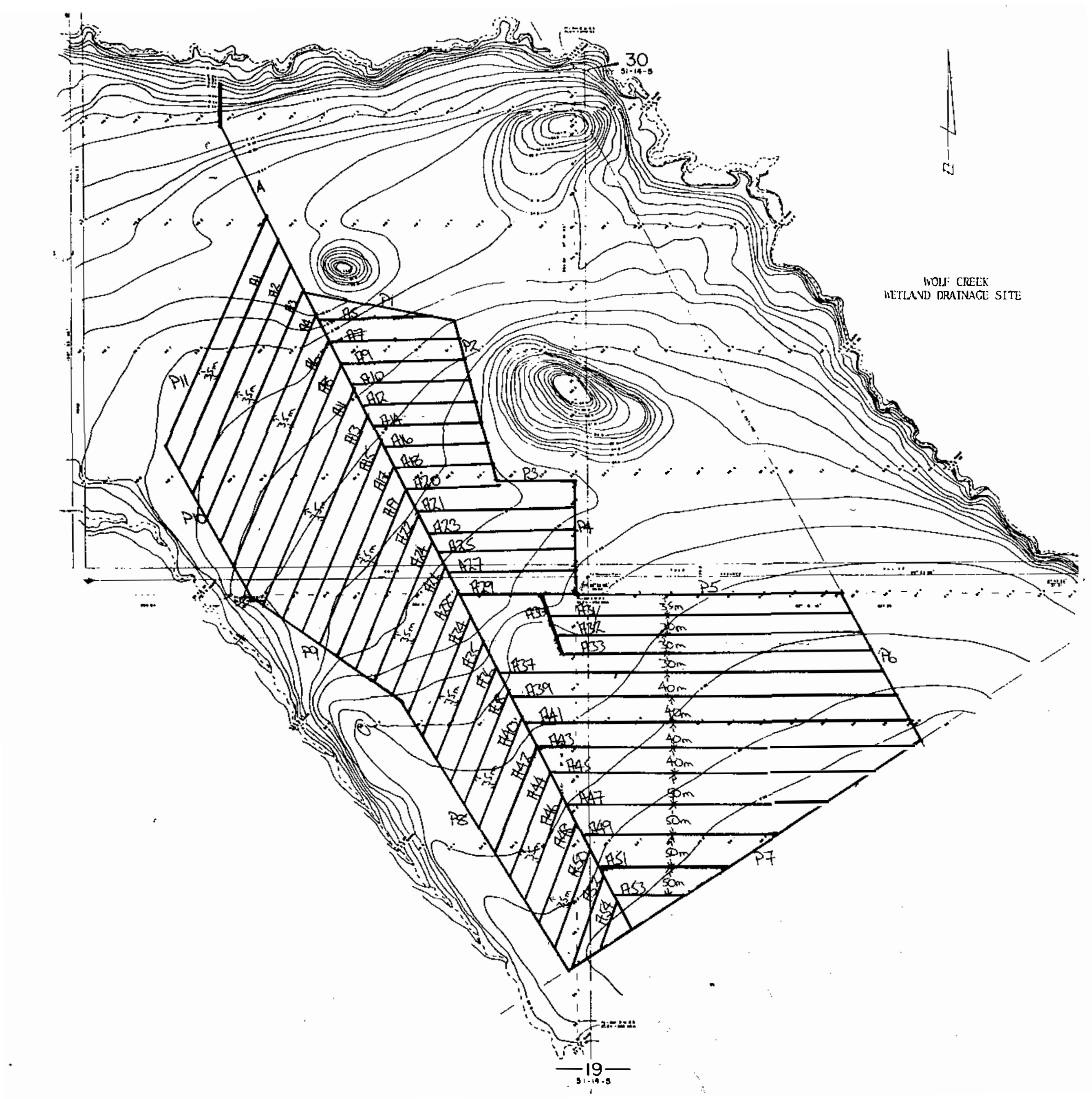

Figure 10. Drainage plan for Wolf Creek. Scale 1:9900.

5. Ground temperature investigations

Ground temperature will be affected by groundwater level control operations. It is an important factor affecting the ground freeze-thaw cycle and tree root growth and development.

One temperature probe, about 3 cm in diameter, was installed on each transect. Each probe, connected to a battery-driven data logger, supported sensors at the air-soil interface and at depths of 0.075, 0.15, 0.30, 0.45, and 1.0 m.

6. Nutrient level studies

Existing levels of nutrients important for tree growth, such as nitrogen, phosphorus, and potassium, need to be determined on the experimental drainage areas.

Peat and groundwater samples were collected from all transects in summer 1986 and prepared for analyses. In late summer 1986, at the end of the growing season but before leaf fall, foliar samples were collected from black spruce and tamarack on each transect.

7. Ground vegetation composition

There is little or no information on the effects of drainage for forestry on ground vegetation composition in Alberta. This information will be obtained through annual measurement of ground vegetation permanent sample plots, each 1 m^2, established near each instrumented transect in 1986.

8. Peat subsidence investigations

Because fibrous surface peat has a very high porosity, draining this material can result in a noticeable drop in the ground surface level. To measure this subsidence, three 13-mm diameter steel reinforcing rods were driven to mineral soil on each transect so that 15 cm projected above the ground surface. The projection above ground will be measured once a year after drainage.

9. Water quality investigations

There are three areas of water quality that need to be considered when investigating the impact of forestry drainage operations: sediment transport, changes in inorganic water chemistry, and changes in organic water chemistry.

The CFS is monitoring sediment loads and inorganic chemical water quality by sampling upstream and downstream from points where water from the main ditch of each drainage network enters the water course. Sediment samples are collected using a DH-48 sediment sampler, and inorganic chemical water quality samples are collected as "grab" samples in 250-ml plastic bottles. Sampling began before any ditching took place.

There is scant information on the effects of forest drainage on organic chemical water quality. We do not know what components of peat have the potential to become water pollutants; nor do we know the accepted tolerable limits for such pollutants.

FUTURE DIRECTION OF FOREST DRAINAGE RESEARCH

The foregoing list of forest drainage-related investigations is by no means exhaustive. In addition to organic chemical water quality, there are several other research topics that merit future consideration. They include the following:

1. The development of a wetlands classification system is an essential prerequisite for operational forest drainage and drainage system design.

2. An investigation of relationships among tree growth, groundwater table levels, and water content in the unsaturated zone for different tree species should be conducted. These relationships can be used to determine which species are best suited for different types of drained sites. They can also be used to determine if a drained site should be cleared of existing trees and replaced with seedlings, perhaps of a different species.

3. Planning drainage network designs for future forestry operations should provide suitable access to drained sites for silviculture and harvesting purposes. Otherwise, frequent movement of vehicles across ditches will cause rapid deterioration of the ditch network. To ensure drainage efficiency, ditch networks should be properly maintained for as long as they are required. Sediment ponds and sediment causing obstruction to water flow should be cleaned out periodically. The design of sediment traps and ponds can be improved and drainage system maintenance procedures developed.

4. Computer simulation models for drainage system design should be developed. Computer simulation models serve as very useful tools because they can simulate many scenarios that would be prohibitively expensive to implement in the field. Toth's adaptation of the U.S. Bureau of Reclamation model (Toth and Gillard 1984) is one example of a model that was applied to forest drainage. It can relate groundwater table levels to ditch spacings. Research in computer modeling for drainage design purposes should be continued.

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APPENDIXES

Appendix 1. Tree species referred to in this report and their common names.

Appendix 2. Glossary of some drainage terms.

APPENDIX 1

TREE SPECIES REFERRED TO IN THIS REPORT AND THEIR COMMON NAMES

Species	Common name
Abies	
balsamea (L.) Mill.	Balsam fir
Betula	
ermanii Cham.	Japanese birch
papyrifera Marsh.	White birch
Larix	
decidua Mill.	European larch
x eurolepsis Henry	Hybrid larch
leptolepis (Sieb. & Zucc.) Gord.	Japanese larch
laricina (Du Roi) K. Koch	Tamarack or eastern larch
sibirica Ledeb.	Siberian larch
Picea	
abies (L.) Karst.	Norway spruce
glauca (Moench) Voss	White spruce
mariana (Mill.) B.S.P.	Black spruce
omorika	Serbian spruce
sitchensis (Bong.) Carr.	Sitka spruce
Pinus	
banksiana Lamb.	Jack pine
contorta var. *latifolia* Engelm.	Lodgepole pine
elliottii Engelm.	Slash pine
strobus L.	Eastern white pine
sylvestris L.	Scots pine
taeda L.	Loblolly pine

APPENDIX 2

GLOSSARY OF SOME DRAINAGE TERMS

Boundary, perimeter, surround, or *trap* ditches intercept water entering the drained area and divert it around the area into a natural watercourse or into a main ditch.

Collector or *main* ditches collect water from the contour ditches and feed it to another collector ditch or natural watercourse. They are located in areas with the steepest gradients and deepest peat or in natural draws.

Contour, drainage, feeder, or *lateral* ditches are designed to lower the groundwater table. They are usually placed parallel to each other in a herring-bone pattern and intersect contour lines at a small angle. (In this report, "drainage ditch" is used in a general way. It is *not* used in the context of the foregoing definition.)