The Canada-Alberta Wetlands Drainage and Improvement for Forestry Program

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ABSTRACT

In 1985, a wetland drainage and improvement for forestry program was instituted under the Canada-Alberta Forest Resource Development Agreement to determine the effects of drainage on tree growth, ground vegetation, soils, peat, and local hydrology. Three experimental areas were chosen and portions of each drained in 1986 and 1987. Data were collected from drained and undrained portions. Additional data were collected from a treed swamp near Fort McMurray that was subjected to different drainage treatments between 1975 and 1980. The intent, in this case, was to obtain an interim estimate of tree growth rates until sufficient time has elapsed to obtain estimates from permanent sample plots on the experimental areas.

Results showed that the average depth to groundwater table after drainage was between 37 and 90 cm and varied with ditch spacing. The corresponding drops in water table levels were between 17 and 78 cm. The test areas with 30-m ditch spacings appeared to be overdrained.

Stream water quality data from one site only have been interpreted so far. They show that drainage had little effect on measured physical and chemical stream water quality during low flows. Further analyses are required to determine the effects of drainage on peak flows.

Initial results from the three experimental areas indicate that drainage has resulted in reduced ground vegetation cover (mosses, sedges and other herbs) and vigor.

Lowering the water table on the swamp near Fort McMurray resulted in sigificant increases in height, diameter and volume of 30-year-old black spruce (Picea mariana). The increase in growth of black spruce was accompanied by an equally impressive growth of alder (Alnus crispa), willow (Salix spp.), birch (Betula pumila), aspen (Populus tremuloides) and balsam poplar (P. balsamifera).

FIGURES

TABLES

1. INTRODUCTION

In 1985, Forestry Canada (FC) and the Alberta Forest Service (AFS) initiated the Wetlands Drainage and Improvement for Forestry Program under the Canada-Alberta Forest Resource Development Agreement (FRDA) (CFS and AFS 1984). The program was designed to develop cost-effective and environmentally sound forest drainage technology appropriate for the boreal forest and to meet the following objectives:

1. to develop optimal silvicultural regimes for increasing the growth of commercial tree species on forested wetlands with lowered water tables, and
2. to assess the effects of drainage on soils, local hydrology, ground vegetation, and tree growth.

The study arose in response to concern by Alberta that the productive forest land base in Alberta was decreasing as more forest land was withdrawn for non-forestry uses. This concern, together with reports from Finland indicating that drainage can increase forest productivity fivefold on the best peatland sites - to a volume increment in excess of 10 m^3 ha^{-1} a^{-1} in some cases (Heikurainen 1964) - led foresters to consider increasing the wood-growing capability of forested wetlands in Alberta. Alberta contains nearly 13 million ha of peatlands, about 4 million of which are considered suitable for drainage and conversion to productive forests. There is, however, very little information on the long-term effects of forest drainage on tree growth and the environment in Canada generally and in Alberta particularly.

In the summer of 1985, a FC-AFS team selected Goose River, McLennan 28 and Wolf Creek wetland areas as experimental drainage sites. The vegetation on each originated after a fire. Although these and several other forested wetland drainage projects were recently implemented in Alberta (Hillman 1987, Toth and Gillard 1988) the time span since drainage is too short to obtain meaningful tree growth response data from them. Consequently, tree growth data from a drainage project established by the Alberta Forest Service near Fort McMurray in 1975 were used to obtain estimates of tree growth response to drainage.

2. SITE DESCRIPTIONS AND TREATMENTS

The four sites investigated under the Wetlands Drainage and Improvement for Forestry Program are located in the mixedwood boreal forest region of Alberta (Rowe 1972). Their locations are shown in Fig. 1 and their legal descriptions and other details are given in Table 1. Descriptions for each site are presented separately.

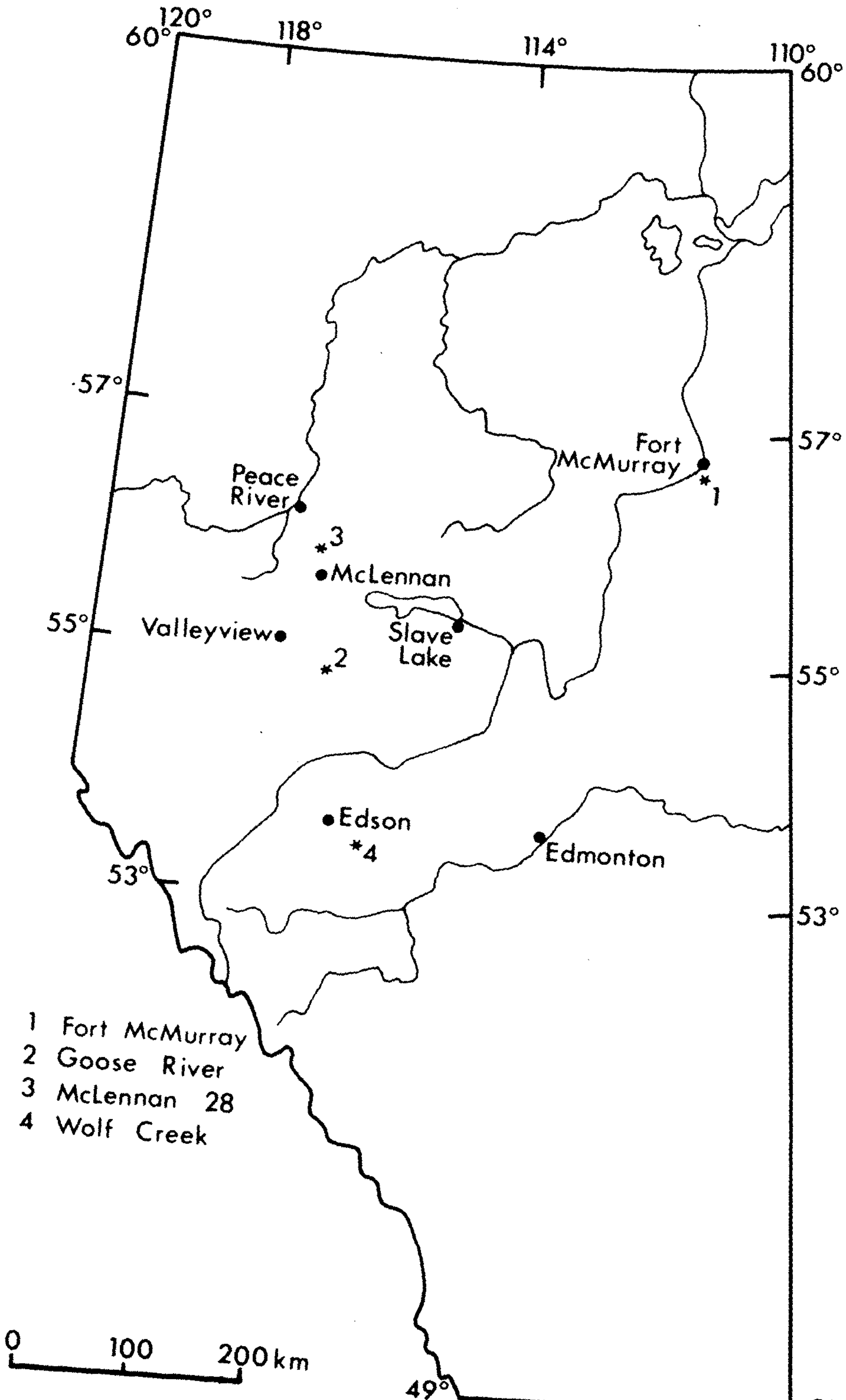

Figure 1. Locations (*) of the experimental drainage areas in Alberta.

Table 1. Canada-Alberta Wetlands Drainage and Improvement for Forestry Program - site information

Site (legal description)	Total area[a] (ha)	Drained Area (ha)	Drained Date completed (d/ m/ a)	Total ditch length (km)	Nominal ditch spacing (m)	Ditch spacings evaluated (m)	Drainage ditch density ($m\ ha^{-1}$)
Goose River (14-68-19-W5[b])	320	135	30/09/86	40	40	30, 40, 50	294
McLennan 28 (28-79-19-W5)	259	90	02/08/87	30	30,40	30,40,50,60	333
Wolf Creek (19-51-14-W5)	132	60	28/10/87	35	35	30, 40, 50	333
Fort McMurray (24-87-9-W4)	89	25[c]	-/-/80[d]	-	10	10	-

[a] Undrained portions were designated as control areas.
[b] Section 14, Township 68, Range 19, West of 5th Meridian.
[c] Data from only a portion of the drained area at Fort McMurray were used in this study.
[d] A number of drainage treatments were carried out between 1975 and 1980.

2.1 Goose River

The Goose River experimental drainage area (Fig. 2) is a black spruce (Picea mariana) swamp situated about 35 km southeast of Valleyview at an elevation of 850 m. The mean annual temperature at Valleyview is 2.3°C. The average January and July temperatures are -15.9°C and 15.8°C, respectively. At the Sweathouse Tower Lookout adjacent to the site, the average July temperature is 14.7°C. The average annual precipitation for Valleyview is 519 mm, 302 mm of which falls during May through September. The average winter snowfall is 169 mm. The average May-September precipitation for the Sweathouse Tower Lookout is 413 mm (Alberta Environment 1987). The area averages 100 frost-free days annually (Longley 1968).

The swamp, which covers about 320 ha, is characterized by thin (less than 1 m) peat over clay. A small creek runs westward across the site cutting through a fairly steep ravine with slopes of about 40%, near the swamp's western edge.

The swamp supports a black spruce stand 40-50 years old and a shrub understory dominated by Ledum groenlandicum. The herb stratum consists primarily of Carex trisperma, Equisetum arvense, E. sylvaticum, and Vaccinium vitis-idaea, with lesser amounts of Rubus chamaemorus. Calamagrostis inexpansa and Oxycoccus microcarpus are constant species but have generally low cover. Sphagnum angustifolium and S. magellanicum are the predominant mosses in the wetter areas; S. fuscum and Pleurozium schreberi predominate in the drier areas. A few patches of Cladina mitis occur in more open, drier, and elevated areas (Johnson 1987).

Ditching at Goose River was started in June, 1986 and completed in September, 1986. In spring 1987, 64 fertilizer and thinning plots were established in a split plot design on the Goose River site (Fig. 3). Half of the plots were thinned from 7000 to 1600 trees ha^{-1} in March and April, 1987; the other plots were not thinned. For each thinning treatment (thinned and not thinned), eight fertilizer treatments were applied: no fertilizer (control), nitrogen (N), phosphorus (P), potassium (K), NP, PK, NK, and NPK. Nitrogen was applied at 200 kg ha^{-1} as ammonium nitrate, phosphorus at 100 kg ha^{-1} as triple superphosphate, and potassium at 100 kg ha^{-1} as muriate of potash (KCl). The design provided for four replicates (Alberta Forest Service 1987).

In August 1987, 2 hectares of cleared land were ditch-mounded (Fig. 3) and later (1988) planted with black spruce, tamarack (Larix laricina), white spruce (Picea glauca), lodgepole pine (Pinus contorta) and Siberian larch (Larix sibirica). The experiment was a randomized block design with four replicates each. (Alberta Forest Service 1988). In one experiment involving two species the mounds versus flat ground was evaluated. Ditch-mounding involved digging ditches 10 meters apart and depositing each bucket of spoil from the ditches as mounds, evenly distributed on the ground between the ditches (Fig. 4).

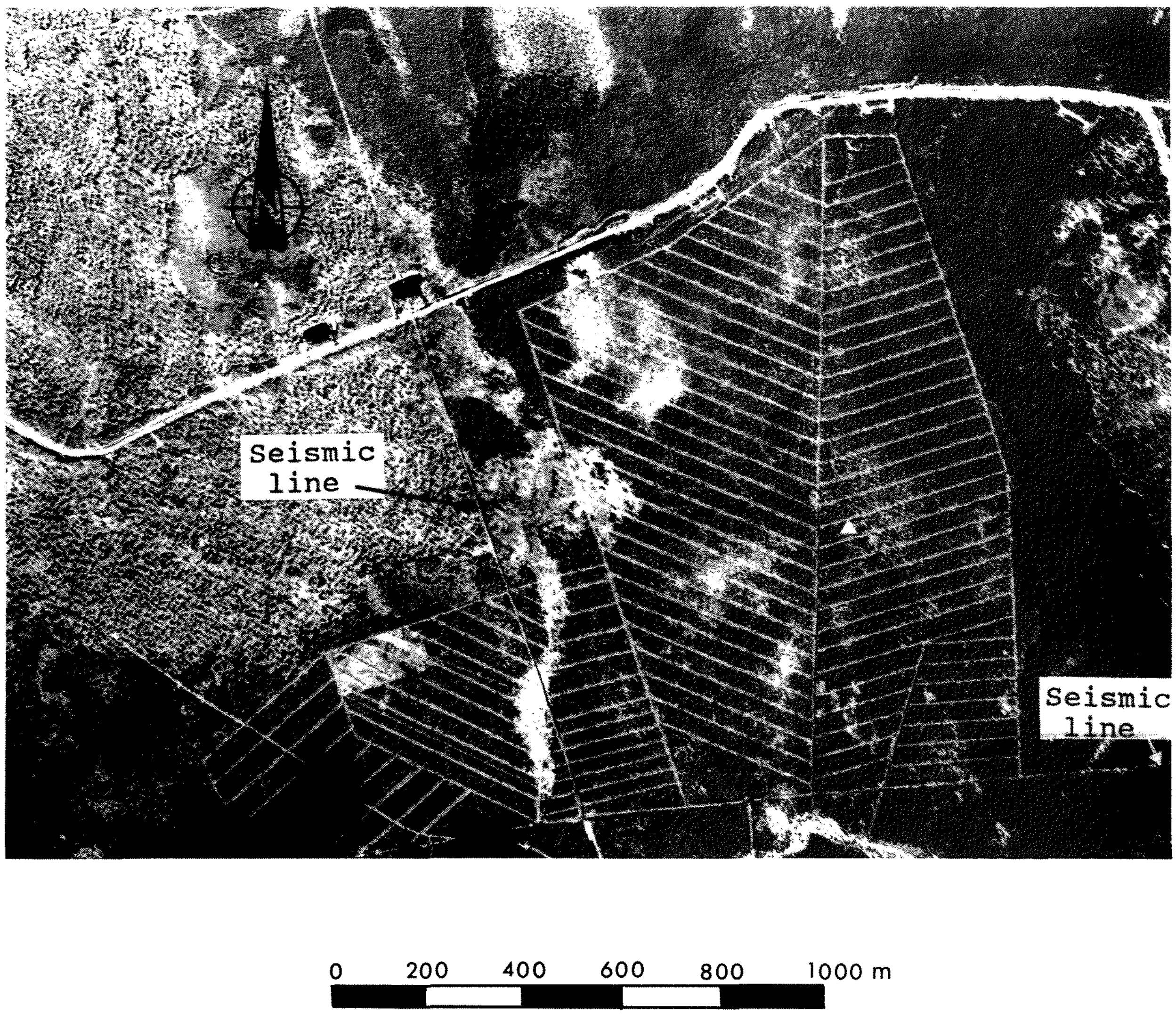

Figure 2. Aerial photo of the Goose River ditch network.

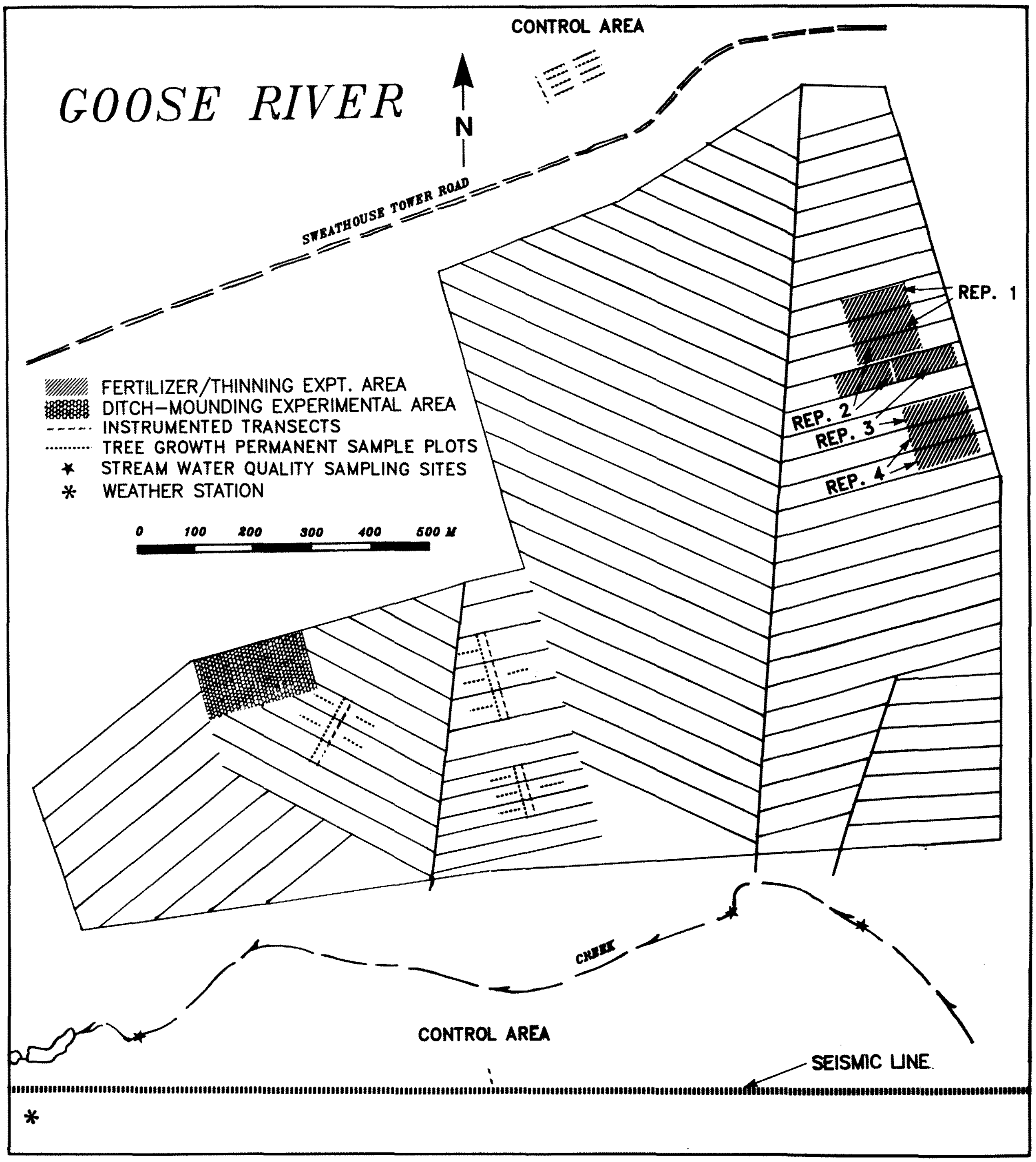

Figure 3. Locations of instrumented transects and permanent sample plots at Goose River.

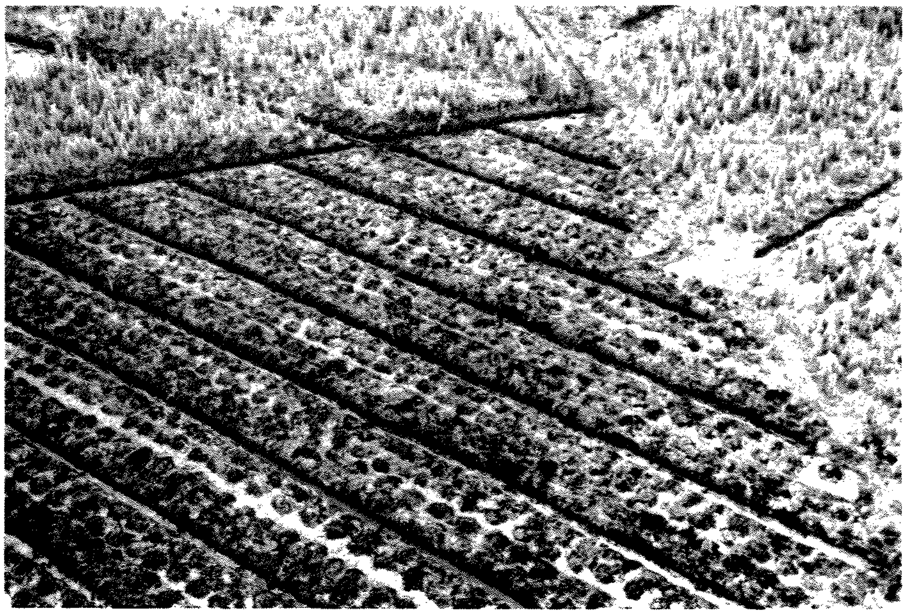

Figure 4. Oblique aerial photo of ditched-mounded area at Goose River.

The seedlings were planted on the mounds. There were also "scoop and dump" mounds the spoil for which did not originate from the ditches. The intent was to ensure 2000 mounds ha-1.

2.2 McLennan 28

The McLennan 28 experimental drainage area (Fig. 5) is a treed fen, characterized by a bog cap in places, supporting young black spruce and tamarack. It is located about 15 km north of McLennan at an elevation of 660 m. Because the area is 6 km from the nearest road, access is difficult and is achieved using all-terrain vehicles.

The mean annual temperature at Falher, a station with long-term weather records and the closest to McLennan 28, is 1.0°C. The average January and July temperatures are -17.4°C and 15.8°C, respectively (Alberta Environment 1979).

At Falher, the average annual precipitation is 423 mm, 237 mm of which falls during May through September. The average annual snowfall is 158 cm. The area averages 100 frost-free days annually (Longley 1968).

A water track located along the western edge of the site feeds into a series of beaver ponds near the northwest corner of the section. The experimental area, which slopes from the southeast toward the beaver ponds, contains only one small well-defined stream channel.

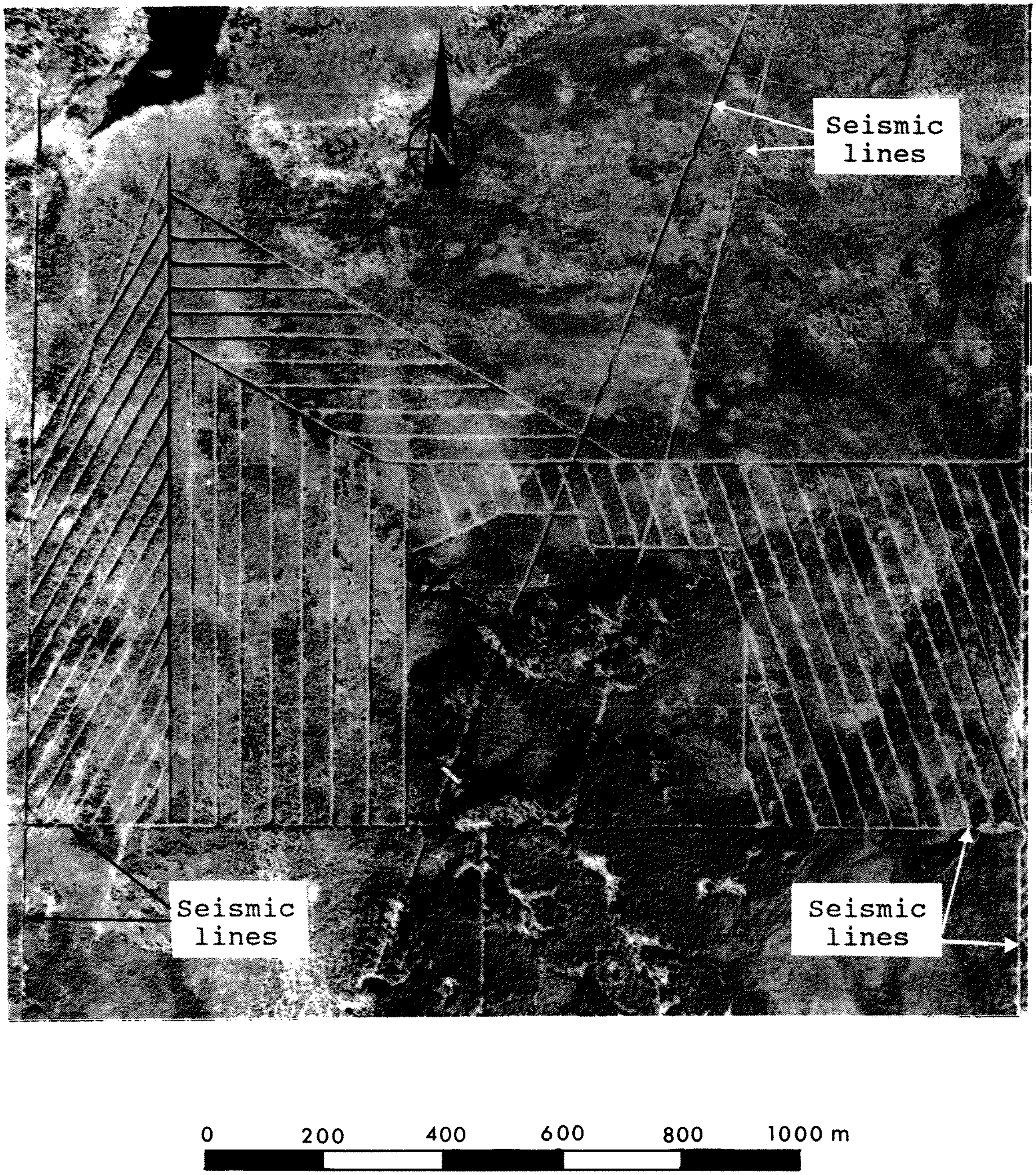

Figure 5. Aerial photo of the McLennan 28 ditch network.

The vegetation on the area was established after fire. The shrub stratum is dominated by various species of Salix (primarily S. farriae and S. planifolia) with lesser amounts of Betula pumila and some Ledum groenlandicum. Empetrum nigrum, a dwarf shrub, occurs sporadically. The herb stratum is dominated by Carex aquatilis, Oxycoccus spp., and Vaccinium vitis-idaea with lesser amounts of Calamagrostis inexpansa, Carex gynocrates, and C. paupercula. Rubus chamaemorus and Smilacina trifolia are constant species with low cover. The predominant mosses are Sphagnum fuscum, S. warnstorfii and Tomenthypnum nitens while Sphagnum angustifolium is present in some areas. Aulacomnium palustre is a constant moss with low cover.

Drainage of about 90 ha in the south and western parts of the section was started in October, 1986 and completed in July 1987. Most of the ditching was done in June, 1987. The remaining area to the north serves as a control.

2.3 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 (Fig. 6) about 30 km southeast of Edson at an elevation of 950 m.

The mean annual temperature for the area is 0.9°C. The average January and July temperatures are -15.4°C and 14.4°C, respectively. The average annual precipitation for Edson is 533 mm, 373 mm of which falls during May through September. The average annual snowfall is 205 cm (Alberta Environment 1987). Similar averages were recorded at nearby Carrot Creek Lookout and Cold Creek Ranger Station. The area averages 80 frost-free days annually (Longley 1968).

The Wolf Creek peatland is a treed fen 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.

The dominant understory shrub is Betula pumila with lesser amounts of Salix pedicellaris and Ledum groenlandicum. Andromeda polifolia is a conspicuous and constant dwarf shrub. The herb stratum is dominated by Carex aquatilis, C. chordorrhiza and Equisetum fluviatile with lesser amounts of Carex diandra and C. limosa. Galium labradoricum, Menyanthes trifoliata, Oxycoccus quadripetalus, Potentilla palustris, Smilacina trifolia, and Triglochin maritima are constant and characteristic species, but with low cover. The predominant moss species are Sphagnum warnstorfii and Tomenthypnum nitens, although Sphagnum

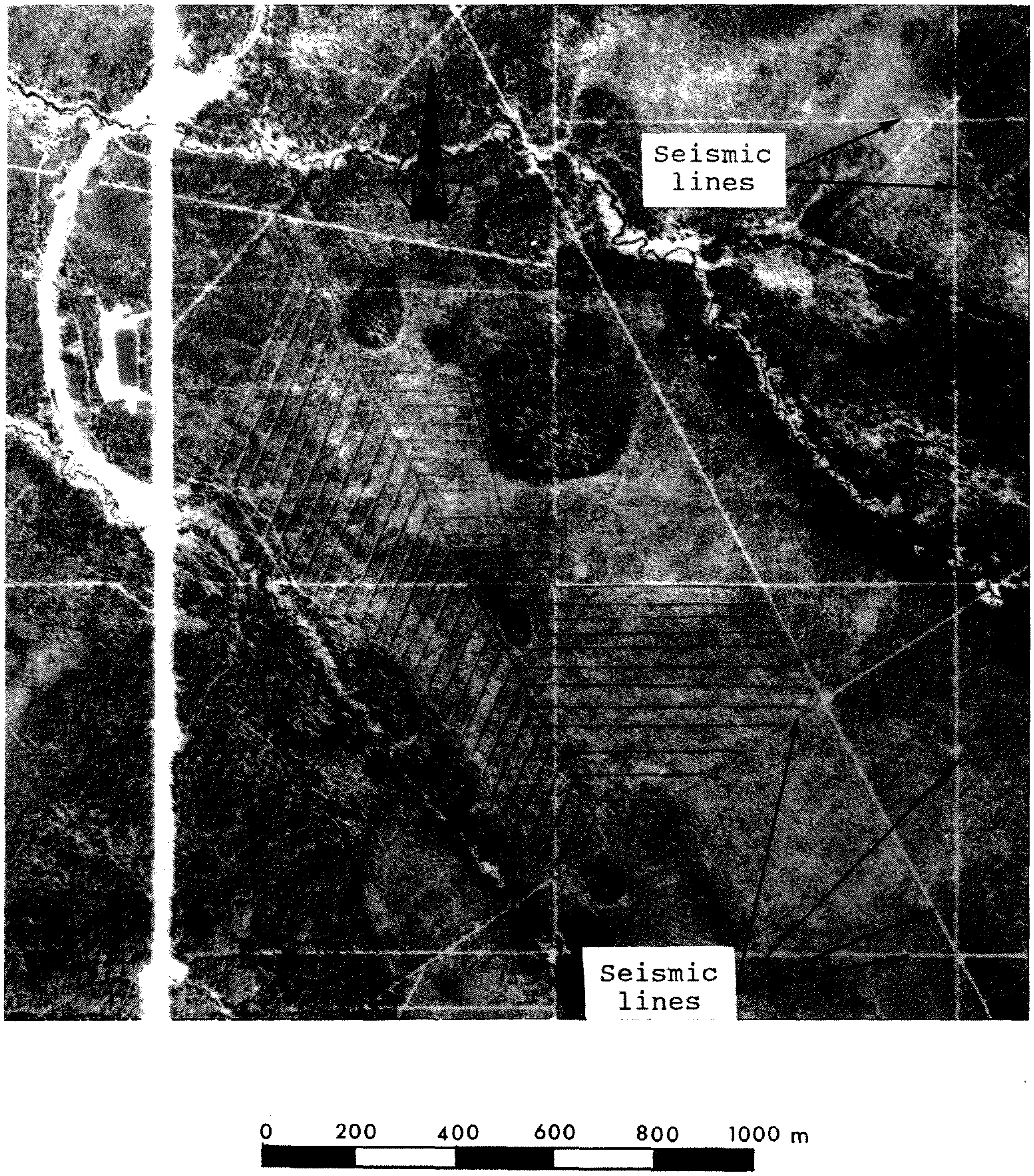

Figure 6. Aerial photo of the Wolf Creek ditch network.

angustifolium is prominent in certain areas; Drepanocladus vernicosus occurs in wet hollows. Aulacomnium palustre and Meesia triquetra are constant species on hummocks and in hollows respectively, but with low cover.

Two years of pretreatment data were collected from the Wolf Creek site before it was drained (60 ha) in September and October, 1987.

2.4 Fort McMurray

The project area (Fig. 7) is located 11 km south of Fort McMurray adjacent to Highway 63 in the Athabasca Forest at an elevation of 400 m. The mean annual temperature for the area is -0.2°C. The average January and July temperatures are -21.8°C and 16.4°C, respectively (Alberta Environment 1987). The frost-free period is about 70 days (Lindsay et al. 1957). The average annual precipitation is 472 mm of which an average of 164 mm falls as snow (Alberta Environment 1987). About 310 mm falls during May through September.

The study area is a coniferous swamp contained within a level glaciolacustrine plain with slopes of 0 to 0.7%. Lateral movement of water from the area is restricted by a clay lip along the creeks. Soil development consists of an impermeable Rego Gleysol at the top of the sediments and a Terric Fibric Mesisol organic layer 0.5 to 1.2 m thick on top of the Gleysol. Vegetation, established after a wildfire in 1953, consists of a dense cover of black spruce associated with Ledum groenlandicum, feathermoss and Sphagnum spp.

Between 1975 and 1981 the AFS imposed a number of different treatments on the area to remove excess soil water and to enhance forest growth. Data were collected from a 25-ha area that was intensively scarified and ditched (Fig. 8) and from an adjacent 16-ha undisturbed control area to the south (Fig. 7).

The 25-ha area was first treated in May 1975. Initial treatment consisted of clearing and scarifying strips of two bulldozer blade widths (i.e., vegetation and the upper layer of peat were cleared from strips 7 m wide) with windrows on either side, leaving undisturbed strips 3.5 m wide. The intent of scarification, in this case, was to remove water from the area. Where ponding occurred, lines were cut through windrows and unscarified strips to facilitate drainage. A 305-m long main ditch 2.1 m wide and 0.9-1.5 m deep, was dynamited between the control and the treated area to carry water away from the site (Fig. 7). No secondary ditches were dug during this phase.

In 1979, secondary ditches 0.76 m deep were dug on the treated area with a Marttiini plough. Average ditch spacing was about 9 m. The following year, an additional 350 m of main drainage ditches (Fig. 7) 1.07 m deep and from 1.06 to 1.22 m wide were

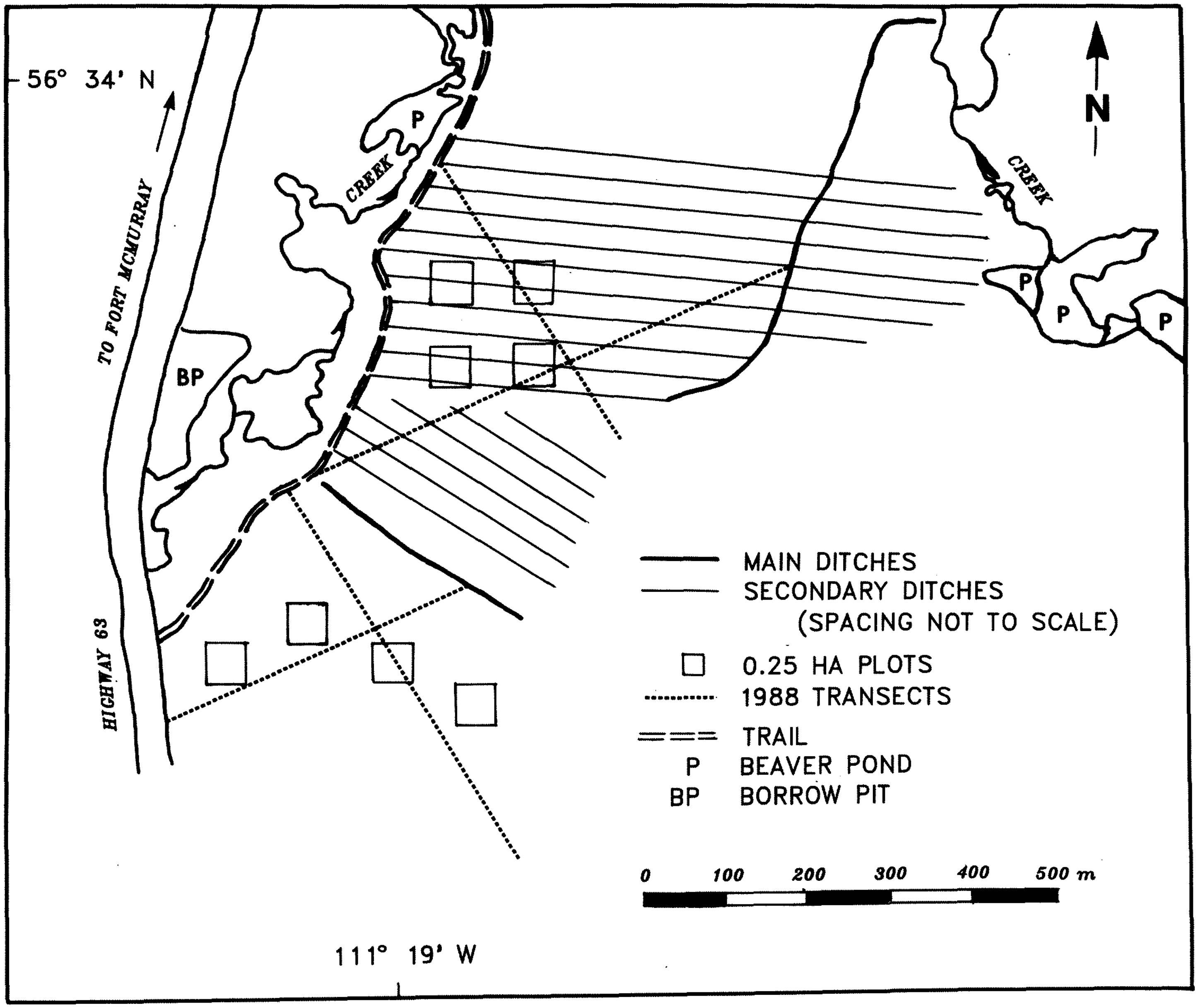

Figure 7. Fort McMurray trial drainage area.

Figure 8. Oblique aerial photo of drained area, Fort McMurray, looking east.

dug on the treated area with large tracked excavators. Because treatment took place over a five year period, for the purpose of analysis the postdrainage period was arbitrarily defined as the period 1979 to 1988.

Four 0.25-ha plots each were installed on the drained and undrained areas in 1980 (Fig. 7). In 1981, one plot on each area was thinned to 1730 stems ha^{-1}, one fertilized with nitrogen (ammonium nitrate, 34-0-0, 359 kg ha^{-1}), and another with phosphorus (triple superphosphate, 0-45-0, 269 kg ha^{-1}); the fourth plot served as a control.

3. METHODS

The experimental design requires that: 1. on each FRDA experimental area, a portion be designated for ditching and the remainder be preserved as control; 2. pretreatment as well as posttreatment data be obtained from each site.

3.1 Preliminary work

The three experimental areas Goose River, McLennan 28 and Wolf Creek were surveyed, instrumented, and sampled in a similar manner. Weather stations consisting of a recording precipitation gauge and a 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. Measurements were taken either on a rectangular grid with 200 m sampling intervals or on two transects running perpendicular to each other across each site. Peat cores were taken with a Macaulay-type sampler with an inside diameter of 4 cm. Core samples (6 cm long) were taken at 15-cm intervals for chemical analyses. The pH of the wet peat was determined immediately below the sampled segment using Duotest pH paper. Saturated hydraulic conductivity was measured in the top 1 m of soil using the piezometer method (U.S. Department of the Interior 1984). Groundwater samples were taken at each coring site.

The core samples were oven-dried at 70^{o}C $\pm$5^{o}C; the moisture content (volumetric and gravimetric) and bulk density were calculated. These samples were then ashed at 480^{o}C $\pm$5^{o}C for 16 hours. The greyish-white ash, after cooling, was treated with 7 mL of aqua regia (HNO_3:HCl 1:4.5) and heated to dryness on a hot plate at low heat (about 50^{o}C). The residue was dissolved with 3 mL of 1.5 **M** HCl, heated over medium heat (about 75^{o}C for 15 minutes), and filtered through a Whatman no. 42 filter paper into a 25-mL volumetric flask. The filter paper and crucibles were washed several times with double distilled water into the volumetric flask and the contents made up to volume with double distilled water. For each set a blank was prepared in the same manner as the sample digests. The extracts were analysed for total elements (Ca, Mg, Na, K, Al, Ti, Pb, As, Cu, Fe, Mn, Zn, Ni, S, P) by an ARL inductively coupled argon plasma spectrometer - Model 34000 (ICPS-AES) (Ali et al. 1988). Available nitrogen, phosphorus, and potassium were determined using the phenoldisulphonic acid method (Jackson 1958, p. 197), the ammonium fluoride method (Sheldrick 1984), and the ammonium acetate extraction method (Atkinson et al. 1958, p. 29), respectively.

The groundwater samples were acidified with HCl to a final concentration of 0.18 **N** HCl and then analysed by ICPS-AES for the same 15 elements analyzed for in the peat samples. Total nitrogen (N) for peat and groundwater samples was determined by the modified Kjeldahl method using a Technicon digestion block and Kjeltec Auto 1030 Analyzer (Tecator) (Jackson 1958, p.183).

In 1986, and prior to ditching, four transects were established on each experimental area, one on the control site and three at different ditch spacings (30, 40, and 50 m)[1] perpendicular to ditch lines, on the area to be drained. The locations of the transects are shown in Figs. 3, 9 and 10 for Goose River,

[1] Five transects were installed at McLennan 28 to evaluate 4 different ditch spacings (30, 40, 50 and 60 m).

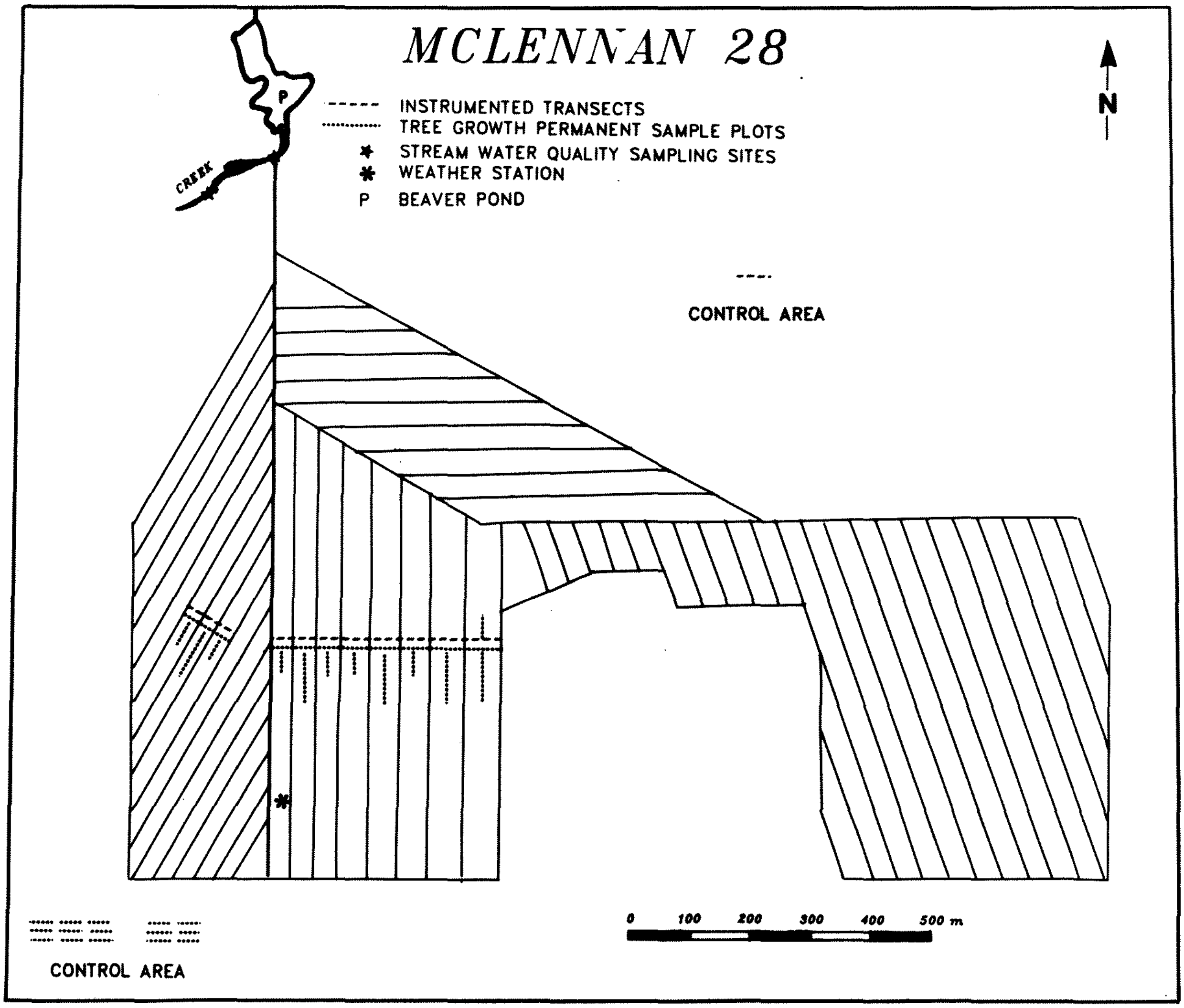

Figure 9. Locations of instrumented transects and permanent sample plots at McLennan 28.

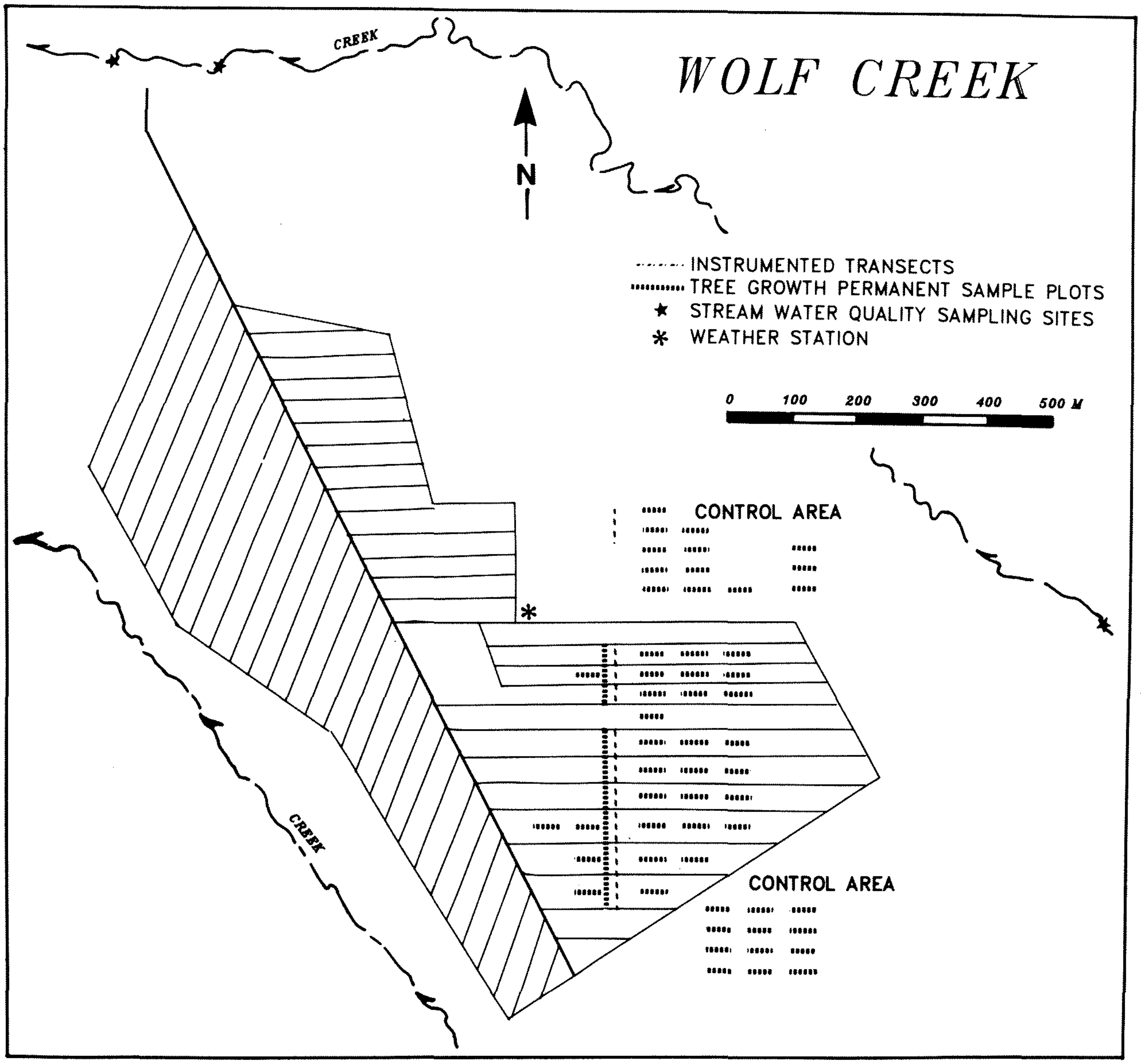

Figure 10. Locations of instrumented transects and permanent sample plots at Wolf Creek.

McLennan and Wolf Creek, respectively. Each transect was instrumented, sampled, and surveyed to measure the effects of drainage on groundwater table levels, ground temperatures, and peat subsidence. Peat, groundwater, and foliage samples were collected from all transects to determine the existing levels of nutrients important for tree growth.

3.2 Ditch networks: design and construction

Drainage ditch network designs were prepared[2] for Goose River, McLennan 28 and Wolf Creek using field observations, topographic maps, and enlarged aerial photos. An adaptation of Toth's synthetic hydraulic curve method (Toth and Gillard 1984, 1988) was used to find the optimum ditch spacings. Each network design allowed for evaluation of different ditch spacings on a homogeneous portion of each site.

The ditch networks were marked and 5-m rights-of-way[3] cleared with a D6 tractor during winter when the ground was frozen. Ditch networks were constructed in unfrozen ground using a Lannen S10 ditcher (Fig. 11). The ditches, parabolically shaped to maintain ditch stability, were 0.9 m deep and about 1.4 m wide. Basic ditch information for each experimental site are provided (Table 1). Large sediment ponds were constructed near the downslope end of each main ditch to capture sediment originating primarily from the main ditches. Buffer strips were left between the main ditches and the water course, i.e., each main ditch terminated before reaching the stream, and effluent water passed through the undisturbed stretch of ground (the buffer) between the ditch and stream before entering the water course. The purpose of the buffers was to filter out sediment particles that may escape the sediment ponds.

3.3 Groundwater table levels

Groundwater table configurations were monitored using between 2 and 13 5-cm diameter wells installed along each transect in 1986. On each experimental area, 2 wells were installed on the control transect, 7 on the 30-m spacing transect, 9 on the 40-m spacing transect and between 10 and 12 wells on the 50-m spacing transect. At McLennan, 13 wells were installed on the 60-m spacing transect, bringing the total number of wells installed on the three areas to 101. Pressure transducers connected to

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[2] M. Rosen, Ontario Ministry of Natural Resources, assisted in this process. The project benefited from his experience in assisting with the design and construction of the Wally Creek drainage ditch network in Ontario.

[3] Rights-of-way at McLennan 28 were 7 m wide.

Figure 11. Lannen S10 ditcher at Goose River.

battery-operated data recorders[4] were inserted in 8 or 10 wells on each experimental area to provide continuous records of changes in water levels with time; data were recorded at 90-minute intervals. The other wells were measured once or twice a month with a carpenter's tape. Two or three 15-cm diameter wells on each experimental area were equipped with Leupold-Stevens F-type water level recorders.

Groundwater table level data were collected May through October, 1986 through 1989. The *t*-test was used to test the hypothesis that there was no difference between the before- and after-drainage means for groundwater table levels ($p < 0.05$).

3.4 Stream water quality

At Goose River and Wolf Creek, stream sediment loads and inorganic chemical water quality were monitored periodically at one or two locations upstream and one or two locations downstream from points where water from the drainage network's main ditch enters the stream (Figs. 3 and 10). At McLennan, the main ditch discharges into a large pond and water quality was monitored near this exit point. A small stream located north of the drainage network and draining into the same pond was also monitored (Fig. 9). Sediment samples were collected in glass bottles using a

[4] Data recorders, pressure transducers and temperature probes were manufactured by Lakewood Systems Ltd., 9258-34A Avenue, Edmonton, Alberta T6E 5P4.

DH-48 sediment sampler, and the total suspended sediment was determined using methods described in APHA et al. (1971).

Inorganic chemical water quality samples were collected as 'grab' samples in 250-ml plastic bottles. The samples were prepared and analyzed in the same manner, and for the same 16 elements, as for the groundwater samples referred to earlier. The paired t test was used to test the null hypothesis for upstream and downstream means ($p \leq 0.05$).

3.5 Ground vegetation composition

Transects consisting of a series of 1-m^2 plots were established on the same ditched and control areas as the instrumentation networks. Plots were located 15 m east of the instrumented lines at Goose River and Wolf Creek (Figs. 3 and 10), and 5 m north of the line at McLennan (Fig. 9). Plots were located every third metre from the centre of a ditch along these transects, starting at 4 m from the ditch centre at Goose River and Wolf Creek, and 7 m at McLennan. The starting point was determined as the point closest to the ditch where the vegetation was undisturbed by the clearing of the ditch rights-of-way. Every third metre spacing was also used on the control areas. Plot centres were thus established at mean distances from ditch centre of 4.5, 7.5, 10.5, 13.5, 16.5, 19.5, and 22.5 m at Goose River and Wolf Creek. The distances at McLennan were 7.5, 10.5, 13.5, 16.5, 19.5, 22.5, 25.5, and 28.5 m. Six replicates were established for each distance from a ditch centre. The distribution of the 150 ground vegetation permanent sample plots among the three experimental areas is shown in Table 2. The sampling design was determined by the availability of time and resources, and compatibility with the Canadian Wetland Registry (Tarnocai 1980).

For each plot, the four corners were marked with metal pins[5], and an aluminum tree tag identifying the plot number was attached to the northwest corner of the plots at Wolf Creek and the drained area at Goose River, and to the southwest corner of the plots at McLennan and the Goose River control. Plot numbers were prefaced with the ditch strip number and numbered consecutively from north to south on transect lines at Wolf Creek and the drained area at Goose River, and from west to east at McLennan and the Goose River control. Contiguous plots at the centre of the 50-m ditch spacing at Wolf Creek and Goose River were numbered from west to east, while those at the 50- and 60-m ditch spacings at McLennan were numbered from south to north.

Percent cover (to the nearest 5% for species with > 10% cover) was recorded for all species in the plots from tall shrubs to mosses and lichens. Coniferous species occurring in the plots were not included in the tally. Species cover values were then

[5] This has not yet been completed at Wolf Creek.

Table 2. Distribution of ground vegetation composition permanent sample plots

Plot locations (Ditch spacings)	Goose River	McLennan 28	Wolf Creek	Total
	Number of plots			
30-m	8	6	8	22
40-m	12	10	12	34
50-m	22	14	22	58
60-m	0	18	0	18
Control	6	6	6	18
Total	48	54	48	150

averaged across the series of six replicates for each distance from ditch centre and the control. Plots at Goose River and McLennan were measured in 1986 before drainage, in 1987, the year immediately following drainage, and again in 1989, the third year following drainage. Plots at Wolf Creek had two years of predrainage measurement in 1986 and 1987, and were remeasured in the second year following drainage in 1989. Plots were measured between mid-June and late August in all years.

3.6 Tree growth

3.6.1 Goose River, McLennan 28 and Wolf Creek

Two different sampling designs were established on the three experimental areas to measure tree growth response to drainage. In the first, a series of 5 x 40 m plots was established on both the control and drained areas. On the drained areas, the long axes of the plots were placed parallel to the ditches and centred on the midpoints between ditches. The instrumented transect line served as the starting point for locating these plots. The first plots were placed 20 and 40 m to the east of this line at Goose River and Wolf Creek, respectively (Figs. 3 and 10), and 20 m to the south of the instrumented lines at McLennan (Fig. 9). All other plots were established in relation to these initial plots. At Goose River and Wolf Creek, parallel plots at any given ditch spacing in the drained area were separated by 20 and 25 m, repectively, in an east-west direction. Control plots at Goose River were separated by 15 m in all directions; those at Wolf Creek were separated by 25 m in all directions. At McLennan, spacing between parallel plots at any given ditch spacing in the drained area was 5 m in a north-south direction; control plots were separated by 10 m in all directions. Control plots at Goose River were located 120 m north of the Sweathouse Fire Tower road and 15 m east of the instrumented transect line (Fig. 3). The locations of those at McLennan were measured from the southwestern corner of the area, 75 m south of the east-west seismic line, and 25 m to either side of the north-south seismic line (Figs. 5 and 9). At Wolf Creek, two blocks of control plots were established. The first was located 50 m north of the centre east-west seismic line, and 200 m east of the centre north-south seismic line (Figs. 6 and 10). The second block of plots was located just south of the drained area, with the northwest corner of the first plot located 40 m east of the northeast-southwest seismic line, measured from a point on the line 230 m northeast from the main ditch (Figs. 6 and 10). The parallel plots were established to determine the most effective ditch spacing for improving tree growth.

The second sampling design involved the establishment of plots perpendicular to the ditches on the drained areas to study tree growth response in relation to distance from the ditch. These plots were 5 m wide and as long as the ditch spacing (30, 40, 50, or 60 m). Plots were established in a line 15 m to the west of the instrumented transect lines at Goose River and Wolf Creek (Figs. 3 and 10), and 15 m south of the instrumented transect lines at McLennan (Fig. 9). Three plots were established for each ditch spacing, except for the 60-m spacing at McLennan which had only two. The distribution of the 136 tree growth permanent sample plots among the three experimental areas is shown in Table 3.

The four corners of each plot were marked with aluminum angle posts[6] tagged with plot number and corner. Control and parallel plots at Wolf Creek were numbered consecutively from 001. Tags on parallel plots at Goose River and McLennan were prefaced with the ditch strip number and numbered consecutively within ditch strips. Tags on these plots were appended with the letter 'D'(erek). Perpendicular plots at all three sites were prefixed with 'Hillman'.

At Wolf Creek, control plots north of the east-west seismic line were numbered from 001 to 013; those to the east of the northeast-southwest seismic line were numbered from 044 to 055. Parallel plots on the drained area were numbered from 014 to 043, starting with the 30-m spacing.

On all plots, trees with a diameter at breast height (dbh) $\geq$ 1.1 cm were tagged with sequentially numbered aluminum tags. Information on each tree in each plot was recorded on AFS Permanent Sample Plot Tally Sheets. This information included tree number, species, dbh (cm), height (m), height to live crown (m), crown class, and condition codes. On the parallel and control plots at Wolf Creek, every third tree was measured for height and height to live crown. On the perpendicular plots at

[6] Forty plots at Wolf Creek have iron rods marking the northwest corner of the plots.

Table 3. Distribution of tree growth permanent sample plots

	Goose River		McLennan 28		Wolf Creek		Total
	C[a]	D	C	D	C	D	
#Parallel plots	8	12	15	17	25	30	107
#Trees	1336	1732	1127	1295	1275	1692	8457
#Trees/plot (mean)	167	144	75	76	51	56	
#Trees/ha	8350	7217	3757	3809	2550	2820	
#Perpendicular plots		9		11		9	29
#Trees		1136		578		396	2100
Total plots	29		43		64		136
Total trees	4204		3000		3363		10567

[a]C = Control, D = Drained

Wolf Creek and all plots at Goose River and McLennan, every measurable tree was measured for height and height to live crown. On all perpendicular plots, the distance of each tree from the centre of a ditch was also measured. Distance from ditch centre was measured from the northside ditch at Goose River and Wolf Creek, and from the westside ditch at McLennan.

A regeneration tally was done on a 5 x 10 m subplot located within each permanent sample plot. On the control plots at Goose River and on the control and parallel plots at Wolf Creek, the regeneration subplots were located at the west end of the main permanent sample plot. On the McLennan control, these subplots were located at the end of the main plot nearest the north-south seismic line, i.e., on the west side for those plots east of the seismic line, and on the east side for those plots west of the seismic line. On the parallel plots at Goose River and McLennan, regeneration subplots were located at the end of the main plot nearest the instrumented transect line. On the perpendicular plots at Goose River and Wolf Creek, regeneration subplots were established at the north end of the main plot; at McLennan it was at the west end of the main plot. Data were recorded onto AFS Regeneration Tally Sheets.

Establishment and initial measurement of the control and parallel permanent sample plots at Wolf Creek was done in October of 1986. Establishment and measurement of the control and parallel plots at Goose River and McLennan, and the perpendicular plots at all three sites was completed in August of 1988. Additional plots in the control areas at Goose River and McLennan were established and measured in the summer of 1989. All plots will be remeasured no later than five years after establishment.

3.6.2 Fort McMurray

To measure predrainage tree growth at Fort McMurray, three transects were established in spring 1976. Leader growth for 1975, total tree height, and age were recorded for each tree sampled. Similar measurements were recorded on a fourth transect installed along the main ditch in October 1976. In the springs of 1981 through 1985, trees in each of the 0.25 ha plots established in 1980 were measured for total height and leader growth. Measurements of diameter at root collar were taken in 1984 and 1985. There were about 25-30 trees in each plot.

In August 1988, 42 trees were randomly sampled along transects crossing the drained and undrained areas (Fig. 7). Trees $\leq$ 1.1 cm in dbh and trees located in the 0.25-ha plots were not included. Twenty-two trees were destructively sampled on the drained area and 20 on the undrained area. Before felling, each tree was examined for external defects, marked at 0.3 and 1.3 m (the stump and breast height, respectively), measured for dbh, and placed in the appropriate crown class i.e. dominant, codominant, intermediate, supressed or open grown.

After felling, the trees were measured and sectioned at intervals along the stem. Total height was determined for each tree and the leader length measured on 23 trees. Cuts were made systematically at heights 0.3, 0.8, and 1.3 m. Subsequent section lengths depended on the height of the tree. Usually, near the top of the tree, 0.25-m sections were cut. A disk was cut from the top of each section to determine age and ring widths in the laboratory. The age of each tree was taken as the total number of annual rings at 0.3 m height. No allowance was made for the time it took for the tree to reach this height.

The disks were prepared on a band sander and measured using a Holman Digimicrometer tree ring increment measuring system and TV camera. Age and ring widths were measured along one radius (the average) on each disk. The resulting data sets were processed using the computer programs DUFFNO and STEM developed by Kavanagh (1983). Program STEM carried out stem analyses and provided tables showing mean annual increment and periodic annual increment for height, dbh, basal area, and volume.

Paired and nonpaired $\underline{t}$-tests were run on data from the destructively sampled trees to test the hypotheses that there were no differences between means for the drained and undrained areas, and between the means for the predrainage and postdrainage periods. Age and ring widths at 0.3 m height were compared, together with total height, leader length, dbh, volume per tree, and periodic annual increments for height and volume.

3.7 Ground temperature

One temperature probe, about 3 cm in diameter, was installed on each transect at Goose River, McLennan 28 and Wolf Creek. Each probe, connected to a battery-driven data recorder, supported sensors at the air-soil interface, and at depths of 0.075, 0.15, 0.30, 0.45 and 1.0 m. Temperature data were recorded at 90-minute intervals (3-hour intervals on some sites in winter).

3.8 Peat subsidence

At Goose River, McLennan 28 and Wolf Creek, subsidence was measured by driving three 13-mm diameter steel reinforcing rods into mineral soil on the control and on three transects for each ditch spacing, so that 15 cm projected above the ground surface. On each transect in the drained area the three rods were placed 5 m from the ditch, at the centre between ditches and at 1/4 the distance between ditches There were only two 60-m strips available at McLennan to be equipped in this way. The projection above ground will be measured periodically in future years.

3.9 Site nutrient status

Peat, foliage and groundwater samples were obtained from each transect at Goose River, McLennan 28 and Wolf Creek, and analyzed for the same 16 elements (including total nitrogen) tested for on each experimental area as a whole. The available nutrients (N, P and K) in peat were analyzed by the methods referred to earlier.

4. <u>RESULTS</u>

4.1 Groundwater table levels

4.1.1 Goose River

For Goose River, the 1986 groundwater table data constitute the predrainage measurements and the remainder are postdrainage data. (Figs. 12a[7], 13a, 14a and 15). As was expected the water table drawdown at and close to the ditches was greater than at the centre between ditches. The average depths to groundwater table across the profiles after drainage were 49, 51 and 37 cm, respectively, for the 30-, 40- and 50-m spacings. The corresponding average drops in water table levels were 26, 22 and 17 cm (Fig. 15). In contrast, on the undrained control, the average depth to groundwater table for the postdrainage period was 15 cm higher than that for the predrainage period (Fig. 15). In the forest drainage literature it is customary to describe the effects of drainage in terms of the mean depth to water table

[7] Note that, in the groundwater table figures which follow, the uppermost, shaded lines represent the ground surface profiles.

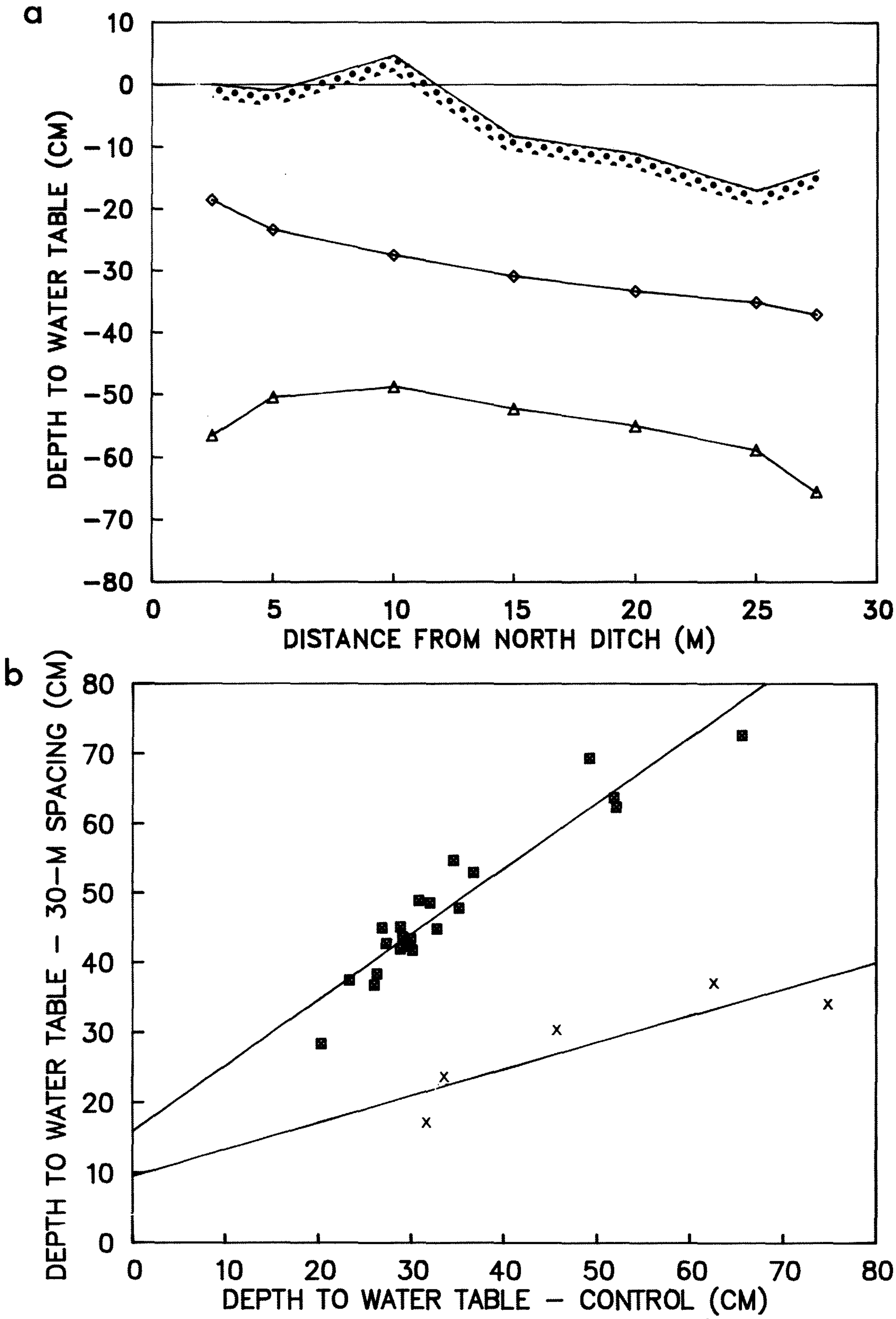


Figure 12. Goose River, 1986-89, 30-m spacing. Depth to mineral soil is 93 cm. a) Average water table profiles before (◇) and after (△) drainage. b) Regression lines before (x) [$y = 0.38x + 9.53$, $r^2 = 0.77$] and after (⊠) [$y = 0.94x + 15.91$, $r^2 = 0.90$] drainage.

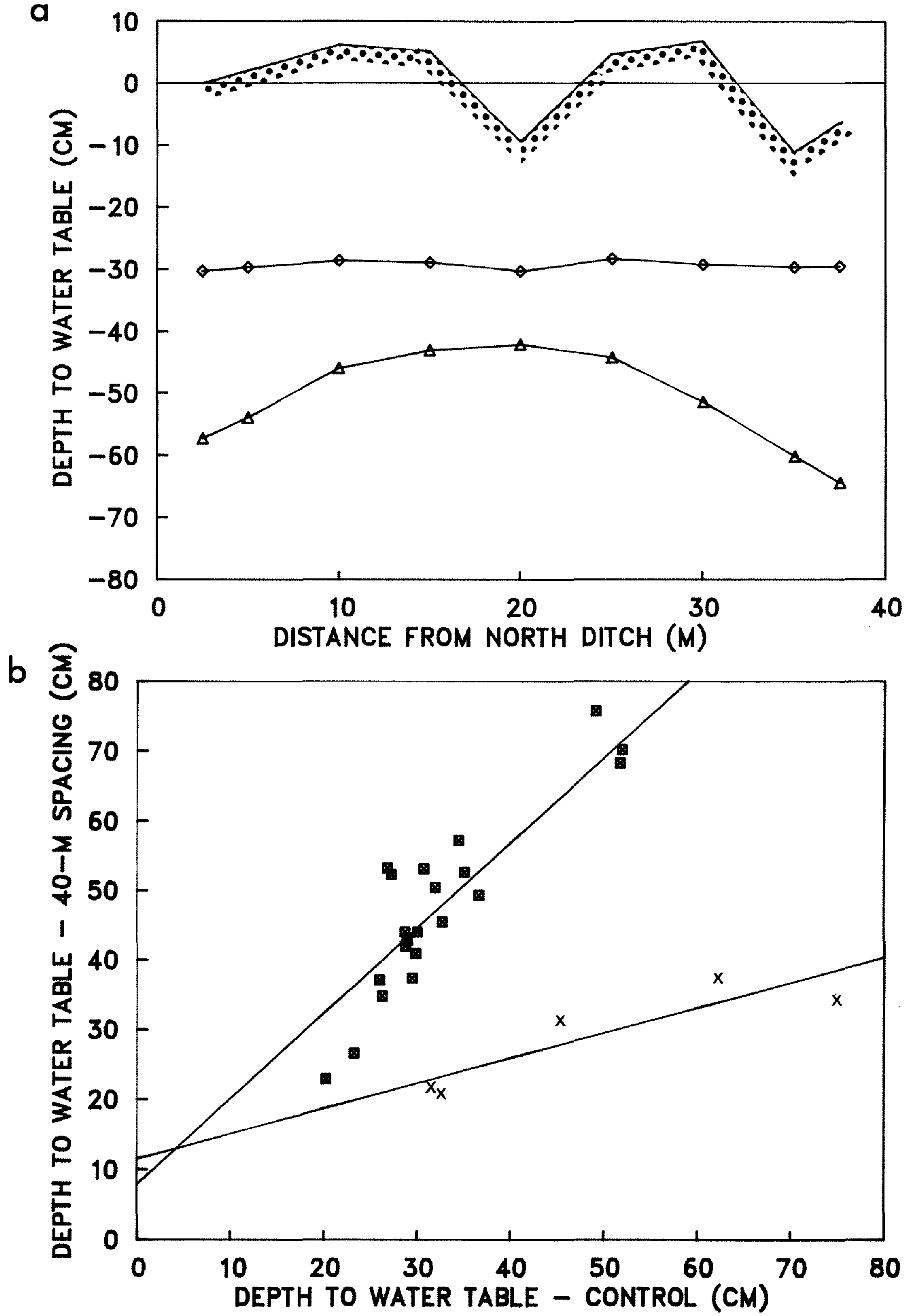


Figure 13. Goose River, 1986-89, 40-m spacing. Depth to mineral soil is 96 cm. a) Average water table profiles before (◇) and after (△) drainage. b) Regression lines before (x) [$y = 0.36x + 11.54$, $r^2 = 0.79$] and after (⊠) [$y = 1.22x + 7.91$, $r^2 = 0.82$] drainage.

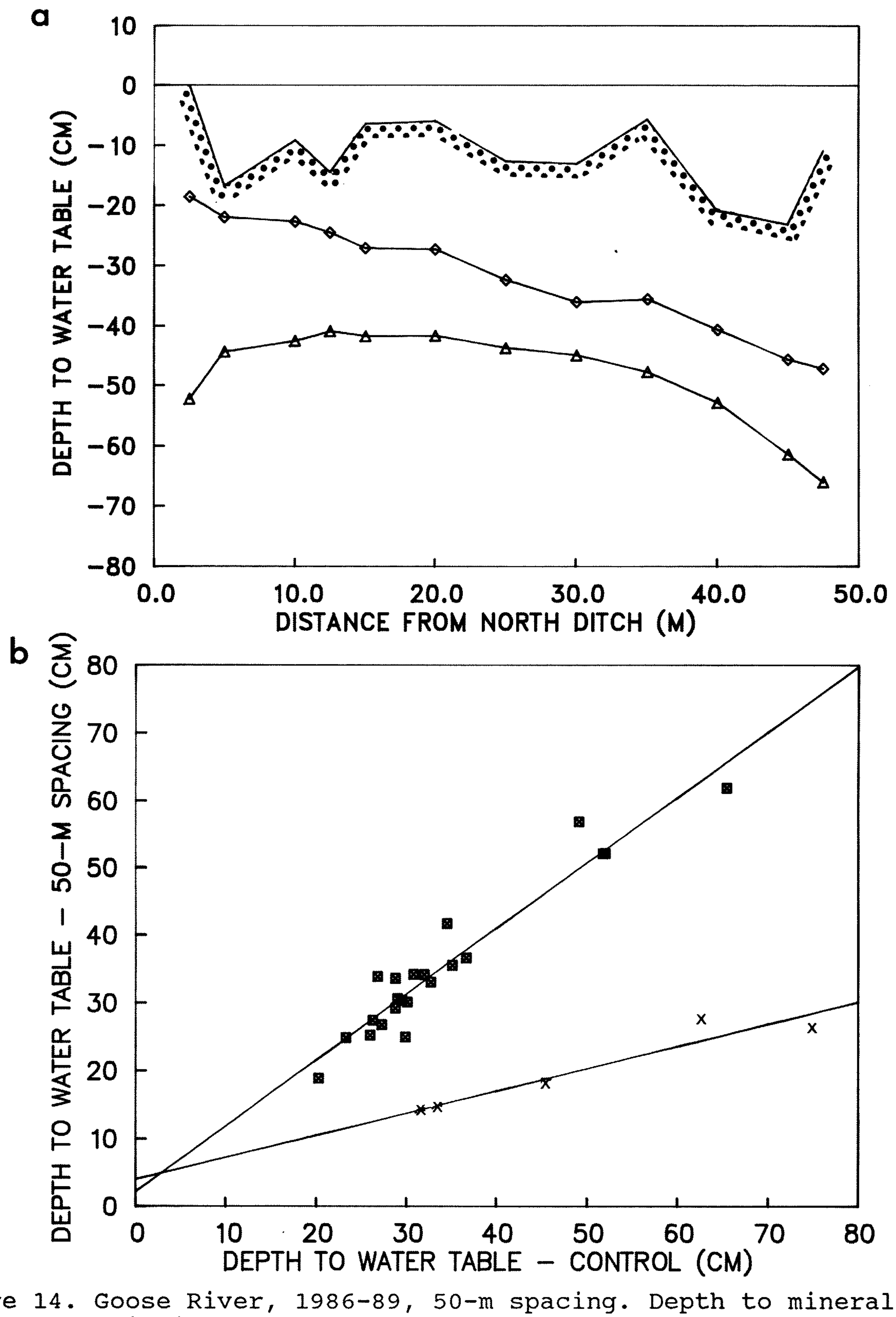


Figure 14. Goose River, 1986-89, 50-m spacing. Depth to mineral soil is 80 cm. a) Average water table profiles before (◇) and after (△) drainage. b) Regression lines before (x) [$y = 0.33x + 3.95$, $r^2 = 0.91$] and after (⊠) [$y = 0.97x + 2.14$, $r^2 = 0.92$] drainage.

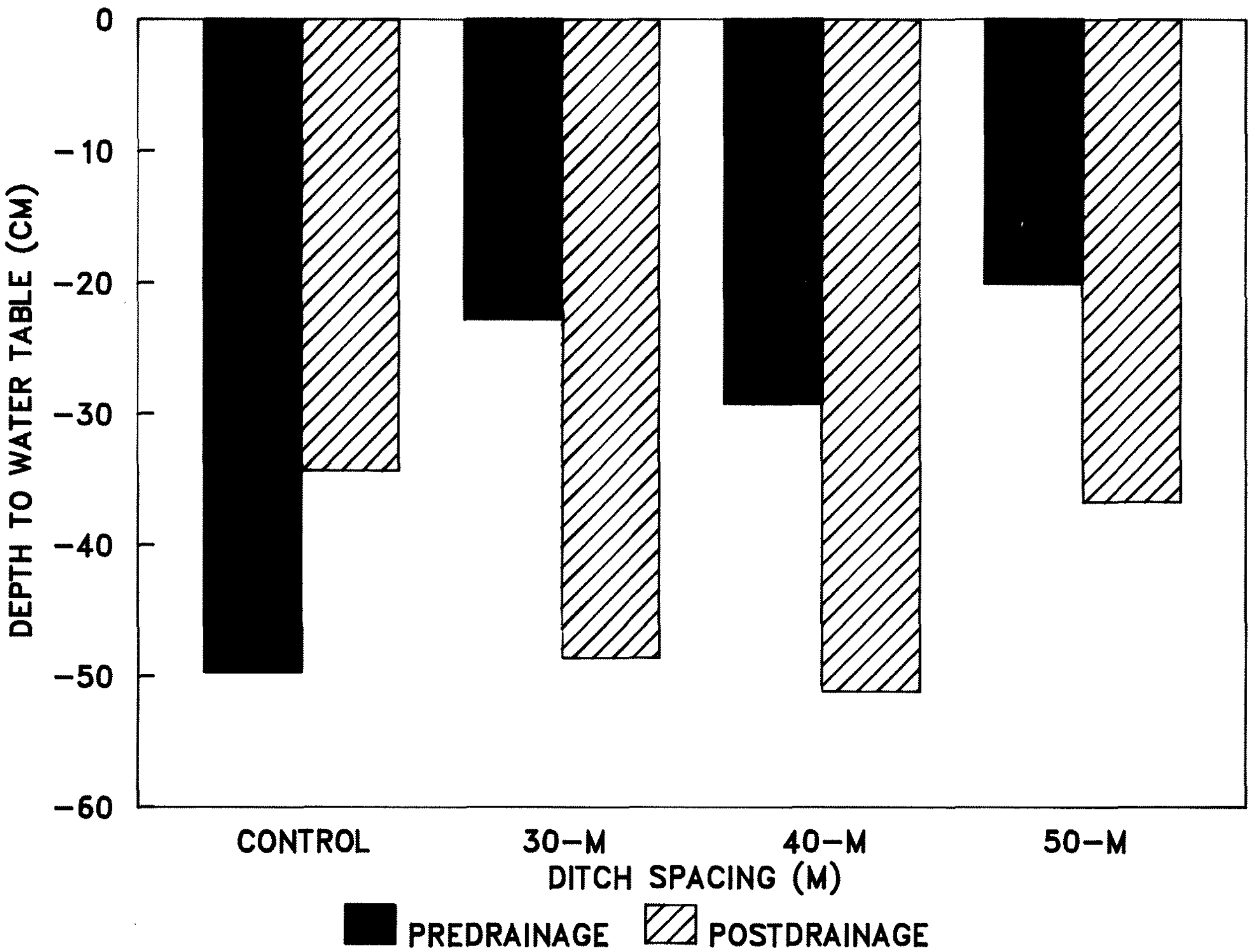


Figure 15. Goose River, 1986-89. Average depth to water table before and after drainage for the control and for the 30-, 40- and 50-m ditch spacings.

after drainage at the midpoints between ditches. For Goose River, these values were 44, 33 and 31 cm, respectively for the 30-, 40- and 50-m spacings and represent average drops in water table levels at the midpoints of 21, 12 and 11 cm (Figs. 12a, 13a and 14a).

At the Sweathouse Lookout Tower, located adjacent to the Goose River experimental area, the 30-year (1951-80) average precipitation for the May-October period was 444 mm (Alberta Environment 1987). At Goose River, precipitation for the May-October period was 396, 337 and 392 mm, respectively, in 1986, 1987 and 1988. The corresponding total annual precipitation was 561, 439 and 540 mm. Evidently 1987 was a drier year - a time during which lower average groundwater table levels could be expected.

To separate the drainage effects from the confounding effects of dry years on groundwater table levels, regression analyses were carried out using depth to groundwater table for the undrained control versus the depth to water table for each ditch spacing (1986-1988 data). The results (Figs. 12b, 13b and 14b) show that, in each case, the postdrainage relation is distinct from the predrainage one and indicate that the drainage treatment had a greater impact on average groundwater table levels than did the drier climatic conditions of 1987. The slopes of the postdrainage graphs are about 3 times those of the predrainage graphs.

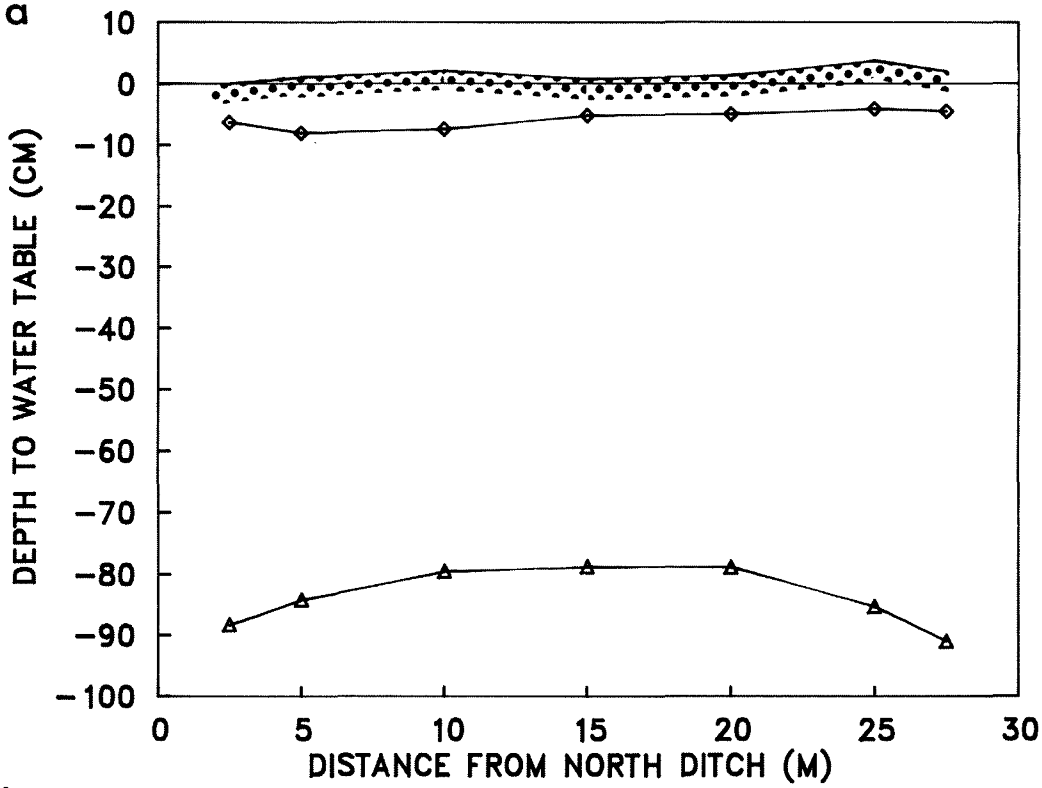
4.1.2 McLennan 28

Drainage of the McLennan site was completed in June 1987. The average groundwater table profiles before and after treatment are shown in Figs. 16a, 16b, 16c and 16d. The average depths to groundwater table after drainage were 85, 83, 81 and 90 cm, respectively, for the 30-, 40-, 50-, and 60-m spacings. The corresponding average drops in water table levels across the profiles after ditching were 78, 60, 54 and 72 cm (Fig. 17). On the undrained control, the average water table level during the postdrainage period was 5 cm lower than during the predrainage period (Fig. 17). The mean depths to water table at the midpoints between ditches were respectively 80, 52, 58 and 72 cm for the 30-, 40-, 50- and 60-m spacings. The corresponding drops in water table levels at the midpoints were 74, 40, 37, and 54 cm (Figs. 16a, 16b, 16c and 16d).

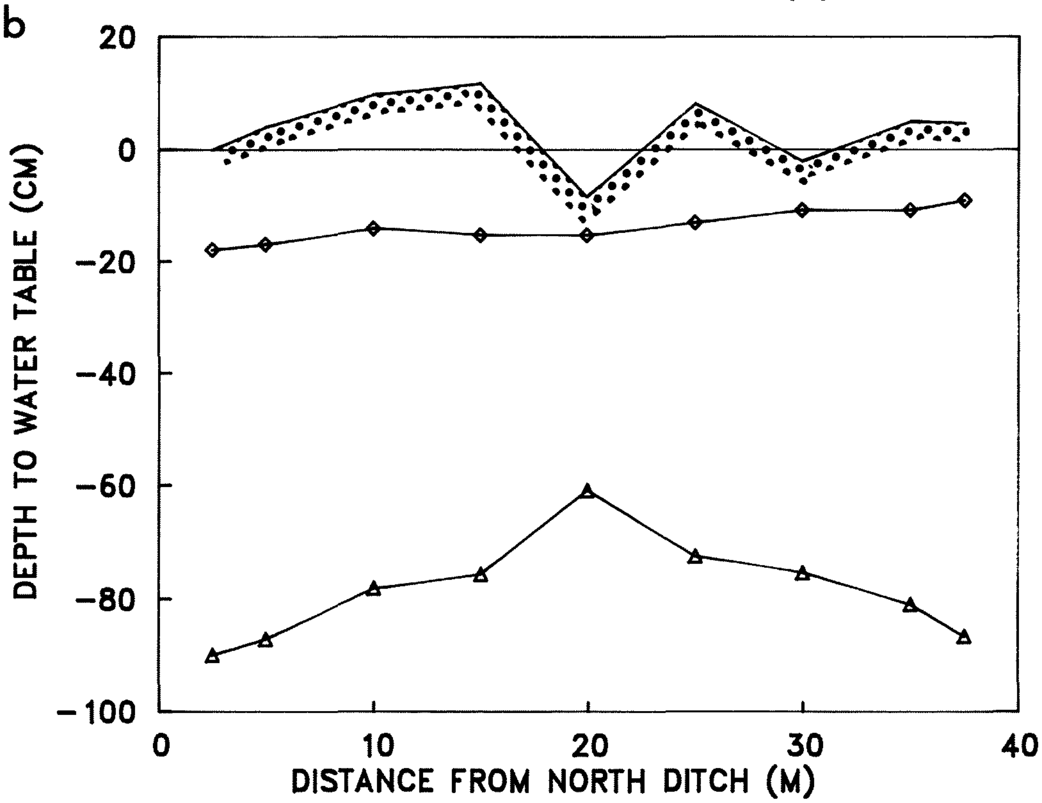
4.1.3 Wolf Creek

Two years of pretreatment data (1986-87) and two years of posttreatment (1988-89) data were obtained for Wolf Creek. Average groundwater table profiles for the two periods are presented in Figures 18a, 18b and 18c. The average depths to groundwater table after drainage were 78, 50 and 56 cm for the 30-, 40- and 50-m ditch spacings, respectively. The corresponding average drops in water table levels across the profiles after ditching were 62, 43 and 46 cm (Fig. 19). On the

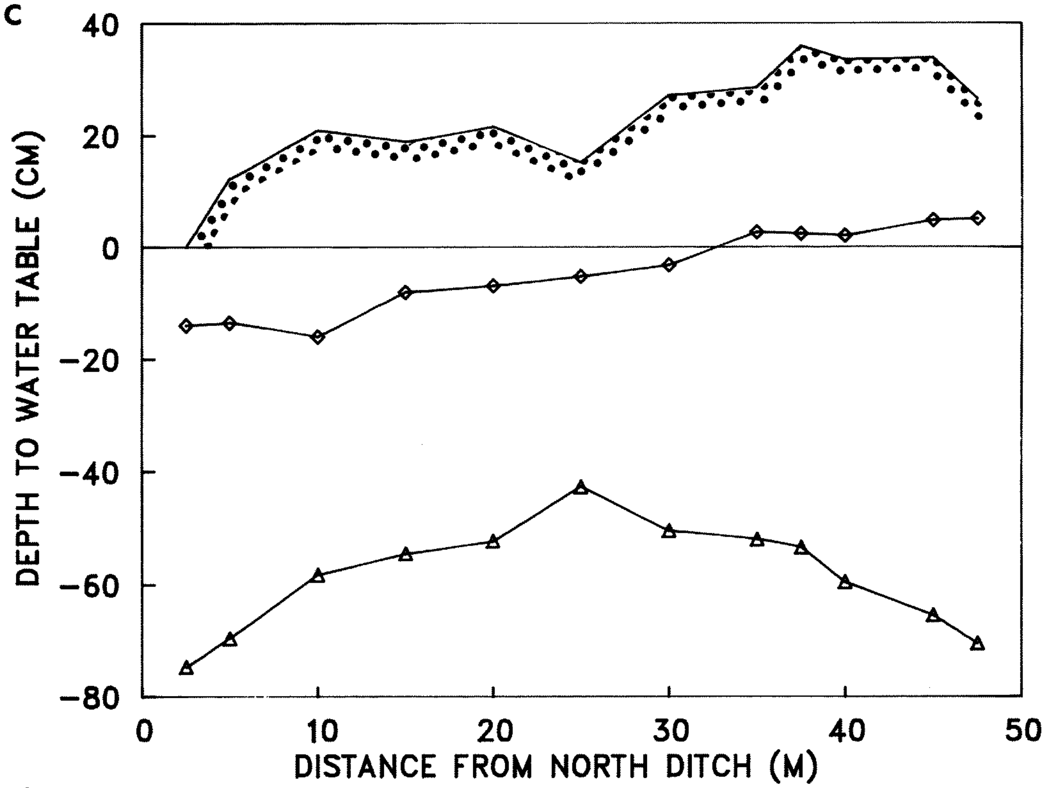
16a


10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
DEPTH TO WATER TABLE (CM)
0
5
10
15
20
25
30
DISTANCE FROM NORTH DITCH (M)

16b


20
0
-20
-40
-60
-80
-100
DEPTH TO WATER TABLE (CM)
0
10
20
30
40
DISTANCE FROM NORTH DITCH (M)

16c



16d

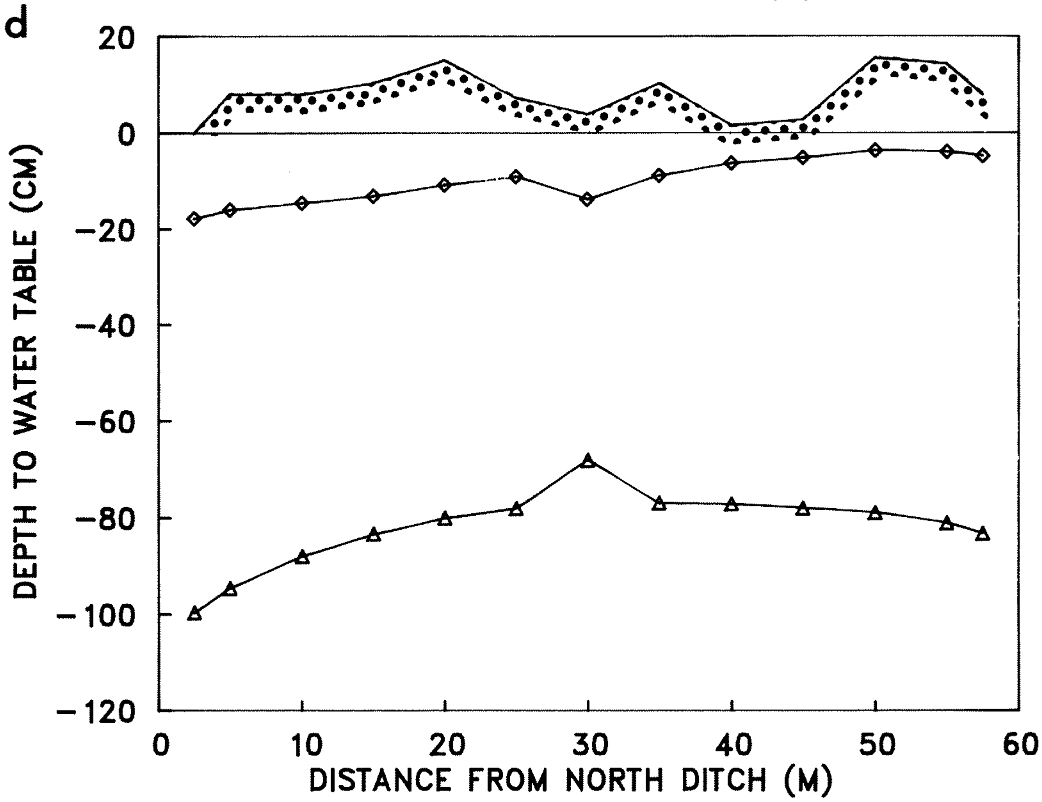


Figure 16. McLennan 28, 1986-89. Average water table profiles before (◇) and after (△) drainage:
a) 30-m spacing. Depth to mineral soil is > 150 cm,
b) 40-m spacing. Depth to mineral soil is > 150 cm,
c) 50-m spacing. Depth to mineral soil is 135 cm,
d) 60-m spacing. Depth to mineral soil is > 150 cm.

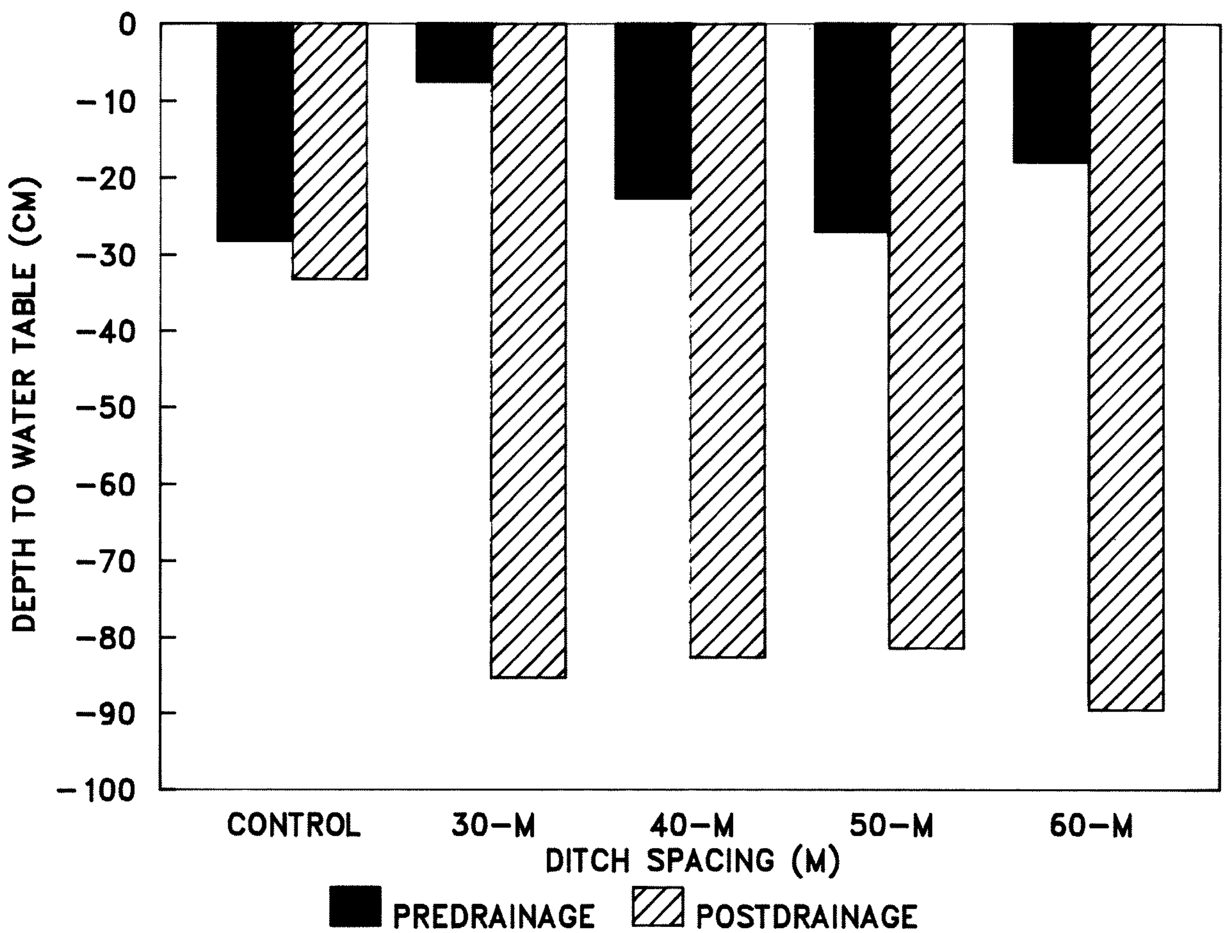
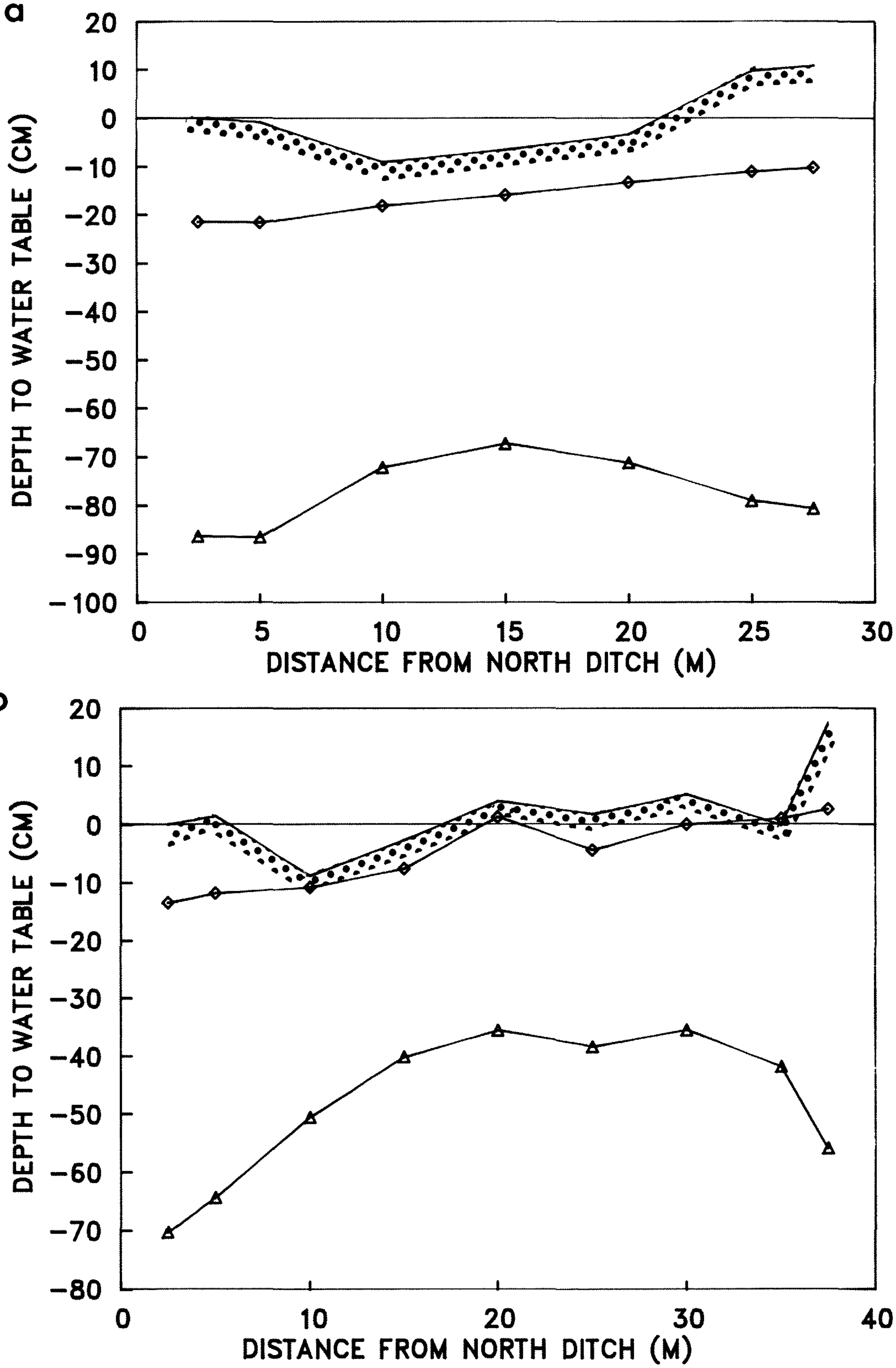


Figure 17. McLennan 28, 1986-89. Average depth to water table before and after drainage for the control and for the 30-, 40-, 50- and 60-m spacings.

18a

18b



20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
DEPTH TO WATER TABLE (CM)
0
5
10
15
20
25
30
DISTANCE FROM NORTH DITCH (M)
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
DEPTH TO WATER TABLE (CM)
0
10
20
30
40
DISTANCE FROM NORTH DITCH (M)

18c

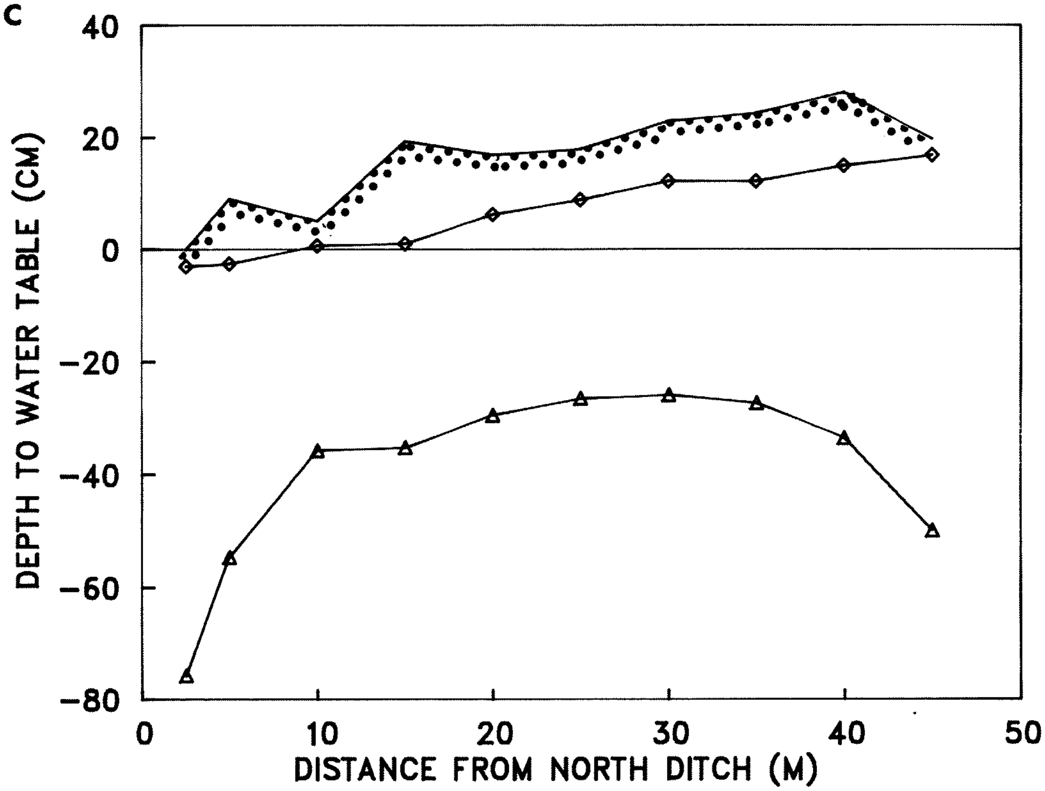


Figure 18. Wolf Creek, 1986-89. Average water table profiles before (◇) and after (△) drainage:
a) 30-m spacing. Depth to mineral soil is > 150 cm,
b) 40-m spacing. Depth to mineral soil is 295 cm,
c) 50-m spacing. Depth to mineral soil is > 150 cm.

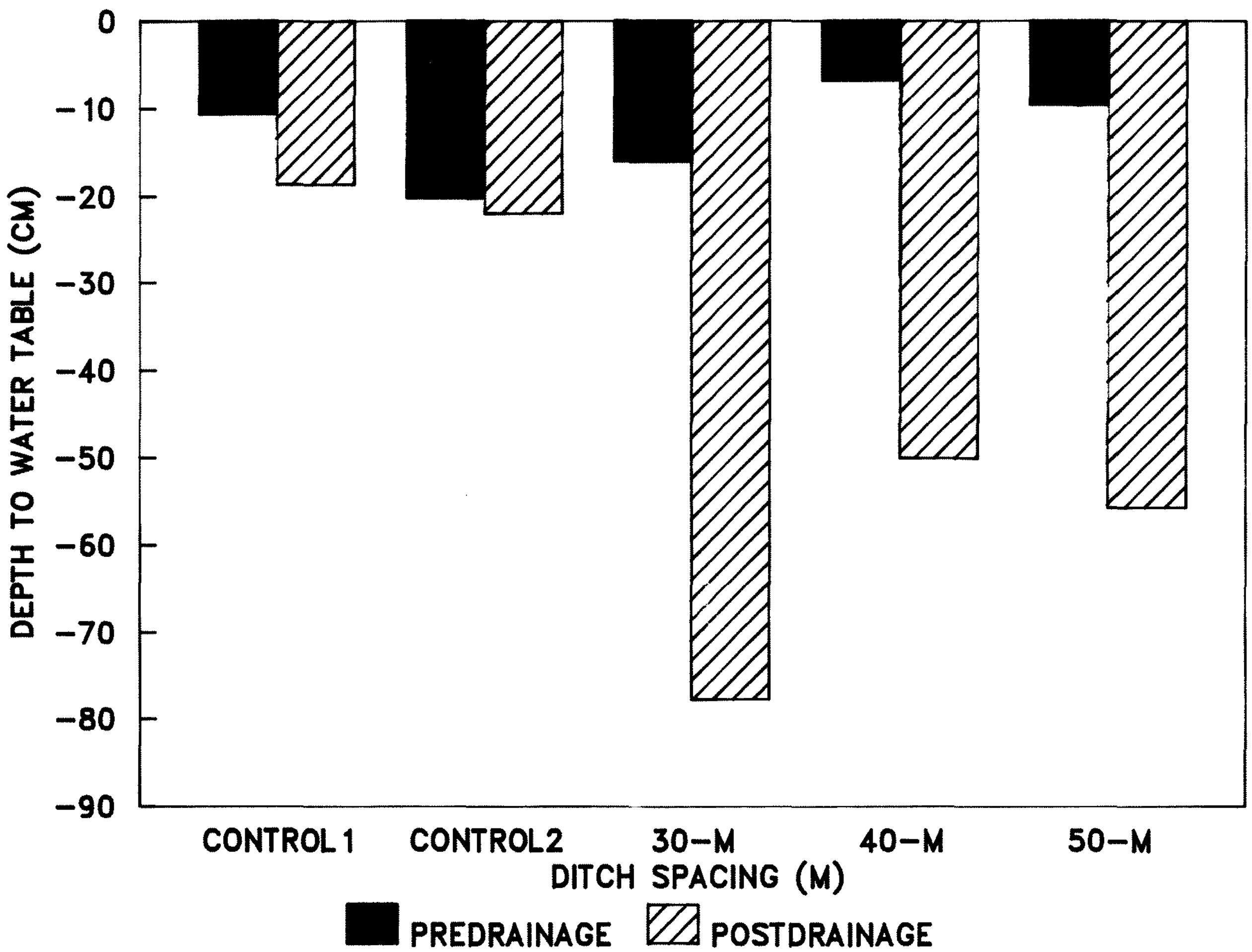


Figure 19. Wolf Creek, 1986-89. Average depth to water table before and after drainage for the control and for the 30-, 40- and 50-m spacings.

two undrained controls, the average drops in the water table during the postdrainage period were 8 and 2 cm (Fig. 19). The mean depths to water table at the midpoints between ditches were respectively 61, 40 and 44 cm for the 30-, 40-, and 50-m spacings. The corresponding drops in water table levels at the midpoints were 51, 37 and 35 cm (Figs. 18a, 18b and 18c).

4.2 Stream water quality

Data obtained from Goose River during ditching operations are used in a preliminary evaluation of the effects of drainage on downstream water quality. During ditching operations in 1986, measured concentrations of Cu, Ni, As, and P in downstream water samples were always below detection limits for these elements. Concentrations of Ti, Pb, and Zn at these locations were frequently below the detection limits as well. The highest concentrations of Ti, Pb and Zn detected in the downstream samples were 0.01, 0.04 and 0.04 mg kg^{-1}, respectively. The large number of non-detectable occurrences did not allow for statistical analyses of data for these elements.

Analyses of the 1986 suspended sediment and chemical water quality data (Table 4) showed that there were no significant differences ($\underline{p} \leq 0.05$) between the upstream and downstream concentrations for suspended sediment, total N, Ca, Mg, Na, Mn, S and specific conductance. The differences were significant for K and Fe. In the case of aluminum (Al), differences between the upstream mean and the mean for the first downstream station (D1) were significant, but differences between the upstream mean and the mean for the second downstream station (D2) were not. The upstream means were significantly greater for K and Al. For Fe, both downstream means were significantly greater.

Table 4. Specific conductance and mean concentrations of postdrainage suspended sediment and chemical elements for the creek at Goose River, 1986

Site	Ss[a]	N	Ca	Mg	Na	K	Al	Fe	Mn	S	Sc[b]
	mg kg^{-1}										µS cm^{-1}
U[c]	20.06	0.92	5.76	1.08	4.79	1.04	0.51	0.64	0.04	0.53	56.66
D1	14.63	0.97	8.04	1.70	7.08	0.11	0.23	1.04	0.04	0.48	74.68
D2	5.23	0.78	8.87	2.00	6.69	0.27	0.31	1.01	0.03	0.55	74.65

[a]Ss = Suspended sediment
[b]Sc = Specific conductance
[c]U = Upstream, D1 = Downstream 1, D2 = Downstream

4.3 Ground vegetation composition

Only some of the more obvious changes in the ground vegetation following drainage can be commented on at this time. Some of the changes occurring are common to all three sites, whereas others are more site-specific, or even plot-specific, and related to the type of peatland and microsite conditons.

At all three sites, the first group of plants to show a negative change following drainage was the bryophytes, particularly the liverworts and those mosses preferring wetter microhabitats (i.e., Calliergon spp., Drepanocladus spp., Meesia triquetra, Sphagnum spp., and Tomenthypnum nitens). In all cases, the species exhibited a strong decline in vigor accompanied by varying amounts of reduced cover, dependent more on microhabitat than distance from a ditch. The plots that showed the greatest negative impacts were those that were most exposed to the drying influence of the sun, those that were well elevated above the water table, or those closest to the ditches, particularly those at the south end of the transects at Goose River and Wolf Creek. This trend was less evident at McLennan where the transects were aligned east-west rather than north-south. Among the vascular plants, the greatest negative changes following drainage were observed in the shallowly rooted species, broad-leaved perennials, and biennials. Plant vigor was greatly reduced and fewer flowers were produced compared to plants growing in the control areas. Leaf size in the broad-leaved species also tended to be smaller after drainage than before. The deeper-rooted species exhibited fewer negative impacts from drainage and in some cases an actual increase in shrub cover occurred over the period of measurement.

4.3.1 Goose River

Less change was evident in the ground vegetation following drainage at the Goose River site than at the other two. Only the most elevated plots and those closest to the ditches, particularly those at the south end of the transects, showed evident signs of decline. Little change in shrub cover was evident in either the control or drained areas, except for Ledum groenlandicum which showed a slight increase in the control area. There was a marginal increase in the cover of Calamagrostis inexpansa in the plots closest to the ditches. This species is very abundant on the spoil piles along the ditches.

Mosses growing in formerly wet pools, such as Calliergon stramineum and Drepanocladus fluitans, showed reduced cover and very poor vigor. Calliergon occurred in 11 plots in the drained area before drainage, but could be located in only two by the third summer after drainage. For Drepanocladus the change was from seven plots to one. The most marked declines occurred in the cover and vigor of the Sphagnum species, particularly S. angustifolium and S. magellanicum. Cover decreased by up to one half in exposed plots close to the ditches.

4.3.2 McLennan 28

In terms of negative changes, the shallowly rooted, low-growing species Empetrum nigrum, Vaccinium vitis-idaea, and Oxycoccus microcarpus showed considerable browning of the leaves and a marked decrease in vigor, if not cover, by the third summer following drainage at McLennan. All sedges showed lowered vigor and the smaller-sized species (i.e., Carex disperma, C. leptalea, and C. tenuiflora) had reduced cover. The dominant species, C. aquatilis, showed mostly reduced vigor. Pedicularis labradorica, a biennial herb, occurred in 30 plots in the drained area prior to drainage, compared to only seven plots by the third summer following drainage. Only one vascular species, Calamagrostis inexpansa, showed a clear increase in cover following drainage, occurring in nine plots before drainage compared to 22 plots by the third summer following drainage. This species, along with Stellaria longifolia, is now extremely abundant on the spoil piles along the ditches.

In terms of changes in the bryophytes, there was a marked decline in the vigor and cover of Calliergon and Drepanocladus spp. in some of the formerly wet holes, but the plants were still alive in the third summer following drainage. The most visible declines occurred in the Sphagnum spp., particularly those favoring the wetter habitats (i.e., S. angustifolium, S. squarrosum, S. teres, and S. warnstorfii). The degree of decline again appeared to depend more on plot exposure rather than distance from a ditch.

Peltigera spp. were quite abundant lichens in the plots at McLennan prior to drainage. Most of these were quite dried out and dying by the third summer after drainage.

Recently-established conifer seedlings, primarily black spruce, were observed in a number of the plots at McLennan during the 1989 measurements. Young seedlings were not evident in the plots at Goose River and Wolf Creek. Establishment of seedlings (black spruce, aspen, and balsam poplar) is occurring on the spoil piles at all three sites.

4.3.3 Wolf Creek

There was a general increase in low shrub cover in both the control and drained areas at Wolf Creek over the four years of measurement. This can be attributed to normal growth of the plants. In the drained area changes were almost all negative. Among the vascular plants, the shallowly rooted species were the first to show an effect. Andromeda polifolia, a low-growing shrub, showed evident browning and dying of the leaves in many plots and in the more exposed plots was clearly dying out in the second summer following drainage. Oxycoccus quadripetalus, a species most often rooted in Sphagnum moss, showed an even more marked decline. A decline in the vigor and cover of the sedges was also evident, particularly in those species normally growing in the wettest microhabitats (i.e., Carex diandra, C. limosa, and to a lesser extent C. chordorrhiza). In comparison to the control area, few sedges in the drained area produced flowering spikes. The cover of Menyanthes trifoliata, a broad-leaved perennial herb, was reduced by more than one half in the drained area by the second summer following drainage (9% to 4% cover averaged over all plots in the drained area). Plants in the drained area produced few flowers when compared to those growing in the control area. Plants of Caltha palustris in the drained area produced smaller leaves and no flowers compared to plants in the control area which were still quite vigorous. The vigor of Equisetum fluviatile was clearly reduced by the second summer following drainage, but the change in cover was not significant. In the drained area before drainage, Drosera rotundifolia occurred in 12 plots. In the second summer following drainage it could not be located in any. Corallorhiza trifida declined from presence in eight plots to none, and Pedicularis parviflora, a biennial, decreased from eight plots to only one in the same time period. The only vascular plant to show a clear increase in cover following drainage was Stellaria longifolia, increasing from presence in 13 plots before drainage to 24 plots by the second summer after drainage.

Several mosses showed a marked decrease in vigor and cover by the second summer following drainage. This was especially so in the cases of Drepanocladus lapponicus, D. vernicosus, Meesia triquetra, Sphagnum angustifolium, S. warnstorfii, and Tomenthypnum nitens, the species favoring the wettest microhabitats. Leafy liverworts had almost disappeared from the plots in the same time period. Again, the plots showing the greatest negative impact were those that were most exposed.

4.4 Tree growth (Fort McMurray)

The pretreatment data (Table 5) indicate that, prior to drainage, the height growth of black spruce on both the treated and untreated areas was poor. Results from t-tests showed that there were no significant differences in age, total tree height and leader length between the two sites. The clearing and scarification treatment greatly reduced stocking in the drained area (Table 5). The measurements taken in October 1976 near the main ditch showed that the average leader growth for 1976 was 3.8 cm. A more-detailed discussion of pretreatment growth rates is presented when tree ring widths are discussed.

The average annual leader growth for black spruce on the drained area, 6-9 years after treatment commenced, was 3.8 times that for black spruce on the undrained area (Table 6). Although there may be some confounding effects due to the fertilizer and thinning treatments, the drainage effect appears to be very much the dominant factor in the analyses.

On the same 0.25-ha plots, average tree height in 1981 was 152 cm on the drained site and 134 cm on the undrained site - a

Table 5. Comparison of pretreatment means (±SD) for black spruce on drained and undrained sites near Fort McMurray

Site	Age in 1976 (a)	Total height (cm)	Annual height increment (cm a^{-1})	1975 Leader length (cm)	1976 stocking (trees ha^{-1})
Drained	15(5)	54.9(48.6)	3.8	2.4(0.9)	3 713[a]
Undrained	16(5)	38.3(53.1)	2.4	2.4(2.3)	35 547
Mean	15	49.0	3.2	2.4	-

[a]This stocking is the composite for alternating strips of trees and clearings. The density on the treed strips was the same as on the undrained area.

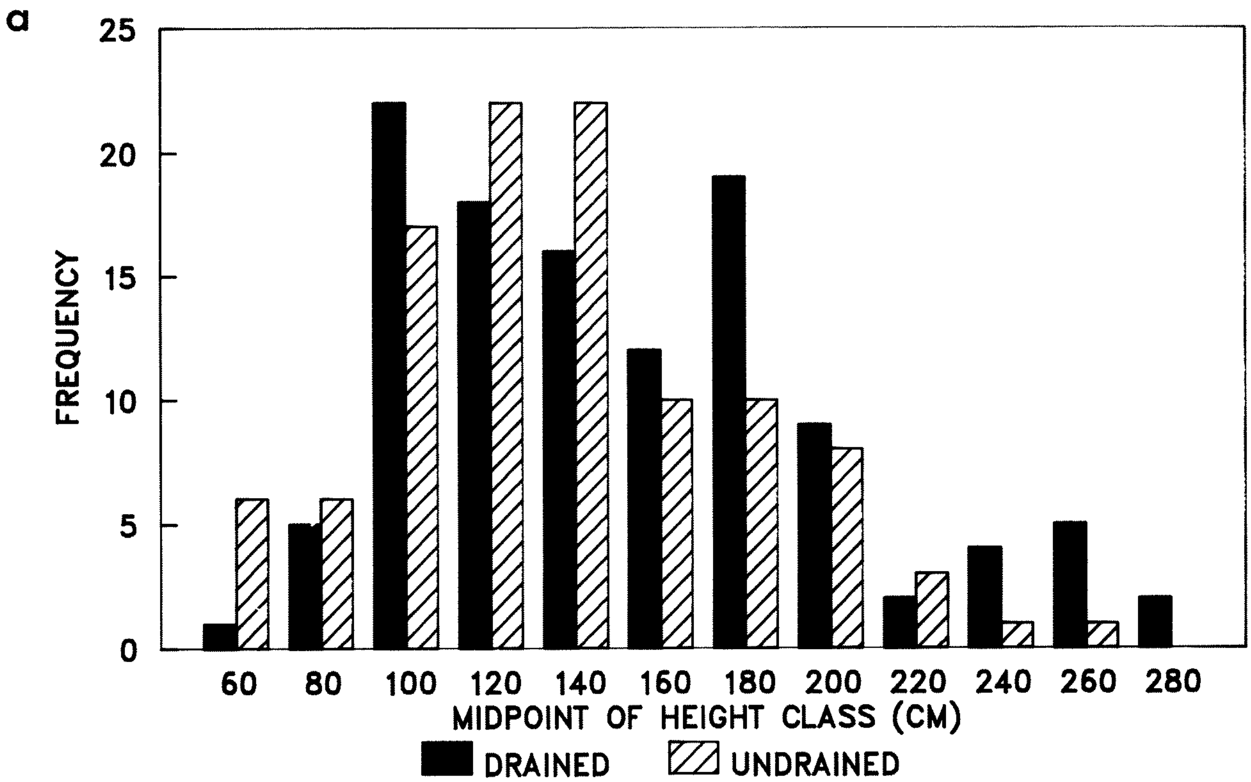
Table 6. Average annual leader growth (cm) in 1981-84 for black spruce near Fort McMurray

Site	Treatment: Phosphorus	Nitrogen	Thinned	Control	Mean
Drained	36.3	33.1	32.2	35.0	34.2
Undrained	5.8	17.3	8.8	6.3	9.1

difference of 18 cm. The tree height frequency distribution for 1981 is shown in Fig. 20a. Four years later, the average tree height was 288 cm on the drained site and 167 cm on the undrained site. The pronounced difference in height growth is reflected in the 1985 height frequency distribution (Fig. 20b), where trees on the drained site fall into the upper height classes, and trees on the undrained site occupy classes at the lower end of the range.

In 1984, the mean tree diameter growth at root collar on the drained area was more than 4 times that on the undrained area (Table 7). It was higher on the drained area for all treatments. In 1985, the mean root collar diameter for trees on the drained site was 5.9 cm compared with 3.7 cm for trees on the undrained site. More than 60% of the trees on the drained site exceeded 5 cm in diameter compared with only 8% on the undrained site (Fig. 21).

Data from the 42 destructively sampled black spruce trees from the Fort Mcmurray drainage area in 1988 verify that drainage had a significant effect on leader growth (Table 8). They also show that the ratio of drained to undrained leader growth was being



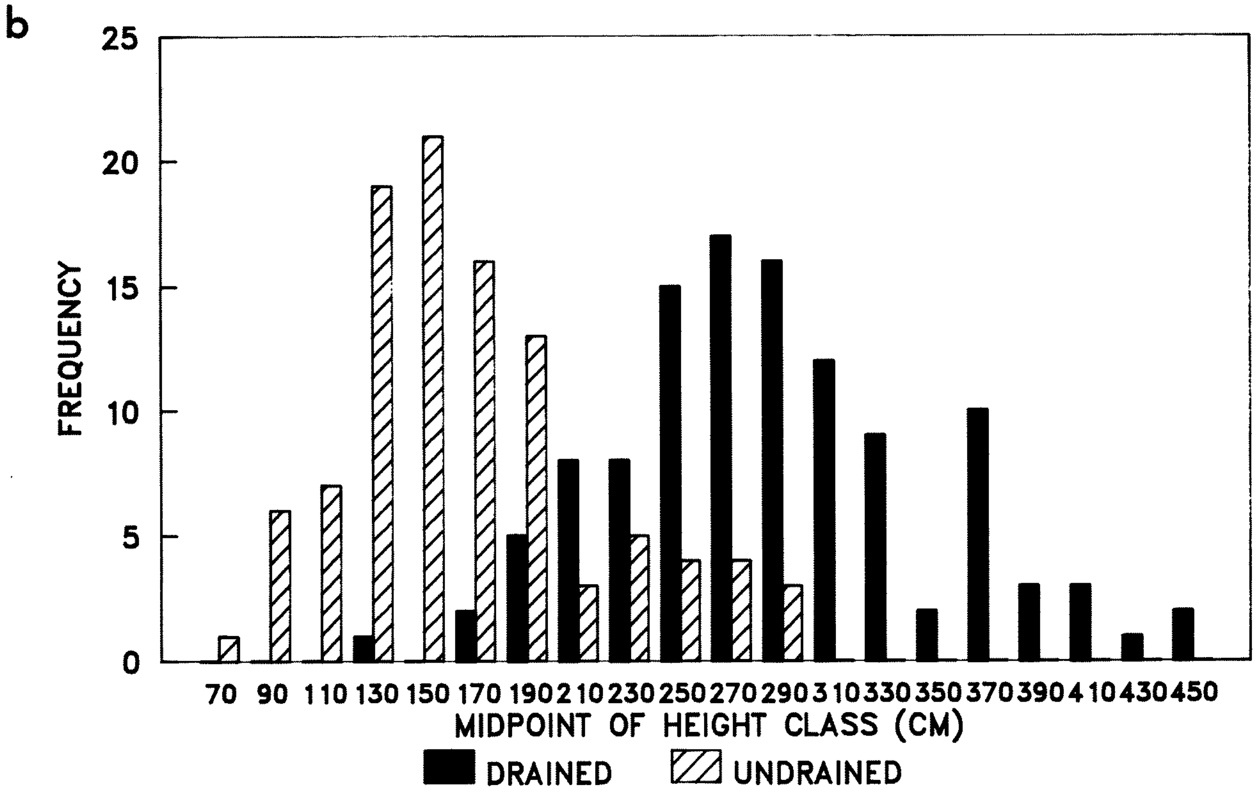


Figure 20. Height distribution of black spruce near Fort McMurray in a) 1981 and b) 1985.

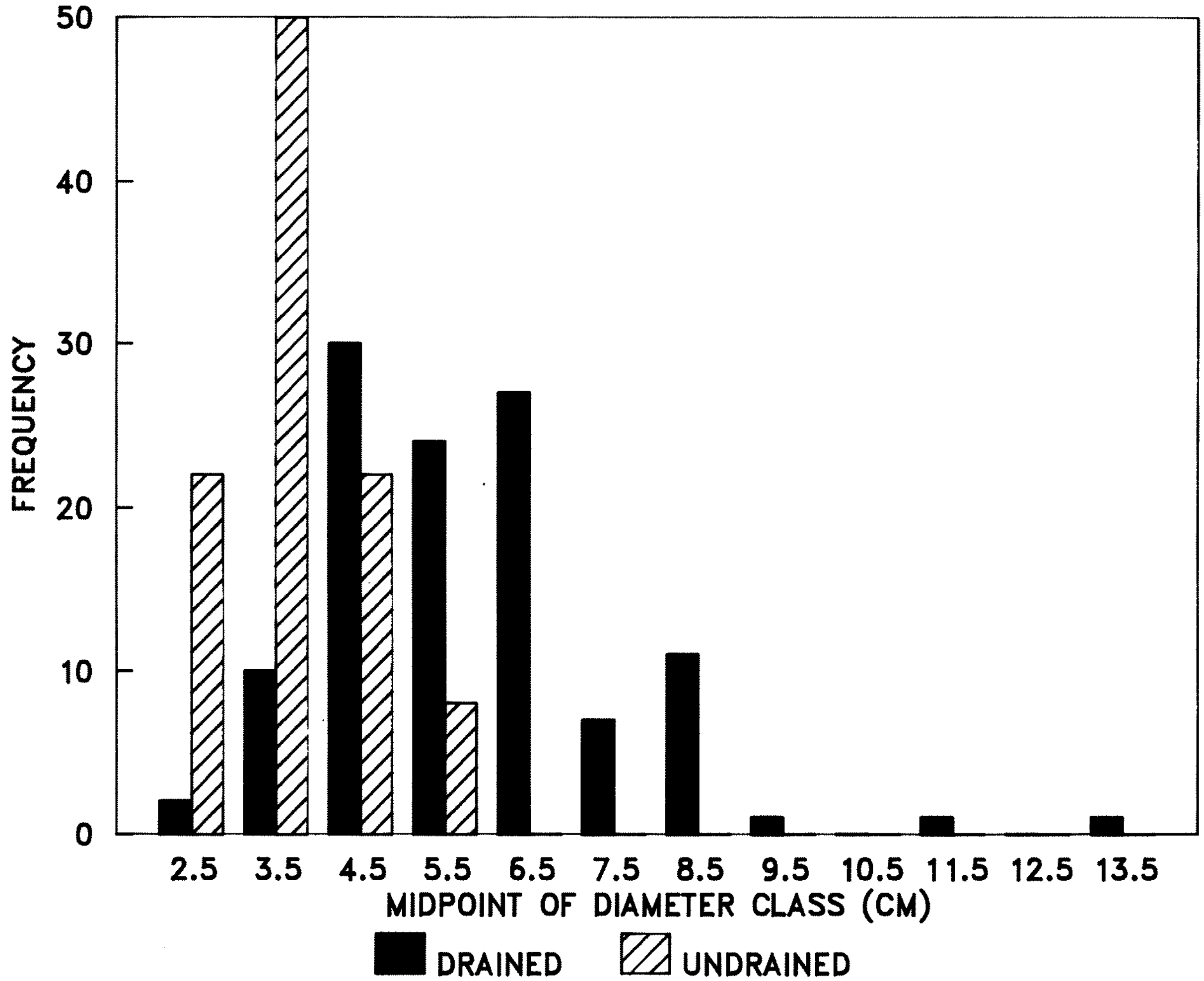


Figure 21. Root collar diameter distribution of black spruce near Fort McMurray in 1985.

Table 7. Average 1984 diameter growth at root collar (cm) of black spruce near Fort McMurray

Site	Treatment				Mean
	Phosphorus	Nitrogen	Thinned	Control	
Drained	0.70	0.89	1.19	1.03	0.95
Undrained	0.06	0.34	0.29	0.23	0.22

Table 8. Statistics for black spruce destructively sampled near Fort McMurray in 1988 (includes ingrowth)

	Drained		Undrained		Drained mean / Undrained mean	df	*t*
	Mean	±SD	Mean	±SD			
Age (a)	17.9	6.6	26.4	2.3	0.7	40	-5.50**
Height (m)	3.48	0.80	2.13	0.34	1.6	40	6.97**
Dbh (cm)	3.4	1.5	1.8	0.5	1.9	40	4.60**
1988 leader growth (cm)	45	8	12	8	3.8	21	9.92**
Volume (m^3)	0.0023591 ±0.0023524		0.0006947 ±0.0003700		3.4	40	3.13*

**$p \leq 0.001$, *$p \leq 0.05$.

maintained at the same ratio as for the 1981-85 period (1:3.8). The average leader growth on the drained area (45 cm) is impressive for black spruce (Fig. 22). The ratios of drained to undrained height and dbh were 1.6 and 1.9, respectively (Table 8).

Multiple leaders, usually two, were frequently observed on trees on the drained area but were less common on trees on the undrained area. This tendency toward multiple leader growth on the drained area was noted earlier by Alberta Forest Service personnel (unpublished reports).

The mean tree age was less on the drained area (17.9 years) than on the undrained area (26.4 years) (Table 8). On the drained area two age groups, related to treatment history, were identified. Half of the trees were between 10 and 14 years old; the remainder were between 20 and 27 years old. The corresponding means were 11.8 and 24.0 years, respectively. It appears that trees belonging to the younger age group came in after the two-blade-wide scarification treatment. The others evidently predated this

Figure 22. Leader growth (1988) of black spruce on the drained portion of the trial drainage area near Fort McMurray.

treatment.

T-tests showed that, on the drained site, height, dbh and volume were significantly lower ($p \leq 0.05$) for trees in the 10- to 14-year class. Consequently, if this ingrowth after treatment is ignored the means for these variables and age on the drained site are increased (Tables 8 and 9).

Table 9. Statistics for black spruce destructively sampled near Fort McMurray in 1988 (ingrowth excluded)

	Drained		Undrained		Drained mean	df	t
	Mean	±SD	Mean	±SD	Undrained mean		
Age (a)	24.0	2.5	26.4	2.3	0.9	29	-2.72*
Height (m)	3.89	0.84	2.13	0.34	1.8	29	8.36**
Dbh (cm)	4.1	1.7	1.8	0.5	2.3	29	5.57**
Volume (m^3)	0.0034885 ±0.0027982		0.0006947 ±0.0003700		5.0	29	4.46**

**$p \leq 0.001$, *$p < 0.05$.

The apparent discrepancy in ages given in Tables 5 and 9 is due to the ages in 1988 being obtained from transects different from those on which the 1976 ages were obtained.

The mean tree height, dbh and volume per tree were, respectively, 3.89 m, 4.1 cm and 0.0034885 m^3 on the drained area compared with 2.13 m, 1.8 cm and 0.0006947 m^3 on the undrained area (Table 9). The difference in each case was highly significant ($p < 0.001$).

A comparison of data for trees within the undrained area showed that there were no significant differences in average ring width at 0.3 m height or in periodic annual height increment (pahi) between the two periods investigated, 1969-78 and 1979-88 (Table 10 and Fig. 23a). The periodic annual volume increment (pavi), on the other hand, was significantly greater (2.6 times) during the later period (Tables 10 and 11).

On the drained area, ring width, pahi and pavi were all significantly higher for the later, postdrainage period than for the 1969-78 interval (Tables 10 and 11; Fig. 23b). Ring width, pahi and pavi during the 1979-88 period were respectively 4, 3 and 39 times greater than the corresponding averages for the earlier period (Table 11). Sample sizes for drained and undrained areas are different (Table 10) because 50% of the trees sampled

Table 10. Statistics from paired t-tests in the comparison of of 1969 to 1978 data with 1979 to 1988 data for black spruce near Fort McMurray

	Undrained			Drained		
	Ring[a] width (mm)	Pahi[b] (m)	Pavi[c] (dm^3)	Ring[a] width (mm)	Pahi[b] (m)	Pavi[c] (dm^3)
Difference[d]	-0.02	-0.003	-0.02868	-1.29	-0.174	-0.33066
±SD[e]	0.20	0.030	0.01982	0.70	0.069	0.27164
t	-0.42	-0.49	-6.47**	-6.16**	-8.33**	-4.04*
df	19	19	19	10	10	10

[a]Measured at 0.3 m height.
[b]Periodic annual height increment.
[c]Periodic annual volume increment.
[d]Mean difference between 1969 to 1978 and 1979 to 1988 values.
[e]Standard deviation of differences.
**$p \geq 0.001$, *$p \geq 0.01$.

Table 11. Statistics for comparison of ring width, periodic annual height increment (pahi) and periodic annual volume increment (pavi) for black spruce near Fort McMurray between the drained and undrained condition for the same time period (ingrowth excluded)

	Ring width[a] (mm)		Pahi (m)		Pavi (dm^3)	
	1969-1978	1979-1988	1969-1978	1979-1988	1969-1978	1979-1988
Drained mean	0.40	1.70	0.082	0.255	0.0086	0.3392
Undrained mean	0.49	0.51	0.064	0.067	0.0182	0.0469
Drained mean / Undrained mean	0.8	3.3	1.3	3.8	0.5	7.2
t	-1.35	6.5**	1.39	12.20**	-2.30*	4.77*
df	29	29	29	29	29	29

[a]Measured at 0.3 m height.
**$p \geq 0.001$, *$p \geq 0.05$.

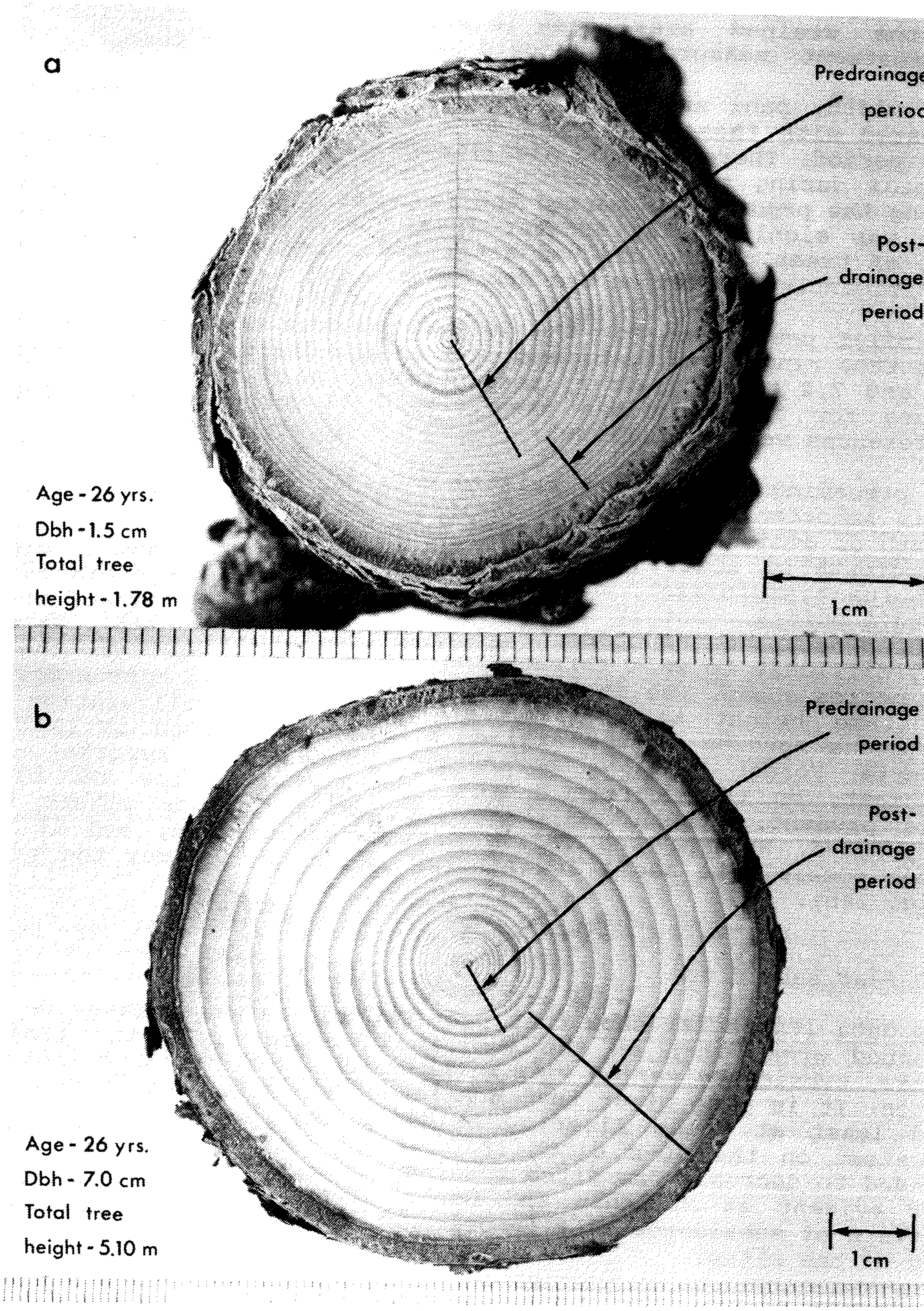


Figure 23. Disks cut from stumps (0.3 m) of a) a tree from the undrained area, and b) a tree from the drained area, near Fort McMurray. Note scale difference.

on the drained area came in after treatment; therefore, no pretreatment measurements could be obtained from them.

Ring width, pahi and pavi for trees on the undrained site were compared with those for trees on the drained area for the same time period. There were no significant differences in ring width or pahi during the predrainage period (Table 11 and Fig. 23). During the predrainage period the pavi for trees on the undrained area was significantly greater ($p \leq 0.05$) and more than twice that of trees on the drained area. After drainage, the pavi was significantly greater on the drained area.

A similar comparison for the 1979-88 postdrainage period showed that tree ring width, pahi and pavi on the drained area were 3.3, 3.8 and 7.2 times greater, respectively, than the corresponding values for the undrained area (Table 11 and Fig. 23); these differences were significant.

The preceding results are related entirely to black spruce, but it is important to note that drainage had a noticeable effect on growth of deciduous species also. No attempt was made to quantify the growth of alder (*Alnus crispa*), willow (*Salix* spp.), aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*) and birch (*Betula pumila*), but it was evident that a dense growth of these species occupied the space between the spruce (Fig. 24a). It was very difficult to walk through and impossible to see more than a few metres ahead. The deciduous canopy had attained approximately the same height as the spruce canopy. The proliferation of deciduous species on the drained areas was observed in 1982 by Alberta Forest Service personnel (unpublished reports). In contrast, on the undrained area, where some willow and birch were present, growth of these species and black spruce was suppressed. Walking was fairly easy in comparison, and it was often possible to see a few hundred metres ahead over the trees (Fig. 24b).

4.5 Peat subsidence

The data (Table 12) show that peat subsidence was greater on the drained areas than on the undrained controls. On the drained areas, subsidence varied with ditch spacing and distance from the ditch. It is also clear that subsidence was greatest at McLennan and least at Goose River. Subsidence on all three areas was greatest on the 30-m ditch spacing. At Wolf Creek, subsidence tended to decrease as ditch spacing increased but this trend was not evident at McLennan and Goose River. There was no clear pattern of subsidence as a function of distance from the ditch on any of the sites.

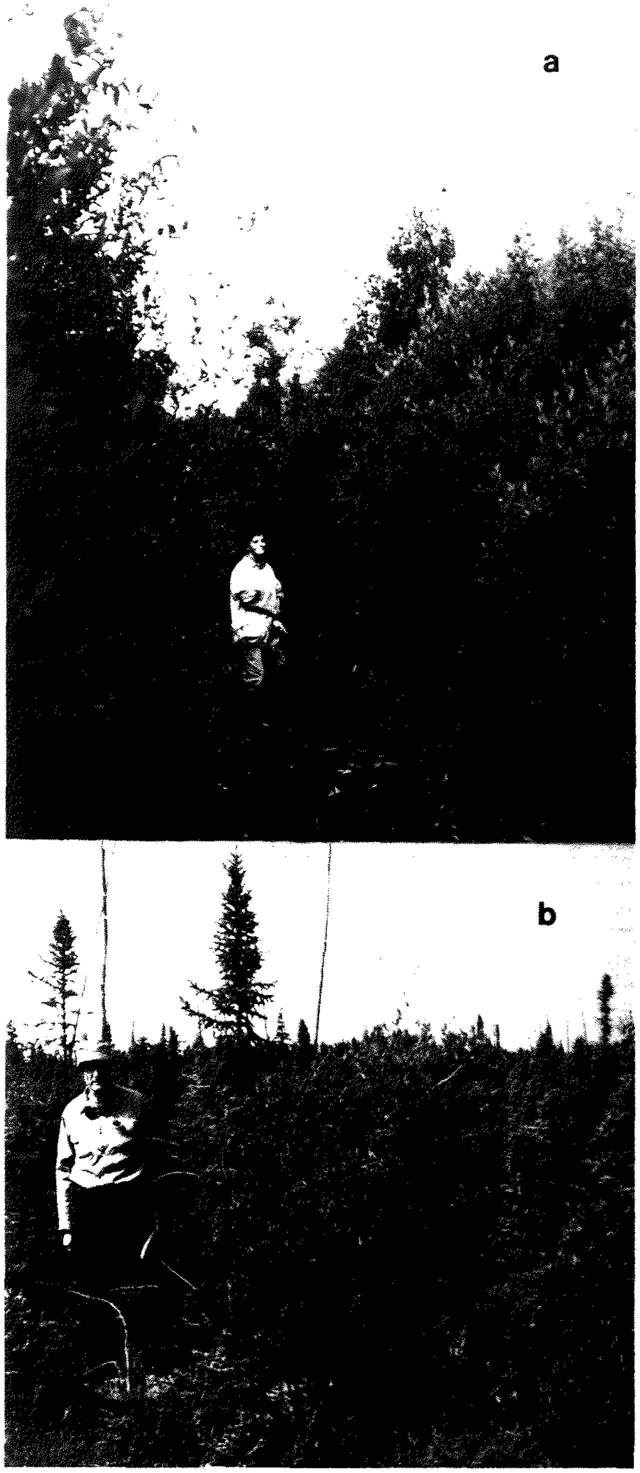


Figure 24. a) Dense growth of deciduous species on the drained area, and b) black spruce and deciduous species growing on the undrained area, near Fort McMurray. (Note the presence of tamarack; a few were found on both the drained and undrained areas).

Table 12. Peat subsidence (cm) on the Goose River, McLennan 28 and Wolf Creek experimental areas

Goose River (24 months after drainage)

Location	Ditch spacings (m)				Control
	30	40	50	60	
Near ditch	6.8	1.8	4.3	-	
1\4 point	10.3	2.0	3.2	-	
Midpoint	4.7	1.2	0.7	-	
					1.5
All	7.3	1.7	2.7	-	1.5

McLennan 28 (26 months after drainage)

Location	Ditch spacings (m)				Control
	30	40	50	60	
Near ditch	19.5	10.2	8.6	9.8	
1\4 point	11.2	9.2	9.2	13.5	
Midpoint	17.5	11.2	6.0	8.3	
					1.0
All	15.4	10.2	7.9	10.5	1.0

Wolf Creek (11 months after drainage)

Location	Ditch spacings (m)				Control
	30	40	50	60	
Near ditch	8.8	14.3	7.3	-	
1\4 point	8.5	6.0	6.6	-	
Midpoint	9.5	7.0	3.5	-	
					2.0
All	8.9	8.4	5.8	-	2.0

5. DISCUSSION

5.1 Groundwater table levels

The greatest changes in groundwater table levels occurred at McLennan and the least at Goose River. The smaller drops in water table levels at Goose River were influenced by the shallowness of the peat on that site.

Results from Goose River so far indicate that drainage there has increased the average depth to water table at the midpoint between ditches by 11 to 21 cm, with the average water table levels lying between depths 31 cm (50-m ditch spacing) and 44 cm (30-m spacing). These depths are within the range of optimum depths (18 to 50 cm) recommended for different tree species, found in forest drainage literature (Heikurainen 1964).

It appears that acceptable depths to water table can be achieved using 50-m ditch spacings but it is not known whether this spacing will result in the best growth of black spruce. This will be determined in the future when the permanent sample plots on Goose River are remeasured. Economics and environmental preservation considerations dictate that ditch spacings be as wide as possible but they must also be close enough to promote acceptable improved tree growth rates.

At McLennan, for the 30-, 40- and 50-m ditch spacings, the average drop in water table levels resulting from drainage decreased as the ditch spacing increased. The 60-m ditch spacing did not follow this trend but showed a drop greater than both the 40- and 50-m spacings. Evidently, the average hydraulic conductivity for the area containing the 60-m spacings was greater than for the area containing the 40- and 50-m spacings.

Drainage at McLennan increased the average depth to water table at the midpoint between ditches by between 37 and 74 cm, with the average water table levels lying between depths 52 cm (40-m ditch spacing) and 80 cm (30-m spacing). The postdrainage profiles for the 40-, 50- and 60-m spacings (Figs. 16b, 16c and 16d) show groundwater "mounds" midway between ditches. It is not clear whether these are natural mounds or mounds resulting from interference by the 15 cm wells installed at these locations. Groundwater mounds were not apparent on the Goose River (Figs. 13a and 14a) and Wolf Creek (Fig. 18) sites where 15 cm wells were also installed.

Because the postdrainage average water table levels for McLennan, particularly those for the 30- and 60-m spacings, lie well below the optimum range suggested for tree growth (18-50 cm), it is possible that the McLennan site was overdrained. Further measurement of the ground vegetation composition and the tree growth permanent sample plots are necessary to confirm this. It is also possible that the McLennan site has a high average hydraulic conductivity and ditch spacings wider than 60-m would have sufficed.

The McLennan drainage area is close to the height of land and, consequently, there is a limited water supply replenishing water lost from the area due to drainage. The groundwater table levels, therefore, tend to remain low. Goose River and Wolf Creek are part of large catchment areas, much of which is upstream from the drained areas. Consequently, there may be some replenishment of water to the drained areas at Goose River and Wolf Creek.

At Wolf Creek, the effects of the 40- and 50-m ditch spacings on groundwater table levels were similar (Fig. 19). These spacings dropped the average water table to within the range of optimum levels for forestry. The 30-m spacing resulted in an average water table drawdown of 61 cm and an average drop of 51 cm at the midpoint between ditches. These data suggest that the 30-m spacing at Wolf Creek resulted in overdrainage and that the 50-m spacing is adequate for draining the Wolf Creek site.

From the values given, there appears to be no simple relation between the average drop in water table across the profile and the average drop in water table at the midpoint between ditches. For the 30-m ditch spacing, the average drop at the centre was about 80 to 95% of the average drop across the profiles. For other ditch spacings the drop at the centre varied between 55 and 86% of the average profile values. It is also apparent that the hydrology or water supply to the wetland has a bearing on the necessary ditch spacing as well as the type and depth of peat.

5.2 Stream water quality

It would appear from the Goose River results that, except for producing an increase in concentration of iron and a reduction in concentrations of potassium and aluminum, ditching had no effect on the measured chemical water quality or suspended sediment concentrations in the stream. An inspection of the sediment ponds and stream channel on July 24, 1986, however, revealed that sediment filled the sediment ponds and also covered the banks of the stream channel near each main ditch. This was the result of the 99 mm of rain that fell in a 9-day period earlier in July during ditching. It was evident that the sediment ponds were functioning well but needed to be cleaned out after a storm of that magnitude. Perhaps several, or larger ponds are needed to capture sediments during and after ditching.

The sediment ponds at Goose River were cleaned out and enlarged in October 1988, but by mid-June, 1989 they were filled again. Once more, there was ample evidence of sediment along the banks of the stream channel. The sediment pond at Wolf Creek was also filled during the first year following drainage but, so far, sediment there appears not to have reached the stream channel.

It is clear that sampling only during the monthly service visits to each experimental area is inadequate for a proper assessment of changes in stream physical and chemical water quality due to drainage. The results so far are probably indicative only of water quality conditions prevailing during low flow periods. Ideally, sampling should also be timed to coincide with the spring runoff and with storms that occur during the remainder of the monitoring period - events during which high concentrations of sediment and chemical elements are most likely to be flushed into the stream channel. Future plans include the use of automatic water sampling devices linked to stage-measuring recorders that activate the samplers during storm flow periods.

One of the main ditches at Goose River is degrading and is a major source of sediment. It is deeper than when first constructed and its banks are undercut and slumping. It was constructed down a 0.7% slope in a natural, vegetated draw. The need to minimize these kind of erosion problems suggests that, for ditch network design purposes, a limit should be imposed on the degree of slope that can be tolerated in ditch construction. A limit on main ditch length is also required.

5.3 Ground vegetation composition

Only some of the more obvious changes in the ground vegetation following drainage have been commented on in the results. More detailed conclusions will require further analysis of the data and additional plot measurements at some future date. A maximum of three years post-drainage conditions is not sufficient time to reveal any more than obvious immediate changes or subtle trends that may or may not persist.

Less change was evident in the ground vegetation following drainage at the Goose River site than at the other two, partly because of a lower species diversity, and partly because of a more consolidated ground-covering mat of Sphagnum moss. Sphagnum peat has a far greater capacity to retain water than do other types of peat. The lower cover of Sphagnum and abundant cover of pleurocarpous mosses and sedges at Wolf Creek and McLennan produces a peat that is less able to retain water and thus support some of the shallowly rooted vegetation, buffering it from some of the effects of drainage. Ongoing studies on available moisture in the peat at the three experimental sites may help to explain differences between them.

Aside from the more obvious changes common to all three sites, the pattern of change in the lesser vegetation at McLennan was less clear than at the other two sites, appearing to depend most on microhabitat and exposure. This was especially true in the case of the deciduous shrubs where some plots showed an increase in cover, some showed a decrease, and others showed no change at all over the four years of measurement. None of these changes appeared at all related to the distance from a ditch.

At Wolf Creek and McLennan there is some indication that the cover of _Aulacomnium palustre_ and the feather mosses may be increasing slightly to fill part of the void left by the declining mosses, notably _Sphagnum_ and _Tomenthypnum_. Further measurements will be necessary to ascertain if this trend persists or is only a short-term or measurement phenomenon.

Sampling design for the ground vegetation permanent sample plots was based on the initial assumption that there would be changes in the vegetation due to drainage and that these changes would be related to the distance from the ditches. However, it appears that the groundwater table has been lowered sufficiently, even at the 60 m spacing at McLennan, to virtually negate the possibility of detecting any changes in the ground vegetation related specifically to distance from ditches. General comments on changes related to drained versus undrained conditions, and changes in the plots in the drained area before and after drainage, have been made, but there are limitations to this. First, there was only one year of predrainage measurements taken at Goose River and McLennan (two years at Wolf Creek). In some cases this makes it difficult to say whether or not a change in the ground vegetation is due to drainage or is simply a reflection of annual variability. More years of predrainage measurement would help to resolve this problem.

The second difficulty in determining the cause of change is observational errors in recording plant cover. Species morphology, the distribution of individual plants, and misidentification of species all contributed to errors. In terms of morphology, the "lacy" growth form of the _Equisetum_ spp. provided the most difficulty with cover estimates varying widely, both up and down, between successive measurements. Leaning branches also contributed to wide fluctuations in cover estimates for the _Salix_ spp. Species with the smallest covers exhibited large measurement errors between successive measurements, indicating that cover estimates for these species are unreliable. Misidentification of species was a greater problem than expected. Following drainage, many of the sedges in the drained areas failed to produce flowering spikes, making identification difficult. Cover estimates were often attributed to different species between successive measurements. In a number of plots in the drained area at McLennan, difficulties occurred in trying to separate _Aulacomnium palustre_ and _Tomenthypnum nitens_ in a desiccated condition. Observational bias cannot be completely overcome. It can be lessened by having the same observer, familiar with the vegetation, measuring the plots at the same time each year, but because it cannot be eliminated entirely, changes in the vegetation need to be greater than 20% before they can be attributed to factors other than annual fluctuation and measurement error (Kennedy and Addison 1987).

Unexpected problems compounding measurement error and annual variability were simple recording errors that were not caught at the time of sampling and misalignment of plots between successive measurements because of missing or bent corner pins. These problems contributed in some cases to large discrepancies in cover estimates between measurements. All of these uncertainties are limiting factors in the utilization of plant cover estimates for biomonitoring purposes.

Certain other difficulties with the sampling procedure became evident with time. Some changes in approach may be necessary to facilitate easier sampling in the future. Considerable trampling around the plots occurs as measurements are being taken. This trampling, by creating a pedestalled plot, could cause changes in the vegetation independent of drainage. For this reason it is recommended that the plots be measured no more frequently than every third, or possibly even every fifth year if long term measurements are contemplated. Also, because of the inherent difficulties in identifying desiccated Sphagnum and Drepanocladus spp. in situ, it would be easier to treat these as species groups rather than trying to separate all species present. Vegetative (and often browsed) willows and sedges are equally difficult to identify to species and could be considered as species groups for easier comparative purposes in the future.

Ground vegetation reflects microenvironmental conditions. Microhabitat differences can be as important as drainage effects in altering the composition of the vegetation. Microhabitat appeared to be the most significant factor affecting changes in the ground vegetation at McLennan, more so than at the other two sites. Under the current ditching regime, exposure of the plots to the drying influence of the sun may be a more important factor than distance from a ditch in determining the degree of change in the vegetation. To record variations in microhabitats and their influence on ground vegetation change, consideration should be given to the use of larger plots to sample the vegetation. A greater proportion of the control areas should have been surveyed as well.

5.4 Tree growth (Fort McMurray)

It is clear that lowering the water table on the study area near Fort McMurray affected tree growth. Trees were larger as a result, showing increases in height, diameter and volume. Although no groundwater table measurements were taken, it is speculated that drainage caused the average water table level to drop 50 cm. After drainage, periodic annual volume increment per tree on the drained area was more than 7 times that on the undrained area.

Two important facts should be kept in mind when assessing the results from the Fort McMurray study. First, the ditch spacing (10 m) is unusually narrow for forest drainage; secondly, the trees are 30 years old or less.

The additional value of the Fort McMurray drainage study is the young age of the stand. If the study area is protected from further disturbance, growth measurements can be taken as the trees pass through different age classes. Such measurements will enable us to learn to what extent the improved growth rates can be sustained.

Comparative data for black spruce of similar age in Alberta and elsewhere in Canada is sparse. Lieffers and Rothwell (1987a) conducted studies on 35-year-old black spruce growing on a drained fen near the Saulteaux River, Alberta. They reported a reduction in leader elongation for 1984 and 1985 compared with predrainage (1979-83) elongation. The reduction was evident on drained and undrained sites and on adjacent undisturbed areas. The depressed growth was attributed to low rainfall during 1984 and 1985. There was also a tendency for leader elongation on the drained site to be less than on the undrained site. In 1985, leader elongations on the drained and undrained sites were 2.9 cm and 6.8 cm, respectively. The corresponding predrainage elongations were 10.7 cm and 11.6 cm.

The difference in results obtained from the two Alberta sites can be related to the length of the postdrainage period and site factors. Evidently, at the Saulteaux River site the trees had not recovered from the shock imposed by drainage and drought during the first, and only, 2 years of postdrainage measurement (1984-85). On the drained site at Fort McMurray, recovery seemed to be faster and leader growth was clearly superior during the abitrarily defined postdrainage period, 1979-88. Examination of annual ring width data for the 11 trees, 20 years and older, on the drained area near Fort McMurray showed that 7 of these trees began to respond to drainage in 1976 or 1977 - very soon after treatment was first implemented.

Differences in site characteristics were also important. Peat depth at Fort McMurray is much shallower than at Saulteaux. It is speculated that tree root systems in the drained peat at the Fort McMurray site were quickly able to take advantage of improved aeration conditions and the proximity of the mineral soil by expanding and taking up extra nutrients.

The Fort McMurray site is further north than the Saulteaux River site and evapotranspiration during the growing season there is probably less than at Saulteaux. Consequently, soil water is not depleted so readily and is conducive to better forest growth.

Because few areas have been drained specifically to improve forest growth, several forest researchers compensated for the lack of suitable study sites by establishing drainage/tree growth studies near highway or agricultural ditches. This method has been used in Alberta (Wang et al. 1985; Lieffers and Rothwell 1987b; Dang 1988), Manitoba (Woons 1988), Ontario (Stanek 1977) and Quebec (Trottier 1986).

Dang (1988) sampled six peatland sites near Highway 2, east of

Slave Lake, Alberta. The locations were drained 21 years previously. He found no growth response in 54- to 128- year-old black spruce, 3 to 6 years after drainage. After that, tree ring growth increased linearly until a maximum was reached 13 to 19 years after drainage. The maximum increase ranged from 0.8 to 7.7 times the growth the trees would have attained if the sites were not drained.

In a similar study of 54-year-old black spruce growing on drained sites, Lieffers and Rothwell (1987b) found that increases in basal area periodic annual increment were related to increased depths to water table. After road construction in 1966, radial growth on undrained sites upslope from the road was significantly lower than predrainage growth. In these instances, the site was too far from the roadside ditch to be affected by drainage, or no ditch was present and the road behaved like a dam.

It is clear from the foregoing discussion that tree growth response to drainage varies from site to site. The most important factor in the situations previously described is the difference between the hydrologic conditions prevailing at a roadside ditch and those at a ditch network designed for forest drainage. Depth to mineral soil may also be an important factor governing initiation of growth response to lowered water tables.

Another factor controlling tree growth response to drainage is the type of peat that exists on the drained sites. At Goose River, the commonest peat is sphagnum peat which tends to retain water better than other peat types such as sedge peats. This tends to make sphagnum peat a better growth medium for trees so far as soil water is concerned. The dominant peats at McLennan are sedge and brown moss peats. Because the peat at Goose River is sphagnum peat and is shallower than the sedge/brown moss peats at McLennan and Wolf Creek, tree growth at Goose River will likely be better than tree growth at McLennan and Wolf Creek.

Results from drainage studies conducted in other parts of Canada show that, in general, drainage has a positive effect on black spruce growth. In Manitoba, Woons (1988) investigated the effects of drainage on stands of 128-year-old black spruce and found that 11 to 50 years after drainage the average width of annual rings after drainage (0.93 mm) was twice that before drainage (0.46 mm).

Stanek (1968) reported that the average annual height growth of uneven-aged black spruce in Leitch Township, northern Ontario, for the first 5 years after drainage (9.5 cm) was 3 times the average for the 5 years before drainage (3.1 cm). The annual height increment 5 years after drainage (14.5 cm) was 5 times the increment for the year preceding drainage (2.8 cm). This is less than one-half the average postdrainage height increment for black spruce on the Fort McMurray site (34.2 cm).

Because soil water content is an important factor governing tree growth, information on the relationships between tree growth, groundwater table levels and water content in the unsaturated zone is essential. Studies, therefore, were initiated by the University of Alberta in 1989 to evaluate the magnitude and spatial/temporal variability of soil water content of the surface 30 cm of drained and adjacent undrained peatlands at Goose River, McLennan 28, Wolf Creek and Saulteaux River. A description of the study and some preliminary results appeared in a recent report (Rothwell and Silins 1989).

5.5 Peat subsidence

Although preliminary subsidence data for the different sites do not have the same time frame (number of months after drainage), it is possible to detect certain trends and to draw some conclusions.

The greatest subsidence was observed on the 30-m spacing transect at McLennan. Before drainage, this transect stood in a water track and the water content of the surface peat was extremely high. When the area was drained the residual surface plant material, which occupied very little volume, quickly subsided. In contrast, at Goose River the peat was shallow and the site was much drier than the water track at McLennan. Consequently, after drainage peat subsidence was considerably less on the Goose River site.

Peat subsidence is usually accompanied by an increase in peat bulk density, a reduction in pore sizes and an increased tendency to retain water - all factors which tend to reduce water availability to plants growing on the peat.

6. CONCLUSIONS

Preliminary results from Goose River, McLennan 28 and Wolf Creek indicated that the average depth to groundwater table after drainage was between 37 and 90 cm. The corresponding drops in the water table levels were between 17 and 78 cm. The greatest changes occurred at McLennan and the least at Goose River. The smaller drops at Goose River were influenced by the shallowness of the peat at this site.

Because we do not yet know the measured tree growth response to the water table drawdown caused by the different ditch spacings, it is not clear what is the best ditch spacing for optimum tree growth. It is suspected, however, that the 30-m spacing caused a greater water table drawdown than was necessary on all three experimental areas, particularly the fen sites at McLennan and Wolf Creek. Additional knowledge, on water content in the unsaturated zone, is required to relate ditch spacings to tree growth.

Stream water quality data from Goose River showed that drainage had little effect on measured physical and chemical stream water quality there during low flow periods. Insufficient data were obtained to analyze changes in water quality during peak flow periods. Automatic sampling devices and procedures should be used for this purpose because they provide the best means of monitoring water quality during spring runoff and storm flow periods. Degradation of some main ditches indicated the need to specify in future ditch network design the maximum permissible slope and the maximum main ditch length to be used in ditch construction. Alternatives, or improvements to the present method of designing and locating sediment ponds are needed because, when existing methods are used, empty sediment ponds usually fill during a single, heavy rainstorm.

Initial results from Goose River, McLennan 28 and Wolf Creek show that almost all the changes occurring in the ground vegetation are negative in terms of reduced plant cover and vigor. Microhabitat appears to be a more important factor influencing changes in the ground vegetation than distance from a ditch. It is too early to tell what effects, if any, changes in the ground vegetation at these three sites are having on tree growth. There is no evidence yet of increased competition from deciduous shrubs. More long-term monitoring of the sites is necessary to determine the pattern of change in the ground vegetation.

Lowering the water table on a forested swamp near Fort McMurray using approximately 10-m ditch spacings resulted in a significant increase in height, diameter and volume of 30-year-old black spruce. The increase was evident from comparison of annual rings before and after drainage for trees on the drained area,and from comparison of annual growth rings for trees on the drained and undrained areas for the same time periods. Because black spruce growing on shallow (0.5 to 1.2 m) peat responded quickly to drainage, the effect of lowering the water table on tree root development and possible penetration of roots into mineral soil warrants further investigation.

The increase in growth of black spruce was accompanied by an equally impressive growth of alder, willow, birch, aspen and balsam poplar. The significance of this increased growth of deciduous species on black spruce productivity merits further study. It may be necessary to develop methods for controlling the deciduous competition.

Preliminary data from Goose River, McLennan 28 and Wolf Creek indicated that the amount of subsidence is related primarily to the pore space and water content of the surface peat. The greatest subsidence occurred on sites that were characterized by deep, wet peats before drainage. The water track on the west side of McLennan 28 is an example of such a site. The least subsidence occurred on sites characterized by shallow dry peats before drainage.

7. RECOMMENDATIONS

1) To gain the maximum benefit from this project it is essential to continue monitoring, at regular intervals (e.g., 5 years), the tree growth and ground vegetation composition permanent sample plots established on Goose River, McLennan 28 and Wolf Creek.

2) There is an urgent need to develop a wetlands classification system that can be used to determine which wetland sites are best suited for drainage and increased wood yields.

3) An operational forest drainage manual should be prepared that provides guidelines for designing and constructing ditch networks. It should be used, in conjunction with the wetlands classification system referred to in recommendation 2), to design drainage systems that maximize the amount of wood produced but at the same time minimize damage to the environment.

4) Because of the importance of soil water to tree growth, further studies on the relationships between tree growth, groundwater table levels and water content in the unsaturated zone should be undertaken on drained and undrained forested sites. They will complement the study, completed in 1989, on soil water content of drained and undrained peatlands.

5) Further study is required on the effects of drainage effluent on downstream water quality during peak flows. Data on sediment, organic and inorganic chemical constituents of stream waters downstream from the ditches should be collected using automatic water samplers and data recorders.

6) Experience shows that existing sediment ponds fill up too rapidly and require frequent cleanout or they become nonfunctional. Improved, or alternative methods of reducing sediment, or containing it within the drained areas need to be devised.

7) The impact of forest drainage on wildlife and wildlife habitat; and the impact of beavers on forest drainage systems should be investigated.

8) The effects of forest drainage on the quantity and timing of streamflows in the Northwest Region is unknown. Studies to address this problem should be initiated.

9) The economic feasibility of forest drainage should be determined before large-scale operational forest drainage projects are undertaken in Alberta.

10) If it is eventually proven that large-scale operational forest drainage projects are harmful to the environment they should be scaled down or not undertaken.

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APPENDIX. List of Plants Mentioned in Text[8]

TREES

Larix laricina (Du Roi) K. Koch	Tamarack
L. sibirica Ledeb.	Siberian Larch
Picea glauca (Moench) Voss	White Spruce
P. mariana (Mill.) BSP.	Black Spruce
Pinus contorta Loudon	Lodgepole Pine
Populus balsamifera L.	Balsam Poplar
P. tremuloides Michx.	Aspen

SHRUBS

Alnus crispa (Ait.) Pursh	Green Alder
Andromeda polifolia L.	Bog Rosemary
Betula pumila L.	Swamp Birch
Ledum groenlandicum Oeder	Common Labrador Tea
Salix farriae Ball	Farr's Willow
S. pedicellaris Pursh	Bog Willow
S. planifolia Pursh	Flat-leaved Willow

DWARF SHRUBS

Empetrum nigrum L.	Black Crowberry

HERBS

Calamagrostis inexpansa A. Gray	Northern Reed Grass
Caltha palustris L.	Marsh Marigold
Carex aquatilis Wahlenb.	Water Sedge
C. chordorrhiza L.f.	Prostrate Sedge
C. diandra Schrank	Two-stamened Sedge
C. disperma Dewey	Two-seeded Sedge
C. gynocrates Wormsk.	Northern Bog Sedge
C. leptalea Wahl.	Bristle-stalked Sedge
C. limosa L.	Mud Sedge
C. paupercula Michx.	Bog Sedge
C. tenuiflora Wahl.	Thin-flowered Sedge
C. trisperma Dewey	Three-seeded Sedge
Corallorhiza trifida Chat.	Pale Coral-root
Drosera rotundifolia L.	Round-leaved Sundew
Equisetum arvense L.	Common Horsetail
E. fluviatile L.	Swamp Horsetail
E. sylvaticum L.	Woodland Horsetail
Galium labradoricum Wieg.	Labrador Bedstraw
Menyanthes trifoliata L.	Buck-bean
Oxycoccus microcarpus Turcz.	Small Bog Cranberry

[8] Nomenclature for the vascular plants follows Moss and Packer (1983); the mosses follow Ireland et al. (1987); and the lichens follow Egan (1987).

O. quadripetalus Gilib.	Swamp Cranberry
Pedicularis labradorica Wirsing	Labrador Lousewort
P. parviflora Smith	Purple Lousewort
Potentilla palustris (L.) Scop.	Marsh Cinquefoil
Rubus chamaemorus L.	Cloudberry; Baked-apple Berry
Smilacina trifolia (L.) Desf.	Three-leaved Solomon's-seal
Stellaria longifolia Muhl.	Long-leaved Chickweed
Triglochin maritima L.	Seaside Arrow-grass
Vaccinium vitis-idaea L.	Bog Cranberry; Lingonberry

MOSSES

Aulacomnium palustre (Hedw.) Schwaegr.	Ribbed Bog Moss
Calliergon stramineum (Brid.) Kindb.	
Drepanocladus fluitans (Hedw.) Warnst.	
D. lapponicus (Norrl.) Smirn.	
D. vernicosus (Mitt.) Warnst.	
Meesia triquetra (Richt.) Aongstr.	
Pleurozium schreberi (Brid.) Mitt.	Schreber's Moss
Sphagnum angustifolium (C. Jens. ex Russ.) C. Jens. in Tolf	Peat Moss
S. fuscum (Schimp.) Klinggr.	Peat Moss
S. magellanicum Brid.	Peat Moss
S. squarrosum Crome	Squarrose Peat Moss
S. teres (Schimp.) Aongstr. ex C. Hartm.	Peat Moss
S. warnstorfii Russ.	Peat Moss
Tomenthypnum falcifolium (Ren. ex Nich.) Tuom.	Golden Moss
T. nitens (Hedw.) Loeske	Golden Moss

LICHENS

Cladina mitis (Sandst.) Hustich	Reindeer Moss
Peltigera spp.	Dog Lichens

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