

THE CANADA-ALBERTA WETLANDS DRAINAGE AND IMPROVEMENT PROGRAM FOR FORESTRY: AN UPDATE

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ABSTRACT

In 1986, 135 ha were ditched near Goose River, one of the three experimental drainage areas set up under the Canada-Alberta Wetlands Drainage and Improvement Program. The average depth to water table after ditching was between 38 and 53 cm. Ditching had little impact on the physical and chemical quality of stream water during periods of low flow. The data were insufficient for determining the effects of ditching on water quality during periods of high flow. At a Fort McMurray site, which was drained between 1975 and 1980, drainage significantly increased growth rates of young black spruce (*Picea mariana*). Average height, diameter at breast height and volume of trees in the drained area were respectively 1.8, 2.3 and 5.0 times greater than for trees in the undrained control. For trees in the drained area, the average annual-ring width for the postdrainage period was 4.3 times that for the predrainage period. It was 3.3 times that of the average annual-ring width of trees in the undrained area for the corresponding post-drainage period. On portions of the drained area, a dense growth of deciduous species, attaining the same height as the spruce, has grown up with the spruce.

RÉSUMÉ

En 1986, des fossés ont été aménagés sur 135 hectares près de la rivière Goose, l'un des secteurs de drainage expérimentaux créés dans le cadre du programme Canada-Alberta d'assainissement et d'amélioration des terres humides. Une fois les travaux terminés, la profondeur moyenne de la nappe phréatique variait de 38 à 53 cm. L'aménagement de fossés a eu peu d'incidences sur les caractéristiques physiques et chimiques de l'eau de la rivière en périodes de faible débit. Les données n'étaient pas suffisantes pour déterminer les effets de l'aménagement de fossés sur la qualité de l'eau en périodes de débit élevé. Le drainage du site de Fort McMurray, qui a eu lieu entre 1975 et 1980, a fait énormément augmenter le taux de croissance des jeunes épinettes noires (*Picea mariana*). La hauteur moyenne, le diamètre à hauteur de poitrine et le volume des arbres du secteur drainé étaient respectivement 1,8, 2,3 et 5,0 fois supérieurs à ceux des arbres de la station témoin non drainée. La largeur moyenne des cernes d'accroissement annuel après les travaux était 4,3 fois supérieure à celle d'avant les travaux et 3,3 fois supérieure à la largeur moyenne des cernes d'accroissement des arbres de la station témoin pendant la période postérieure aux travaux correspondants. Une végétation dense composée d'essences feuillues est apparue dans certaines parties.

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INTRODUCTION

The Canada-Alberta Wetlands Drainage and Improvement Program is in its fifth year of operation. It was initiated by the Canadian Forestry Service (now Forestry Canada) and the Alberta Forest Service under the Canada-Alberta Forest Resource Development Agreement (Anon. 1984). The reasons for implementing the program, its objectives, the research plan, and the methodology were described earlier (Hillman 1987, 1988a,b).

In the summer of 1985, a Canadian Forestry Service-Alberta Forest Service team selected Goose River, McLennan 28 and Wolf Creek wetland areas as experimental drainage sites. Subsequently, instrumentation and permanent sample plots were installed on the sites to measure changes in the water-table levels of groundwater, ground temperatures, stream-water quality, ground-vegetation composition and tree growth.

These and several other forested wetland drainage projects were recently implemented in Alberta (Hillman 1987, Toth and Gillard 1988), but too little time has elapsed since drainage for meaningful data on tree growth response to be available. Consequently, data from a drainage project established by the Alberta Forest Service near Fort McMurray in 1975 were used in obtaining estimates of tree-growth response to drainage.

The purpose of this paper is to outline some of the results obtained so far — namely, the effects of drainage on groundwater levels and stream-water quality at Goose River, and on tree growth at Fort McMurray.

SITE DESCRIPTIONS AND TREATMENTS

The sites investigated are located in the mixedwood boreal forest region of Alberta (Rowe 1972). In each case, existing vegetation grew in after fire. Legal descriptions and other details for the Goose River and Fort McMurray sites are provided in Table 1.

The Goose River experimental drainage area is a swamp situated about 35 km southeast of Valleyview

(54° 54'N, 116° 45'W) at an elevation of 850 m. The swamp supports a black spruce (*Picea mariana*) stand 40 to 50 years old and a shrub understory dominated by Labrador tea (*Ledum groenlandicum*). Peat depth is less than 1 m. Ditching at Goose River was started in June 1986 and completed in September 1986. A more detailed description of the Goose River site and its treatment is given by Hillman (1988a).

The 89-ha Fort McMurray project area is a coniferous swamp located 11 km south of Fort McMurray (56° 34'N, 111° 19'W), adjacent to Highway 63 in the Athabasca Forest at an elevation of 400 m. Vegetation, established after a wildfire in 1953, consists of a dense cover of black spruce and a Labrador tea, feathermoss (mainly *Pleurozium schreberi*) and sphagnum moss (*Sphagnum* spp.) association.

Between 1975 and 1980 the Alberta Forest Service imposed a number of different treatments on the area to remove excess soil water and thereby enhance forest growth. Although different treatments were applied to separate portions of the area to test three drainage intensities, data collected from only one of the drained areas was used in the tree growth analyses described in this paper — the 25-ha area that was most intensively scarified¹ and ditched, and that lies adjacent to the 16-ha control (undrained) area. Preliminary analyses (Alberta Forest Service, unpublished reports) indicated that the effects of drainage were most pronounced on this site. Further information on site description and treatments is provided by Hillman (1987; unpublished report, 1989). The drainage took place over a six-year period, from 1975 to 1980; hence, for the purpose of analysis, the postdrainage period was arbitrarily defined as extending from 1979 to 1988.

¹ Scarification consisted of blading the vegetation and upper layer of peat with a bulldozer; this resulted in bladed strips 7 m wide alternating with spoil rows and undisturbed strips 3.5 m wide.

Table 1. Details of the Goose River and Fort McMurray drainage areas

Site (legal description)	Total area (ha)	Drained area (ha)	Date completed (d m ⁻¹ yr ⁻¹)	Total ditch length (km)	Nominal ditch spacing (m)	Ditch spacings evaluated (m)	Drainage ditch density (m ha ⁻¹)
Goose River (14-68-19-W5 ^a)	320	135	30/09/86	40	40	30, 40, 50	294
Fort McMurray (24-87-9-W4)	89	25 ^b	1980	—	10	10	—

^a Section 14, Township 68, Range 19, west of 5th meridian.

^b Data from only a portion of the drained area at Fort McMurray were used in this study.

METHODS

Groundwater

Water-table configurations for groundwater at Goose River were monitored by means of between 7 and 12 wells, each 5 cm in diameter, which were installed, before drainage in 1986, perpendicular to ditches at three different ditch spacings. Two wells were installed on the undrained control. Depth to water table was obtained with a carpenter's tape measure once or twice a month.

Stream-water Quality

At Goose River, sediment loads and inorganic chemicals in water were monitored periodically at one location upstream and two locations downstream from points at which water from the drainage network's longest main ditch enters the creek. Sampling station D1 was located 300 m downstream from the upstream station (U) and 100 m from the nearest main ditch. Station D2 was located 1700 m downstream from station U and downstream from three main ditches. Sediment samples were collected in a DH-48 sediment sampler. The total suspended sediment was determined by methods described in Anon. (1971). "Grab" samples of water containing inorganic chemicals were collected in 250-ml plastic bottles and analyzed for total concentrations of Ca, Mg, Na, K, Al, Ti, Pb, As, Cu, Fe, Mn, Zn, Ni, S, P and N, according to the methods described by Hillman (1988a,b).

Tree Growth

Predrainage tree growth data were obtained from three transects established on the Fort McMurray site in the spring of 1976. Leader growth for 1975, total tree height and age were recorded for each tree sampled.

Four 0.25-ha plots were installed in the undrained area and in each of the drained areas in 1980. In 1981, one plot in each area was thinned to 1730 stems ha⁻¹, one plot was fertilized with nitrogen, another was fertilized with phosphorus and the fourth plot served as a control. In each plot, about 30 trees were measured for total height and leader growth each spring from 1981 through 1985. Leader-growth data for the 4-year period were analyzed by 2 x 4 (two site and four treatment conditions) factorial analyses of variance². Duncan's multiple-range test ($P = 0.05$) was used to compare the means.

² The two primary treatments were 'drained' and 'undrained'. To facilitate the analyses of variance, thinning and nitrogen/phosphorus fertilization were considered secondary treatments.

In August 1988, 42 trees were randomly sampled along transects crossing the drained and undrained areas. Twenty-two trees in the drained area and 20 in the undrained area were sectioned and measured. Disks were cut from the top of each tree section and were later used for age and ring-width determinations.

The disks were measured with a Holman Digimicrometer tree-ring increment measuring system and television camera. The resulting data sets were processed by means of the DUFFNO and STEM computer programs developed by Kavanagh (1983). The STEM program carried out stem analyses and provided tables showing mean annual increment and periodic annual increment for height (pahi), DBH, basal area and volume (pavi).

Paired and nonpaired t-tests were run on data from the destructively sampled trees to test the hypothesis that there were no differences between means for the drained and undrained areas, or between the means for the pre-drainage and post-drainage periods. Age and ring widths at 0.3 m height were compared, together with total height, leader length, DBH, volume per tree, pahi and pavi.

RESULTS

Groundwater

Data on the Goose River groundwater table are for May through October, from 1986 to 1988. The 1986 data constitute the pre-drainage measurements and the remainder are post-drainage data. The updated average water-table profiles of the pre- and post-drainage periods for the 30-, 40- and 50-m spacings (Fig. 1a, 2a and 3a, respectively) are not very different from previously presented profiles (Hillman 1988a) for 1986-1987. The average drops in water-table levels across the profiles after ditching were 27, 24 and 18 cm, respectively (Fig. 4). In contrast, on the undrained control, the average depth to groundwater table for the postdrainage period was 13 cm greater than that for the pre-drainage period. The average drops in water-table levels are greater than those reported previously (Hillman 1988b).

At Goose River, precipitation from May to October was 396, 337 and 392 mm, respectively, in 1986, 1987 and 1988. The corresponding total annual precipitation was 561, 439 and 540 mm. Of the three years, 1987 was the driest; during that year, lower average levels of groundwater table could be expected. At a lookout tower at Sweathouse, located adjacent to the Goose River experimental area, the 30-year (1951 to 1980) average precipitation for May to October was 444 mm (Anon. 1987).

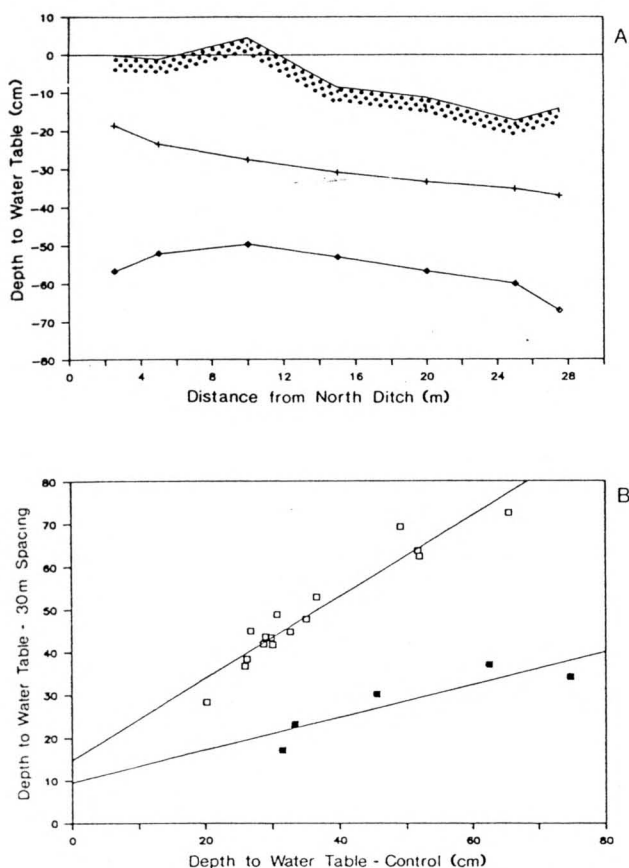


Figure 1. Goose River, 1986-1988, 30-m spacing. Depth to mineral soil is 93 cm. A) Average water-table profiles before (+) and after (◆) drainage. B) Regression lines before (■) [$y = 0.38x + 9.53$, $r^2 = 0.77$] and after (□) [$y = 0.95x + 14.84$, $r^2 = 0.92$] drainage.

To minimize the confounding effects of dry years on levels of groundwater table, regression analyses were carried out on values for depth to groundwater tables for the undrained control and for each ditch spacing. The results (Fig. 1b, 2b and 3b) indicate that, in each case, the post-drainage relation is distinct from the predrainage one; consequently, the drainage treatment had a greater impact on average levels of groundwater table than did the drier climatic conditions of 1987. The slopes of the post-drainage graphs are about three times those of the predrainage graphs.

Streamwater Quality

In 1986, 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 also frequently below the detection limits. The highest concentrations of Ti, Pb and Zn de-

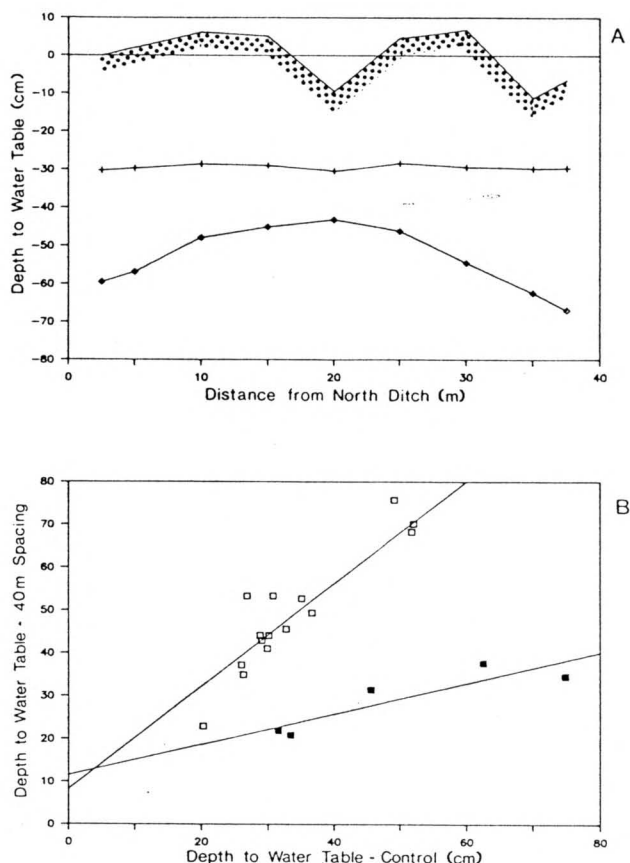


Figure 2. Goose River, 1986-1988, 40-m spacing. Depth to mineral soil is 96 cm. A) Average water-table profiles before (+) and after (◆) drainage. B) Regression lines before (■) [$y = 0.36x + 11.54$, $r^2 = 0.79$] and after (□) [$y = 1.20x + 8.36$, $r^2 = 0.87$] drainage.

tested in the downstream samples were 0.01, 0.04 and 0.04 mg kg^{-1} , respectively. The large number of zero values did not allow for statistical analysis of data for these elements.

Analyses of the 1986 data on suspended sediment and chemicals in water (Table 2) showed that there were no significant differences between 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. Both downstream means were significantly greater for Fe.

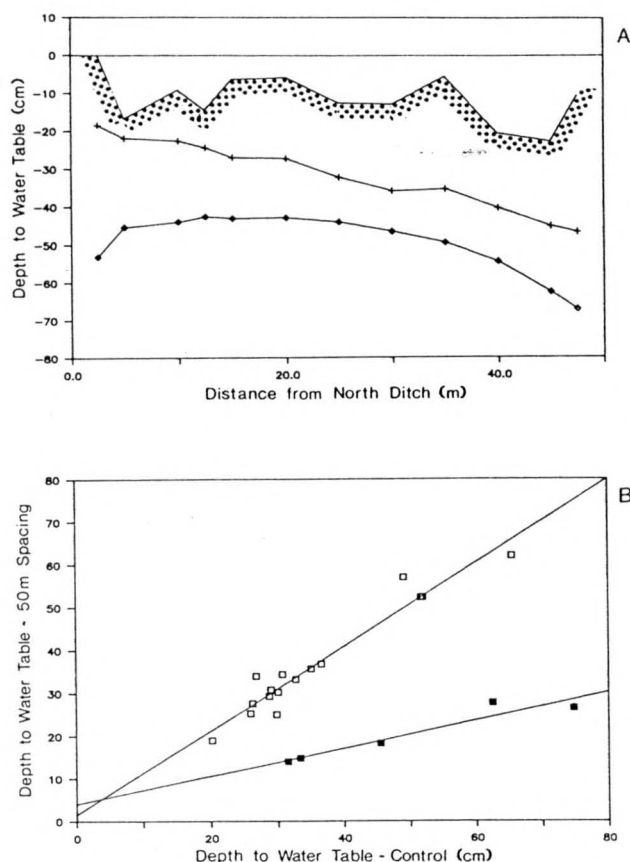


Figure 3. Goose River, 1986-1988, 50-m spacing. Depth to mineral soil is 80 cm. A) Average water-table profiles before (+) and after (◆) drainage. B) Regression lines before (■) [$y = 0.33x + 3.95$, $r^2 = 0.91$] and after (□) [$y = 0.98x + 1.43$, $r^2 = 0.93$] drainage.

Tree Growth

The results cited here are treated more fully in an unpublished report³. The pretreatment data indicated that, before drainage, the height growth of black spruce in both the treated and the untreated areas was poor. There were no significant differences in age, total tree height and leader length between the two sites. The average age for all trees measured in 1976 was 15.4 years. The clearing and scarification treatment greatly reduced stocking in the drained area.

Table 2. Specific conductance and mean concentrations of post-drainage suspended sediment and chemical elements for the creek at Goose River, 1986

Site ^a	Suspended sediment	N	Ca	Mg	Na	K	Al	Fe	Mn	S	Specific conductance ($\mu\text{S cm}^{-1}$)
U	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 U = Upstream, D1 = Downstream 1, D2 = Downstream 2

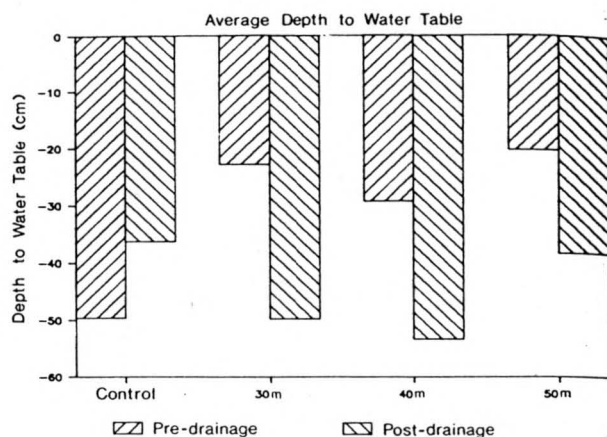


Figure 4. Goose River, 1986-1988. Average depth to water table before and after drainage for the control and for the 30-, 40- and 50-m ditch spacings.

The average annual leader growth for black spruce in the drained area, 6-9 years after treatment began, was 3.8 times that for black spruce in the undrained area. Neither the fertilizers nor the thinning had a significant effect on tree leader growth in the drained area but nitrogen did have a significant effect on leader growth in the undrained area; leader growth on the nitrogen-treated plots was nearly three times that on the control plots.

The 1988 data from the 42 destructively sampled black spruce trees verified that drainage had a significant effect on leader growth. They also showed that the ratio of drained to undrained leader growth was being maintained at the same ratio as for the 1981-1985 period (3.8:1). The average leader growth on the drained area was 45 cm. Mean tree height, DBH and volume per tree were, respectively, 3.89 m, 4.1 cm and 0.0034885 m^3 in the drained area in comparison with 2.13 m, 1.8 cm and 0.0006947 m^3 in the undrained area. The difference was highly significant in each case.

³ Hillman, G.R. 1989. Tree growth on drained forested peatland near Fort McMurray, Alberta. (Unpublished report).

In the undrained area, there were no significant differences in average ring width at a height of 0.3 m or in pahi between the two periods investigated, 1969 to 1978 and 1979 to 1988. The pavi was significantly greater (2.6 times) during the latter period. In the drained area, ring width, pahi and pavi were all significantly higher for the later, post-drainage period than for the 1969 to 1978 interval. During the 1979 to 1988 period, ring width, pahi and pavi were respectively 4, 3 and 39 times greater than the corresponding averages for the earlier period.

Ring width, pahi and pavi for trees on the undrained site were compared with those for trees in the drained area for the same period. There were no significant differences in ring width or pahi during the pre-drainage period. During this period, the pavi of trees in the undrained area was more than twice that of trees in the drained area. (The difference was significant.) A similar comparison for the 1979 to 1988 post-drainage period showed that tree ring width, pahi and pavi in the drained area were 3.3, 3.8 and 7.2 times greater, respectively, than the corresponding values for the undrained area; these differences were significant.

Drainage also had a significant effect on growth of deciduous species. No attempt was made to quantify the growth of alder (*Alnus crispa*), willow (*Salix* spp.), aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*) or birch (*Betula pumila*), but it was evident that a dense growth of these species filled the space between the spruce and had attained approximately the same height as the spruce canopy. In contrast, in the undrained area, growth of willow, birch and black spruce was suppressed.

DISCUSSION

Groundwater

Results from Goose River so far indicate that drainage has increased the average depth (across the drained profile from ditch to ditch) to the saturated zone by between 18 and 27 cm, with the average water table lying between depths of 38 and 53 cm. These depths are comparable to the range of optimum depths recommended for different tree species that are found in forest-drainage literature (Heikurainen 1964).

It appears that acceptable depths to water table can be achieved with 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 when the permanent sample plots on Goose River are remeasured. Economics and considerations of environmental preservation dictate that ditch spacings be as wide as possible, but they must also be narrow enough to promote acceptable improvement in tree growth rates.

The results tell us nothing about the residual water content in the unsaturated zone. Because trees must have an adequate water supply, it is important to know the water content in the rooting zone after drainage. An arid rooting zone is as undesirable as an excessively wet one. Preliminary results from McLennan and Wolf Creek indicate that drainage has caused water tables there to drop as low as, or even lower than, those at Goose River. Because of this and because of the complete lack of information on soil moisture conditions on these sites, soil-water sampling programs were begun in drained and undrained areas on all three experimental sites in 1989. This part of the program is a cooperative effort between Forestry Canada, the Alberta Forest Service, and the Forest Science Department at the University of Alberta.

Drainage reduces the capacity of peat to store water by introducing numerous hydraulic gradients into the natural system. Peat depth is between 80 and 100 cm in the ditch-spacing evaluation area at Goose River. It was previously reported (Hillman 1988a) that most of the water running into the lateral ditches came from the interface between the peat and mineral (clay) soils and that the ditch depth need not extend much below that level. Measurements from pressure transducers installed at Goose River before drainage have indicated that water table levels fell more rapidly after drainage than before drainage (Hillman 1988a). This change reflects the increase in hydraulic gradients as a result of drainage. The foregoing observations are related to a reduction in the water-storage capacity of the peat.

The strips between ditches may be considered a series of isolated hydrodynamic systems, and so long as the water levels in the adjacent ditches are lower than the water table level in the strips, Darcy's Law dictates that groundwater will move out of the strips into the open ditches. One aspect of conventional forest-drainage-ditch network design (used on Goose River) that enhances water movement out of the strips is the requirement that lateral ditches be oriented at a sharp angle to the contours. As a result, the strips are oriented almost perpendicularly to the slope, and the water flux through the strips has a strong downslope component.

There are two ways in which the water-storage capacity of peat in a drained area can be increased, and conversely, drainage effectively curtailed. Either the hydraulic gradients can be reduced or eliminated, or the saturated hydraulic conductivity can be reduced. The first will occur when water is backed up in the ditches and the second may occur over time with peat settlement and decomposition.

Streamwater Quality

It would appear from the results that, except for producing an increase in the concentration of iron and a reduction in the concentrations of potassium and aluminum, ditching had no effect on the chemical quality of water or suspended-sediment concentrations in the stream. An inspection of the sediment ponds and stream channel on 24 July 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 during ditching earlier in July. It was evident that the sediment ponds were functioning well but needed to be cleaned out after a storm of that magnitude. Perhaps several larger ponds are needed to control sediment movement.

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 after 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 the physical and chemical quality of stream water that result from drainage. The results so far are probably indicative only of water-quality conditions that prevail during periods of low flow. Theoretically, 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 have been undercut. It was dug in a natural, vegetated draw with a relatively steep slope of 0.007. The need to minimize this kind of erosion problem suggests that, for the purposes of ditch network design, a limit should be imposed on the degree of slope that can be tolerated in ditch construction.

Tree Growth

It is evident that lowering the water table in the study area near Fort McMurray affected tree growth. Trees were larger as a result, showing increases in height,

diameter and volume. Although no measurements of groundwater table 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 in the drained area was more than seven times that in the undrained area.

Two important facts should be kept in mind when one is assessing the results from the Fort McMurray study. First, the ditch spacing (10 m) is unusually narrow for forest drainage; second, 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.

CONCLUSIONS

Preliminary results from Goose River indicated that the average depth to groundwater table after drainage was between 38 and 53 cm. Additional knowledge about water content in the unsaturated zone is required to relate ditch spacings to tree growth.

Data on streamwater quality showed that drainage had little effect on the physical and chemical quality of water during periods of low flow. Automatic sampling devices and procedures are needed to monitor 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 for use in ditch construction.

At Fort McMurray, where the ditch spacing was about 10 m, young trees responded positively to drainage. Tree height, DBH and volume were greater in the drained area than in the undrained control. Deciduous species also grew vigorously in the drained area; if they should adversely affect black spruce growth, some form of weed control will be necessary.

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