THE FEASIBILITY OF DRAINING STANDS OF BLACK SPRUCE TO INCREASE GROWTH RATES IN SOUTHEASTERN MANITOBA

by

© François J. M. Woons, Jr.

A Practicum Submitted
in Partial Fulfillment of the
Requirements for the Degree,
Master of Natural Resources Management

Natural Resources Institute
The University of Manitoba
Winnipeg, Manitoba, Canada
June 1988

ISBN 0-315-47861-6

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A practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of Master of Natural Resources Management.

In dedication to:

my father:	the late François J. M. Woons, Sr.
my mother:	Louise M. Woons (née Tau)
my wife:	Christa Rösger (née Heissenberg)
my children:	Katharine Rösger
	Martin P. Woons
	Frank Rösger
	Phil W. Woons
	Michelle C. Woons
	Kimberly S. Woons
	Stephan-Ernst Rösger
	Marc J. Woons
my sister-in-law:	Ursula Heissenberg

ABSTRACT

The climate and topography found in Manitoba, as in much of the Boreal Region of Canada, are conducive to the formation of peat. It is thought that this process commenced as glacial Lake Agassiz receded, about 10,000 years ago.

These organic soils are characterized by free water tables near or above (during the spring run-off) the surface of the soils. Only a few tree species are able to cope with this growing condition and the boreal climate. Black spruce, tamarack, cedar, and some hardwoods are the most significant species.

Black spruce, which survives under the conditions described above, is highly valued for the production of pulp and paper due to its long fibers and low lignin content. However, it is thought that growing conditions for this tree species can be improved greatly by lowering the free water table.

A literature review indicated that extensive drainage of organic soils in Finland, since the beginning of this century, improved tree growth. It has been reported that drainage, often in conjunction with fertilization, improved the annual increment of the forests treated by 100% to 900%.

Results of a field study in southeastern Manitoba were partially disappointing as it did not produce the results expected (a diminishing timber volume per unit of area as the distance from the ditch increases). This was possibly due to two factors: a) the stands examined were drained at a point in time too far into the rotation period and b) some stands seemed overdrained, especially that part of the stand closest to the drainage ditch.

Because there are few data on forest drainage in Manitoba, a benefit-cost analysis was based partially on assumed figures. It showed a benefit-cost ratio smaller than unity at the inflation corrected interest rate of a sound investment like Canada Savings Bonds. However, it might still be wise to invest in drainage if a wood shortage is predicted, especially in close proximity to the pulp mills.

Finally, recommendations are made on the future of forest drainage in southeastern Manitoba.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the members of my practicum committee: Mr. Gary Ardron, Manitoba Department of Natural Resources, Forestry Branch; Mr. Laurie Gravelines, Manitoba Department of Natural Resources, Communication, Economics & Planning Branch; Dr. John Gray, Professor of Economics, University of Manitoba; Dr. Walter Henson, Director, Natural Resources Institute, University of Manitoba; and Dr. Graham Hillman, Canadian Forestry Service, Edmonton, Alberta, for their valuable and much appreciated advice and guidance.

Thanks are extended to Mr. Roeland Bout, College for Agriculture, Groningen, The Netherlands and Ms Shelley Vescio, Manitoba Department of Natural Resources, Forestry Branch, for their assistance with the collection of data in the field and to Mrs. Marilyn Daoust-Savoie, Canadian Forestry Service, Winnipeg, for her assistance with the analysis of tree discs.

I am especially grateful to Mr. J. P. Stefanson, Manitoba Department of Natural Resources, Water Resources Branch, for his assistance in obtaining information regarding drains; to Mr. Michael Rosen, Ontario Ministry of Natural Resources, for sharing some of his knowledge concerning the relationships between stands of black spruce and drainage, and editing the first draft of this practicum; and to Mr. Fred Haavisto, Canadian Forestry Service, Sault Ste. Marie, Ontario, for supplying me with literature and critically reading a draft of this practicum.

Finally I thank my friend Theo de Vos, Graduate Student, University of Manitoba, for his assistance in editing the manuscript.

Financial support from Manitoba Department of Natural Resources, Forestry Branch, is acknowledged with gratitude.

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INTRODUCTION

1.1 THE PROBLEM

The Forestry Branch, Manitoba Department of Natural Resources, has indicated that in this province approximately 1,500,000 hectares of black spruce [Picea mariana (Mill.) B.S.P.] stands are found in areas of poor drainage and are growing very slowly. In southeastern Manitoba [in the Pineland Forest Section which is comprised of Forest Management Unit (FMU)[1] 20 and FMU 23] about 100,000 hectares of black spruce stands with high water tables are encountered.

Black spruce is a valuable pulpwood species due to its long fibers and low lignin content. Some black spruce stands are located near mills. It could be beneficial to lower the water table in selected black spruce forests in order to increase the productivity of the stands in question.

There are indications that there will be a shortage of wood in the areas currently harvested in the near future (Government of Canada - Manitoba Natural Resources, 1984).

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[1] For a list of abbreviations and symbols used, see Appendix C on page 103.

Therefore the productivity in these areas should be increased. One way to accomplish this might be to drain stands of black spruce presently growing under very wet conditions.

The initial beneficiaries of improved growth close to pulp mills would be the forest industry, as hauling distances would be shorter. However, in the long run the people of Manitoba, as owners of the Crown Land, will benefit from the higher yielding forests through increased royalties and the creation of additional employment.

1.2 THE SETTING

Manitoba, the most eastern of Canada's three Prairie Provinces, exhibits a varied topography. The extreme south of this province is part of the Saskatchewan Plain; rolling pastures and level prairies. To the north is the Manitoba Lowland; the basin that once held glacial Lake Agassiz. Lake Winnipeg, Lake Winnipegosis, and Lake Manitoba are the remnants of Lake Agassiz. The area drained by the Red and Assiniboine Rivers, into Lake Winnipeg, is marked by upland plateaus, limestone outcrops, wooded river valleys, forests, and swamps. To the north and east of the lowland is the Canadian Shield, an area of forests, rocks, and rivers. It encompasses sixty percent of the province's area and is drained by the Nelson and Churchill Rivers into the Hudson Bay. Along this bay, the Hudson Bay Lowland extends 160 km inland as a flat, almost treeless plain of tundra and muskeg. The highlands of Manitoba are on the border with Saskatchewan. The Porcupine, Duck, and Riding Mountains form the Manitoba Escarpment. Baldy Mountain, at 831 m above sea level, is the highest elevation in Manitoba.

Due to the varied topography described above, a great number of rivers, lakes, sloughs, potholes, swamps, etc. are found in Manitoba. Many of the swamps support slow growing, usually coniferous, forests. Most of these are black spruce stands on organic soils.

1.3 OBJECTIVES

The primary purposes of this research were:

1. To establish whether drainage of excess water from a black spruce forest with a high water table will improve incremental growth.
2. To establish if drainage is economically feasible, that is, to establish if the costs of drainage are offset by the additional income generated as a result of this activity.
3. To recommend whether drainage should be undertaken in Manitoba.
4. To indicate which stands, in general terms, will benefit the most.

1.4 RESEARCH METHODOLOGY

The research was split into three distinct sections. They were:

1. A literature review to discover if the removal of excess water in black spruce stands on organic soils in locations other than Manitoba resulted in an improved mean annual incremental growth, and if so, to what extent.
2. A field study in southeastern Manitoba to establish if stands of black spruce on drained peatlands benefited from this activity (no forests in Manitoba were drained specifically for this purpose; some were drained for agricultural purposes or by roadside ditches).
3. A benefit-cost analysis to establish if forest drainage is economically feasible.

The literature review produced data regarding the spacing, depth, width, construction cost, maintenance frequency and costs of the drainage ditches. In addition information on length of rotation periods (before and after drainage) and the volume of the harvest at the end of the rotation period (before and after drainage) was obtained. These parameters are necessary for a benefit-cost analysis.

1.5 LIMITATIONS

This study did not establish the physiological reasons why drained forests grow faster than those impaired by a high water table. Only the increase in growth rate and its potential economic benefit was examined. This paper dealt only with the situation in southeastern Manitoba. The present values of both benefits and costs may differ in other jurisdictions, and this may affect the economic feasibility.

In addition, the mandate of this practicum excluded the investigation of the impacts of drainage on the environment, plant associations, wildlife habitat, etc.

1.6 SUMMARY

Manitoba has many stagnant stands of black spruce that are the result of a high water table. The removal of excess water may improve the productivity of these stands.

This study will attempt to establish if drainage of these stands is attractive from an economic perspective.

Chapter II

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose in reviewing the related literature was to discover what has been done with respect to forest drainage and to learn to what conclusions and recommendations other investigators have come.

Forested peatlands are also found in other provinces including Alberta, Ontario, Quebec, and Newfoundland. In addition, this type of forest is found in Finland, the Soviet Union, and many other countries. Some of the literature pertaining to these jurisdictions was also examined.

2.2 DRAINAGE, WHERE AND FOR WHAT?

2.2.1 Drainage outside of Canada for forestry purposes

In Finland more than 5,000,000 ha of peatlands have been drained for forestry purposes since 1910 [Heikurainen, 1980; Lännen(?), 1982], through the construction of approximately 1,000,000 km of ditches (Hakmet, 1986). Between 1967 and 1980 an average of 150,000 ha of peatlands were drained annually (Heikurainen, 1968 and 1980). This has resulted in an increase in annual wood production of about 4,000,000 m^3 in 1985. Additional annual wood production, due to drainage, is expected to rise to 15,000,000 m^3 by the year 2020 [Lännen(?), 1982].

Other countries where forests have been drained include: Sweden, Norway, Russia, Estonia, Latvia, Lithuania and the United States of America (Stanek, 1976). This list is probably not exhaustive.

According to Stoeckeler (1961), the annual production of forests (black spruce and others) in the U.S. could be increased by 15,000,000 m^3 if forest drainage possibilities were realized.

2.2.2 Drainage in Canada outside of Manitoba

Hillman (1987) reports on forest drainage in Newfoundland, Quebec, Ontario, and Alberta. Most of these projects are research oriented and conducted on a relatively small scale. Although the first experiment was carried out in 1929 (north of Iroquois Falls, Ontario), most other experiments have been undertaken in the past 30 years, which is a short length of time compared to the average rotation length of black spruce stands.

In British Columbia (research forest of the University of British Columbia at Haney, B.C.), forests have been drained on a trial basis (Walters, Tessier, and Soos; 1959). Before the ditches were created, with the aid of dynamite, stands of western red cedar (*Thuja plicata* Donn) and western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] were harvested. After ditching, Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], western hemlock, western red cedar, and sitka spruce [*Picea sitchensis* (Bong.) Carr.] were planted. The results of this experiment were not found in the literature.

Rosen[2] (pers. comm.) hypothesizes that drainage of an established stand of black spruce will reduce the remainder of the rotation period by 50%, with no effect on harvest volume. If this is true for all stand ages the mean annual increment (MAI) can be increased by 100% if drainage is performed when the stand is established, as the rotation period is halved and the same volume is harvested at the end of the rotation period. Stanek (1976; after Heikurainen, 1959) reports that tree growth after drainage ranged from 200% to 1,000% of growth before drainage, in Finland. Thus an increase of 100% in the tree growth rate as a result of drainage seems possible.

However, Rosen's hypothesis has not been sufficiently tested.

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[2] Mr. M. R. Rosen is a Registered Professional Forester employed by the Ontario Ministry of Natural Resources.

2.3 OPEN DRAINAGE DITCHES COMPARED TO SUBSURFACE DRAINING

Volmuller (1972) lists the pros and cons of open drainage ditches versus subsurface drainage systems (in agriculture as well as forestry) in The Netherlands. They are:

- open drains are cheaper to construct per linear meter (cost ratio 1 : 3).
- open drains require more maintenance (annual costs are approximately 7% of construction costs).
- open drains have to be spaced closer (to achieve the same amount of lowering of the water table) as they cannot be dug as deep as subsurface drains can be installed, unless one is willing to move large volumes of soil.
- open drains cause loss in area.
- open drains restrict the movement of machinery.

Volmuller (1972) comes to the conclusion that the costs of both systems are more or less equal. However, uneven settling of, especially organic, soils might make subsurface drainage systems undesirable.

While Volmuller (1972) points out that subsurface drainage systems are practically maintenance free, Slager (1984) states that subsurface systems sometimes get plugged by iron deposits and tree roots, especially if the water table fluctuates from above to below the drain and vice versa.

2.4 DRAINAGE IN CONJUNCTION WITH FERTILIZING AND THINNING

A further increase in growth rate could be provided when drainage is accompanied by fertilizing. Stanek (1975) mentions an incremental growth of 10.9 m^3 ha^{-1} yr^{-1} after fertilizing with nitrogen, phosphorus, potassium, and copper compounds. Fertilizer enhances the low amounts of nutrients in some peats. Some peats exhibit a low pH which has a negative influence on growth of some tree species. However, black spruce may grow reasonable well on soils with a pH of as low as 4.

This practicum is limited to drainage only and does not examine drainage in combination with fertilization and/or thinning.

2.5 ECONOMICS OF DRAINAGE

Information regarding the financial implications of drainage of stands of black spruce is scant. Heikurainen (1968) mentions some costs of drainage in Finland; he converted markkaa into Canadian dollars using the exchange rate and concluded that it is difficult to compare the situation in Newfoundland to the one found in Finland.

Payandeh (1973b) states that on the best drainable sites the expected rate of financial return is frequently as high as 10%. Mr. Payandeh based this conclusion on data collected in Ontario.

Nadeau and Parent (1982) came to the conclusion that, in Quebec, the best stand age for the installation of the drainage network (from an economic point of view) is 45 to 75 years, that the forest should be harvested 15 to 20 years after ditching, and that the rate of financial return, on Crown Lands and from the perspective of the Provincial and Federal Governments, ranges from 4.4 to 14.0% yr^{-1}.

2.6 MACHINERY USED FOR DITCHING

Hillman (1987) lists a number of machines that have been used for ditching in Alberta and Ontario. They include: a Marttiini plough, D6, D7, and D8 bulldozers, Caterpillar 215, 235, and 245 backhoes, a Kopo trencher, a Mallett wheel ditcher and a Lännen S 10. Some of these machines were found not to be suitable for penetrating clay or frozen peat or removing stumps.

The Lännen S 10 is a backhoe specifically designed for peatland ditching and has been imported from Finland. Its bucket (a "contour bucket") has, more or less, the shape of a truncated parabola. The Finnish experience is that this shape results in ditches showing little slumping over time.

2.7 SPACING AND SIZE OF DRAINAGE DITCHES

Spacing and size of drainage ditches are important parameters as they influence the growth rate of a forest, and the initial and maintenance costs of the ditch network.

After drainage, the surface of the free water table between ditches is convex. In order to meet a certain drainage norm (the distance between the forest floor and the level of the free water table at the midpoint between two adjacent parallel ditches) one can either construct deep ditches far apart or shallow ditches closely spaced. Both alternatives have pros and cons and a compromise must be found.

Preliminary results of experiments show that ditches should be spaced from 30 m to 60 m and be 0.6 m to 1.2 m deep (Hillman, 1987). It should be noted that there is an optimum biological spacing and an optimum economic spacing; the latter being the greatest (Päivänen, 1984b).

The ditches dug with a Lännen S 10 bucket have a width at the bottom of 0.24 m and a width at the top of 1.21 m to 1.61 m, depending on the depth of the ditch. This parameter ranges from 0.6 m to 0.9 m [Hakmet, 1986; Lännen(?), 1982].

2.8 POTENTIAL FOR FOREST DRAINAGE IN MANITOBA

In the literature there is no mention of intentional drainage in Manitoba for forestry purposes. However, forests have been drained in this province by draining adjacent agricultural lands or by roadside ditches. The field portion of this study examined some of these forests.

In the province of Manitoba, black spruce stands are grouped into three Site Classes:

Site Class 1: Upland Stands,

Site Class 2: Stands on deep organic terrain (usually accompanied by high water tables), and

Site Class 3: Dry stands on higher beaches, outwash and moraine ridges. These stands are quite rare.

From information supplied by the Manitoba Department of Natural Resources, Forestry Branch, I have calculated that the average MAI for black spruce in southeastern Manitoba (FMUs 20 and 23) is 1.10 $m^3 ha^{-1}$ for Site Class 1 [a harvest of 88.3 $m^3 ha^{-1}$ net merchantable volume (NMV) at the end of a 80 year rotation period] and 0.47 $m^3 ha^{-1}$ for Site Class 2 (a harvest of 65.1 $m^3 ha^{-1}$ NMV at the end of a 140 year rotation period).

It is hypothesized that drainage of a Site Class 2 stand could elevate its MAI to the level of a Site Class 1 stand (Ardron[3], pers. comm.). If this hypothesis is correct,

[3] Mr. G. Ardron is a forester employed by the Manitoba Department of Natural Resources, Forestry Branch.

drainage must result in a 134% increase in the MAI, which is well within the possibilities mentioned by Stanek (1976). Again, there are no data available to support this hypothesis.

Forestal (1981) has recommended drainage of 12,000 ha of forests during the period 1986 to 2000 in the Pineland and Mountain Forest Sections (6,000 ha in each), financed by a "silvicultural fund" to be established. Thus far this recommendation has not been implemented.

Agricultural land, on the other hand, has been drained extensively in Manitoba. Elliott (1978) reports that by the year 1934 853,528 ha (2,109,154 acres) had been drained by 5,862 km (3,643 miles) of ditches.

Undrained peatlands yield a total stem-wood volume of 15 - 70 m^3 ha^{-1} and have an annual increment of 0.7 - 2.6 m^3 ha^{-1} in southern Finland (Heikurainen, 1968). In comparison, Stanek (1976; after Heikurainen, 1959) states:

> The improvement of growth after drainage on the best peatland areas (swamp types) in southern Finland, under good climatic conditions, should serve as an example. At the time of harvest, volumes of 300 m^3/ha and annual increments of 12 m^3/ha were found.

These figures are very high if we compare them to Canada's best forests (those found on Vancouver Island and the adjacent mainland). These forests have a MAI[4] of

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[4] In theory, a forest should be harvested when its current annual increment (CAI) declines and becomes equal to its MAI.

approximately 6 m^3 ha^{-1} yr^{-1}. In comparison, Manitoba's best forests have a MAI of approximately 2 m^3 ha^{-1} yr^{-1} (Bickerstaff, Wallace, and Evert; 1981).

However, the potential of increasing the MAI for Site Class 2 forests in Manitoba, though much less than the Finnish possibilities, might be economically feasible.

2.9 COMPARISON BETWEEN THE SITUATION IN FINLAND AND IN MANITOBA

As Finland seems to be the leading country in forest drainage, Manitoba foresters often refer to Finnish literature to establish what could be done in their province. When doing so, they should keep in mind that: a) the Finnish climate differs from the Manitoba climate. Finland is farther north than Manitoba but Finland's climate is influenced by the Gulf Stream, which affects temperatures and levels of precipitation and b) tree species differ between Manitoba and Finland. In Finland the tree species involved in drainage are: Norway spruce [*Picea abies* (L.) Karst.], Scots pine (also known as Scotch pine and Scotch fir) (*Pinus sylvestris* L.), and birch species (*Betula spp.* L.). Of the two evergreen species mentioned, Norway spruce is the best growing. Early indications are that Canada's tree species suitable for drainage (black spruce) performs more or less like the Scots pine in Finland (Heikurainen, 1968).

2.10 SUMMARY

The literature consulted has indicated the following:

1. In Finland, where climate, peats, and tree species are slightly different to those found in Manitoba, many hectares of forests on peatlands have been drained.
2. In Finland drainage of forests with high water tables resulted in an annual increment as high as 12 m^3 ha^{-1} yr^{-1}.
3. In Canada forests have been drained in British Columbia, Alberta, and Ontario but on a small (experimental) scale only. Quebec is an exception: between 1980 and 1986, 5,224 ha of forest land were drained. In Newfoundland open peatlands have been drained to facilitate afforestation (Hillman, 1987).
4. Nearly all drainage in Canada for forestry purposes was done only recently and although little data is available, it appears that a 100% increase in tree growth rate as a result of drainage is possible.
5. In Canada, the relationship between tree growth rate and distances from the ditch is unclear.
6. Some peats are too poor in nutrients and/or too low in pH to be considered for drainage.
7. As a head is needed to remove excess water, not all areas are readily drainable.

8. There are indications that forest drainage can be economically attractive and, on the best drainable sites, may yield an expected rate of financial return as high as 14% yr^{-1} (Nadeau and Parent, 1982).
9. Drainage for forestry purposes has not been done in Manitoba, but it is hypothesized that, on some sites, drainage can result in a 134% increase in the MAI.
10. To obtain a maximum return on the money invested, a stand must be drained during the first half of the rotation period.
11. A drainage norm of 30 cm is suggested in the literature for Finland. In Manitoba, where the circumstances are slightly different, a different value for the drainage norm might be justified. Additional research has to establish this.

Chapter III

FIELD STUDY

3.1 INTRODUCTION

As stated earlier, one of the objectives of the field study was to evaluate the effects of drainage on black spruce stands in southeastern Manitoba, to see if drainage has resulted in accelerated tree growth.

Another objective was to establish relationships between distance from the ditch versus depth of the groundwater table and between distance from the ditch versus tree volumes, thus indicating the spacing of ditches.

The objective of the annual ring analysis was to establish if the installation of ditches caused an increase in the average width of the annual rings, and hence an accelerated increase in tree volumes.

The gathering of data in the field took place during the period May - August 1987.

3.2 METHODS

3.2.1 Selection of suitable stands

Potential sites, within southeastern Manitoba, were selected by comparing drainage maps from Manitoba Department of Natural Resources, Water Resources Branch with forest cover maps from the same Department, Forestry Branch. These sites were then examined in the field.

A stand was deemed suitable for sampling if it met all of the following criteria:

1. it was a pure or almost pure black spruce stand,
2. it was immediately adjacent to a maintained ditch, and
3. it was considered to have relatively homogeneous stem density and tree size.

Many stands did not meet all criteria mentioned, either because stands were next to ditches blocked by beaver dams thus exhibiting extremely high water tables, or commenced one or more decameters from the ditch, such that it was impossible to implement the sampling procedure. Very few stands in FMU 20 and FMU 23 met all criteria.

The six stands selected for sampling are located as follows (Figure 1):

Stand 1: Township 13, Range 9E, section 32; just south of Highway 435.

Stand 2: Township 15, Range 9E, section 15.

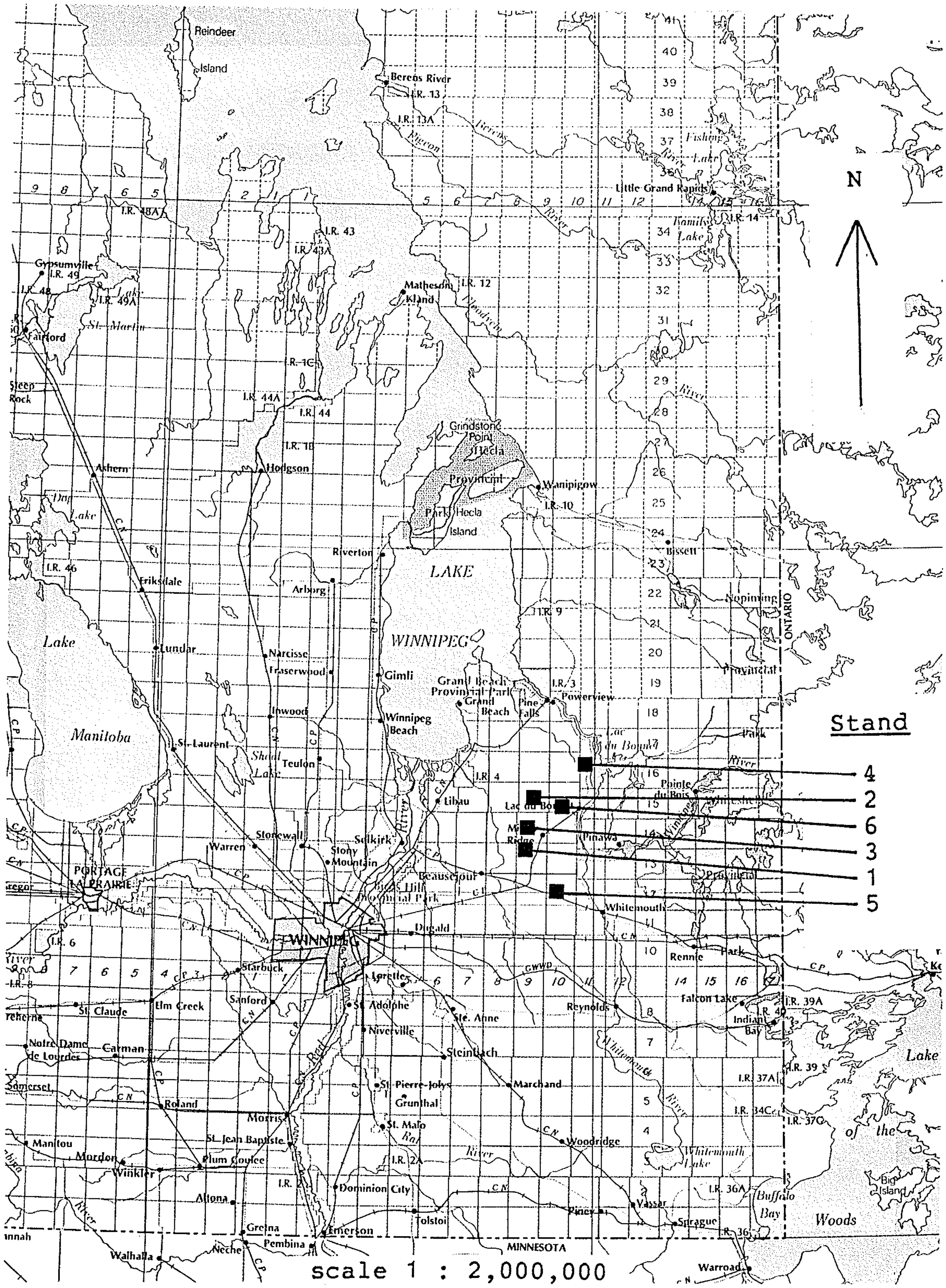

Figure 1: The location of sampled stands.

Stand 3: Township 14, Range 9E, section 16; south of the power line running through that section.

Stand 4: Township 16, Range 11E, section 33; just west of highway 11.

Stand 5: Township 12, Range 10E, section 9.

Stand 6: Township 15, Range 10E, section 3.

Stands 1, 2, and 3 are located in the Brokenhead River Watershed, Stands 4 and 6 in the Lac du Bonnet Area Watershed and Stand 5 in the Lower Whitemouth River Watershed.

A short description of the status and ages of the ditches along these stands is as follows:

Stand 1: The roadside drain along this stand is about 1 m wide, about 0.4 m deep, occasionally blocked by beaver dams, and had poor water flow at the time of sampling. Highway 435 was extended eastwards from a point 1.6 km (1 mile) east of its intersection with Highway 316 to Highway 214 in 1975. It is assumed that the ditch along this road was dug then. Mr. Adolph Rattai, who has farmed a quarter of section 31, Township 13, Range 9E since 1935, stated that a ditch was dug along the northern boundary of section 31 a few years after he started to farm there. This ditch might have drained the forest sampled since that time.

Stand 2: The agricultural drain along this stand is about 2 m deep, and well maintained. The ditch was dug in the early 1940s. The exact date is unknown.

Stand 3: The drain (with black spruce forests on both sides) is about 0.5 m deep and flowing. The power line next to this stand was constructed in 1976. It is assumed that the ditch was dug then.

Stand 4: The drain, flanked on both sides by black spruce stands, is about 4 m wide, deep and nearly stagnant. Its water surface is circa 1 m below the forest floor. A right-of-way plan indicates that it was surveyed in 1954 or 1955 (Stefanson[5], pers. comm.). This does not pinpoint the time of construction but is a good indication of the date.

Stand 5: The roadside drain along this stand is about 0.3 m deep and running only slightly; presently it is poorly maintained. It was dug in 1947/1948.

Stand 6: The agricultural drain along this stand (dug in 1971) is circa 2 m deep and flowing well.

The data concerning ages of ditches were obtained from the Manitoba Department of Natural Resources, Water Resources Branch, the Rural Municipalities involved, the Manitoba Department of Highways, a local farmer, and Fisons (stand 5 is located on land leased to this peat harvesting company by the Provincial Government).

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[5] Mr. J. P. Stefanson is a Professional Engineer employed by the Manitoba Department of Natural Resources, Water Resources Branch.

3.2.2 Organization of plots and subplots

Once a stand was judged to be suitable for sampling, a line perpendicular to the ditch was laid out. On this line, at 5 m, 15 m, 25 m, 35 m, and 45 m from the edge of the ditch, the centres of the subplots were marked. Around each centre a circle with a radius of 5 m was drawn. These circles (subplots) were labelled "a", "b", "c", "d", and "e" starting at the ditch. A string of five subplots (seven in Stand 4) is called a "transect" or a "plot".

To reduce errors caused by chance, three plots per stand were established. These plots are numbered 1 to 18. Stand 1 consists of plots 1, 5, and 6; Stand 2 of plots 2, 7, and 8; Stand 3 of plots 3, 9, and 10; Stand 4 of plots 4, 11, and 12; Stand 5 of plots 13, 14, and 15, and finally, Stand 6 of plots 16, 17, and 18 (Figure 2).

If, as the literature indicates, ditches should be spaced from 30 m to 60 m (Hillman, 1987), the influence of a ditch is about 15 m to 30 m at either side of it. Therefore it was assumed that the "e" subplots (their centres being 45 m from the ditch), and possibly the "d" subplots, would serve as controls. After some calculations and graphing was done, it was deemed necessary to extend the transects in Stand 4 by two more subplots labelled "f" and "g" in all three transects in that stand. The reason for this will be explained in subsection 3.3.1.

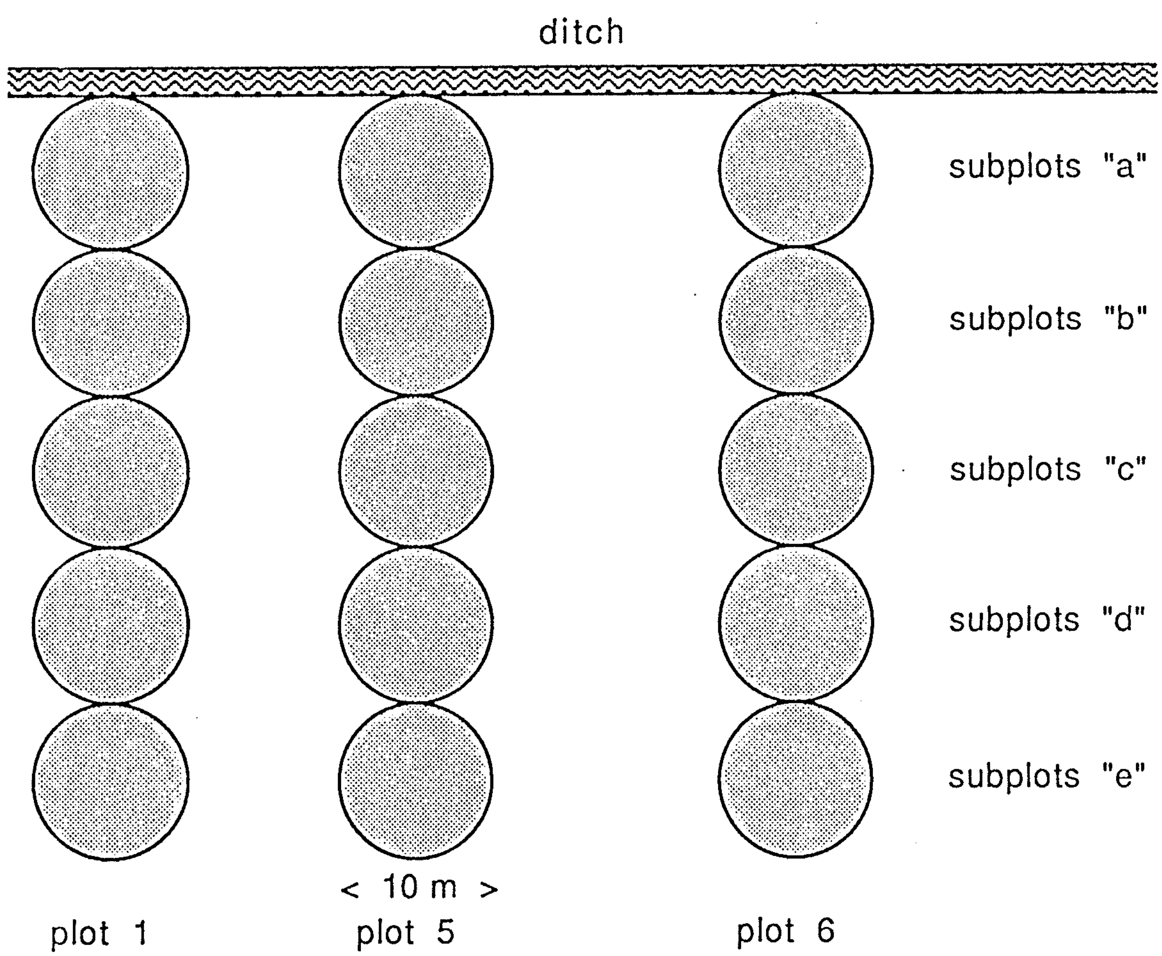

Figure 2: An example of the layout of the plots and subplots, Stand 1.

3.2.3 Measurement and manipulation of data

In each subplot each tree was numbered and its diameter measured at breast height (DBH) (i.e. at 1.3 m above the forest floor) outside the bark. The height of each tree was established by measuring the horizontal distance from the viewer to the tree and the viewing angle, between the horizontal and the top of the tree. Simple trigonometry allowed the height of the tree to be calculated. In total, 2683 trees were measured.

The volume of each tree was calculated using a formula developed by Evert (1983). This formula is as follows:

$$TSV = 0.0005 + 3.71 \times 10^{-5} D^2H - 1.0 \times 10^{-10} (D^2H)^2 \qquad [1]$$

- TSV is total stem-wood volume from ground to tip (m^3).
- D is diameter outside bark at a height of 1.3 m (cm).
- H is height from ground to tip (m).

This formula is for black spruce only. In a few cases tamarack (also known as larch) [<u>Larix laricina</u> (Du Roi) K. Koch] and deciduous trees were encountered in a subplot. Formula [1] was applied to these trees also to calculate their volumes, though with a small error. It was noted that the few tamaracks encountered were usually much larger than the black spruce.

To obtain the volume per subplot the volumes of all trees in that subplot were summed. To convert this number to m^3

ha^{-1} the multiplication factor 127.3 was used as this number of circles with a 5 m radius have an area of 1 ha.

The water level was established in each of the 96 subplots. It is realized that this was a "snap-shot" approach and that water levels fluctuate over the seasons and also between years as a result of precipitation patterns. Due to a lack of time, water tables were measured only once. Rutulis (1987) states: "The average magnitude of annual groundwater level fluctuations ranges from 0.5 m to 1.5 m. Only a few monitoring stations show seasonal fluctuations of around 3.0 m." and " ... that water levels in major aquifers are only slightly lowered by extended periods of minimal recharge ... ".

3.2.4 Sampling and preparation for tree ring analyses

In each stand from an "a", "b", "c", "d", and "e" subplot (in Stand 4 also from an "f" and "g" subplot) a disc was collected from either a dominant or co-dominant tree at 30 cm above the forest floor, for a total of 32 discs.

The discs were smoothed with sandpaper. For each disc, the largest and smallest distance from the pith to the edge of the disc was measured. The mean of these two distances was calculated. Subsequently a radius with that mean was found and marked on the disc.

The widths of the annual rings were measured along this radius with a digital micrometer at the Canadian Forest Service office in Winnipeg.

3.3 RESULTS AND DISCUSSION

3.3.1 Wood volume and groundwater table levels

The results of the volume calculations and water level measurements are shown in the Figures 3 to 8. In some cases water tables could not be reached due to heavy clay. Under these circumstances digging was suspended.

In figures 3 to 8, a downward arrow is used to indicate those cases in which the free water table could not be reached. For more detailed data, see the tables in Appendix A.

In many cases the wood volume (m^3 ha^{-1}) did not follow the hypothesized trend, that is, with increasing distance from the ditch, the volume did not always decrease. This might be because most stands were relatively old (more than 75% of the rotation period had expired) when the ditches were dug. Stand 4 showed the predicted pattern in subplots "c", "d", and "e". To establish if this pattern continued, subplots "f" and "g" were put in. The "f" subplot followed the hypothesized pattern; but, the "g" subplot showed the largest volume of all subplots in that stand! Also in Stands 5 and 6, the highest wood volume was

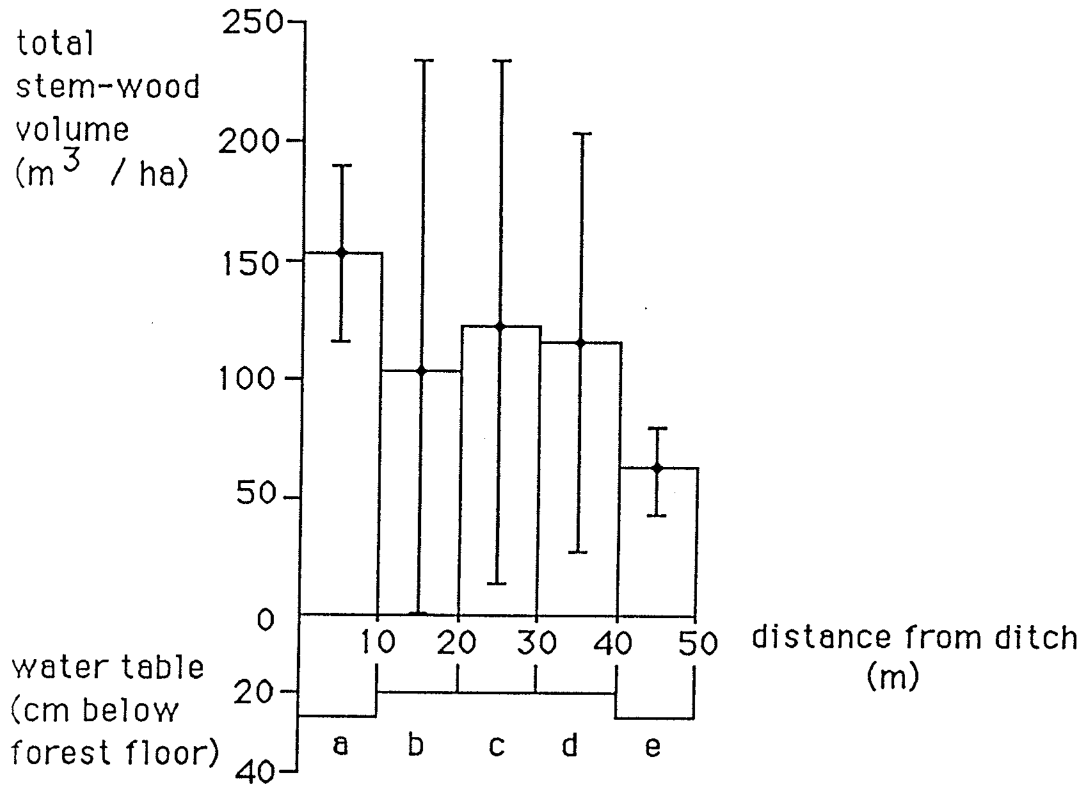

Figure 3: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 1, May 1987.

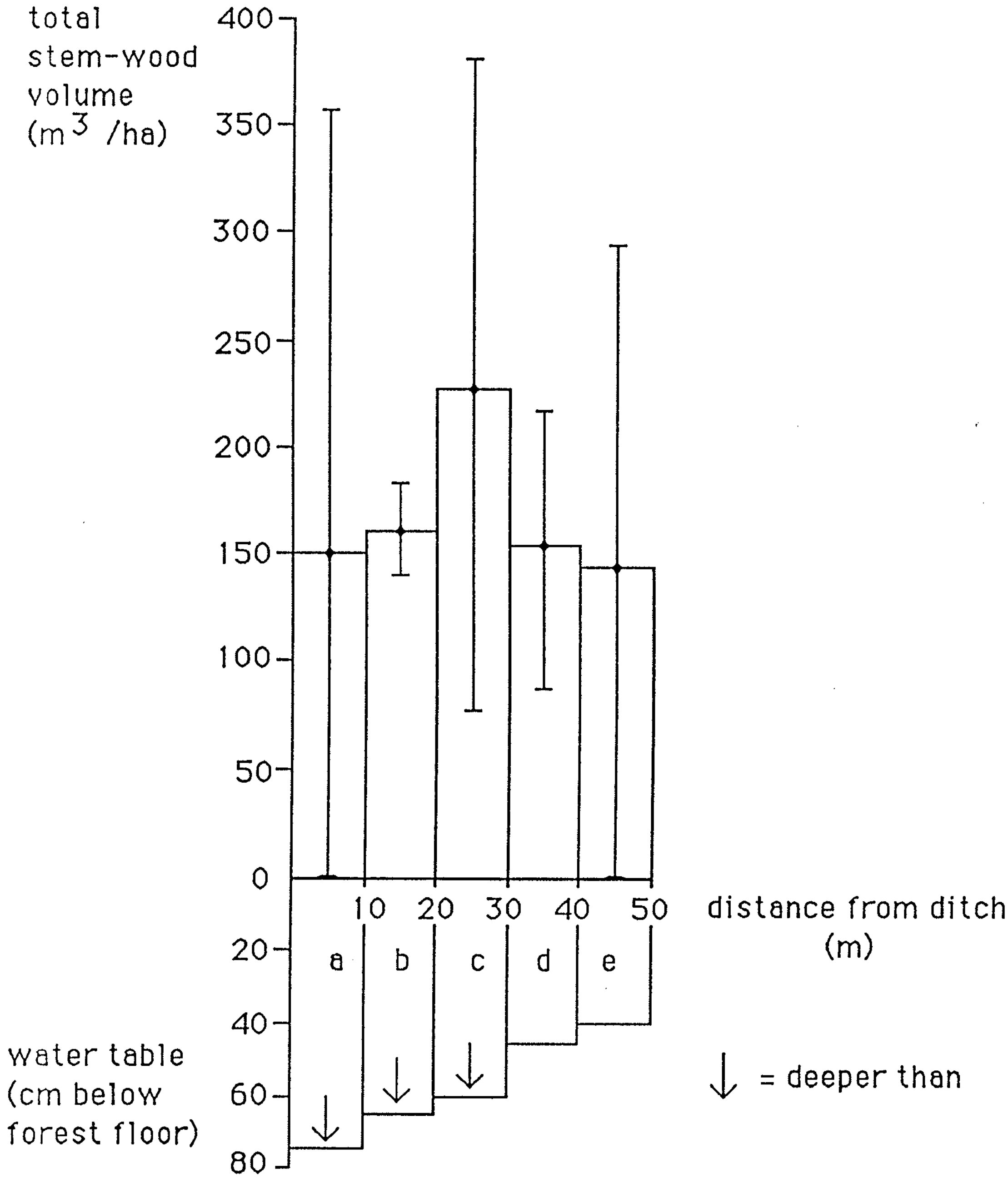

Figure 4: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 2, May 1987.

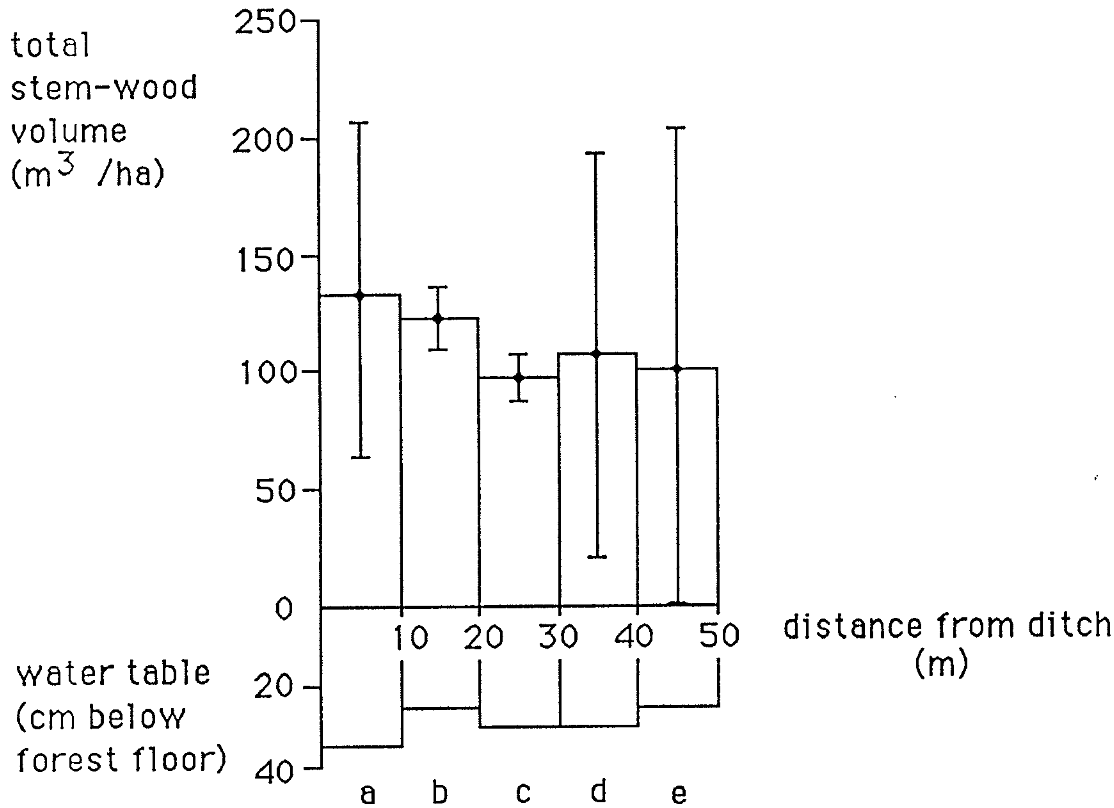

Figure 5: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 3, June 1987.

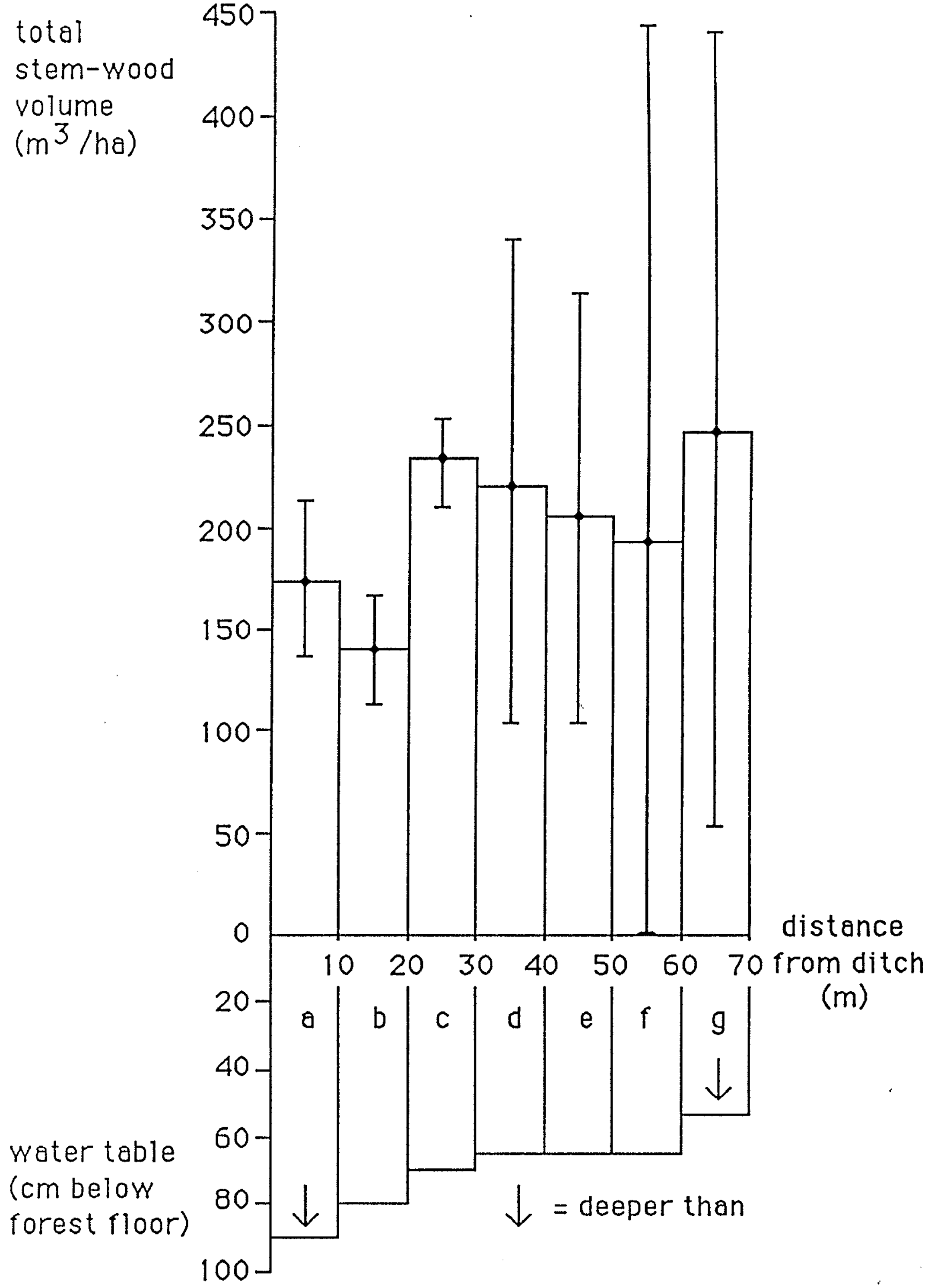

Figure 6: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 4, July 1987.

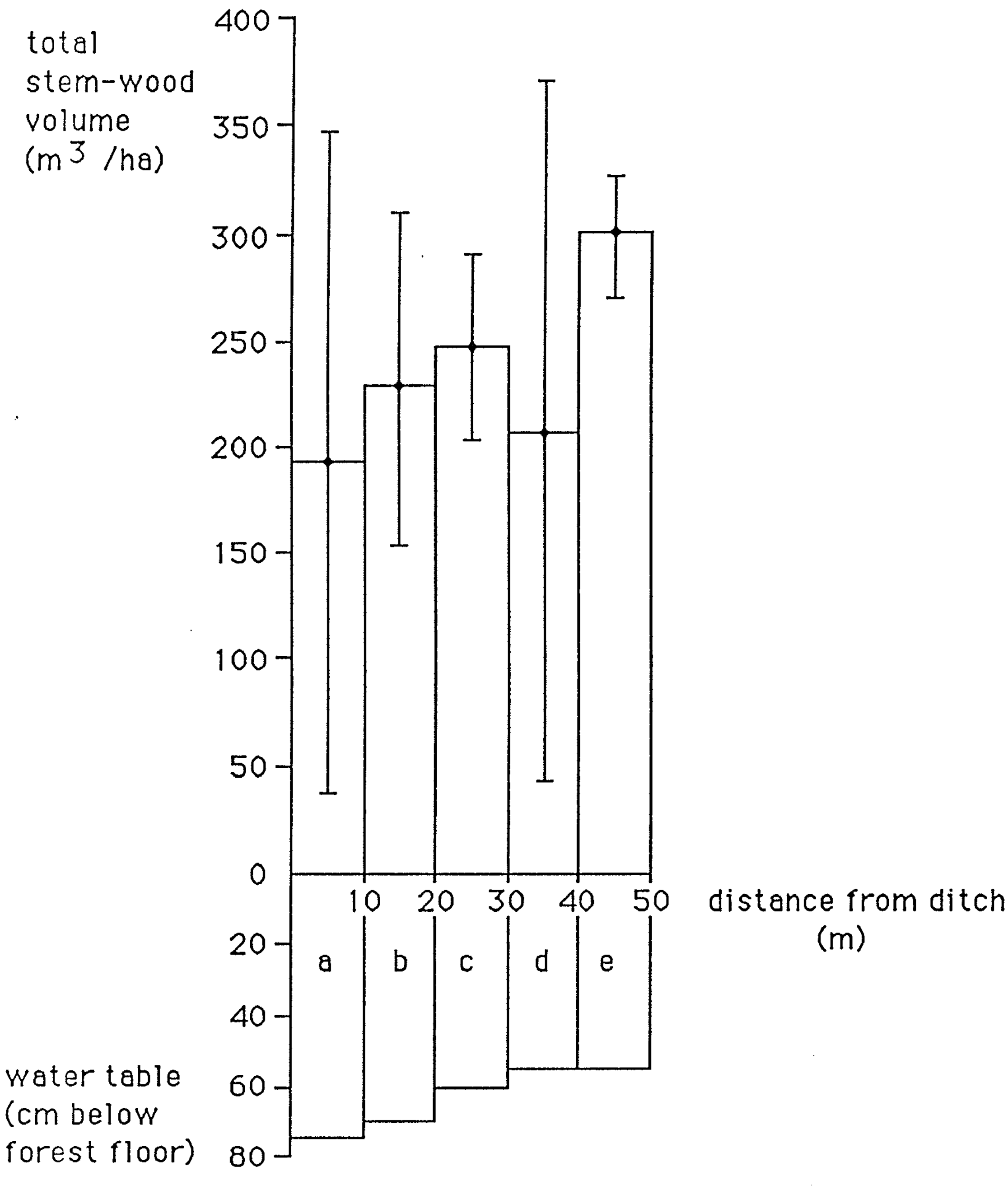

Figure 7: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 5, August 1987.

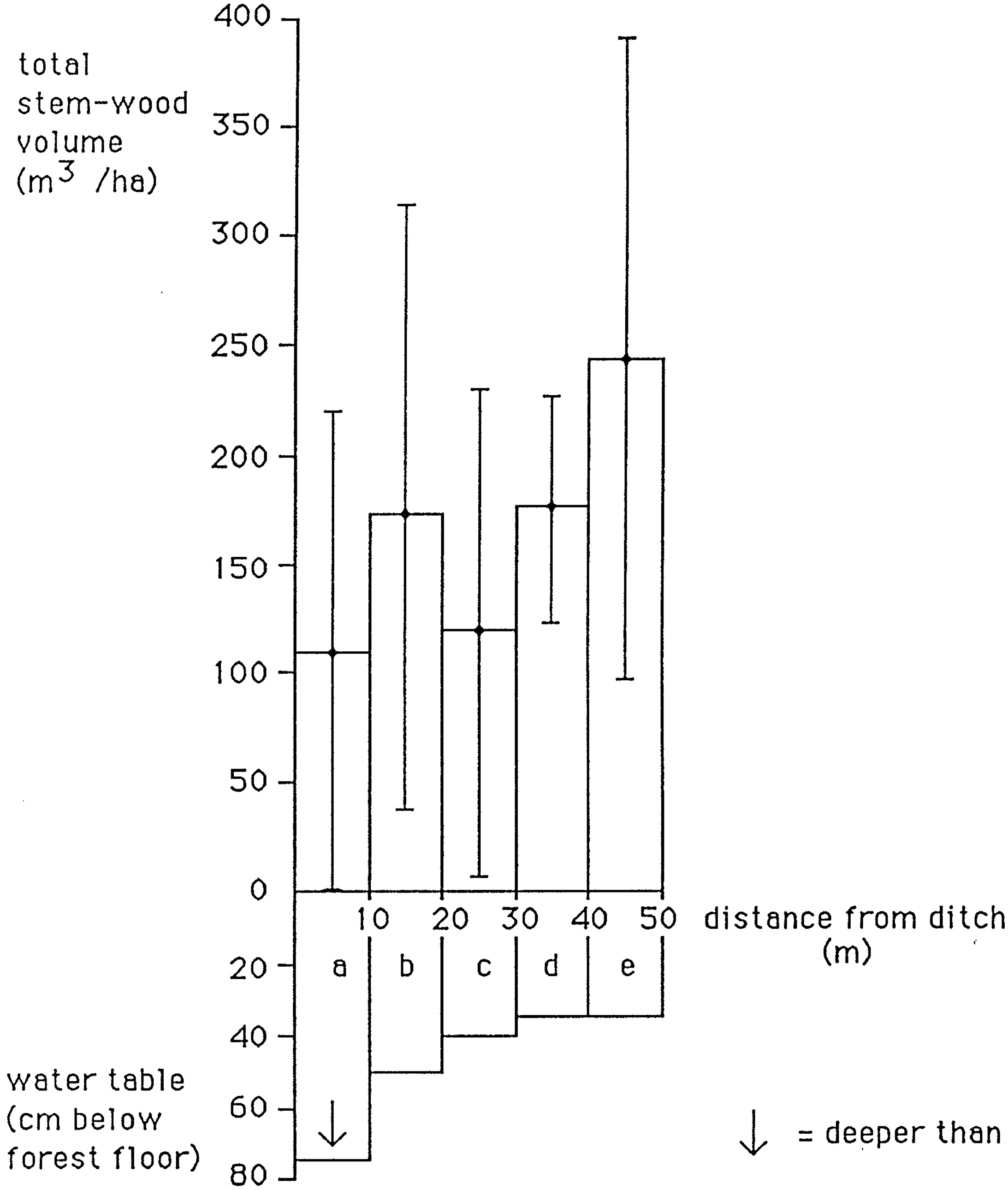

Figure 8: The relationship between wood volume (indicating 95% confidence intervals), the depth of the water table, and the distance from the ditch in Stand 6, August 1987.

found in the subplot the farthest from the ditch. Only Stands 1 and 3 follow the hypothesized pattern in the relationship between wood volume and distance from the ditch.

The calculations of the 95% confidence intervals concerning the stem-wood volumes of subplots labelled identically and belonging to one stand, based on the data in Table 14 and depicted in Figures 3 - 8, show in general a relatively large range within subplots indicating that most stands are relatively heterogeneous. In addition, the intervals show a large degree of overlap indicating that the hypothesis that timber volumes decrease with increasing distance from the ditch was not supported by the findings of this field study.

In some cases a low volume was found in the "a" subplots, compared to the other subplots within the same stand, especially when the water table was deep. Lieffers and Rothwell (1987) report that even in dry stands of black spruce few roots are found lower than 30 cm below the forest floor; in very wet stands, no roots are found lower than 20 cm below the forest floor. Thus, overdrainage could have been responsible for these low volumes. However, the data presented in Table 2 (on page 37) and Figures 9 to 14 (on pages 38 - 43) do not indicate overdrainage. Therefore, I must come to the conclusion that I am unable to detect a relationship between stand volume and depth to the water table and between stand volume and distance from the ditch. With respect to overdrainage, Päivänen (1984a) states "the studies conducted in Finland seem to indicate that there is evidently no risk of overdrainage in the case of forest drainage" due to the great water holding capacity of peat.

I have the impression that better than the average stands of black spruce were selected as in some cases volumes close to 300 m^3 ha^{-1} (TSV) were encountered compared to 88.3 m^3 ha^{-1} (NMV) for the average Site Class 1 black spruce stand, at harvest time. Unfortunately, no conversion factor from TSV to NMV could be obtained.

In most cases, the level of the water table followed the hypothesized pattern, that is, with increasing distance from the ditch, the depth to the water table decreased.

3.3.2 Tree ring analyses

From the data obtained from the discs, tables listing the ages of the trees (Table 1), the average widths of the annual rings (before and after drainage; Table 2), and graphs showing the increase of the radii over time (Figures 9 to 14), were constructed.

The data in Table 2 were subjected to a "paired t-test" to test the null hypothesis that there is no difference between the average widths of the annual rings before and after drainage. Because the obtained value of the test

TABLE 1

Average ages of trees sampled, at 30 cm from forest floor, and ages of ditches (years)

Stand	Average ages of trees	Ages of ditches[6]
1	144	50?
2	114	ca.45
3	119	11
4	137	32
5	131	40
6	117	16
ave.	128	

statistic t (7.604) is outside the critical limits of ±2.745 (31 degrees of freedom; 1% level of significance), the null hypothesis was rejected. The average width of the annual rings after drainage (0.93 mm) is about twice that of before drainage (0.46 mm) (from Table 2).

The graphs shown in Figures 9 - 14 indicate the following:

1. For Stand 1: The radii of the trees sampled increased, on the average, by about 0.23 mm yr^{-1} before drainage; by about 1.04 mm yr^{-1} following drainage. This represents an increase of more than

[6] In 1987.

TABLE 2
Average width of annual rings of trees sampled, before and after drainage (mm).

	Stand 1		Stand 2		Stand 3		Stand 4		Stand 5		Stand 6		average	
	pre drainage	post drainage	pre drainage	post drainage	pre drainage	post drainage	pre drainage	post drainage	pre drainage	post drainage	pre drainage	post drainage	pre drainage	post drainage
a	0.18	0.97	0.36	1.29	0.62	0.84	0.34	0.91	0.63	0.53	0.53	0.79	0.44	0.89
b	0.24	1.34	0.71	1.49	0.50	1.04	0.48	0.99	0.42	0.89	0.59	0.82	0.49	1.10
c	0.18	0.90	0.58	0.64	0.55	1.75	0.43	0.65	0.61	0.64	0.65	0.86	0.50	0.91
d	0.15	1.04	0.32	0.77	0.40	0.98	0.45	0.58	0.48	0.67	0.54	0.66	0.39	0.78
e	0.41	0.97	0.69	0.61	0.58	0.81	0.41	0.99	0.48	0.94	0.40	0.93	0.50	0.88
f	----	----	----	----	----	----	0.38	1.61	----	----	----	----	0.38	1.61
g	----	----	----	----	----	----	0.34	0.97	----	----	----	----	0.34	0.97
ave	0.23	1.04	0.53	0.96	0.53	1.08	0.40	0.96	0.52	0.73	0.54	0.81	0.46	0.93

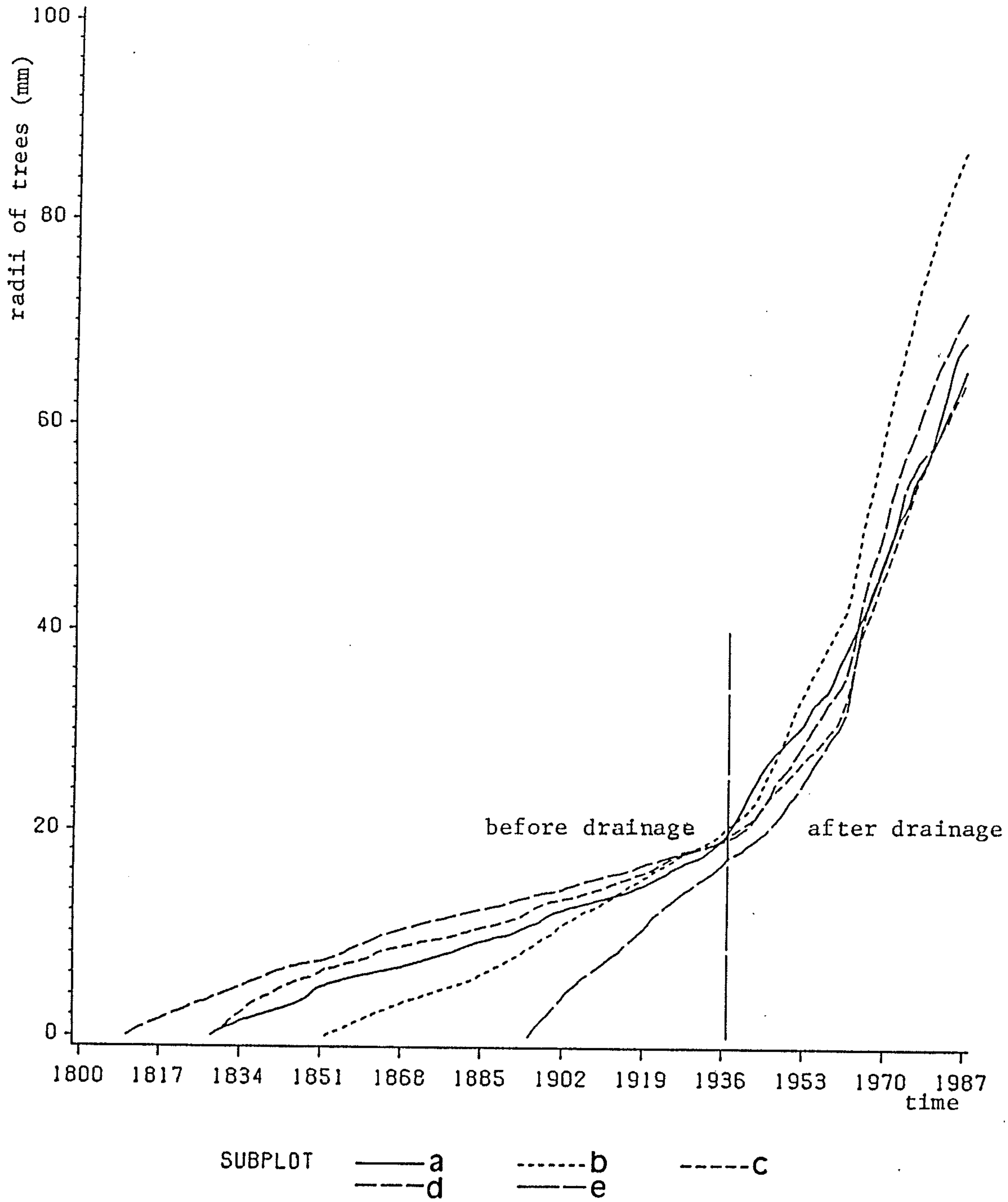

Figure 9: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 1.

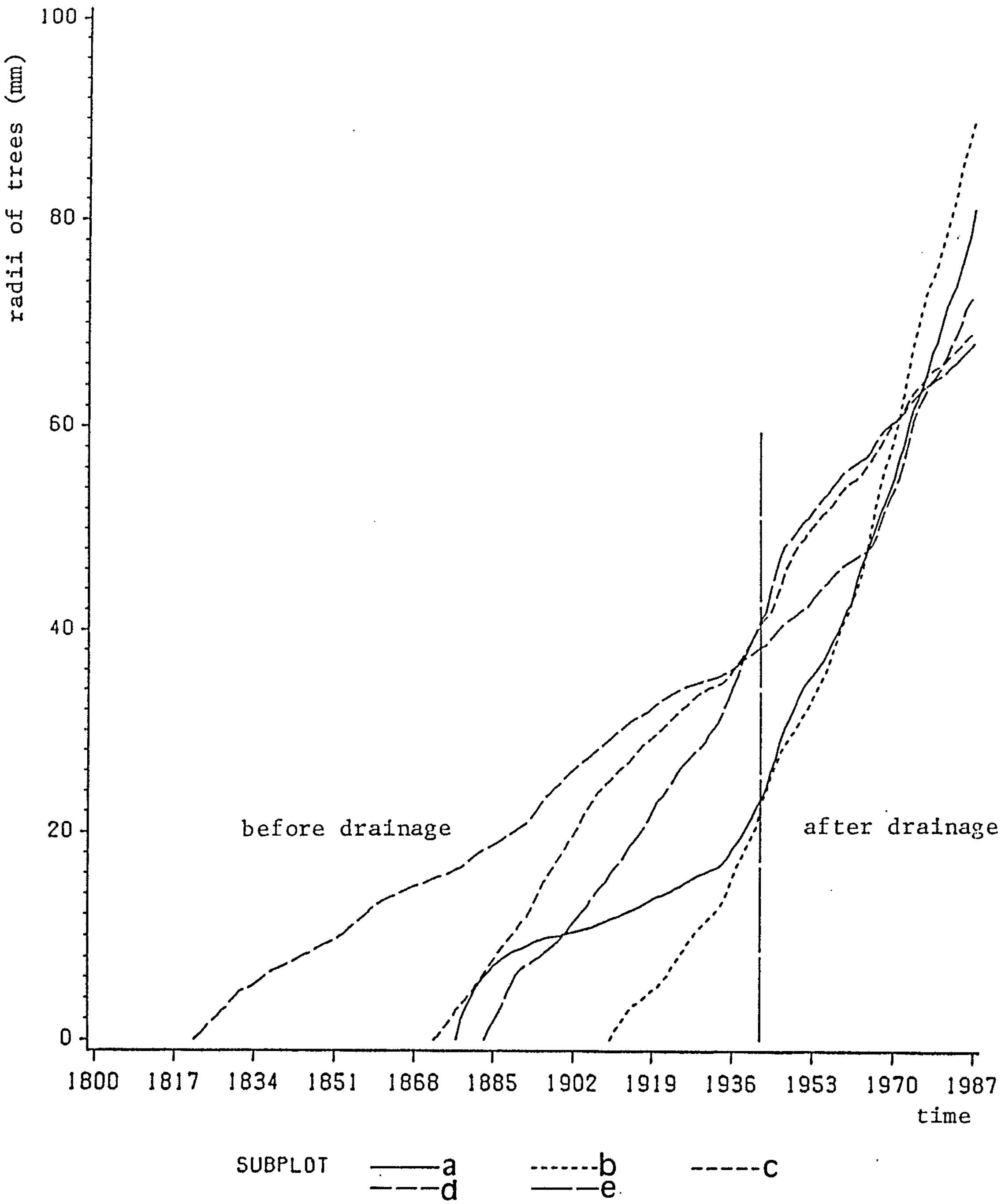

Figure 10: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 2.

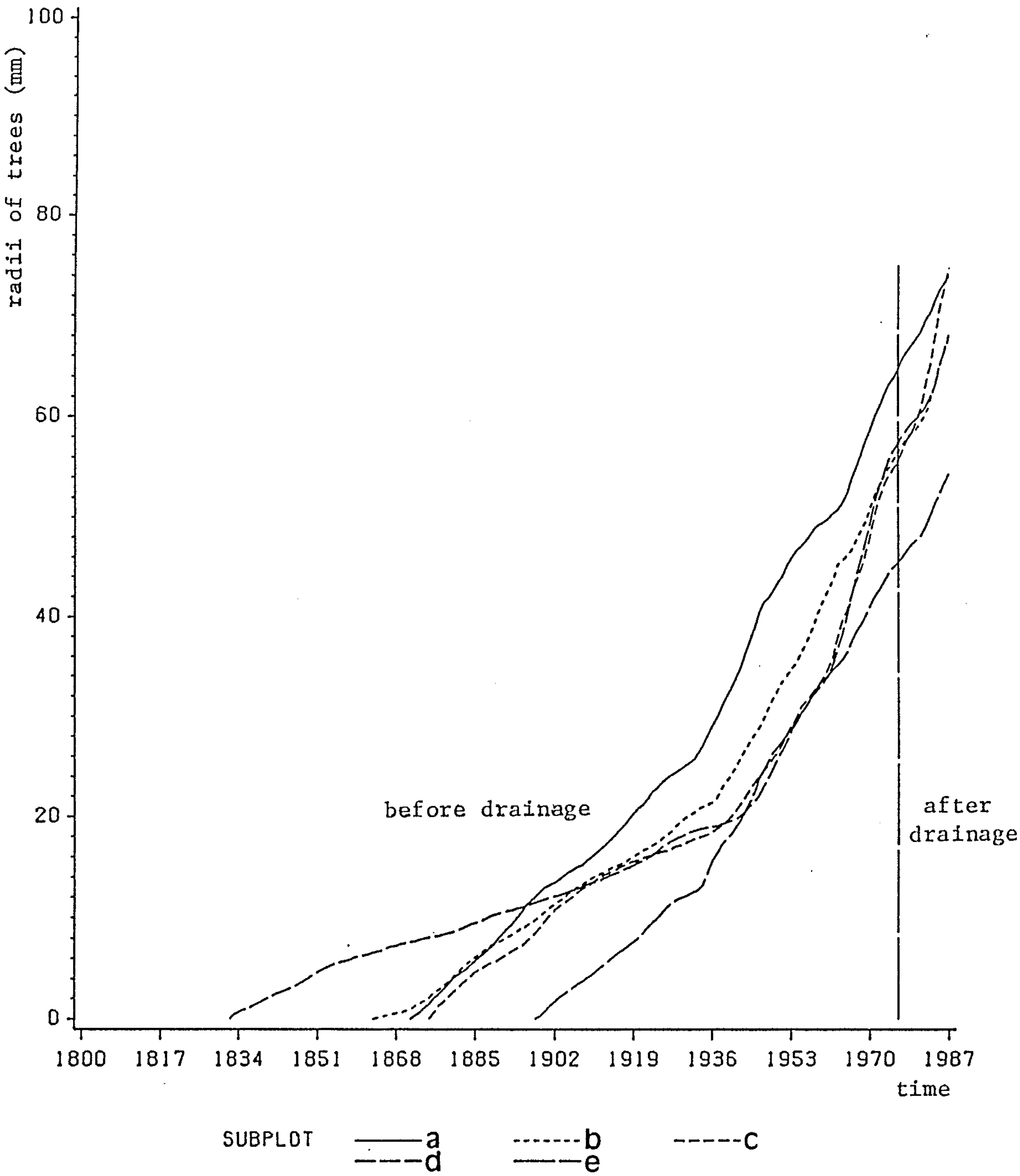

Figure 11: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 3.

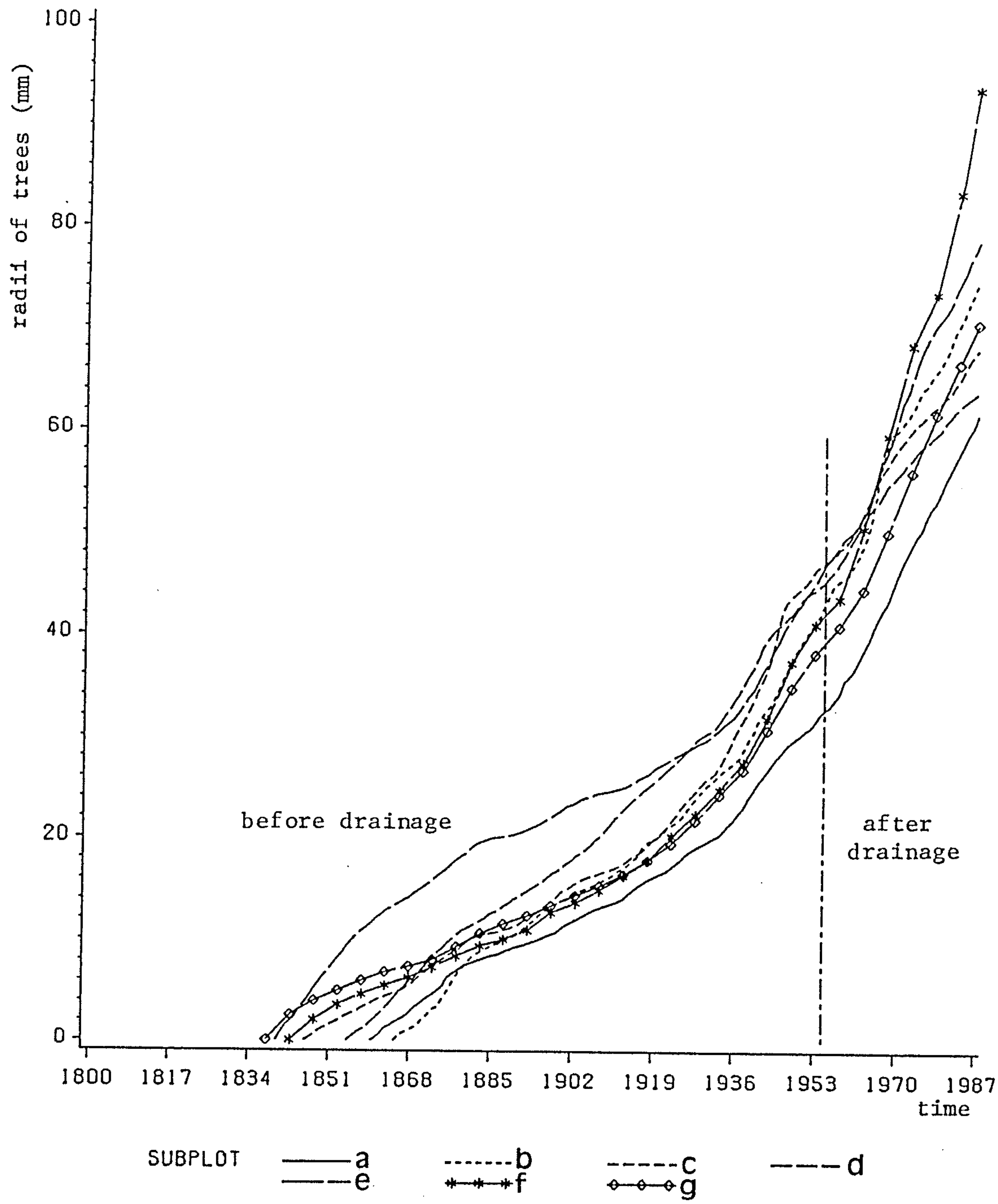

Figure 12: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 4.

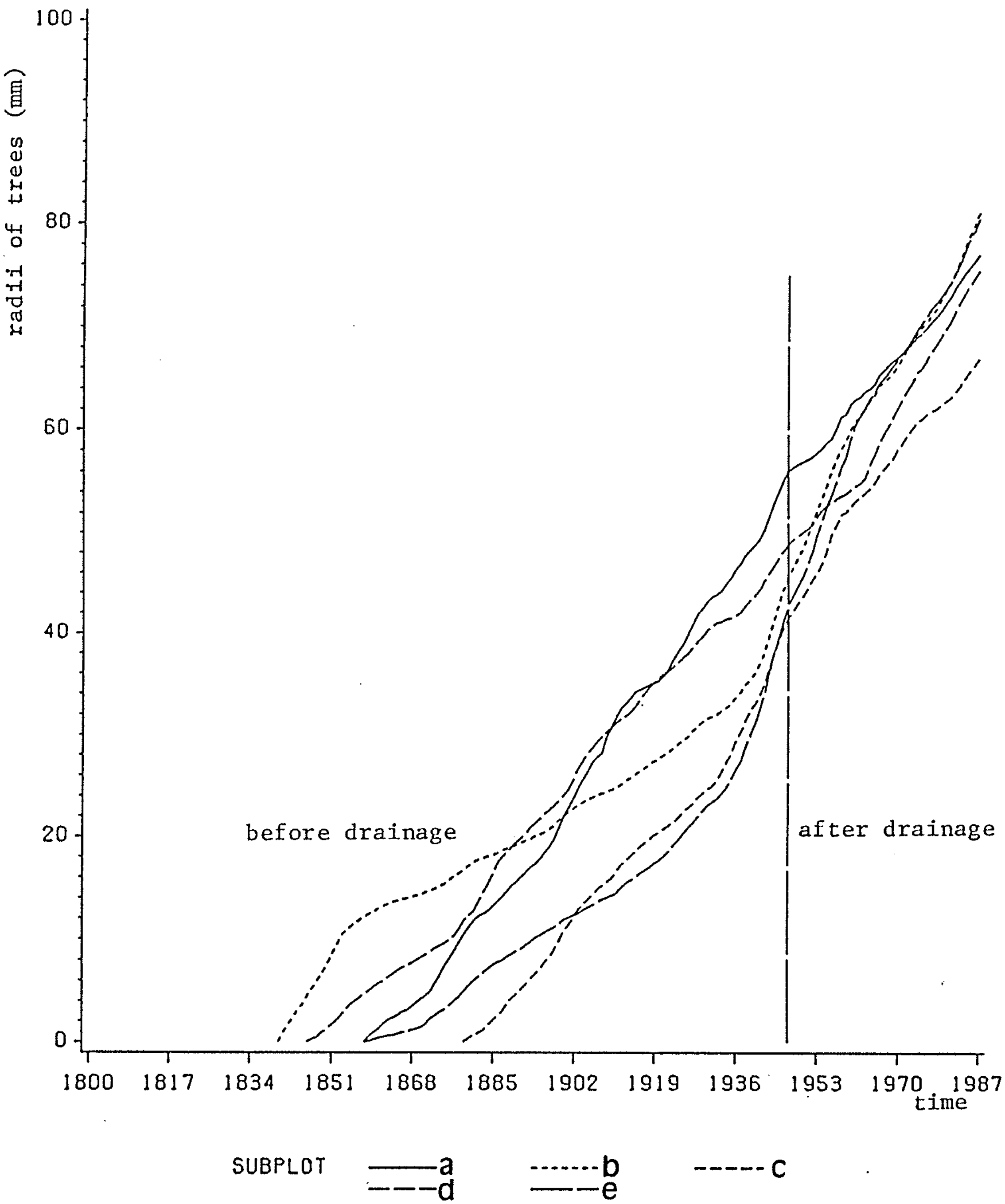

Figure 13: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 5.

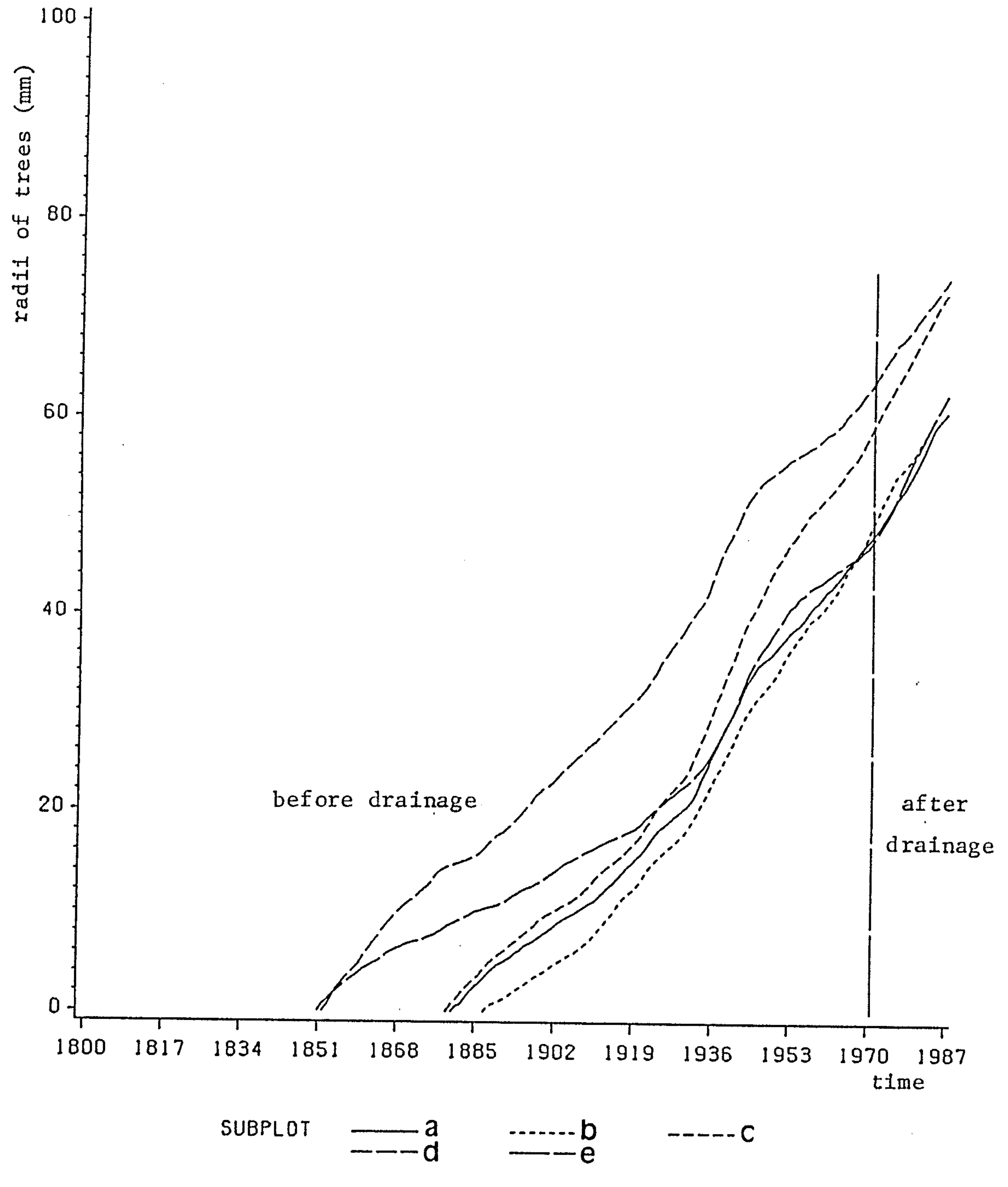

Figure 14: The radial growth (cumulative) over time at height 0.3 m of the trees sampled in Stand 6.

352%[7]. The date of inflection (approximately 1938) in the graphs shown in Figure 9 coincides more or less with the date of the installation of the drainage ditch along section 31, Township 13, Range 9E as mentioned in subsection 3.2.1.

2. For Stand 2: The graphs depicted in Figure 10 show an inflection around 1942 when the ditch along this stand was dug. Table 2 shows that the average widths of the annual rings before drainage is 0.53 mm and 0.96 mm after drainage.
3. For Stand 3: Radial tree growth shows a inflection around 1936, well before the ditch was created. The reason for this can not be explained. Table 2 indicates that the average widths of the annual rings after drainage is more than twice that of before drainage.
4. For Stand 4: The graphs depicted in Figure 12 show a slight inflection around 1945, approximately 10 years before the ditch was dug. The reason for this is unknown. The rate of radial growth before 1945 was approximately 0.4 mm yr^{-1} and after 1945 approximately 0.7 mm yr^{-1}.

[7] It should be noted that an increase of 352% in the rate of radial growth does not necessarily reflect the same rate of increase in volumetric growth per hectare as this parameter depends on increase in DBH of trees, increase in height of trees, and change in stem density.

5. For Stand 5: The radial growth of the trees in this stand is more or less linear over time. The influence of the ditch is rather small. The average widths of the annual rings is 0.52 mm before drainage compared to 0.73 mm after drainage (Table 2).
6. For Stand 6: The ditch along this stand is rather young; it seems to have some influence on the rate of radial growth (Table 2).

It should be noted that most stands show an increase in the rate of radial growth around 1936, even in those stands drained after that date (Figures 9 to 14). The reason for this is unknown. It might be attributed to favourable weather conditions. This increase in radial growth confounds the data presented in Table 2.

3.4 CONCLUSIONS

1. No relationship between wood volume and distance from the ditch could be found. In some cases the highest volume was found closest to the ditch (e.g. Stands 1 and 3) and in others farthest from the ditch (e.g. Stands 4, 5, and 6). In Stand 2 the highest volume was encountered in the "c" subplots, their centres being 25 m from the edge of the ditch. In Stands 1 and 3 the wood volumes are relatively low and the levels of the free water table relatively close to the ground surface (i.e. within 35 cm). In the

remaining stands sampled, the wood volumes are relatively high and the level of the free water table in the "a" subplots is greater than or equal to 75 cm below the ground surface.

2. In general, the level of the free water table followed the hypothesized pattern: with increasing distance from the ditch the distance from the ground surface to the free water table decreased.
3. On the average, the widths of the annual rings after drainage is more than twice that of before drainage.

Chapter IV

BENEFIT-COST ANALYSIS

4.1 INTRODUCTION

Once it has been established that drainage results in an increase in the MAI, a forest owner should determine if drainage is financially and/or economically beneficial. This can be accomplished by a benefit-cost analysis.

For this practicum it was decided to perform a limited economic (or social) benefit-cost analysis rather than a financial benefit-cost analysis. An economic benefit-cost analysis is based on the stumpage value of the timber which is much higher than the royalty (the basis for a financial benefit-cost analysis) charged by the Provincial Government. The decision by the Provincial Government to charge a royalty much smaller than the stumpage value is political and is partially based on the assumption that it stimulates employment. The social benefit-cost analysis was used as the Provincial Government could raise the royalty up to the stumpage value of the timber.

The social benefit-cost analysis is limited as it does not include all benefits and cost involved. Those not included are the social benefits and costs attached to the impact of drainage on the environment, plant communities, wildlife habitat etc. (see page 5, "Limitations"). These impacts are extremely difficult to quantify. The net value of these impacts could be either positive or negative.

In addition, the benefit-cost analysis is limited insofar as that no attempt was made to obtain shadow prices for the initial drainage cost and the maintenance costs as shadow pricing falls outside the scope of this practicum.

The benefit-cost analysis presented here is not based on the field study, but on data gathered independently.

A social benefit-cost analysis consists of several steps. Step 1: Identification of all benefits and costs for the project. Step 2: Construction of tables showing the flow of economic values by allocating benefits and costs to the year of occurrence. Step 3: Discounting of benefits and costs to a common point in time, usually to the beginning of the project, and summation to obtain the present value of the benefits and of the costs. Step 4: Analysis of a criterion such as the present value of benefits minus the present value of costs ("net benefits"), or the ratio of the present value of benefits to the present value of costs ("benefit-cost ratio"), or the internal rate of return (IRR; the discount rate at which the present value of benefits equals the present value of costs) to determine if the proposed enterprise has economic potential (Gravelines and Schellenberg, 1985).

4.2 IDENTIFICATION AND ESTIMATION OF BENEFITS AND COSTS

4.2.1 Identification of benefits and costs

Regarding the situation before drainage: the benefits are a harvest at the end of each rotation period and there are no costs.

Concerning the situation after drainage: the benefits are an increased harvest and a reduced rotation period, and the costs are 1) an initial drainage cost, 2) maintenance costs of the ditches, and 3) the value of the harvests before drainage as one is interested in the incremental performance of the forest as a result of drainage.

When a forest is improved by planting, thinning, fertilization, drainage or other measures, the investment must be protected against pests, fires etc. The cost of this protection must be included in a benefit-cost analysis. However, in southeastern Manitoba all forests are well protected due to the relatively dense population and the interests of the forest industry. Drainage will not increase the level of protection. Therefore no additional protection costs are included in the benefit-cost analysis.

The financial situation before and after drainage is shown graphically in Figures 15 and 16.

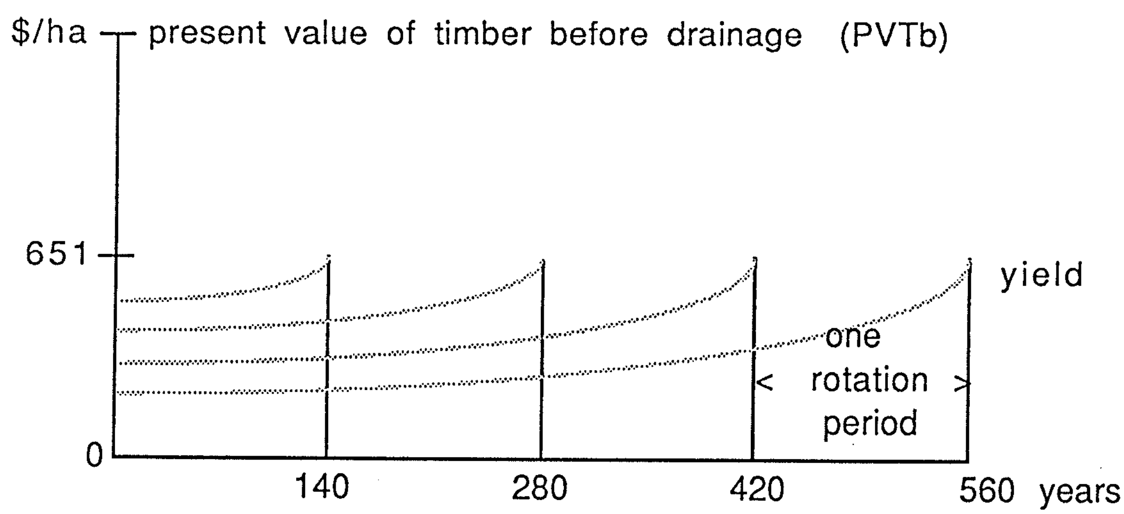

Figure 15: The discounting of benefits shown graphically, before drainage.

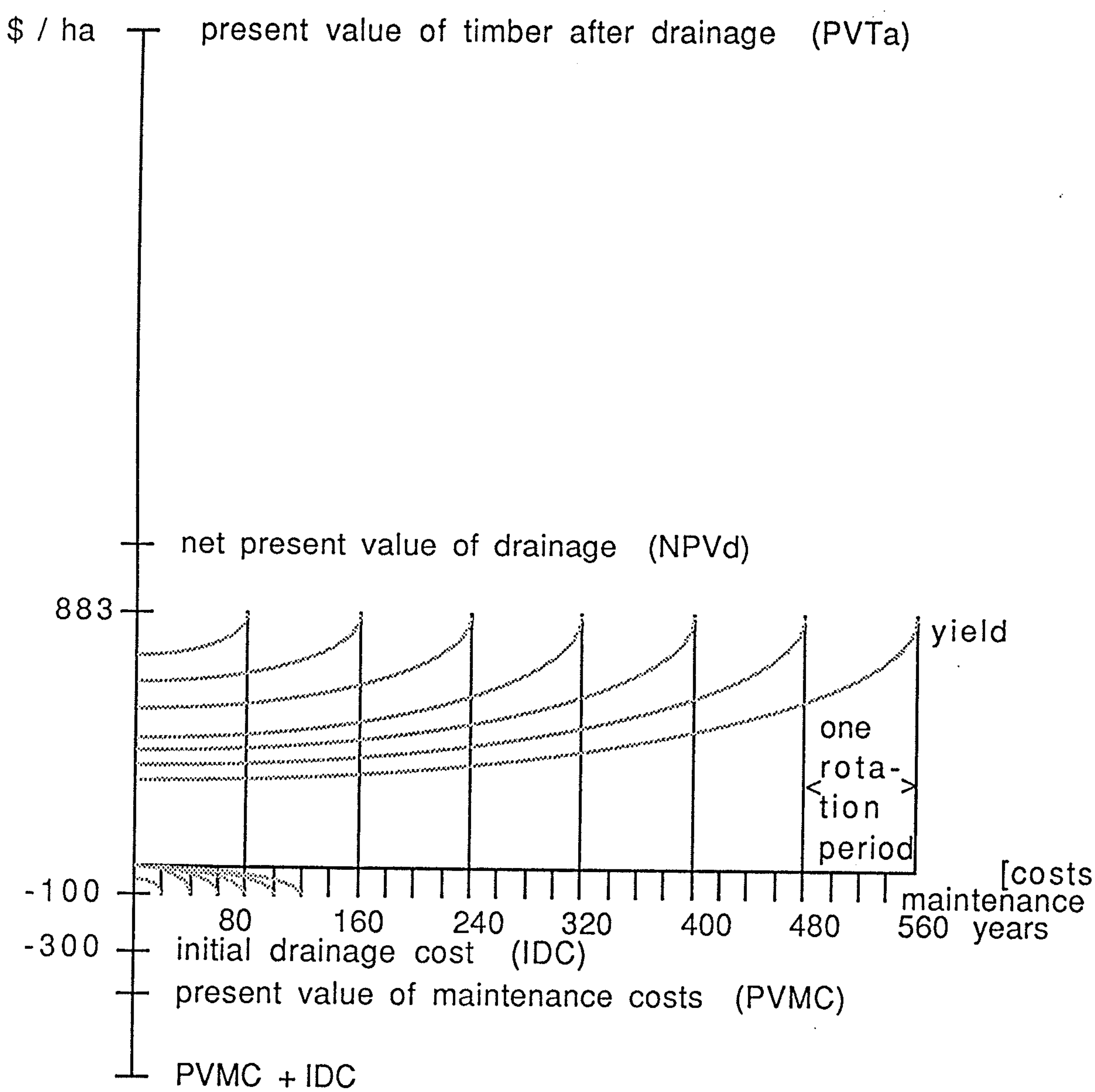

Figure 16: The discounting of benefits and costs shown graphically, after drainage.

4.2.2 Estimation of benefits and costs

A stumpage value in the amount of \$ 10 m^{-3} for the timber at the end of the harvest is realistic. This value is calculated by deducting the transportation costs of an average (60 km) haul (\$ 5 m^{-3}; Peacock[8], pers. comm.) from the residual value (\$ 15 m^{-3}). The residual value is the value of the roundwood at mill gate which is equal to the value of the wood standing in the forest minus logging costs (not including transportation costs) (Gravelines[9], pers. comm.).

With respect to the initial drainage cost, I received two values: one from Ontario (Rosen, pers. comm.) and one from Alberta (Hillman[10], pers. comm.). Both sources quoted approximately \$ 300 ha^{-1} drained.

The values obtained for the maintenance cost per treatment (\$ 100 ha^{-1}) and the time period between two subsequent maintenance treatments (20 years) are educated guesses (Rosen, pers. comm.).

All values given are in 1988 dollars (i.e. in real terms).

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[8] Mr. T. H. Peacock is a Divisional Forester employed by Abitibi-Price Inc.

[9] Mr. L. Gravelines is an economist employed by the Manitoba Department of Natural Resources.

[10] Dr. G. Hillman is a research scientist employed by the Canadian Forest Service.

Concerning the yields and lengths of the rotation periods, before and after drainage: If we assume that in Manitoba stands of black spruce are elevated from a Site Class 2 to a Site Class 1 as a result of drainage, we can estimate the net merchantable volume before drainage (NMVb), the length of the rotation period before drainage (Rb), the net merchantable volume after drainage (NMVa), and the length of the rotation period after drainage (Ra). They are as follows (from page 13):

NMVb = 65.1 m^3 ha^{-1},

Rb = 140 years[11],

NMVa = 88.3 m^3 ha^{-1}, and

Ra = 80 years[11].

The effect of drainage is two-fold: a) a greater volume at harvest time and b) a shorter rotation period.

4.3 FLOW OF ECONOMIC VALUES, BEFORE AND AFTER DRAINAGE

In order to perform the benefit-cost analysis, it had to be decided how long a period of time to take into consideration. There were two options: an infinite or a finite number of years. The advantage of an infinite number of years is that the formulas [3], [4], [5] and therefore [10] (see subsection 4.4) would be simpler. However, the

[11] These rotation periods are probably optimum biological rotation periods (when the current annual increment declines and becomes equal to the mean annual increment; this leads to a maximum production in timber volume) rather than optimum economical rotation periods. The latter is shorter.

formula used in subsection 4.8 (see also Appendix B) is for a finite number of terms (equivalent to a finite number of years) only. Therefore it was decided to take into account a finite number of years. A period of 560 years was selected as this number of years is the smallest common multiple of the rotation period before drainage (140 years) and the one after drainage (80 years). The difference between an infinite period of time and a period of 560 years, with respect to the criteria used in the benefit-cost analysis (net benefits and benefit-cost ratio), is negligible when the discount rate is equal to or greater than 1% yr^{-1}.

Before drainage, there is a harvest once every 140 years. The value of each harvest is 65.1 m^3 ha^{-1} X \$10 m^{-3} = \$651 ha^{-1}. There are four harvests. As stated earlier, there are no costs.

After drainage, the benefits (B) (or revenues) consist of a harvest every 80 years. The value of each harvest is 88.3 m^3 ha^{-1} X \$10 m^{-3} = \$883 ha^{-1}. There are seven harvests. The costs (C) are comprised of the initial drainage cost in the amount of \$ 300 ha^{-1} at year 0 and the maintenance costs in the amount of \$ 100 ha^{-1} starting at year 20 and reoccurring subsequently every 20 years, the last one in the year 540 (Table 3).

TABLE 3

Flow of economic values, before and after drainage and net flow after drainage minus net flow before drainage (α) ($ ha^{-1})

	before drainage			after drainage			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(7)-(4)
Year	B	C	B-C	B	C	B-C	α
0	0	(0)	0	0	(300)	(300)	(300)
20	0	(0)	0	0	(100)	(100)	(100)
40	0	(0)	0	0	(100)	(100)	(100)
60	0	(0)	0	0	(100)	(100)	(100)
80	0	(0)	0	883	(100)	+783	+783
100	0	(0)	0	0	(100)	(100)	(100)
120	0	(0)	0	0	(100)	(100)	(100)
140	651	(0)	651	0	(100)	(100)	(751)
160	0	(0)	0	883	(100)	+783	+783
180	0	(0)	0	0	(100)	(100)	(100)
200	0	(0)	0	0	(100)	(100)	(100)
220	0	(0)	0	0	(100)	(100)	(100)
240	0	(0)	0	883	(100)	+783	+783
260	0	(0)	0	0	(100)	(100)	(100)
280	651	(0)	651	0	(100)	(100)	(751)
300	0	(0)	0	0	(100)	(100)	(100)
320	0	(0)	0	883	(100)	+783	+783
340	0	(0)	0	0	(100)	(100)	(100)
360	0	(0)	0	0	(100)	(100)	(100)
380	0	(0)	0	0	(100)	(100)	(100)
400	0	(0)	0	883	(100)	+783	+783
420	651	(0)	651	0	(100)	(100)	(751)
440	0	(0)	0	0	(100)	(100)	(100)
460	0	(0)	0	0	(100)	(100)	(100)
480	0	(0)	0	883	(100)	+783	+783
500	0	(0)	0	0	(100)	(100)	(100)
520	0	(0)	0	0	(100)	(100)	(100)
540	0	(0)	0	0	(100)	(100)	(100)
560	651	(0)	651	883	(0)	+883	+232

As we are comparing the situation after drainage to the one before, the column α has been included in Table 3 to demonstrate the incremental effect of drainage on the flow of economic values.

4.4 DISCOUNTING OF BENEFITS AND COSTS

As shown in Figure 15 there is a yield at the end of each rotation period. The volume harvested (m^3 ha^{-1}) is multiplied by the stumpage value ($ m^{-3}) to arrive at the wood value ($ ha^{-1}) of one yield. This value is discounted to the present. This is done for each yield and all these discounted values are summed to obtain the present value of the timber before drainage. In formula:

$$PVTb = \frac{NMVb \cdot V}{(1+d)^{Rb}} + \frac{NMVb \cdot V}{(1+d)^{2 \cdot Rb}} + \ldots + \frac{NMVb \cdot V}{(1+d)^{n \cdot Rb}} \qquad [2]$$

or

$$PVTb = \frac{NMVb \cdot V}{(1+d)^{Rb} - 1} \cdot \left[1 - (1+d)^{-n \cdot Rb} \right] \qquad [3]$$

- PVTb is the present value of the timber before drainage ($ ha^{-1}).
- NMVb is the net merchantable volume of the timber per harvest before drainage (m^3 ha^{-1}).

- V is the stumpage value of the timber ($ m^{-3}).
- d is the discount rate (% yr^{-1}).
- Rb is the length of the rotation period before drainage (years).
- n is the number of harvests before drainage.

Figure 16 indicates that a) the harvest at the end of each rotation period is larger after drainage than before, b) the rotation period is shorter after drainage than before, c) there is an initial drainage cost (the cost of the construction of the ditches), and d) there are maintainance costs of the ditches at regular intervals.

The derivation of the present value of the timber after drainage is similar to that for the present value of the timber before drainage:

$$PVTa = \frac{NMVa \cdot V}{(1+d)^{Ra} - 1} \cdot \left[1 - (1+d)^{-N \cdot Ra} \right] \qquad [4]$$

- PVTa is the present value of the timber after drainage ($ ha^{-1}).
- NMVa is the net merchantable volume of the timber per harvest after drainage (m^3 ha^{-1}).
- Ra is the length of the rotation period after drainage (years).
- N is the number of harvests after drainage.

The present value of the maintenance costs is:

$$PVMC = \frac{M}{(1+d)^{F} - 1} \cdot \left[1 - (1+d)^{-q \cdot F} \right] \qquad [5]$$

- PVMC is the present value of the maintenance costs ($ ha^{-1}).
- M is the cost per maintenance treatment ($ ha^{-1}).
- F is the time period between two subsequent maintenance treatments (years).
- q is the number of maintenance treatments.

To calculate the net present value of the drainage activity, the following formulas are used:

NPVd = PVB - PVC [6]

- NPVd is the net present value of the drainage activity ($ ha^{-1}).
- PVB is the present value of the benefits ($ ha^{-1}).
- PVC is the present value of the costs ($ ha^{-1}).

PVB = PVTa [7]

PVC = PVTb + PVMC + IDC [8]

- IDC is the initial drainage cost ($ ha^{-1}).

Equations [6], [7], and [8] result in:

NPVd = PVTa - (PVTb + PVMC + IDC) [9]

Substituting our estimates of the parameters important in calculating the NPVd into formulas [3], [4], [5], and [9] will give the following equation (n=4, N=7, and q=27):

$$NPVd = \frac{88.3 \times 10}{(1+d)^{80} - 1} \times \left[1 - (1+d)^{-560} \right]$$

$$- \frac{65.1 \times 10}{(1+d)^{140} - 1} \times \left[1 - (1+d)^{-560} \right]$$

$$- \frac{100}{(1+d)^{20} - 1} \times \left[1 - (1+d)^{-540} \right] - 300 \qquad [10]$$

This equation was solved by varying d from 0.00 % yr^{-1} to 10.00% yr^{-1} in increments of 1.00 % yr^{-1}. In addition, the value of 2.85% yr^{-1} [the average inflation corrected interest rate for Canada Savings Bonds (CSBs) for the period 1964-1986 (Bank of Canada, 1975 and 1986)] was substituted for d (Table 4). This value of 2.85% yr^{-1} can be considered to be the social discount rate.

4.5 <u>RELATIONSHIPS BETWEEN BENEFITS AND COSTS</u>

In interpreting Table 4, one of three criteria must be used. These criteria are: 1) the net benefits (= PVB-PVC), usually abbreviated to B-C, 2) the benefit-cost ratio (= PVB/PVC), usually abbreviated to B/C, or 3) the IRR.

TABLE 4

Relationship between discount rate (d) and present value of benefits (PVB), present value of costs (PVC), net present value of the drainage activity (NPVd = PVB-PVC), and PVB/PVC **(g = 0% / yr)**

d ($\% \ yr^{-1}$)	PVB ($\$ \ ha^{-1}$)	PVC ($\$ \ ha^{-1}$)	NPVd ($\$ \ ha^{-1}$)	PVB/PVC
0.00	6181.00	(5604.00)	577.00	1.10
1.00	722.97	(966.29)	(243.32)	0.75
2.00	227.84	(549.19)	(321.35)	0.41
2.85	104.25	(445.57)	(341.32)	0.23
3.00	91.59	(434.60)	(343.01)	0.21
4.00	40.05	(386.65)	(346.60)	0.10
5.00	18.18	(361.19)	(343.01)	0.05
6.00	8.43	(345.49)	(337.06)	0.02
7.00	3.96	(334.90)	(334.94)	0.012
8.00	1.87	(327.33)	(325.46)	0.006
9.00	0.90	(321.72)	(320.82)	0.003
10.00	0.43	(317.46)	(317.03)	0.001

The values shown in Table 3 in the column labelled α change from negative to positive and vice versa thirteen times. For every time that there is a change in sign, there is, in theory, an IRR. Therefore, in this case, the IRR is not a suitable criterion to evaluate whether drainage is economically attractive. In this study, it has been decided to use the benefit-cost ratio. However, the Manitoba Government has no set discount rate for the evaluation of benefit-cost analyses. The discount rate has a very large impact on the benefit-cost ratio as is demonstrated in Table 4.

4.6 INTERPRETATION OF THE BENEFIT-COST RATIO

As indicated in Table 4, the benefit-cost ratio at 2.85% yr^{-1} (the average net yield of CSBs) is smaller than unity, so that drainage appears to be economically less attractive than investing money in CSBs or similar investments (caeteris paribus).

However, the benefit-cost ratio (B/C) of drainage should be compared to the B/C for other forestry related activities such as planting, thinning, fertilization, firefighting, insect control etc. One might come to the conclusion that it is wiser to invest in drainage than in thinning, for example. A comparison to other forestry activities is not in the realm of this practicum.

4.7 A SENSITIVITY STUDY OF THE BENEFIT-COST RATIO

Once the B/C has been established, it is of interest to know how this B/C is affected by changes in the nine parameters of which it is a function.

The indicator used to express the relationship between the change in one parameter and the change induced in an other is "elasticity" (E). The elasticity, in this case, is the relative change in the B/C divided by a relative change in one of the parameters (P). In formula:

$$E = \frac{\Delta(B/C)}{B/C} \div \frac{\Delta P}{P} = \frac{\Delta(B/C)}{B/C} \cdot \frac{P}{\Delta P} \qquad [11]$$

Elasticities of the parameters used to calculate the B/C at a discount rate of 2.85% yr^{-1} were examined by varying each parameter independantly to values 25% above and below the estimates used to calculate the baseline B/C. This procedure could not be implemented for the growth rate of the stumpage value (g) as the baseline value for this parameter is 0% yr^{-1}. Its elasticity was calculated in the interval g = 0% yr^{-1} to g = 1% yr^{-1}. The elasticity values for each parameter are recorded in Table 5.

TABLE 5

Elasticities of the nine parameters of the benefit-cost ratio

		E	
		magnitude	slope
1.	rotation period after drainage	2.77	-
2.	harvest volume after drainage	1.00	+
3.	stumpage value of the timber	0.97	+
4.	initial drainage cost	0.69	-
5.	growth rate of stumpage value	0.44	+
6.	period between maintenance treatments	0.40	+
7.	maintenance costs	0.30	-
8.	rotation period before drainage	0.14	+
9.	harvest volume before drainage	0.03	-

Five of the nine parameters have a positive elasticity and four a negative one. As a measure of the relationship between a parameter and the B/C, positive elasticity describes a situation in which the B/C increases with an increase in the parameter. Negative elasticity describes a situation in which the B/C decreases with an increase in the parameter.

The parameters with the highest magnitudes have the greatest influence on the B/C. Thus, to increase the B/C, one should manipulate parameters with as high a magnitude as possible.

The parameters with an absolute elasticity greater than unity are called elastic, meaning that a relatively small change in one of these parameters will cause a relatively large change in the B/C. The parameters with an absolute elasticity smaller than unity are called inelastic, meaning that a relatively small change in one of these parameters will cause an even smaller relative change in the B/C.

It should be noted that the length of the rotation period and the harvest volume after drainage have a great influence on the B/C (numbers 1 and 2 in Table 5). A 1% decrease in the length of the rotation period after drainage will cause a 2.77% increase in the benefit-cost ratio and a 1% increase in the harvest volume after drainage will cause a 1% increase in the benefit-cost ratio. This is in sharp contrast to the situation before drainage (numbers 8 and 9 in Table 5). A 1% increase in the length of the rotation period before drainage will cause a 0.14% increase in the benefit-cost ratio and a 1% decrease in the harvest volume before drainage will cause a 0.03% increase in the benefit-cost ratio.

4.8 THE INFLUENCE OF AN EVER INCREASING STUMPAGE VALUE OF THE TIMBER ON THE BENEFIT-COST RATIO

Gray[12] (pers. comm.) stated that an increase in the real (i.e. inflation corrected) stumpage value of the timber in the amount of approximately 1% yr^{-1} is realistic, possibly due to scarcity.

To estimate the influence of an ever increasing stumpage value, Table 4 has been recalculated for three different growth rates: 0.5% yr^{-1}, 1 % yr^{-1}, and 2 % yr^{-1} (Tables 6, 7, and 8). The formula to calculate the present value of a number of regularly reoccurring benefits (or costs) which are growing at a steady relative rate is presented in Appendix B on page 102.

The Tables 4, 6, 7, and 8 indicate that when g increases, the B/C increases when a specific discount rate is observed. It has been calculated that at d = 2.85% yr^{-1} and g = 1.70% yr^{-1}, B/C = 1. Therefore it is attractive to drain stands of black spruce on peatlands with high water tables when the social discount rate drops to below 2.85% yr^{-1} and/or the growth rate of the value of the stumpage rises to above

[12] Dr. J. Gray is a Professor of Economics at the University of Manitoba.

1.70% yr^{-1}.

TABLE 6

Relationship between discount rate (d) and present value of benefits (PVB), present value of costs (PVC), net present value of the drainage activity (NPVd = PVB - PVC), and PVB/PVC **(g = 0.5% / yr)**

d (% yr^{-1})	PVB (\$ ha^{-1})	PVC (\$ ha^{-1})	NPVd (\$ ha^{-1})	PVB/PVC
0.00	41143.45	(22858.88)	18284.57	1.80
1.00	1699.20	(1360.62)	338.58	1.25
2.00	388.66	(599.32)	(210.66)	0.65
2.85	164.92	(459.23)	(294.31)	0.36
3.00	143.81	(445.62)	(301.81)	0.32
4.00	61.04	(389.40)	(328.36)	0.16
5.00	27.38	(361.90)	(334.52)	0.08
6.00	12.62	(345.68)	(333.06)	0.04
7.00	5.91	(334.95)	(329.04)	0.02
8.00	2.80	(327.34)	(324.54)	0.01
9.00	1.34	(321.73)	(320.39)	0.004
10.00	0.64	(317.46)	(316.82)	0.002

TABLE 7

Relationship between discount rate (d) and present value of benefits (PVB), present value of costs (PVC), net present value of the drainage activity (NPVd = PVB - PVC), and PVB/PVC **(g = 1% / yr)**

d (% yr^{-1})	PVB ($ ha^{-1})	PVC ($ ha^{-1})	NPVd ($ ha^{-1})	PVB/PVC
0.00	421499.03	(229914.15)	191584.88	1.83
1.00	6181.00	(3358.42)	2822.58	1.84
2.00	733.25	(723.93)	9.32	1.01
2.85	269.85	(488.25)	(218.40)	0.55
3.00	232.35	(468.74)	(236.39)	0.50
4.00	93.95	(394.95)	(301.00)	0.24
5.00	41.34	(363.33)	(321.99)	0.11
6.00	18.90	(346.06)	(327.16)	0.05
7.00	8.82	(335.05)	(326.23)	0.03
8.00	4.17	(327.37)	(323.20)	0.013
9.00	1.99	(321.73)	(319.74)	0.006
10.00	0.96	(317.46)	(316.50)	0.003

TABLE 8

Relationship between discount rate (d) and present value of benefits (PVB), present value of costs (PVC), net present value of the drainage activity (NPVd = PVB - PVC), and PVB/PVC **(g = 2% / yr)**

d (% yr^{-1})	PVB ($ ha^{-1})	PVC ($ ha^{-1})	NPVd ($ ha^{-1})	PVB/PVC
0.00	72,734,938.40	(45,470,980.22)	27,263,958.18	1.60
1.00	401,494.97	(216,483.15)	185,011.82	1.85
2.00	6,181.00	(3,112.78)	3,068.22	1.99
2.85	928.02	(726.22)	201.80	1.28
3.00	734.53	(646.12)	97.41	1.15
4.00	236.87	(429.93)	(193.06)	0.55
5.00	96.34	(371.93)	(275.59)	0.26
6.00	42.66	(348.31)	(305.65)	0.12
7.00	19.63	(335.65)	(316.02)	0.06
8.00	9.22	(327.53)	(318.31)	0.03
9.00	4.39	(321.78)	(317.39)	0.014
10.00	2.11	(317.48)	(315.37)	0.007

4.9 SUMMARY

The objective of the benefit-cost analysis was to establish if drainage is economically feasible.

The benefits and costs occurring during a 560-year period, before and after drainage, were discounted to the present.

In order to calculate benefits and costs in the "before" and "after" drainage situation, the value of a number of parameters had to be assumed due to the lack of drainage experience in Manitoba.

The benefit-cost ratio was calculated for a number of discount rates (0% yr^{-1} - 10% yr^{-1}) and for a number of growth rates in the real value of the stumpage (0% yr^{-1} - 2% yr^{-1}).

In spite of the fact that the benefit-cost ratio calculated for the drainage activity is lower than unity at a discount rate of 2.85% yr^{-1} (the net yield of a sound investment such as Canada Savings Bonds) and at a constant value of the stumpage, drainage should not simply be ignored. In the future a shortage of wood may occur in the immediate vicinity of pulp mills, thus increasing the value of such timber, subsequently increasing the benefit-cost ratio. In addition, drainage projects provide employment (directly and indirectly) and create increased incomes to both the Federal and Provincial Governments in the form of taxes etc. Furthermore, an increase in wood supply will contribute to an increase in the wealth of the province.

The Forestry Branch has a fixed amount of money available for several projects. To obtain the highest return, the benefit-cost ratio, or other criterion, should be calculated for each of these projects in order to determine which projects should be undertaken.

Also a sensitivity study, of the parameters of the benefit-cost ratio was performed. The benefit-cost ratio is most sensitive to the length of the rotation period after drainage, the volume of the harvest after drainage, and the value of the timber. The first two parameters mentioned could be influenced by selecting promising locations, that is soils which are relatively rich and in an area where high yields can be expected (e.g. in the Lac du Bonnet-Pinawa-Pine Falls area; see map: Environment Canada, Canada Land Inventory, Land Capability for Forestry, Manitoba-South Part, 1977).

The stumpage value of the timber can be influenced by selecting stands or areas to be drained close to pulp mills.

Chapter V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY

Manitoba has large tracts of organic soils forested with black spruce, one of the few species of trees that is able to cope with the boreal climate and the high water tables in organic soils. Most black spruce stands grow very slowly; they have a mean annual increment (MAI) of about 0.47 m^3 ha^{-1}. This growth rate can be improved by at least 100% (Stanek, 1976) by lowering the water table to approximately 30 cm below the forest floor by means of open drainage ditches. Drainage in conjunction with other silvicultural activities, such as fertilization and/or thinning, could further improve the rate of growth in stands of black spruce. This practicum considered drainage only.

Literature on the effect of forest drainage on wood volume was surveyed. The literature was also examined to establish the spacing and size of ditches in countries where drainage of coniferous forest is a common practice, e.g. in Finland.

To determine if stands of black spruce in southeastern Manitoba have shown an increase in growth rate as a result of agricultural or road drainage (no drainage for forestry was carried out in this province intentionally), six stands were sampled.

As a separate exercise, the financial implications of drainage was evaluated and a benefit-cost analysis was performed. Net benefits (B-C) and benefit-cost ratios (B/C) were calculated at a number of discount rates and growth rates of the stumpage value. A sensitivity study of the relevant parameters of the B/C was executed.

5.2 CONCLUSIONS

5.2.1 Conclusions as a result of the literature review

1. In Finland more than 5,000,000 ha of forests have been drained since 1910 using more than 1,000,000 km of ditches. As a result an additional 4,000,000 m^3 of wood was harvested in 1985. It is estimated that this will increase to 15,000,000 m^3 by the year 2020.
2. The MAI of stands of black spruce can be improved by 100% to 900%, depending on length of growing season, levels of nutrients in the soil, and possibly some other factors (i.e. stand age, site type, stand history, etc.).
3. Open ditches should be spaced about 30 m to 60 m depending on the level and pattern of precipitation, topography, and other factors.

4. A ditch depth of 60 cm to 100 cm is sufficient.
5. Operational forest drainage in Canada is in its infancy.
6. Presently, experiments concerning the drainage of stands of black spruce are being conducted in Ontario (Cochrane area), Alberta (Goose River, McLennan, and Wolf Creek areas), Nova Scotia, New Brunswick, and Quebec.
7. The initial drainage costs are about \$ 300 ha^{-1}.
8. The maintenance costs are estimated to be \$ 100 ha^{-1} once every 20 (to 30) years.
9. Drainage will a) shorten the rotation period of a stand, and/or b) increase the harvest volume at the end of the rotation period.
10. Forests should be drained at an early age to give a maximum effect.
11. Nadeau and Parent (1982) report for Quebec that the highest rate of financial return is obtained when a black spruce stand with too high a water table is ditched at age 45 to 75 years and harvested 15 to 20 years later. Under these circumstances the rate of financial return could be as high as 14% yr^{-1} (from the perspective of the Federal and Provincial Governments).
12. According to some authors, overdrainage does not appear to be a problem.

13. As black spruce roots only in the top 30 cm of the soil, overdrainage may be possible.

5.2.2 Conclusions of the field study

No relationship between wood volume and distance from the ditch and between wood volume and depth to the water table could be found. This is a result of sampling stands that were not drained for forestry purposes. Stands drained for forestry purposes are not found in Manitoba.

The field study indicated that the average width of the annual rings after drainage is about twice that of before drainage, however, most stands show an increase in the rate of radial growth around 1936 due to unknown causes. This confounds the data presented in Table 2.

In most cases the free water table levels showed the hypothesized relationship to the distance from the ditch: the farther from the ditch the closer the free water table to the forest floor.

Of the stands examined, it seemed that many had a larger volume than the average Site Class 1 stands at the end of the rotation period (in one subplot more than 300 m^3 ha^{-1} of total stem-wood volume was found; see Table 14, Stand 5, subplot 13e). This indicates that at least some stands can yield much more than the 88.3 m^3 ha^{-1} (net merchantable wood volume) used in the benefit-cost analysis. A figure higher than 88.3 m^3 ha^{-1} would increase the present value of the timber after drainage and thus raise the B/C as calculated in Chapter 4.

5.2.3 <u>Conclusions of the benefit-cost analysis</u>

The B/C calculated for the drainage activity, based partially on assumed values, is lower than unity at the inflation corrected interest rate for a sound investment like Canada Savings Bonds (2.85% yr^{-1}) and for a growth rate of the stumpage value smaller than 1.70% yr^{-1}. However, some of the values used in this calculation were assumed due to the lack of drainage data in Canada and could be on the conservative side. It was assumed that, in Manitoba, an undrained stand (Site Class 2) was elevated to a Site Class 1 stand (production wise) as a result of drainage. This implies an increase of the MAI from 0.47 m^3 ha^{-1} to 1.10 m^3 ha^{-1} (net merchantable volume), a 134% increase. This should be viewed in the light of reports that drainage could increase the MAI by 100% to 900%. A 900% increase would be equivalent to a MAI of 4.7 m^3 ha^{-1} after drainage (from 0.47 m^3 ha^{-1}).

According to a "Land Capability for Forestry" map[13], some areas of Manitoba are able to yield a MAI of 5.0 to 6.3 m^3 ha^{-1} (71 to 90 cubic feet per acre) gross merchantable

[13] Environment Canada, Canada Land Inventory, Manitoba-South Part, Cat. No. 64-13/4.

volume[14] so that an increase in the MAI of more than 134% seems possible. A higher yield and/or a shorter rotation period after drainage will have a positive influence on the B/C.

The sensitivity study indicated that the three factors with greatest influence on the B/C are: the length of the rotation period, the yield at the end of the rotation period (both after drainage), and the value of the timber, in that order. The first two factors can be influenced by selecting the most promising sites. The third factor could be influenced by selecting sites close to the pulp mills as transportation costs will be low and therefore stumpage values high.

5.3 RECOMMENDATIONS

Presently the allowable annual cut (AAC) is fully committed in southeastern Manitoba. It is predicted that there will be a shortage of timber in the year 1995 (Government of Canada - Manitoba Natural Resources, 1984). This, in conjunction with an increasing demand for pulp and paper and a reduction in the world's forested areas, has led to the following recommendations:

[14] Unfortunately no numerical relationships between total stem-wood volume (TSV), gross merchantable volume (GMV), and net merchantable volume (NMV) could be obtained for Manitoba. Known is that TSV > GMV > NMV. However, for Ontario, the relationship between gross total volume (GTV) and GMV for mature black spruce stands can be calculated from the data presented by Plonski (1981): GTV X 0.6 = GMV (approximately).

1. To drain on an annual basis, for 5 to 10 years, a fairly small area, a few hundred hectares, of young stands of black spruce. This will require an investment of about $500,000 - $1,000,000. In these stands permanent sample plots should be established to determine more precisely the values of the parameters used in the benefit-cost analysis. When these new values become known, 10 to 30 years after ditching, the benefit-cost ratio should be recalculated and the decision made to increase the rate of drainage (in hectares per year) if the benefit-cost ratio is greater than unity at the social cost interest rate, to decrease the rate of drainage or discontinue drainage altogether if the benefit-cost ratio is smaller than unity at the social cost interest rate.
2. The first areas drained should be considered as test sites. On these sites some parameters such as ditch spacing, ditch depth and levels of fertilization could be varied in order to obtain the optimum values of these parameters.
3. The selection of the sites to be drained should be based on the following criteria:

   i) The sites should be as close to the pulp mill in Pine Falls as possible to reduce transportation costs. The Pine Falls area has a high capability for forestry, according to a map produced by Environment Canada, Canada Land Inventory.

ii) The sites should be in areas which can be drained naturally (a slope of 1:100 for main ditches and 1:300 - 1:2000 for secondary ditches is mentioned in the literature), and

iii) The sites should meet minimum standards concerning the natural richness of the soils with respect to minerals available for black spruce. They are, in per cent dry weight of peat: 1.00 nitrogen, 0.04 - 0.09 phosphorus, 0.08 potassium, and 0.14 - 0.29 calcium. A pH value smaller than 3.5 is considered too low for a vigorous growth of black spruce.

4. To inventory the existing drainage network, evaluate it, and have the few ditches that do exist already cleaned, if necessary. This could well be the most cost efficient measure the Province of Manitoba could undertake with respect to forest drainage.

If the above recommendations are followed, the production of Manitoba's forests may increase subsequently and contribute to the economy of this province in a positive way.

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Appendix A

RESULTS OF FIELD MEASUREMENTS (TABLES)

TABLE 9

Number of trees per subplot, black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	total	ave.
a	33	36	33	102	34.0
b	23	47	19	89	29.7
c	34	45	34	113	37.7
d	43	36	27	106	35.3
e	19	22	18	59	19.7
total	152	186	131	469	
ave.	30.4	37.2	26.2		31.3

Stand 2

	2	7	8	total	ave.
a	15	20	31	66	22.0
b	18	19	28	65	21.7
c	37	26	41	104	34.7
d	28	15	14	57	19.0
e	32	16	25	73	24.3
total	130	96	139	365	
ave.	26.0	19.2	27.8		24.3

Stand 3

	3	9	10	total	ave.
a	44	33	25	102	34.0
b	40	29	51	120	40.0
c	36	22	34	92	30.7
d	35	25	33	93	31.0
e	46	26	36	108	36.0
total	201	135	179	515	
ave.	40.2	27.0	35.8		34.3

cont.

TABLE 9 (continued)

Stand 4

	4	11	12	total	ave.
a	41	40	40	121	40.3
b	28	24	27	79	26.3
c	37	34	35	106	35.3
d	24	25	30	79	26.3
e	21	16	24	61	20.3
f	35	21	16	72	24.0
g	32	34	18	84	28.0
total	218	194	190	602	
ave.	31.1	27.7	27.1		28.7

Stand 5

	13	14	15	total	ave.
a	23	25	31	79	26.3
b	22	21	30	73	24.3
c	22	35	23	80	26.7
d	28	12	23	63	21.0
e	31	36	27	94	31.3
total	126	129	134	389	
ave.	25.2	25.8	26.8		25.9

Stand 6

	16	17	18	total	ave.
a	27	41	7	75	25.0
b	36	35	13	84	28.0
c	19	16	13	48	16.0
d	28	22	10	60	20.0
e	30	31	15	76	25.3
total	140	145	58	343	
ave.	28.0	29.0	11.6		22.9

TABLE 10

Number of trees per hectare, black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.
a	4202	4584	4202	4329
b	2928	5984	2419	3777
c	4329	5730	4329	4796
d	5475	4584	3438	4499
e	2419	2801	2292	2504
ave.	3871	4736	3336	3981

Stand 2

	2	7	8	ave.
a	1910	2546	3947	2801
b	2292	2419	3565	2759
c	4711	3310	5220	4414
d	3565	1910	1783	2419
e	4074	2037	3183	3098
ave.	3310	2445	3540	3098

Stand 3

	3	9	10	ave.
a	5602	4202	3183	4329
b	5093	3692	6494	5093
c	4584	2801	4329	3905
d	4456	3183	4202	3947
e	5857	3310	4584	4584
ave.	5118	3438	4558	4371

cont.

TABLE 10 (continued)

Stand 4

	4	11	12	ave.
a	5220	5093	5093	5135
b	3565	3056	3438	3353
c	4711	4329	4456	4499
d	3056	3183	3820	3353
e	2674	2037	3056	2589
f	4456	2674	2037	3056
g	4074	4329	2292	3565
ave.	3965	3529	3456	3650

Stand 5

	13	14	15	ave.
a	2928	3183	3947	3353
b	2801	2674	3820	3098
c	2801	4456	2928	3395
d	3565	1528	2928	2674
e	3947	4584	3438	3989
ave.	3209	3285	3412	3302

Stand 6

	16	17	18	ave.
a	3438	5220	891	3183
b	4584	4456	1655	3565
c	2419	2037	1655	2037
d	3565	2801	1273	2546
e	3820	3947	1910	3226
ave.	3565	3692	1477	2911

TABLE 11

Average height of trees (m), black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.[15]
a	8.5	8.7	8.1	8.4
b	7.6	8.5	7.5	8.1
c	8.1	8.8	6.5	7.9
d	7.6	8.1	7.2	7.7
e	6.5	7.3	7.2	7.0
ave.[15]	7.8	8.4	7.3	7.9

Stand 2

	2	7	8	ave.[15]
a	8.0	7.9	10.4	9.1
b	8.9	11.0	10.2	10.1
c	9.0	12.9	9.8	10.3
d	7.9	12.3	10.7	9.7
e	7.7	12.8	8.6	9.1
ave.[15]	8.3	11.4	9.9	9.7

Stand 3

	3	9	10	ave.[15]
a	8.5	8.2	8.5	8.4
b	8.2	8.5	6.9	7.7
c	7.2	8.6	7.3	7.6
d	7.6	9.3	6.7	7.7
e	6.8	8.5	5.8	6.9
ave.[15]	7.7	8.6	6.9	7.7

cont.

[15] weighted average

TABLE 11 (continued)

Stand 4

	4	11	12	ave.[16]
a	8.4	8.8	9.2	8.8
b	9.0	9.7	10.6	9.8
c	10.6	10.7	11.9	11.1
d	11.1	12.8	11.7	11.9
e	12.8	12.1	12.9	12.7
f	12.5	12.1	8.2	11.4
g	12.0	11.6	9.3	11.3
ave.[16]	10.8	10.9	10.7	10.8

Stand 5

	13	14	15	ave.[16]
a	9.4	9.5	11.3	10.2
b	12.5	11.1	12.4	12.1
c	13.1	10.4	13.8	12.1
d	11.9	10.3	12.9	12.0
e	13.1	10.6	13.7	12.3
ave.[16]	12.1	10.4	12.7	11.7

Stand 6

	16	17	18	ave.[16]
a	8.5	8.2	9.5	8.4
b	8.9	8.5	12.8	9.3
c	9.1	8.7	10.7	9.4
d	10.0	10.6	9.4	10.1
e	10.3	11.3	13.7	11.4
ave.[16]	9.4	9.4	11.6	9.7

[16] weighted average

TABLE 12

Average DBH of trees (cm), black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.[17]
a	9.5	9.4	9.3	9.4
b	9.0	8.3	8.5	8.5
c	9.0	8.4	7.7	8.4
d	8.3	8.9	7.9	8.4
e	6.5	7.3	7.2	7.0
ave.[17]	8.6	8.5	8.2	8.5

Stand 2

	2	7	8	ave.[17]
a	9.7	9.4	11.2	10.3
b	11.2	11.6	10.3	10.9
c	9.5	12.7	9.9	10.5
d	9.1	13.2	13.1	11.2
e	8.4	13.6	9.4	9.9
ave.[17]	9.4	12.0	10.5	10.5

Stand 3

	3	9	10	ave.[17]
a	8.7	8.8	9.3	8.9
b	8.1	9.4	7.4	8.1
c	7.6	9.7	8.1	8.3
d	8.4	10.5	7.3	8.6
e	7.2	9.7	6.5	7.6
ave.[17]	8.0	9.6	7.6	8.3

cont.

[17] weighted average

TABLE 12 (continued)

Stand 4

	4	11	12	ave.[18]
a	9.0	8.6	9.3	9.0
b	9.4	10.0	10.1	9.8
c	10.2	10.5	10.6	10.4
d	10.6	12.0	11.1	11.2
e	12.5	12.0	12.6	12.4
f	10.9	12.4	8.6	10.8
g	11.7	11.2	10.6	11.3
ave.[18]	10.5	10.7	10.4	10.5

Stand 5

	13	14	15	ave.[18]
a	11.0	10.6	11.9	11.2
b	12.3	11.6	11.6	11.8
c	12.7	9.7	13.0	11.5
d	11.4	11.5	12.3	11.7
e	12.1	10.8	12.5	11.7
ave.[18]	11.9	10.7	12.2	11.6

Stand 6

	16	17	18	ave.[18]
a	9.5	8.5	12.8	9.3
b	9.1	8.6	14.8	9.8
c	9.8	9.7	12.2	10.4
d	10.6	11.0	12.6	11.1
e	9.7	11.4	15.6	11.6
ave.[18]	9.7	9.7	13.8	10.4

[18] weighted average

TABLE 13

Average total stem-wood volume per tree (dm³), black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.[19]
a	33.8	36.9	34.7	35.2
b	29.4	26.9	25.3	27.2
c	27.6	29.4	18.4	25.5
d	23.4	31.3	21.9	25.7
e	22.7	25.2	26.1	24.7
ave.[19]	27.4	30.1	25.3	27.9

Stand 2

	2	7	8	ave.[19]
a	39.9	51.3	60.8	53.2
b	67.2	66.0	47.8	58.5
c	35.7	87.4	43.8	51.8
d	34.4	90.8	90.1	62.9
e	26.1	105.1	36.0	46.8
ave.[19]	37.9	79.1	51.7	54.0

Stand 3

	3	9	10	ave.[19]
a	29.2	31.2	33.5	30.9
b	24.7	35.0	18.2	24.4
c	20.6	36.4	21.8	24.8
d	23.4	45.2	17.5	27.2
e	17.9	41.9	12.4	21.8
ave.[19]	23.2	37.5	19.7	25.7

cont.

[19] weighted average

TABLE 13 (continued)

Stand 4

	4	11	12	ave.[20]
a	31.0	33.5	37.7	34.0
b	38.2	42.9	44.0	41.6
c	47.4	53.4	54.1	51.5
d	54.4	77.1	66.2	66.1
e	77.7	81.6	81.9	80.4
f	63.9	78.8	42.2	63.4
g	71.3	68.0	68.8	69.4
ave.[20]	53.0	58.7	55.0	55.5

Stand 5

	13	14	15	ave.[20]
a	53.2	49.1	66.8	57.2
b	76.9	78.5	69.8	74.4
c	87.1	52.0	90.8	72.8
d	70.5	86.3	81.7	77.6
e	78.6	62.9	87.1	75.0
ave.[20]	73.4	62.0	78.2	71.3

Stand 6

	16	17	18	ave.[20]
a	35.0	28.4	69.9	34.6
b	34.7	28.8	142.3	48.9
c	43.5	39.7	102.1	58.1
d	50.7	54.6	151.6	68.9
e	46.3	65.9	152.4	75.2
ave.[20]	41.6	41.7	128.8	56.4

[20] weighted average

TABLE 14

Total stem-wood volume (m^3 ha^{-1}), black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.
a	141.9	169.1	145.8	152.3
b	86.2	161.0	61.1	102.8
c	119.7	168.2	79.6	122.5
d	128.0	143.6	75.2	115.6
e	55.0	70.6	59.8	61.8
ave.	106.2	142.5	84.3	111.0

Stand 2

	2	7	8	ave.
a	76.2	130.6	240.0	148.9
b	154.0	159.6	170.3	161.3
c	168.2	289.4	228.6	228.7
d	122.5	173.5	160.7	152.2
e	106.3	214.2	114.6	145.0
ave.	125.4	193.5	182.8	167.2

Stand 3

	3	9	10	ave.
a	163.8	131.3	106.5	133.9
b	125.6	129.1	118.4	124.4
c	94.6	101.9	94.2	96.9
d	104.2	143.9	73.4	107.2
e	104.9	138.7	56.8	100.1
ave.	118.6	129.0	89.9	112.5

cont.

TABLE 14 (continued)

Stand 4

	4	11	12	ave.
a	162.0	170.7	191.9	174.9
b	136.1	131.0	151.2	139.4
c	223.4	231.2	241.2	231.9
d	166.4	245.2	252.9	221.5
e	207.8	166.3	250.3	208.1
f	284.9	210.6	86.0	193.8
g	290.6	294.4	157.7	247.6
ave.	210.2	207.0	190.2	202.5

Stand 5

	13	14	15	ave.
a	155.8	156.4	263.5	191.9
b	215.3	209.8	266.7	230.6
c	243.9	231.8	265.9	247.2
d	251.4	131.8	239.2	207.5
e	310.4	288.1	299.3	299.3
ave.	235.4	203.6	266.9	235.3

Stand 6

	16	17	18	ave.
a	120.4	148.2	62.3	110.3
b	159.1	128.2	235.6	174.3
c	105.3	80.8	169.0	118.4
d	180.8	153.0	193.0	175.6
e	177.0	260.1	291.0	242.7
ave.	148.5	154.1	190.2	164.2

TABLE 15

Water table below forest floor (cm), black spruce stands, southeastern Manitoba

Stand 1

	1	5	6	ave.[21]
a	15	35	20	25
b	20	30	15	20
c	25	20	20	20
d	20	25	20	20
e	25	25	25	25
ave.[21]	20	25	20	25

Stand 2

	2	7	8	ave.[21]
a	>90	>50	>80	>75
b	60	>65	>70	>65
c	55	>75	55	>60
d	35	55	45	45
e	35	50	40	40
ave.[21]	>55	>60	>60	>55

Stand 3

	3	9	10	ave.[21]
a	20	40	40	35
b	20	25	30	25
c	25	20	40	30
d	30	20	35	30
e	20	20	35	25
ave.[21]	25	25	35	30

cont.

[21] Rounded off to the nearest 5 cm.

TABLE 15 (continued)

Stand 4

	4	11	12	ave.[22]
a	>80	100	95	>90
b	80	85	80	80
c	60	75	70	70
d	55	75	60	65
e	65	60	65	65
f	65	55	70	65
g	55	60	>50	>55
ave.[22]	>65	75	>70	>70

Stand 5

	13	14	15	ave.[22]
a	75	60	90	75
b	70	55	90	70
c	55	50	80	60
d	55	45	65	55
e	60	45	60	55
ave.[22]	65	50	75	60

Stand 6

	16	17	18	ave.[22]
a	>65	80	75	>75
b	40	55	50	50
c	25	50	45	40
d	30	40	40	35
e	25	35	40	35
ave.[22]	>40	50	50	>45

[22] Rounded off to the nearest 5 cm.

TABLE 16

Ages of trees sampled and ages of ditches (years)

	Stand						
	#1	#2	#3	#4	#5	#6	ave.
a	159	110	116	127	129	107	125
b	135	77	124	122	147	100	118
c	159	115	112	141	108	108	124
d	177	166	155	132	141	135	151
e	92	104	89	147	129	136	116
f	---	---	---	144	---	---	144
g	---	---	---	149	---	---	149
ave.	144	114	119	137	131	117	128
age of ditch[23]	50?	ca.45	11	32	40	16	

[23] in 1987

Appendix B

FORMULA TO CALCULATE THE PRESENT VALUE OF A STREAM OF BENEFITS OR COSTS WHICH ARE SPACED EVENLY OVER TIME AND ARE GROWING AT A CONSTANT RELATIVE RATE

The formula to calculate the present value of a number of regularly reoccurring benefits or costs which are growing at a steady relative rate is as follows:

$$PV = a \cdot \left[1 - \frac{(1+g)^{np}}{(1+d)^{np}} \right] \cdot \left[\frac{(1+g)^{p}}{(1+d)^{p} - (1+g)^{p}} \right]$$

- PV is the present value at year zero ($).
- a is the value of the benefit or cost at year zero ($).
- g is rate at which "a" is growing (% yr^{-1}).
- d is the discount rate (% yr^{-1}).
- p is the period of time between subsequent benefits or costs (years).
- n is the number of occurrences of the benefit or cost.

Note: The value of "a" at year zero is not included in the present value.

Appendix C

LIST OF ABBREVIATIONS AND SYMBOLS USED

α - net flow of economic values after drainage minus net flow of economic values before drainage
AAC - allowable annual cut
B - benefits
B-C - net benefits
B/C - benefit-cost ratio
C - costs
CAI - current annual increment
CSBs - Canada Savings Bonds
d - discount rate
D - diameter breast height
DBH - diameter breast height
E - elasticity
F - time period between subsequent maintenance treatments
FMU - Forest Management Unit
g - relative rate of growth of the stumpage value of the timber
GMV - gross merchantable volume
GTV - gross total volume
H - tree height
IDC - initial drainage costs
IRR - internal rate of return
M - maintenance costs
MAI - mean annual increment
n - number of harvests before drainage
N - number of harvests after drainage
NMV - net merchantable volume
NMVa - net merchantable volume of a harvest after drainage
NMVb - net merchantable volume of a harvest before drainage
NPVd - net present value of the drainage activity
P - parameter
PVB - present value of benefits
PVC - present value of costs
PVMC - present value of the maintenance costs
PVTa - present value of the timber after drainage
PVTb - present value of the timber before drainage
q - number of maintenance treatments
Ra - length of the rotation period after drainage
Rb - length of the rotation period before drainage
TSV - total stem-wood volume
V - stumpage value
yr - year