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UNIVERSITY OF ALBERTA

THE EFFECTS ON VOLUME AND VALUE OF ALTERNATIVE HARVEST REGIMES:

AN ALBERTA CASE STUDY

BY

DANIEL H. PETERSON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE ©

IN

FOREST ECONOMICS

DEPARTMENT OF RURAL ECONOMY

EDMONTON, ALBERTA

SPRING, 1991

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TITLE OF THESIS: THE EFFECTS ON VOLUME AND VALUE OF ALTERNATIVE HARVEST REGIMES: AN ALBERTA CASE STUDY

DEGREE: MASTER OF SCIENCE IN FOREST ECONOMICS

YEAR THIS DEGREE GRANTED: 1991

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SUBMITTED BY DANIEL H. PETERSON
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN FOREST ECONOMICS.

Dr. Micheal Percy

Luis Constantino

Dr. Luis Constantino

Dr. Jack Heidt

Date: February 8, 1991

DEDICATION

To my father, whose belief that the opportunity for a good education is the most precious gift we can pass on to our children.

To my wife, Jane, and daughter, Rebecca, what are you doing this weekend?

ABSTRACT

This thesis investigates the potential tradeoffs that timber supply policies create between flows of volume and value from the forest. Whereas the primary unit of investment for the forest manager is at the stand level, the primary planning unit is at the forest level. The almagamation of these two levels may not allow optimal stand investment to occur. A case study has been developed, and fourty-two yield tables derived, to estimate the benefits and costs of stand management by modifying the Tait model. The harvest scheduling model MUSYC was employed to evaluate four forest management regimes: unconstrained economic and biological maximization, and constrained economic and biological maximization. Deviations from the optimal stand treatment regime were noted and quantified. The effects on employment, by periodic harvest flow and silvicultural treatment, were quantified.

This research has shown that policies which espouse sustained yield and volume maximization are not without costs. Resource misallocations occur as a result of the allowable cut effect and minor model effects. A policy which incorporates economic maximization with sustained yield has been shown to minimize the allowable cut effect and provide a much greater return to the forest manager. The alteration of the forest level objective to economic maximization has also shown greater returns to employment.

AKNOWLEDGEMENTS

I wish to thank Dr. Mike Percy, Dr. Luis Constantino, and Dr. Jack Heidt for their advice and assistance as well as their undaunting optimism regarding the completion of this thesis. I am very grateful to Dr. Glenn Manning of Forestry Canada's Pacific Forestry Centre for affording me the opportunity to finish this project. I would also like to acknowledge family members and friends who went out of their way not to inquire about the defence date and my wife, who never stopped inquiring.

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1.0 INTRODUCTION

There is increasing concern that annual timber harvests for Canada as a whole and certainly for a number of regions will decline in the future. The potential decline in harvest arises from a variety of factors - the possible fall down in harvest volumes accompanying the shift from overmature timber stands to regrowth, lags in restocking harvested areas, and the loss of highly productive forest land to non-timber uses.

In all but the Prairie provinces, shortages of timber have been predicted. At this time, these shortages are most pronounced in British Columbia. Regional evidence for the Coast suggests that, at current harvesting rates, overmature timber will be liquidated in 5 to 20 years. Even today, second growth forests make up large portions of the allowable cut in some areas. As increasing pressure by interest groups forces land withdrawals from the productive forest landbase, the falldown in annual harvest will be immediate and devastating. Reed (1978) suggested that even a 10% reduction would eliminate calculated reserves. Elsewhere in Canada, combinations of insect infestations and overcutting to liquidate overmature forests will also result in timber falldowns. The spruce budworm problem in New Brunswick and Nova Scotia could very well lead to reductions in softwood allowable cuts of up to 70% in some areas (Reed, 1978). It is estimated that current infestations in Quebec degrade approximately 300 million cubic metres of softwood growing stock each year (Ibid). In Ontario, elevations of allowable harvest to liquidate areas of decadent timber will result in future falldowns as corresponding decreases to the allowable cut must be made once these areas have been harvested.

The reliance of Canada on its forest resource is well known. Canada possesses 16% of the world's softwood resource and 3% of the global hardwood resource (Forestry Canada, 1990). The forested landbase accounts for 10% of the world's total. Canada is the world's primary exporter of newsprint (59%), softwood lumber (40%), and wood pulp (36%). The contribution to the national economy of forestry is approximately 3.5% of gross domestic product. Forest products accounted for 17% of all Canadian exports, and contributed $20 billion dollars to the balance of trade in 1989; more than agriculture, fishing, mining, and energy combined. Approximately 7% of the country's labour force relies on the forest sector for employment. Most of this employment is situated in forestry-dependant communities, of which there were 348 in 1987.

The forest sector is, therefore, of vital regional importance. In British Columbia it is the economic base and certainly the mainstay of the Interior economy. Forestry accounts for 60% of provincial exports and contributed approximately $10 billion dollars to the balance of trade in 1989 (Forestry Canada, 1990).

In Alberta, 6% of provincial exports were made up of forest products and $683 million dollars was added to their balance of trade in 1989. Forestry accounted for only 1% of Alberta's GDP in 1989. Thus, the Alberta government has been actively seeking to diversify their economy by more intensively using and managing their forest resource. Recent announcements by Daishowa Ltd. in Peace River and the Alberta Pacific consortium in Athabasca show there to be an attempt by Alberta's government to aggressively support these industrial projects. Estimates for 1987 showed there to be provincial government involvement, at all levels, approaching $1.2 billion dollars (Anon., 1987).

The importance of the forest resource has led the provincial Crown's, particularly in Alberta, to actively manage their timber base. The high degree of economic intervention therefore reflects both the existence of Crown ownership and the reality of the sector's national and regional economic importance. These economic factors, combined with significant market failures related to the existence of non-timber values, have acted as a catalyst for government regulation of the forest industry.

As the forest industry in Alberta is still relatively young, provincial policies are geared to avoid the timber supply problems predicted for the rest of the country. The key element of Alberta forest management policy centres on the goal of ensuring a sustained yield from the forest landbase. This continuity of timber supply is directed towards preserving community stability and ensuring the continued existence of forest-dependant communities (Anon, 1985b). What is required, however, is an analysis of how best to forecast and arrive at this sustained yield. The rapid surge in forest sector investment will enhance the shift from overmature forests towards the normal forest. As this shift occurs, there must also be linkages between sustainability and profitability to maintain levels of industrial investment. Thus, how much should society invest and where should investments, in terms of sites and techniques, occur? How intensive should applications of labour and capital be to promote the forest stock and its harvest?

The annual allowable harvest determined by the Alberta government is based on forest level modeling. In this way, management policies and parameters can be met to ensure the greatest possible sustainable harvest (Anon, 1985b). The forest is, however, very large, maintaining a range of ecological diversity with differing site qualities and timber classes. Stands of timber which make up the forest are the primary unit of investment in forest management. Thus, while allowable harvests are determined on a forest wide basis, investment opportunities must be analyzed at the much smaller, stand level. The ability to amalgamate these two levels of management makes more complex the achievement of the sustained yield goal, especially in the context of optimization behavior. Optimizing behavior at the stand level may be inconsistent with the level of sustained yield desired by forest managers or a forested area encompassing the particular stand.

The focus of this thesis is to investigate the potential trade-off between a forest level policy of ensuring a sustained yield from the forest base and optimizing behavior at the stand level. This issue is examined in the context of a case study for a forested area in the province of Alberta. The data for the exercise derive forty-two yield tables for three site classes and a range of treatments from natural regeneration to a variety of intensive management regimes. Using these data and employing both biological and economic investment criteria for a choice of rotation ages, an assessment of the timber volume and income streams, for a representative forest, across sites and treatments will be made.

The optimal investment policy at the stand level may not, in most cases, be consistent with the sustained yield flow of timber from the forest base desired by policy makers. To assess this issue, the Multiple Use Sustained Yield Calculation (MUSYC, Johnson and Jones, 1980) model will be employed. This planning tool was designed to deal with timber harvesting schedules under a variety of constraints appropriate to forest level management and policy issues. Four separate harvesting regimes are examined and their implications for the flow of timber and revenues through time are assessed.

The first regime is unconstrained in terms of a sustained yield and the objective is to maximize the net present value of the forest base over a planning horizon of 250 years. The second regime is also free of constraints but the objective function is changed to maximize the volume from the land base. The third regime adopts the objectives, rotation ages, and even flow requirements similar to current Alberta allowable cut policies, again for 250 years. The fourth regime combines the objective of maximizing the net present value of the forest base with a harvest regime identical to regime three. Each of these regimes will also contain an additional scenario which evaluates the implications of investment into forest management via silvicultural opportunities. Differences among these regimes in terms of timber volume flows and net present values thus provide a basis for assessing the costs of forest level constraints. That is, what is the cost to society of more timber in terms of possible foregone revenue from the timber base? An additional contribution of this thesis is an effort to include possible employment effects of alternative forest management strategies, Here the focus is whether the employment consequences of various strategies differ significantly across regime/scenario combinations and whether these differences are important enough to provide some justification for choosing one regime over another.

The structure of the thesis proceeds as follows. Chapter Two provides an overview of forest management objectives in Alberta, particularly in regards to annual allowable cut determination, and outlines the example forest base characteristics for the case study of this thesis. This section also includes a detailed review of the stand level data and silvicultural investment possibilities for the case study. Chapter Three provides an overview of the issues related to investments at the stand level. The focus here is on the issue of rotation age and competing objective functions - biological vs. economic - in the choice of a rotation age. Calculations of timber volumes and net present values for differing treatment regimes across three site classes are provided to assess tradeoffs between economic and biological stand optimization criteria. Chapter Four assesses forest level optimization objectives and employs MUSYC to undertake the four regimes discussed earlier. The focus in this chapter is on the implications of differing forest management regimes for timber volumes and the value of the forest base for a 250 year planning horizon. The policy issues which arise here concern the tradeoffs between timber volume and value, and the potential differences in employment accompanying these scenarios. This chapter concludes with the nature of the apparent inconsistencies between stand optimization and forest level management objectives and the implications that this has for forest managers. Chapter Five provides a summary of significant results and the conclusions of this thesis.

2.0 AN ALBERTA EXAMPLE

Under provisions set out in the British North America Act, control of regional natural resources was given to the respective provinces. The government of Alberta is therefore responsible for the determination and approval of harvest levels on the lands under its control. Alberta maintains approximately 25.4 million hectares of productive forest land of which 89% is under the direct control of the provincial government. An estimated 20.5 million hectares of this area has been classed as fully stocked, nonreserved, forest land, retaining 2.6 billion cubic metres of timber volume (Forestry Canada, 1990).

2.1 Forest Management Objectives

The objective of forest management in Alberta is ensure that the benefits from the timber resource accrue to the people over the long term (Anon, 1985b). To achieve this, the government has deemed that sustained yield timber harvesting will optimally allocate the resource for maximum public benefit. Sustained yield implies managing a forest property for continuous production, with the goal of achieving an approximate balance of net growth and harvest (Davis, 1966). Thus, sustained yield is meant to: maintain stability in the timber industry and thus maintain community stability; provide maximum flexibility within reasonable parameters to take into account special management considerations and; maximize volume harvested in the existing forest subject to reasonable timber management principles (Anon, 1985b). In determining the sustained yield for an area, the Guidelines for the Establishment of Long Term Timber Supply Levels in Alberta (Anon, 1985b) are used. These guidelines identify the appropriate assumptions and requirements for accurately determining periodic harvest levels and will be used as the basis for the formulation of regime/scenarios later in this thesis.

The forest land in Alberta is divided into forest management units (FMU's) with each unit having an annual allowable cut determined through the aforementioned guidelines. To investigate the tradeoffs between forest and stand level management an example must be formulated. The following sections will outline the example forest used in this thesis and the alternative stand management investment possibilities.

2.2 The Area

The initial areas chosen to facilitate this research were forest management units E1 and R4, located southeast of Hinton, Alberta. These FMU's have been the focus of a previous study (Beck et. al.,1988) making the initial accumulation of inventory characteristics much easier. For the purpose of this study, two assumptions were made about the size and species content of these areas. First, the entire area is assumed to contain lodgepole pine (Pinus contorta var. latifolia). In actuality, the areas are more than 60% pine at the present time. This assumption was made in order to limit the requirement for a not as yet conceived managed stand model for an entire range of species and possible silvicultural treatment options. Appendix I contains the initial species, site, and area characteristics. The second assumption relates to the size of the areas. In order to examine a forest of a realistically operable size, the area contained in each age class was doubled. The following table displays the age class structure of the forest.

Table 1

Age Class Structure of the Present Forest

Age Class (decades)	Area ('000 ha)	Volume (MM m3)
0	-	-
1	12.294	-
2	2.638	-
3	29.656	-
4	3.560	-
5	15.280	-
6	2.902	0.013
7	25.308	1.996
8	12.524	1.812
9	148.144	27.610
10	12.130	2.799
11	67.462	18.984
12	4.878	1.796
13	6.592	2.410
14	0.660	0.281
15	-	-
16	0.132	0.064
17	0.132	0.069
18	-	-
19	-	-
20	-	-

2.3 Yield Table Generation

In order to examine changes in investment strategies, a prediction of how each stand will grow and respond to treatments must be made. The projection of timber growth is done using a stand based model. These types of models are primarily designed to reflect the characteristics of a single stand containing a homogeneous species. The majority of these models rely on the individual tree as the primary growth component. As such, stand based models are, for the most part, biological models which sum the effects of individual tree growth to project the conditions of a stand throughout its management cycle. The importance of selecting a model which can properly represent the species being examined is obvious. The model chosen to simulate lodgepole pine growth for this research is the Tait model (Tait et.al., 1988).

Tait and Jahraus(1988) reported on a general model to display the stand dynamics of six species of conifers. Varying only through specific parameters, the model's basic structure was the same for all species. The conifers examine were: Douglas-fir(*Pseudotsuga menziesii*), lodgepole pine, Western hemlock(*Tsuga heterophylla*), white spruce(*Picea glauca*), red pine(*Pinus resinosa*), and jack pine(*Pinus banksiana*). For the purpose of this research, the following will concentrate on the model as it pertains to lodgepole pine.

The model, applied to Alberta lodgepole pine by Tait et.al.(1988), is based on hypotheses relating tree growth as a function of tree size and density as well as mortality being a function of tree growth and density. The resultant model structure represents variable-density, variable-site yield equations. The first equation reflects the site-determined growth potential of the species; the second equation reflects the reduction in growth that results from stand crowding; and the third equation reflects a density-independent mortality rate(Tait and Jahraus, 1988). The equations are:

1. $V_{t+1} = V_t + \left(\frac{a2 \cdot as \cdot Vt\hat{}2/3}{a_2 + V_t\hat{}2/3 \cdot d_t} \right) - a_3 \cdot V_t$

2. $d_{t+1} = d_t(1 - a_4(V_{t+1}^{2/3} - V_t^{2/3})d_t) - a_5)$

3. $a_s = a_1 \cdot PI + a_6$

where: V_t = the volume at time t of the average tree (m^3)

d_t = the density at time t (stems/ha.)

$V_t^{2/3}$ = the tree area index eg. a tree having $1m^3$ has an index of $1m^2$

a_2 = the level of crowding that will reduce the potential anabolic gain by 50%

a_3 = the species specific catabolic loss rate (m^3/m^3)

a_4 = the density-dependant mortality rate per unit index of stand growth

a_5 = the density-independant mortality rate per year

a_s = the maximum growth rate per unit of tree area index

a_1 & a_6 = the coefficients of a linear relationship between the measure of site quality(PI) as developed by Johnstone(1976a) and anabolic potential

Tait et.al.(1988) provide the following parameter estimates: a_1 = 0.0453, a_2 = 541, a_3 = 0.0106, a_4 = 0.00103, a_5 = 0.00612, a_6 = -0.00861. Johnstone's productivity index(1976) provides the basis for site quality in the model. PI is a ratio of the observed top height over a standard top height as calculated by a density-dependant height equation for Alberta lodgepole pine. A stand on an average site would therefore retain a PI of 1.0. The model was calibrated using permanent sample plot data and compared favorably to the unmanaged stand yield tables produced by the Alberta Forest Service(Anon, 1985a).

In order to examine its predictive capabilities, when silvicultural treatments occur, the model was used to project the effects of a thinning. Tait, et.al.(1988) compared Johnstone's(1982a and b) research into thinning lodgepole pine with results obtained from their model. Over Johnstone's 22 year study period, the model predicted an almost identical volume but had predicted 30% fewer trees. The stocking difference is a result of the model using a higher rate of mortality than what would normally occur in the widely spaced, more vigorous trees left behind after a thinning. In estimating growth response due to thinning an adjustment, based on treatment intensity, should therefore be made to the model's mortality parameters.

2.4 Silvicultural Treatments

The forest, being a biological entity, allows for man to enhance its desired attributes over and above those which would occur naturally. These attributes, inclusive of merchantable volume, wood quality, site quality, and rotation age, can be manipulated through intensively managing stands with treatments such as thinning and fertilization. As well as a beneficial biological response, intensive management can provide for a beneficial economic response. Shorter time periods are required for trees to attain a certain diameter. As well, harvest and mill costs are reduced by the larger and more homogenous logs.

2.4.1 Thinning

The incorporation of thinning response into the Tait model was tempered by studies performed by Johnstone(1981a, 1981b, 1982a, 1983). Johnstone's research covers a large proportion of the characteristics most influencing the development of lodgepole pine once thinning has occurred; height, diameter, and volume. The initial age of stands in his studies ranged from 7 to 75 years. As well as a complete range of site classes, these treatments also covered a spectrum of thinning intensities.

Two inputs are required to initiate the Tait model, stem density and tree volume. These post thinning inventory values were obtained from

Johnstone's research so as to better represent the site class/intensity interaction. For this thesis, three possible thinning regimes on each of three site classes were simulated: 1.5 x 1.5m, 2.5 x 2.5m, and 3.5 x 3.5m spacing on each of good, medium, and poor sites. Thinnings were assumed to have occurred within the second decade of establishment, giving the stand ample time to recoup any lost volume while allowing the best possible individual tree response.

Since thinning reduces the mortality of the remaining stand, the Tait model's mortality values need to be examined. As was previously alluded to, these values may be too high if a thinning is to be simulated early in the stand's development. They therefore need to be reduced to reflect the increase in overall stand vigor and additional growing space which occurs following a treatment. Once a thinning has occurred, each spacing level will retain a lower mortality rate than a stand which has not been treated. Instead of the 6% used by Tait et. al.(1988) for unmanaged stands, stands spaced to 1.5m were given a mortality rate of 4%. Mortality rates of 3% were used for 2.5m, and 2% for 3.5m spacings.

2.4.2 Fertilization

The ability of lodgepole pine to adapt to extreme sites has led to the belief that, on these sites, many trees are nutritionally deficient(Weetman et.al., 1985). It is therefore suggested that fertilization of these lower quality areas will substantially increase the productive capacities of lodgepole pine and in turn create merchantable timber where there would otherwise be none of consequence.

Since the result of fertilization is an increase in site productivity for approximately 15 years (Yang 1985a, 1985b), Johnstone's productivity index was augmented for this amount of time within the Tait model. Poor, medium, and good sites retained PI's of 0.8, 1.0, and 1.2, respectively(Johnstone, 1976). Once fertilization occurs, the PI will increase to 1.0, 1.2, and 1.4 for these same sites. Fertilization was simulated immediately following a thinning and at 50 years of age for thinned stands. As well, the fertilization of a stand which has not been thinned was simulated once the stands had reached 60 years of age on good sites, 70 on medium sites and at 80 years of age on poor sites. Stands on poor sites were not fertilized until 80 years due to the retention of large numbers of stems and relatively small volumes up to this point in time. Unmanaged stands were not fertilized at earlier ages due to the effects of mortality as noted by Yang(1985a, 1985b).

2.5 Reforestation after Harvest

The regeneration of cutover areas once a harvest has occurred is provided for within Alberta's Timber Management Regulations. All areas must be adequately reforested within 10 years of the final harvest. This reforestation may be natural or assisted by man as in the case of planting. In either case, the area will require some form of scarification to expose the required mineral soil for an adequate seed or seedling bed. In keeping with Alberta allowable cut regulations it is assumed that future regenerated stands will be fully stocked.

2.6 Volume Estimation

Simulation of the various treatmental regimes was done through adapting the Tait model to a Lotus 1-2-3 application. A total of 42 yield tables were simulated, representing the three site classes and their respective treatments as well as the unmanaged stands.

As the determination of merchantable volume is not specifically addressed by the Tait model, relationships were developed based on 15/10 utilization standards, as set out by the Alberta Forest Service(AFS). That is, trees with a minimum 15cm stump and a 10cm top are considered merchantable.

Initially two equations, based on the 41 observations present in the AFS yield tables for unmanaged stands (Anon, 1985a), were estimated. As it was determined that site type had greatly influenced the equations, attention was turned to estimating the merchantable volume and stems for each site type. The intercept for each equation was forced through the origin. In order to generate a more practical equation the dependent variables used were ratios of the merchantable and gross volume and stem estimates. The ratio can then be multiplied by the gross estimates.

The equations approximated for each site type are as follows, numbers in brackets are the associated t-statistics:

Volume Equations

Good Site

$$(1)\quad VR = \underset{(-19.31)}{-3.0261\text{x}10^{-4}(ST)} - \underset{(-1.67)}{2.4899\text{x}10^{-4}(VSQ)} + \underset{(28.59)}{0.0973(LVS)}$$

where: VR = the calculated merchantable to gross volume ratio
ST = gross number of stems
VSQ = the square of gross volume
LVS = natural log of gross volume times gross stems

Medium Site

$$(2)\quad VR = \underset{(-58.34)}{-2.3502\text{x}10^{-4}(ST)} + \underset{(13.398)}{8.8167\text{x}10^{-7}(VSQ)} + \underset{(73.95)}{0.0790(LVS)}$$

Low Site

$$\text{(3)}\quad VR = \underset{(-81.81)}{-2.1010\times10^{-4}(ST)} + \underset{(19.638)}{1.6126\times10^{-6}(VSQ)} + \underset{(82.06)}{0.0708(LVS)}$$

Stem Equations

Good Site

$$\text{(4)}\quad SR = \underset{(-17.11)}{-2.7466\times10^{-4}(ST)} + \underset{(2.71)}{7.0745\times10^{-4}(AGE)} + \underset{(20.96)}{0.0754(LVS)}$$

where: SR = the calculated merchantable to gross stem ratio
ST = gross number of stems
AGE = age of the stand
LVS = natural log of gross volume times gross stems

Medium Site

$$\text{(5)}\quad SR = \underset{(-12.59)}{-1.9239\times10^{-4}(ST)} + \underset{(6.47)}{1.8927\times10^{-3}(AGE)} + \underset{(11.88)}{0.0525(LVS)}$$

Low Site

$$\text{(6)}\quad SR = \underset{(-9.86)}{-1.0194\times10^{-4}(ST)} + \underset{(11.72)}{2.6755\times10^{-3}(AGE)} + \underset{(5.30)}{0.0211(LVS)}$$

Once the merchantable volume and number of merchantable stems were estimated for each year, the quadratic mean diameter of the stand was determined by using equations provided in the AFS yield tables for unmanaged stands(Anon, 1985a). Values were then placed in tabular form to arrive at the yield tables used in this research (see Appendix II).

2.7 Harvesting Costs

The equations estimated by Beck et.al.(1988) for tree to truck and truck to mill costs are to be used in this research. Their woodlands cost, defined as the sum of: the woodlands overhead, tree to truck, and camp costs; was approximated with the following:

$$\text{(7)}\qquad WC = 8.9465 - 2.6288(LNLOG)$$

where: WC = woodlands cost
LNLOG = the natural log of tree volume

Costs governing the truck to mill phase are primarily a function of the haul distance. The estimate developed by Beck et.al. is:

(8) $TM = 0.7616 + 0.03795(HD) + 65.7272(ISD)$

where: TM = truck to mill cost
HD = haul distance
ISD = inverse of the utilization stump diameter

Truck to mill costs were defined as consisting of haul cost, road maintenance, logyard cost, and scaling cost. For the purposes of this research a constant haul distance of seventy-five kilometers was used.

As a proxy for the estimation of processing costs, values associated with a 1987 aggregation by the Alberta Forest Products Association (A.F.P.A.) and the AFS was used. Based on a pulp recovery factor of 0.1786 ADMT = $1m^3$ of greenwood, the 1987 costs of production($/ADMT) were $506.20 or $\$90.41/m^3$. Production cost was assumed to include all associated costs of production including: labour, energy, delivered wood cost, administration, and supplies. By using this cost and assuming that the values generated by the equations from Beck et. al. are representative of Alberta woodlands and truck to mill costs, an average delivered wood cost can be determined from the unmanaged stands and subtracted from the aggregate cost such that any decrease in cost accruing to silvicultural treatments can be explicitly viewed and documented.

2.8 Harvest Values

In order to correspond to the costs of harvesting, 1987 prices for bleached kraft pulp were used in this study. These prices, as were the costs, were taken from aggregations made by the A.F.P.A. and the AFS. The gross price in 1987 dollars was $767.00/ADMT or $\$137.00/m^3$.

2.9 Treatment Costs

2.9.1 Thinning

The cost for thinning is based upon quoted contract bids, as received by the AFS(McCullough, per comm, 1988). Thinning a 20 to 30 year old stand to an approximate spacing of 2.5 x 2.5m cost $600.00/ha. in 1987. This figure has been, for the most part, independent of either site type or initial density. To account for differing intensities of treatment, the base amount of $600.00 is assumed to vary by +/- $50.00/ha., given 3.5 or 1.5m spacing, respectively. This will allow for an examination into the cost of, versus the response to, treatmental regimes.

2.9.2 Fertilization

The assessment of cost for an application of fertilizer varies not only with the type of fertilizer used but with the method of application as well. As such, average values were used to represent a cross-section of possible treatments. The B.C. Ministry of Forests and Lands Annual Report for 1986-87 and 1987-88 suggests that the average cost of fertilization, based on on-site operating cost inclusive of equipment, transportation, and wages, over the entire province was approximately $190.00/ha. and $170.00/ha. respectively. Costs of application in the Prince George region were almost equal to the B.C. provincial averages. It will be assumed in this research that the values given by the two B.C. Annual Reports are more representative of the actual cost of an industrial application of fertilizer. The cost of fertilization used here was $180.00/ha., so as to account for the apparent decrease in average cost from 1986-87 to 1987-88.

2.9.3 Reforestation after Harvest

Site preparation for the purpose of natural restocking cost. was on average, $180.00/ha. in 1987 (Annual Report, B.C. MoF, 1988). Site preparation for planting was valued at $295.00/ha.(Ibid). The average cost for planting, excluding the cost of seedlings, was $360.00/ha.(Ibid). Assuming an average cost for seedling production of 20 cents per tree, and a target establishment level of 1600 trees/ha. (2.5 x 2.5m spacing), the total average cost for planting is approximately $975.00/ha..

3.0 STAND LEVEL OPTIMIZATION

The previous chapter established the biological and economic costs and benefits associated with managing individual stands. Once these estimates have been made, an examination of optimal stand management can occur. This chapter will focus on the issues surrounding stand level investments under competing biological and economic objectives and the tradeoffs between these objectives.

3.1 Biological Stand Investments

The Alberta guidelines for establishing long term timber supply levels requires that the objective of forest management be to maximize the volume harvested from an area (Anon, 1985b). In managing a forest for volume production, the biological characteristics of individual stands are of primary importance to the investor.

The yardstick with which to measure returns to biological investments focuses on the growth of the stand. The investment, which is optimal, then generates the greatest biological return, as measured by the increase in stand growth relative to the no investment case. To evaluate the biological returns of stand volume growth, mean annual increment (MAI) is used. MAI is define as the average annual increase, to any age, of the stand's volume. It is determined by dividing the cumulative volume of the stand by the stand's age.

$$MAI = \frac{Va}{a} \tag{9}$$

where: MAI = mean annual increment
Va = volume at current age a
a = current age of the stand

The age at which MAI is at its maximum level then becomes synonymous with the optimal biological rotation age. Timber harvests occurring at this age, ad infinitum, would generate the greatest possible volume from the stand. Thus, a policy of volume maximization implies that harvests would occur at the maximum MAI age.

3.2 Economic Stand Investments

The forest is a source of revenue as firms competitively vie for harvesting rights and niches in the market place. Their goal being to maximize profit, firms are concerned with determining the age at which to harvest individual stands. The forest is also a source of revenue for the provincial government. Being the owner of the resource, the government charges the firm rent, in the form of stumpage, for the rights to harvest the timber.

Faustmann(1849) was the first to arrive at the solution to the optimal economic rotation age. In dealing with the continuous harvest of even-aged stands, the solution rests in choosing an age which equates the rate of value growth of the stand with the opportunity costs associated with retaining the standing timber and the land itself. Thus, the forest manager will continue to grow the crop as long as its' increment in value exceeds its' increment in costs (Pearse, 1990). Pearse(1967) and Samuelson(1976) provide excellent interpretations of the Faustmann formulation.

Presented with land suitable only for growing timber and costs and values which remain constant through time, the forest manager must determine the value of future harvests. This value can be determined through an infinite series of continual harvests. The result is commonly referred to as the soil expectation value (SEV) and is represented by the following.

$$\text{(10)} \qquad SEV = \frac{Rj(1+i)^{(r-tj)} - Cj(1+i)^{(r-tj)}}{((1+i)^{r})-1}$$

where: SEV = soil expectation value
Rj = revenue received at time j
Cj = costs occurring at time j
r = rotation age
tj = number of years until the cost or revenue will occur
i = the discount rate

Therefore, the optimal economic rotation is the age which generates the greatest SEV. The length of the optimal economic rotation is influenced by a variety of factors including: site characteristics, harvest costs, product values, property taxes, and interest rates. With the exception of the discount rate, all other influences have been either addressed or assumed away.

3.2.1 Discount Rates

The choice of whether to consume today or wait for a future period is embedded in the preference society has towards present consumption. Given any positive discount rate, a cost is associated with foregoing consumption today. As such, there must be growth in the value of an asset in order for a rational investor to wait until tomorrow to liquidate it. This growth must then be discounted to the present for determination of which investment alternatives generate the largest returns. The use of a positive discount rate is a controversial issue in forestry. Even when there is agreement that future incomes must be discounted, the choice of an appropriate rate to evaluate investment decisions is a difficult matter and has been widely argued. Different opinions lie in the quantification of benefits which are to be derived from the forest, social or private, and within this, the source of funds which must be expended to derive these benefits.

Only under the guise of perfect competition will the market rate of interest allocate resources with complete efficiency. In such a scenario, social and private benefits and costs converge. This situation is, however, based solely in theory, as the assumptions qualifying a perfectly competitive market require complete certainty of future events; no externalities to confound the attainment of a market equilibrium; equivalent lending and borrowing costs; no barriers to entry or exit from the market place; and no economies of scale. As such, there is a divergence between social and private discount rates.

Given that the objectives of government are related to the maximization of social benefit and not profit, the use of a market rate of interest does not suffice (Manning, 1977). This makes the choice of an appropriate discount rate much more difficult. Some other rate should be utilized for evaluations but the guidelines regarding the derivation of this rate are somewhat open.

The approach for determining a suitable social discount rate deals with the preference society has for consumption today versus consumption tomorrow. The primary argument is that reliance on market interest rates leads to an inefficient intertemporal allocation of resources. Generations historically prefer consuming today in lieu of the future populus. This view leads to long term projects being discounted too heavily, thereby eliminating any socially desirable investments which provide returns far into the future (Manning, 1977).

Percy(1986) and Heaps and Pratt(1989) argue that forestry investments should be evaluated using a social, rather than a market, discount rate because of the length of time involved before realization. This is due in part to the intergenerational issues involved in sustainable development. Higher discount rates value short term investments not normally associated with forestry projects. Increased levels of timber production and neglect of intensive forestry practices would result from these higher rates (Percy, 1986).

Heaps and Pratt(1989) present a rationale behind the choice of a social discount rate for silvicultural investments. They demonstrate that using discount rates of 8 - 10% will lead to an undervaluation of the net social benefits of long term forestry investments. Recommending a rate between 3 and 5%, they suggest that allowing forest managers to deviate from a set harvest age would alleviate much of the risk associated with silvicultural investments. This would allow the discount rate to be reduced by an amount normally included as a risk premium. Their rate is therefore a riskless rate. The real discount rate used for the evaluations made in this research was 4%[1].

3.3 Biological vs. Economic Rotations

Given the same tract of forest land, the use of either biological or economic criteria will usually result in different rotation ages. Which criteria will result in the shortest rotation is extremely dependant on the stand and economic characteristics used in the analysis. Heaps (1984) cites Goundrey (1960) who determines the optimal economic

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[1] The British Columbia Ministry of Forests uses a real discount rate of 4% for economic forestry analysis(Source: Industry Development and Marketing Branch, MoF, Victoria.).

rotation for coniferous stands in Quebec as being 52 years. The optimal biological rotation age for those same stands was 80 years. Heaps (1984) examined rotation ages for stands of Douglas fir in British Columbia. Volume based rotations resulted in significant economic losses on good quality sites. Economic rotations on medium and poor sites, however, were not significantly shorter. He also found that silvicultural treatments would serve to alter both biological and economic rotation ages. The timing and intensity of treatments were the determining factors in the magnitude of the shift. Duke et. al (1989) found economic rotations to be longer than biological rotations in all but the heaviest thinning treatments for a poor site in coastal B.C. They concluded that optimal economic and biological rotations can increase or decrease by 10 to 20 years, depending on the type and intensity of treatment. Nawitka Resource Consultants performed a study on the impact of intensive forestry on stand values in B.C. (1987). Thinning Interior stands, where the usual alternative would be a long rotation, slow growing stand, was found to shorten economic rotations. Fertilization treatments were also found to shorten economic rotations but they concluded that more information was required before this practice should be used intensively.

When examining the implications of each criteria one must remember that biological rotations do not account for any of the costs associated with producing timber. This is equivalent to saying that the discount rate is equal to zero and implies that there is no cost to holding the forest capital for an additional year.

3.4 Optimal Rotation Ages and Values

The age at which to harvest an individual stand has centered around two criteria. The biological criteria, as measured by maximum mean annual increment, and the economic criteria, as measured by maximum soil expectation value. The following tables provide a summary of the rotation ages associated with each of the treatment regimes, on each site type, for both the economic and biological criteria. The optimal rotation ages for the case study forest were determined through equations (9) and (10).

Table 2

Summary of Optimal Rotation Ages
for Biological and Economic Criteria
on Good Sites

Treatment Type	Biological (yrs)	Economic (yrs)
Unmanaged Stand	120	70
Unmanaged Fertilize at age 60	110	70
Thin to 1.5 metre spacing	120	60
Thin to 2.5m spacing	120	60
Thin to 3.5m spacing	140	60
Thin to 1.5m Fertilize at age 20	110	60
Thin to 2.5m Fertilize at age 20	110	50
Thin to 3.5m Fertilize at age 20	130	60
Thin to 1.5m Fertilize at age 50	110	70
Thin to 2.5m Fertilize at age 50	110	60
Thin to 3.5m Fertilize at age 50	130	70
Plant to 2.5m spacing	110	60
Plant and Fertilize at age 20	100	60
Plant and Fertilize at age 50	100	60

Table 3

Summary of Optimal Rotation Ages for Biological and Economic Criteria on Medium Sites

Treatment Type	Biological (yrs)	Economic (yrs)
Unmanaged Stand	170	80
Unmanaged Fertilize at age 70	160	80
Thin to 1.5 metre spacing	150	70
Thin to 2.5m spacing	160	60
Thin to 3.5m spacing	180	70
Thin to 1.5m Fertilize at age 20	140	60
Thin to 2.5m Fertilize at age 20	150	60
Thin to 3.5m Fertilize at age 20	170	70
Thin to 1.5m Fertilize at age 50	140	70
Thin to 2.5m Fertilize at age 50	150	70
Thin to 3.5m Fertilize at age 50	170	70
Plant to 2.5m spacing	160	70
Plant and Fertilize at age 20	160	70
Plant and Fertilize at age 50	150	70

Table 4

Summary of Optimal Rotation Ages for Biological and Economic Criteria on Poor Sites

Treatment Type	Biological (yrs)	Economic (yrs)
Unmanaged Stand	180	100
Unmanaged Fertilize at age 80	160	100
Thin to 1.5 metre spacing	170	80
Thin to 2.5m spacing	180	80
Thin to 3.5m spacing	180	90
Thin to 1.5m Fertilize at age 20	170	70
Thin to 2.5m Fertilize at age 20	180	80
Thin to 3.5m Fertilize at age 20	180	80
Thin to 1.5m Fertilize at age 50	160	70
Thin to 2.5m Fertilize at age 50	180	80
Thin to 3.5m Fertilize at age 50	180	80
Plant to 2.5m spacing	180	80
Plant and Fertilize at age 20	180	80
Plant and Fertilize at age 50	170	70

As can be seen from the preceeding tables, as site quality becomes progressively worse, both the optimal biological and the economic rotation age become longer. In comparing the two types of rotations, the economic rotation age is approximately half that of the biological rotation age. Treatments have generally decreased both types of optimal rotations when compared to the unmanaged stand.

What is required, however, is to examine what the associated values of each of the treatments are at the optimal rotation ages. In this way the optimal treatment can be identified for the forest manager. Tables 5, 6, and 7 display the mean annual increment values associated with the previously shown optimal rotation age. Tables 8, 9, and 10 show the optimal soil expectation values for each of the previously shown optimal rotation ages.

Table 5

Summary of Mean Annual Increments for Optimal Biological and Economic Rotation Ages on Good Sites

Treatment Type	Biological (m3/ha/yr)	Economic (m3/ha/yr)
Unmanaged Stand	3.44	2.52
Unmanaged Fertilize at age 60	3.59	2.66
Thin to 1.5 metre spacing	3.69	2.46
Thin to 2.5m spacing	3.75	2.81
Thin to 3.5m spacing	3.38	2.03
Thin to 1.5m Fertilize at age 20	3.80	2.78
Thin to 2.5m Fertilize at age 20	3.87	2.66
Thin to 3.5m Fertilize at age 20	3.47	2.31
Thin to 1.5m Fertilize at age 50	3.83	3.29
Thin to 2.5m Fertilize at age 50	3.90	2.96
Thin to 3.5m Fertilize at age 50	3.49	2.74
Plant to 2.5m spacing	3.69	2.69
Plant and Fertilize at age 20	3.82	3.01
Plant and Fertilize at age 50	3.85	2.84

Table 6

Summary of Mean Annual Increments for Optimal Biological and Economic Rotation Ages on Medium Sites

Treatment Type	Biological (m3/ha/yr)	Economic (m3/ha/yr)
Unmanaged Stand	3.16	1.71
Unmanaged Fertilize at age 70	3.28	1.84
Thin to 1.5 metre spacing	2.79	1.84
Thin to 2.5m spacing	2.67	1.54
Thin to 3.5m spacing	2.38	1.22
Thin to 1.5m Fertilize at age 20	2.87	1.74
Thin to 2.5m Fertilize at age 20	2.75	1.79
Thin to 3.5m Fertilize at age 20	2.45	1.40
Thin to 1.5m Fertilize at age 50	2.90	2.14
Thin to 2.5m Fertilize at age 50	2.77	2.09
Thin to 3.5m Fertilize at age 50	2.46	1.43
Plant to 2.5m spacing	2.57	1.67
Plant and Fertilize at age 20	2.64	1.88
Plant and Fertilize at age 50	2.66	1.93

Table 7

Summary of Mean Annual Increments for Optimal Biological and Economic Rotation Ages on Poor Sites

Treatment Type	Biological (m3/ha/yr)	Economic (m3/ha/yr)
Unmanaged Stand	1.40	0.92
Unmanaged Fertilize at age 80	1.48	1.12
Thin to 1.5 metre spacing	1.64	0.96
Thin to 2.5m spacing	1.40	0.71
Thin to 3.5m spacing	1.29	0.71
Thin to 1.5m Fertilize at age 20	1.69	0.94
Thin to 2.5m Fertilize at age 20	1.46	0.84
Thin to 3.5m Fertilize at age 20	1.26	0.60
Thin to 1.5m Fertilize at age 50	1.71	0.98
Thin to 2.5m Fertilize at age 50	1.47	0.86
Thin to 3.5m Fertilize at age 50	1.28	0.63
Plant to 2.5m spacing	1.47	0.92
Plant and Fertilize at age 20	1.52	1.06
Plant and Fertilize at age 50	1.53	0.97

Table 8

Summary of Soil Expectation Values for Optimal Biological and Economic Rotation Ages on Good Sites

Treatment Type	Biological ($/ha)	Economic ($/ha)
Unmanaged Stand	31.11	422.82
Unmanaged Fertilize at age 60	99.49	440.58
Thin to 1.5 metre spacing	-205.43	293.49
Thin to 2.5m spacing	-219.32	424.21
Thin to 3.5m spacing	-360.90	145.16
Thin to 1.5m Fertilize at age 20	-201.36	308.88
Thin to 2.5m Fertilize at age 20	-210.49	453.86
Thin to 3.5m Fertilize at age 20	-397.02	149.13
Thin to 1.5m Fertilize at age 50	-140.93	324.62
Thin to 2.5m Fertilize at age 50	-149.98	448.59
Thin to 3.5m Fertilize at age 50	-338.78	181.70
Plant to 2.5m spacing	-671.86	-201.70
Plant and Fertilize at age 20	-639.95	-182.06
Plant and Fertilize at age 50	-577.50	-177.44

Table 9

Summary of Soil Expectation Values for Optimal Biological and Economic Rotation Ages on Medium Sites

Treatment Type	Biological ($/ha)	Economic ($/ha)
Unmanaged Stand	-140.89	126.31
Unmanaged Fertilize at age 70	-135.12	139.41
Thin to 1.5 metre spacing	-365.08	- 21.29
Thin to 2.5m spacing	-407.10	- 22.88
Thin to 3.5m spacing	-454.82	-204.60
Thin to 1.5m Fertilize at age 20	-420.25	- 34.23
Thin to 2.5m Fertilize at age 20	-469.78	- 32.11
Thin to 3.5m Fertilize at age 20	-527.60	-245.92
Thin to 1.5m Fertilize at age 50	-362.26	30.16
Thin to 2.5m Fertilize at age 50	-412.22	4.57
Thin to 3.5m Fertilize at age 50	-470.52	-174.72
Plant to 2.5m spacing	-931.16	-632.21
Plant and Fertilize at age 20	-1012.04	-663.82
Plant and Fertilize at age 50	-937.74	-589.22

Table 10

Summary of Soil Expectation Values for Optimal Biological and Economic Rotation Ages on Poor Sites

Treatment Type	Biological ($/ha)	Economic ($/ha)
Unmanaged Stand	-168.12	- 90.64
Unmanaged Fertilize at age 80	-163.44	- 76.46
Thin to 1.5 metre spacing	-411.47	-277.74
Thin to 2.5m spacing	-441.64	-347.39
Thin to 3.5m spacing	-460.99	-365.83
Thin to 1.5m Fertilize at age 20	-492.99	-330.20
Thin to 2.5m Fertilize at age 20	-636.76	-493.71
Thin to 3.5m Fertilize at age 20	-547.83	-474.22
Thin to 1.5m Fertilize at age 50	-428.04	-257.99
Thin to 2.5m Fertilize at age 50	-441.04	-314.78
Thin to 3.5m Fertilize at age 50	-490.81	-408.70
Plant to 2.5m spacing	-962.68	-850.96
Plant and Fertilize at age 20	-1044.39	-908.74
Plant and Fertilize at age 50	-982.44	-839.39

Depending on the forest manager's goal, the following treatments would be prescribed for each site type. For volume maximization on good sites, each stand would be naturally regenerated and thinned to a 2.5 metre spacing at age 20, then fertilized at age 50. Rotations would then occur every 110 years and the soil expectation value(SEV) would be $-149.98 per hectare. For value maximization, each stand would be thinned to a 2.5 metre spacing and fertilized at age 20. Rotations would occur every 50 years and the SEV would be $453.86 per hectare. The opportunity cost of biological stand management would therefore be $603.84 per hectare in this case.

For volume maximization on medium sites, each stand would be naturally regenerated and then fertilized at age 70. The rotation age would be 160 years and the SEV would be $-135.12 per hectare. For value maximization the treatment is identical to volume maximization.

Rotations, however, would occur every 80 years, leading to a SEV of $139.41 per hectare. The difference in SEV can therefore be attributed to discounting, leading to an opportunity cost of $274.53 per hectare when stands are managed according to biological criteria.

For volume maximization on poor sites, each stand would be naturally regenerated and thinned to a 1.5 metre spacing at age 20, then fertilized at age 50. Rotations would occur every 160 years and the SEV would be $-428.04. For value maximization, the least cost treatment would be to naturally regenerate the stand and fertilize at age 80. Rotations would occur every 100 years and the SEV would be $-76.46 per hectare. As there are no positive values associated with managing the poor site types, these areas would not be included within the economic landbase. The opportunity cost of managing these areas with biological criteria is $428.04 per hectare. As no positive returns are generated, there would also be an opportunity cost to managing these areas based on economic criteria. The cost is $76.46 per hectare.

In the absence of constraints, the allocation of resources to forest management would occur at the stand level. That is, the merits of managing each homogenous forest grouping would be examined individually, optimal treatments identified, and investment would occur. However, while management concerns may focus at the stand level, overall planning functions occur at the forest level. The result being that treatment regimens specified for the stand level may not be optimal once movement is made to the forest level. The constraints imposed on forest level management by forest modeling techniques and provincial regulation may alter the mix of stand treatments, leading to inefficiencies.

The next chapter will assess forest level optimization objectives and employ MUSYC to evaluate four regime/scenario combinations. The inconsistencies between stand and forest level optimization arising out of policy issues are examined to demonstrate the implications for forest managers.

4.0 FOREST LEVEL OPTIMIZATION

This chapter will assess the apparent inconsistencies between optimization at the stand level, as identified in the previous chapter, and forest level management concerns. By employing the MUSYC model across a range of forest management regimes and investment alternatives, tradeoffs between volume and value can be investigated.

Upon review of the MUSYC model, constraints to the integration of the stand into the forest level modeling are examined. The forest management regimes identified earlier are expanded upon and the results of these regimes are summarized and discussed. Policy constraints on the optimal forest level solution are then explored and the costs of these policies are estimated. The implications for forest managers, for long term planning and profitability are then investigated.

4.1 Forest Level Modeling

To facilitate forest management decisions, a tool is required that can accommodate alternative forest management and policy parameters. The provincial government requires that a planning model which optimizes volume flows subject to management and policy constraints must be used (Anon, 1985b). The forest level analysis model is, therefore, of primary importance, as it is used to perform a form of volume control while including chosen aspects of management and policy. These types of models are intended to facilitate an examination into the large number of uses the forest maintains and are solved using mathematical techniques such as linear programming (LP). Thus, the ability to maximize or minimize desired forest traits is possible.

The usefulness of LP as it relates to harvest scheduling became apparent in the sixties as several authors began using this technique for forest management interpretations (Curtis, 1962; Loucks, 1964). The optimization of present net worth in conjunction with forest rotations was investigated by Nautiyal and Pearse(1967). The requirement by managers for a more inclusive LP model led to the development of Timber RAM(Navon, 1971), and its successor, MUSYC(Johnson and Jones, 1980).

4.1.1 Multiple Use Sustained Yield Calculation (MUSYC)

The forest level planning model selected for use in this research was the Multiple Use Sustained Yield Calculation (MUSYC) model. MUSYC was developed for the United States Forest Service to address several of the deficiencies in Timber RAM. Aside from the inclusion of Model II capabilities, MUSYC also allows for the user to develop many more timber class identifiers and constraints. One can therefore define an activity to occur on any given management unit in great detail.

Iverson and Alston(1986) determined that MUSYC's "... improved constraint specification was helpful in projecting more realistic harvest schedules." They believed that the added flexibility in model definition and constraint specification had led to the model's general acceptance. Given the initial conditions of the forest and the policy parameters to be used as constraints, the MUSYC model is capable of optimizing a chosen objective function, either volume or value. Thus, MUSYC is able to facilitate an examination into the allocation of resources across time and site while arriving at an optimal solution. There are, however, several restrictions that forest level modeling techniques place on the data used by them.

4.1.2 Stand and Forest Integration

The forest is large and diverse, containing numerous stands, set apart from one another based on characteristics such as age, site, and location. The ability of forest level models to accurately depict these stands is constrained by the limitations of the models themselves.

Forest level models such as MUSYC are typically unable to differentiate stands based on location. In attempting to include the relational locations of individual stands the problem size that occurs makes analysis impractical. Thus, stands which retain similar age and site qualities are grouped together. As well, forest models maintain an upper boundary on the total number of stands it can incorporate. The maximum number of timber classes within the MUSYC model is 400. While this boundary was not met in this research, stands may have to be aggregated further in order to meet these bounds in other areas. These constraints on problem size serve to erode the integrity of individual stand identification. Forest managers are then required to prescribe a single treatment based on the average response of a group of stands rather than an individual stand. As could be seen in Chapter Three the movement from one stand treatment to another can lead to a much different optimal result.

Forest level models also retain a finite time or planning horizon. Criteria used to determine optimal treatment regimes at the stand level, whether it be MAI or SEV, create a set rotation age for optimization. Any deviation from this rotation age will lead to an inefficient solution. While the forest model will select the optimal treatment and rotation age the vast majority of the time, the model may alter the optimal treatment regime to coincide with the end of the planning horizon. For example, if the planning horizon is set to 300 years and optimal stand management calls for harvests to occur every 80 years to maximize SEV, the forest model should only harvest the stand three times. What may occur, however, is that the model will harvest the stand a fourth time at age 60 to meet the planning horizon constraint. Although the model would not be maximizing the SEV of the stand, any positive value obtained from the harvest is greater than that not received by not harvesting.

4.1.2.1 Case Study Integration

In theory, each site type would retain only one treatment, that which was optimal. However, the aforementioned model constraints will influence the treatments which are prescribed for the forest. Several treatment types may then be prescribed by the model to meet its objective function.

This research generated forty-two treatment options, including: three possible thinning regimes on each site (9), a combination fertilization and thinning treatments at two different ages (18), planting options with provisions for fertilization at two ages (9), natural stand progression (3), and a possibility to fertilize the natural stand (3). As the MUSYC model is only able to incorporate five management alternatives for each stand, the treatment options were entered stepwise to determine which set of management alternatives best met the objective function for each stand/site classification.

The presence of multiple treatments required the generation of decision criteria for treatment selection. Each treatment which passed through the criteria was retained. This process continued until all treatment options were exhausted and only the best five(or fewer) remained for each site type. The criteria were:

1) Determine the total number of treatments and the total area treated throughout the planning horizon
2) Determine the number of times each treatment was used and the total area treated by that alternative.
3) If any treatment was used for greater than 60% of the total number of treatments as well as on greater than 60% of the total area, then it is the only treatment to continue.
4) Otherwise, the number of times a treatment was used is multiplied by the total area treated by that alternative. Upon ranking, alternatives will be included singularly, in descending order, until criteria 3 is satisfied.

This selection criteria ensures that only the treatments which are of primary importance to the optimal solution are included.

4.1.3 Forest Management Regimes

The constraints to forest management imposed by provincial regulation are not without costs. Flow policies predicated on sustained yield coupled with forest management based on biological characteristics may create inefficiencies which lead to a misallocation of resources. In order to quantify these costs, a methodology was required to examine the flows of volume and value from the forest under changing policy parameters.

Four forest management regimes were developed to estimate the tradeoffs between volume and value which could occur under differing forest management policies. Within each regime, an alternative scenario was developed to examine silvicultural investment possibilities.

The first regime emulated a neoclassical approach to forest management. Thus profit, via net present value, was maximized and no sustained yield constraints were imposed. This regime required rotation decisions be based on economic criteria. The absence of government intervention would suggest that this regime should provide a measure of the most economically efficient allocation of resources. There were no treatments available other than reforestation for the first scenario (I-1). The second scenario (I-2) incorporated silvicultural investment opportunities.

The MUSYC model's only constraint was that of the 250 year planning horizon. The model's objective function was set to maximize the net present value from the forest base for the entire twenty five periods to ensure economic optimality in every time period. The real discount rate used throughout was 4%.

The second regime examined a purely biological approach to forest management. Therefore, no constraints were placed on the model and the objective function was set to maximize volume for the entire two hundred and fifty years so as to ensure biological optimality in every period. This regime provided the most efficient biological allocation of resources, as such, the MAI criteria was used. As before, silvicultural treatments were included as a second scenario (II-2) and the real discount rate was 4%

The third regime was designed to simulate operations under conditions set out by government policy, particularly in regards to sustained yield and rotation length. In setting the model's objective function to maximize the volume harvested from the landbase, the MAI criteria was used. The model was, therefore, required to harvest each reforested area at the age of maximum MAI. The inclusion of silvicultural alternatives, in the second scenario (III-2), allows for an examination into which stand treatments can best be incorporated into a volume objective. As provisions for a 10% fluctuation in rotation age were included in the allowable cut guidelines, the age at which to harvest regenerated areas was not constrained in this scenario. This scenario shows how investment dollars are allocated to provide the greatest impact on volume.

The planning horizon was again set at 250 years. The selected average rotation period, in keeping with provincial guidelines, was assumed to be 100 years. The model, therefore, extracted the greatest amount of volume it could during the first 100 years. During this time no fluctuations were allowed in the harvest level. Thus perfect sustained yield was required for the first 100 years. For the remaining 15 periods, harvests were allowed to fluctuate ± 95%. That is, harvests from one period to the next can deviate by 95% of the previous period's harvest. It has been demonstrated by Armstrong et.al. (1984), that as updates occur to harvest plans, the magnitude of periodic harvest fluctuations will not be as large as the 95% deviations above, and that forest structures will remain reasonably regular. The benefit to this methodology is the greatly reduced possibility of infeasible LP solutions when more constraints are added to the model. The real discount rate used throughout the analysis was 4%.

The fourth regime focused on the operating environment in the absence of one provincial constraint. A shift was made from volume maximization to value maximization. While the firm is still constrained by sustained yield requirements, this regime should allow greater economic efficiency and thus fewer opportunity costs.

The methodology resembled that of the third regime's in that a case was formulated for constrained maximization. In setting the MUSYC model's objective function to maximize value, the soil expectation value(SEV) criteria was used. For reasons mentioned earlier, the maximization period was set to include the entire planning horizon of 250 years. The constraints to harvest flow remained identical to that of the volume cases. That is, perfect sustained yield for the first 100 years, with ± 95% fluctuations for the remainder of the planning horizon. The inclusion of silvicultural investment opportunities occurs in the second scenario (IV-2). The real discount rate was 4%.

In summary, the following represents the regime/ scenario combinations used in this thesis:

Regime I - Unconstrained Value Maximization
    Scenario 1 - No silvicultural treatment options
    Scenario 2 - With silvicultural treatment options

Regime II - Unconstrained Volume Maximization
    Scenario 1 - No silvicultural treatment options
    Scenario 2 - With silvicultural treatment options

Regime III - Constrained Volume Maximization
    - harvest flow and rotation length constraints
    Scenario 1 - No silvicultural treatment options
    Scenario 2 - With silvicultural treatment options

Regime IV - Constrained Value Maximization
    - harvest flow and rotation length constraints
    Scenario 1 - No silvicultural treatment options
    Scenario 2 - With silvicultural treatment options

Refer to Appendix IV for an example of the input file used in the MUSYC model.

4.2 Forest Level Results

The aforementioned regimes allow an investigation into the policy issues surrounding the tradeoffs between volume and value. This can be done by comparing the flows of volume and/or value between each regime/scenario combination.

The inclusion of silvicultural options occured in the second scenario of each regime. In repeating the comparisons, an indication of how firms would invest, given differing operating conditions, and the effects of policy constraints on these investment decisions, were investigated.

To account for each regime's effects on community stability, employment measures relating to total jobs and total job value were calculated (Appendix IV). The comparisons can then be repeated to determine what the net benefits of provincial policies are on employment. As silvicultural treatments can create additional employment, these effects were also investigated using the inter-regime comparisons.

4.2.1 Constraints on Investment

While overall provincial policy is based at the forest level, the basic management and investment unit of the forest manager is the stand. The constraints placed on forest management by modeling techniques and policy may not allow for the optimal stand level investment to occur.

The following tables show the silvicultural treatment options which passed through the aforementioned decision criteria and were included in the final MUSYC run for each regime. These Tables therefore represent the treatments which were selected by the model to be included in the final optimal solution. The Times Used column represents the number of times the treatment type was used throughout the entire planning horizon. The Area Treated column represents the total area treated with each treatment type over the entire planning horizon.

Table 11

Summary of Silvicultural Treatments on Regenerated Areas for the Unconstrained Value Maximization Regime

Site Type	Treatment Type	Times Used	Area Treated ('000ha.)
GOOD	fertilized at age 60	2	0.528
	thinned to 2.5m & fertilized at age 20	11	173.512
		13	174.040
MEDIUM	natural stand	1	23.066
	fertilized at age 70	17	821.408
	thinned to 2.5m & fertilized at age 20	2	16.612
		20	861.086
POOR	fertilized at age 80	10	13.980

By definition, the selection of treatments by the model, for this scenario (I-2), should generate the greatest possible financial benefit. Thus, one would expect that, in the absence of constraints, the selected treatments would be those which retain the greatest soil expectation value when examined at the stand level. Recalling Chapter Three, at the stand level, treatments would be to thin and fertilize at age 20 on good sites, fertilize at age 70 on medium sites, and no treatment would be selected for poor sites. The least cost treatment on poor sites was to fertilize at age 80. As can be seen in the above table, while the optimal stand treatment is used in most cases, the economist's theory of value maximization at the stand level does not hold, in all cases, when forest level planning is required.

The first case of this is that the poor site stands are treated once they have been harvested. In the unconstrained case, one would expect that the MUSYC model would harvest these stands and then remove them from the operable landbase as they do not retain positive SEV's. What appears to have occurred is a further effect of the model. The poor stands must initially be included in the operable landbase so the stock of mature timber can be harvested. Once this has occurred, the model is unable to then exclude them from being treated. While the model has chosen the least cost method of regeneration and treatment, these sites still retain negative values. Although the amount of area encompassed by poor stands, and the value lost to treatment, are relatively small, this still represents an inefficiency.

The second case involves the use of non-optimal treatments, at the stand level, when such treatments are available. This is a function of forest level modeling constraints. The economic theory of maximization at the stand level assumes an infinite time horizon and that soil expectation value is the decision tool used to evaluate investments. The scenarios generated for this research use a time period of two hundred and fifty years. While this is a considerable length of time, any deviation from the infinite time horizon will create deviations from the theoretically optimal solution. In using the medium site treatments as an example, we see that while 95.4% of the area treated during the planning horizon was done so with the optimal stand treatment, two suboptimal treatment types were used. By examining the output generated from the MUSYC model it was found that the suboptimal treatments were selected such that their final harvests would coincide with the end of the planning horizon.

Table 12

Summary of Silvicultural Treatments on Regenerated Areas for the Unconstrained Volume Maximization Regime

Site Type	Treatment Type	Times Used	Area Treated (Mha.)
GOOD	thinned to 2.5m & fertilized at age 50	9	69.616
		9	69.616
MEDIUM	fertilized at age 70	8	303.298
	thinned to 2.5m & fertilized at age 20	1	0.396
		9	303.694
POOR	fertilize at age 80	2	3.562
	thinned to 1.5m & fertilized at age 50	5	3.428
		7	6.990

The selection of treatments for the unconstrained volume maximization scenario (II-2) should provide the greatest biological return to the landbase. At the stand level, these treatments would be to thin the naturally regenerated site to a 2.5 metre spacing at age 20 then fertilize at age 50 for good sites, fertilize the naturally regenerated medium site at age 70, and thin to a 1.5 metre spacing and fertilize at age 50 on poor sites. It is evident from the Table 12 that treatments selected for optimizing at the forest level generally agree with treatments selected to optimize at the stand level. The exceptions are very minor in the case of medium sites where only 0.13% of the total area treated was done so with a sub-optimal alternative. On poor sites, approximately half of the total area treated was done so with a sub-optimal treatment type. As was described for I-2, these exceptions were due to forest modeling constraints.

Table 13

Summary of Silvicultural Treatments on Regenerated Areas for the Constrained Volume Maximization Regime

Site Type	Treatment Type	Times Used	Area Treated (Mha.)
GOOD	thinned to 2.5m at age 20	1	0.600
	thinned to 2.5m & fertilized at age 20	11	80.928
		12	81.528
MEDIUM	fertilized at age 70	4	127.477
	thinned to 1.5m & fertilized at age 20	13	293.848
	thinned to 2.5m & fertilized at age 20	8	169.596
		25	590.921
POOR	fertilized at age 80	2	3.034
	thinned to 1.5m & fertilized at age 50	4	4.220
		6	7.254

As would be expected, the use of sustained yield constraints on volume maximization has altered the mix of treatments when comparisons are made with the previous scenario (II-2). The volume maximization objective has shifted treatments close to, but has not equated them with, mean annual increment maximization. This is because the sustained yield constraint appears to have produced an allowable cut effect (ACE, see Appendix V for in depth explanation). The model has chosen to proceed with treatments which offer the optimum combinations of greatest volume and shortest rotation. By doing so, the number of future harvests can increase, creating more overall volume during the planning horizon. Part of this increased volume can then be transferred back into the sustained yield period to augment the volume harvested. This allowable cut effect will be estimated later. Treatments prescribed for the medium site class best display the deviation from the optimal stand alternative. Where the optimal biological alternative would be to fertilize at age 70, the large majority of both treatments and treatment area were thin to a 1.5 metre spacing and fertilize at age 20. While some increment in in terms of MAI is lost (Table 6), stands treated this way are able to reach their optimal rotation 20 years prior to the fertilization at age 70 option (Table 3).

Table 14

Summary of Silvicultural Treatments on Regenerated Areas for the Constrained Value Maximization Regime

Site Type	Treatment Type	Times Used	Area Treated (Mha.)
GOOD	fertilized at age 60	4	38.379
	thinned to 2.5m & fertilized at age 20	14	95.649
		18	134.028
MEDIUM	natural stand	3	134.251
	fertilized at age 70	16	465.717
	thinned to 2.5m & fertilized at age 20	5	103.325
	thinned to 1.5m at age 20 & fertilized at age 50	3	93.984
		27	797.277
POOR	natural stand	1	1.582
	fertilized at age 80	6	10.022
	thinned to 1.5m & fertilized at age 20	1	0.132
	thinned to 1.5m at age 20 & fertilized at age 50	1	0.924
		9	11.078

The model for constrained value maximization with silvicultural treatments selected one primary silvicultural activity, with other treatments being used to accommodate the planning horizon and flow constraints (Table 14). As can be seen here, the total area treated with silvicultural options over the planning horizon has increased dramatically over III-2 (maximize volume inclusive of silvicultural treatments). Area treated equals 942,383 thousand hectares under this scenario (IV-2) while only reaching 679,703 thousand hectares under III-2. This is due to the economic rotations being shorter than biological rotations, thus allowing for a greater number of harvests and treatments during the planning horizon.

There has also been a shift in the types, and amounts, of treatments used. While the good sites maintained their primary treatment type, the medium and poor sites opted for fertilization of the natural stands as their primary management regime. In maximizing for net present value under flow constraints, the model, therefore, trades off volume for value requirements.

As can be surmised by the diversity of treatments, the economically optimal treatment was not used in every instance. The primary cause of this misallocation of resources is the sustained yield constraint. A similar allowable cut effect (ACE) is present in this scenario as was seen in III-2. The ACE, in this case, is focused on providing treatments which will increase present value. By selecting treatments which trade off some increment of value for a larger increase in volume, the harvest during the period of sustained yield can be increased. As this harvest increases, the present value received during the initial decades of the planning horizon also increases. The loss in value which would be realized well into the future is then almost negated due to discounting.

The previous section has demonstrated the effects of integrating stand level management considerations into a forest level modeling platform. Forest level modeling constraints were shown to force deviations from the optimal set of stand management alternatives in the unconstrained cases(I-2 & II-2). A small percentage of suboptimal treatments were used to meet the model's planning horizon constraints. Poor stands were retained in the economic landbase even though no treatments retain positive SEV's. This was due to the value which could be received from the stock of overmature stands. As policy constraints on forest management were implemented, the deviations grew. The requirement for sustained yield has generated an allowable cut effect. The ACE has created a number of shifts away from the optimal stand treatment as future volumes and values are captured during the present. As regimes became more economically efficient, more area was treated. These treatments, however, became less intensive as volumes are traded for values.

4.2.2 Harvest Volume and Value Flows

The flows of volume and value from the forest under differing policy parameters and objective functions allows comparisons to assist in identifying investment strategies and quantifying constraint costs. The following Tables represent the results from the four regimes. Table 15 summarizes the decadal flow of timber harvest over the planning horizon for each of the scenarios. Table 16 summarizes the decadal flow of net present value from the timber harvested for the planning horizon. Table

17 summarizes the overall totals of volume harvested, value realized, area harvested, and employment effects. Located in Appendix VI are expanded versions of these results.

Table 15

Summary of Regime/Scenario Decadal Flows of Harvest Volume

Decade	I-1	I-2	II-1	II-2	III-1	III-2	IV-1	IV-2
1	55.832	55.832	4.888	4.888	11.843	13.983	12.947	13.968
2	3.107	3.571	0.333	0.333	11.843	13.983	12.947	13.968
3	0.524	0.575	5.944	5.944	11.843	13.983	12.947	13.968
4	1.902	2.002	1.490	1.443	11.843	13.983	12.947	13.968
5	0.457	0.630	0.256	0.330	11.843	13.983	12.947	13.968
6	3.926	8.366	3.161	3.295	11.843	13.983	12.947	13.968
7	0.338	0.407	31.351	0.743	11.843	13.983	12.947	13.968
8	7.197	1.825	69.649	37.447	11.843	13.983	12.947	13.968
9	27.650	31.138	4.404	83.307	11.843	13.983	12.947	13.968
10	3.024	3.422	18.589	7.658	11.843	13.983	12.947	13.968
11	0.459	4.689	12.198	12.941	1.175	1.207	2.946	0.699
12	1.902	2.123	4.876	5.689	2.292	0.262	5.214	0.764
13	0.560	0.562	5.430	6.069	4.469	0.511	4.663	1.490
14	3.914	4.384	7.295	7.986	0.910	0.997	3.934	2.906
15	5.947	0.381	0.042	0.466	1.774	1.943	6.075	5.667
16	1.737	5.884	0.000	0.000	3.459	1.927	4.995	7.609
17	27.701	31.154	0.000	0.000	6.745	3.757	9.741	10.189
18	2.959	3.383	0.000	0.000	13.152	7.327	7.339	20.127
19	0.355	0.401	0.000	0.000	17.942	14.288	3.222	1.248
20	1.776	2.128	0.000	0.000	17.376	27.861	5.214	0.744
21	0.560	4.892	0.000	0.000	13.718	1.666	4.751	1.450
22	9.522	4.423	0.000	0.000	12.417	3.249	6.005	2.828
23	0.464	0.381	0.214	0.000	15.181	6.336	5.041	5.514
24	2.768	1.969	3.161	3.455	13.777	12.354	6.489	10.753
25	29.592	36.704	161.020	163.428	0.689	24.091	7.061	20.968

where: I-1 = unconstrained value maximization
I-2 = unconstrained value maximization with silviculture
II-1 = unconstrained volume maximization
II-2 = unconstrained volume maximization with silviculture
III-1 = constrained volume maximization
III-2 = constrained volume maximization with silviculture
IV-1 = constrained value maximization
IV-2 = constrained value maximization with silviculture
units = millions of cubic metres

Table 16

Summary of Regime/Scenario Decadal Flows of Net Present Value

Deca	I-1	I-2	II-1	II-2	III-1	III-2	IV-1	IV-2
1	1975.271	1971.663	175.185	171.577	421.912	494.356	461.306	495.064
2	73.062	83.525	8.067	7.606	284.494	331.567	311.125	334.979
3	8.290	0.457	97.188	93.405	192.128	216.084	210.572	218.825
4	20.394	21.270	16.456	15.557	130.105	146.741	141.858	146.588
5	3.315	3.599	1.904	- 0.138	87.980	98.422	95.988	98.322
6	19.228	41.302	15.885	16.236	59.348	67.016	64.854	66.701
7	1.121	1.176	106.425	2.304	40.170	45.350	43.870	44.432
8	16.281	0.958	159.653	85.881	27.098	30.920	29.563	31.068
9	41.802	46.959	6.797	128.999	18.313	20.418	19.809	21.261
10	3.090	3.466	19.430	7.978	12.334	13.921	13.361	13.960
11	0.314	3.232	8.597	9.102	0.827	0.476	2.033	0.477
12	0.885	0.982	2.318	2.690	1.090	- 0.026	2.430	0.351
13	0.175	- 0.017	1.759	1.983	1.448	- 0.002	1.467	0.447
14	0.832	0.930	1.595	1.763	0.199	0.204	0.837	0.550
15	0.866	0.046	0.006	- 0.001	0.262	0.166	0.877	0.764
16	0.168	0.489	0.000	- 0.094	0.346	0.178	0.468	0.715
17	1.617	2.039	0.000	- 0.007	0.454	0.207	0.641	0.672
18	0.131	0.128	0.000	- 0.006	0.597	0.331	0.320	0.886
19	0.011	0.010	0.000	- 0.002	0.550	0.431	0.096	0.037
20	0.036	0.043	0.000	0.000	0.360	0.564	0.105	0.012
21	0.008	0.065	0.000	0.000	0.192	0.015	0.062	0.017
22	0.089	0.039	0.000	0.000	0.117	0.017	0.056	0.024
23	0.003	- 0.001	0.001	0.000	0.097	0.040	0.031	0.032
24	0.007	0.004	0.014	0.015	0.059	0.052	0.027	0.045
25	0.084	0.104	0.469	0.477	0.002	0.068	0.020	0.059

where: units = millions of dollars
abbreviations as before

Table 17

Aggregate Regime/Scenario Values

Regime/ Scenario	Harvest Volume (MMm3)	Harvest Area (Mha)	Harvest NPV (MM$)	LRSY (MMm3/ period)	Silviculture Treatment Area (Mha)
I-1	193.174	1307.710	2167.279	10.534	-
I-2	211.225	1393.410	2182.469	11.042	1049.106
II-1	334.298	724.340	621.752	10.534	-
II-2	345.822	725.132	545.325	11.042	380.300
III-1	243.503	581.747	1280.470	10.534	-
III-2	247.604	1001.458	1467.517	11.042	679.703
IV-1	211.984	1068.532	1401.800	10.534	-
IV-2	233.239	1288.846	1476.288	11.042	942.383

MM = millions of units
M = thousands of units
abbreviations as before

As can be seen in Table 17, the unconstrained economic scenario (I-1) generates a total net present value of $2.167 billion dollars. Approximately $1.975 billion, or 91%, of the total NPV is obtained within the first ten years (Table 16). This is due to the absence of the flow constraints, as the entire stock of old growth forest which is above the maximum SEV rotation age, is harvested. Large harvests are thus followed by periods of unused capacity (Table 15). Where the medium site classes are reharvested every eighty years, good sites are reharvested every seventy years, and poor sites are reharvested every one hundred and ten years. These rotations correspond with the optimal SEV rotation ages. The total harvest during the planning horizon is only 193.174 million cubic metres, at least a 20 million cubic metre reduction from other scenarios.

The inclusion of silvicultural treatments (I-2) has allowed for increases in all reference levels when compared to I-1. The objective function has risen to $2.182 billion, an increase of $15 million over I-1 (Table 17). Due to the option for investment, there has been a slight shift in the flow of value from the forest. Net present value obtainable in the first period is slightly lower than I-1($4 million) while NPV from the second period is approximately $10 million dollars higher. As was the case in I-1, large amounts of forest are initially harvested, followed by lengthy periods of unused capacity. The inclusion of silvicultural treatments serves to fill in some of the cyclical gaps as the total volume harvested over the planning horizon has increased by almost 20 million cubic metres. This in no way mitigates the boom/bust nature of this regime however. The long run sustained yield has also increased because of the option for silvicultural treatments.

Of interest, is that during periods thirteen and twenty-three, the model determined that it is of overall benefit to retain negative NPV's. Further investigation into the output itself revealed these periods to be when areas of the poor site class were reharvested. If an examination were to occur on a stand by stand basis, these poor site areas would not have been treated. As was previously, mentioned, these areas should not be included within a completely unconstrained case. The inability of the MUSYC model to exclude these areas once they had been harvested was the cause of this.

As expected, the unconstrained volume maximization scenario (II-1) generates much larger volumes than the other regimes. Just as with I-1, however, this scenario is characterized by harvests followed by periods of unused capacity. In periods 16 to 22, there were no volumes harvested whatsoever. These fluctuations are due to the purely biological management the forest is undergoing. Where rotations fell into line with maximum SEV in regime I, rotations are equating themselves with maximum MAI's for this regime. When the option for silvicultural investments is included (II-2), all values are increased with the exception of total NPV (Table 17). Intuitively, this is expected, as the results in Chapter Three have shown that the conditions for volume maximization are not normally associated with positive net present values. Where total volume harvested has increased by 11.5 million cubic metres, the total net present value has decreased by approximately $76.5 million dollars.

In examining the regimes unconstrained by policy it must be recognized that the obtainable values are in fact upper bounds. These regimes ignore capacity constraints. In reality, as production increases, a rising marginal cost curve would not allow the realization of the entire values estimated here. To properly evaluate the results of the unconstrained regimes an accounting of the costs of constructing the additional capacity must be set against the benefits which could be received from the extra harvest.

The average annual harvest for the constrained volume maximization scenario (III-1), over the initial one hundred years, is approximately 1.18 million cubic metres (Table 15). Due to the age class structure of the forest, the harvest for the next seventy years is somewhat lower, averaging only 297,000 cubic metres annually. As the stands which were initially harvested reach MAI, the average annual harvest for periods eighteen to twenty-four increases to 1.48 million cubic metres. As was previously mentioned, continual updating would lessen these severe fluctuations until periodic harvest reaches the long run sustained yield of 10.534 million cubic metres (Table 17). The total net present value obtainable through this scenario is $1.28 billion. Approximately 55% of this amount is available in the first two periods with 99.5% coming from the initial 100 years (Table 16). The effects of discounting can be seen through the periodic flows of NPV. Given that harvests are equal for the first ten periods, the associated values differ only through these discounting effects.

The incorporation of silvicultural treatments as management alternatives (III-2) has allowed the objective function to rise to 139.827 million cubic metres, an increase of 18% over scenario III-1. Total harvest over the planning horizon has gone up by approximately 4 million cubic metres. The increase in the objective function also translates itself into a larger NPV. Total net present value is 15% greater than scenario III-1. The allowable cut effect plays an important role in the increased NPV's by allowing greater harvest during the conversion period.

As can be seen from Table 17, the total net present value obtainable from the harvest in scenario IV-1 is approximately $1.401 billion dollars. In comparison, the total NPV from harvest in the constrained volume scenario (III-1) was $1.280 billion. This represents an increase of $120 million dollars over the planning horizon. Approximately 55% of the increased NPV is retrievable within the first twenty years, showing the greatest return to the forest coming early in the planning horizon. After year one hundred, any monies generated by harvesting are almost entirely dismissed due to discounting. This scenario shows a substantial reduction in the total harvest when compared to III-1. Approximately 32 million less cubic metres are extracted over the planning horizon. This despite an increase in annual harvest during the first one hundred years of 110,000 thousand cubic metres. By examining the areas harvested and relating them to the volumes extracted, we see relatively larger areas required to sustain a harvest level. This observance of shorter, more frequent economic rotations is consistently noted when comparisons are made to volume based scenarios.

The addition of silvicultural treatments as management alternatives (IV-2) has allowed for increases when compared to IV-1. The objective function has increased to $1.476 billion, up by 5.3% over IV-1. The majority of this increase, approximately 81%, is contained within the first two periods with 95% of the increased NPV coming by year one hundred. This is in part due to the ACE and shows discounting's effects on obtainable value as gains must be received early in the planning horizon to have a measurable effect. Total harvest over the planning horizon has increased to 233 million cubic metres. This represents an improvement over IV-1 of 22 million cubic metres. The increase is primarily within the first ten periods with additional annual harvests of 100,000 cubic metres above IV-1. Although the volume harvested has increased over the initial ten periods, the harvest fluctuations are generally greater for the remainder of the planning horizon. This is due to the timing of additional volumes generated by silvicultural treatments. The long run sustained yield has also been increased due to the availability of greater volumes from treated areas. LRSY is now equal to the other scenarios which include silvicultural options. When comparisons are made to III-2, volume maximization with silviculture options, we see an increase in NPV of approximately $10 million dollars while total harvest is approximately 14 million cubic metres less.

As a progression is made between scenarios not including silviculture options several trends develop in the tradeoffs between volume and value. Moving from unconstrained value to constrained value to constrained volume to unconstrained volume maximization we see a total harvest volume increase of 73% and a decrease in the total NPV of 72%. In looking solely at the differences between regimes III and IV, regime III allows a 15% greater total harvest but at the expense of 9% less NPV.

Once silvicultural investments are included in the examination of tradeoffs, the results alter somewhat. The progression from unconstrained value to unconstrained volume now shows an increase in total volume harvested of 64% and a corresponding reduction in NPV of 75%. The differences between regimes III and IV have lessened quite dramatically, as regime III allows for a 6% increase in volume harvested and only a 0.6% reduction in total NPV.

These comparisons appear to show that, when silvicultural treatments are included, the differences between an objective of constrained volume maximization and an objective of constrained value maximization are not that far apart in relative terms. The constraints imposed by policies must, however, be accounted for in these comparisons as previous results have shown these constraints to alter the flows of both volume and value.

4.2.3 Evaluation of Policy Constraints

4.2.3.1 Without Silvilcultural Investment

To examine the effects of differing policies in the absence of investment, the scenarios not including silvicultural alternatives are investigated. To determine the true opportunity cost of volume objectives, the differences in harvest and value schedules between the unconstrained biological and economic scenarios are examined (I-1 & II-1). Values accruing over the entire planning horizon show that while II-1 will accumulate an additional 141 million cubic metres of harvest volume, I-1 will retain $1.546 billion more dollars. The differences in these amounts truly underline the opportunity cost of biological forest management.

The impact of the sustained yield constraint on volume objectives is identified by examining II-1 and III-1. For III-1, the annual allowable cut over the period of sustained yield is 11.843 million cubic metres per decade. The net present value accrued during the one hundred year period is $1.274 billion dollars. In comparing this constrained scenario with the unconstrained(II-1), the value of sustained yield can be approximated, as it is the only policy difference between these two regimes. To facilitate the comparison, the average flows of volume and value for II-1 over the period of constraint are used. 14.006 million cubic metres per decade are harvested and the total NPV over this one hundred year period is $607 million dollars. Therefore, the effect of having a sustained yield harvest is a reduction in the periodic average harvest and an increase in the NPV. By smoothing out the fluctuations in periodic harvest which occur in the unconstrained II-1, a lower overall harvest, but much larger periodic harvests, are available in the first six decades. These larger harvests earlier in the planning horizon are then not subject to the full effects of discounting. The sustained yield constraint has therefore generated an additional $667 million dollars worth of NPV over the first one hundred years while creating a reduction in the average periodic harvest of 2.17 million cubic metres.

The changes in flows between I-1 and IV-1 display the effects of the sustained yield constraint on economic objectives. The decadal flows of volume and value over the first one hundred years for IV-1 are 12.947 million cubic metres per decade and total NPV of $1.392 billion dollars. The same measures for I-1 are 10.396 million cubic metres and $2.162 billion dollars. Therefore the effects of the sustained yield constraint are to increase the average periodic flow of volume by 2.551 million cubic metres per decade and reduce the total NPV by $770 million dollars. The sustained yield constraint thus creates an opportunity cost of $770 million dollars.

The differences between scenarios III-1 and IV-1 show competing biological and economic objectives in the presence of the sustained yield constraint. In the case of IV-1, not only are the periodic harvests 1.1 million cubic metres higher, but the value which accrues to this scenario is $118 million dollars greater than III-1. Management for volume objectives in the presence of sustained yield, therefore, creates an opportunity cost of $118 million dollars. Much of this cost arises out of the difference in rotation lengths, seen in Chapter Three, as timber values are received earlier, and the effects of discounting.

Forest management, without the possibility for silvicultural investment opportunities, can provide many different benefits and costs, depending on the forest manager's objectives. In the absence of policy constraints, maximization of economic objectives has been shown to generate an additional $1.546 billion dollars of net present value over the planning horizon when compared to a goal of volume maximization.

Once sustained yield is required, the difference between economic and biological objectives is reduced to almost half. This is due to the removal of harvest fluctuations early in the planning horizon, thereby creating larger average periodic harvests and thus larger revenues. The opportunity cost of managing the forest for volume concerns coupled with sustained yield was shown to be $888 million dollars over the constraint period. The sustained yield constraint itself, makes up the greatest proportion(87%) of this cost. This constraint was, however, shown to be of positive value in the case of unconstrained biological management. Although average periodic harvest volumes were reduced through smoothing, the effect of larger volumes obtained earlier in the planning horizon, provided an additional $667 million dollars over the unconstrained case.

The inclusion of silvicultural investment options should provide for increases in harvest levels and generate differing effects on net present values.

4.2.3.2 With Silvicultural Investments

To obtain a true measure of the effects of silviculture on volume and value, comparisons of the two unconstrained regimes were made. Silvicultural investments in the absence of policy constraints and an objective of net present value provide a measure of economically efficient investment opportunities. Subtracting the flows of volume and value in I-2 from those of I-1 (Table 17) shows intensive forest management to have increased the total NPV obtainable by $15.2 million dollars, as well as, increasing the total harvest volume by 18 million cubic metres. Managing the forest for biologically efficient silvicultural options (II-2 - II-1) increases the harvest level by 11.5 million cubic metres but reduces the obtainable NPV by $77 million dollars. Thus, the opportunity cost of unconstrained biological forest management increases to $1.637 billion dollars (from $1.546) when there are options for intensive forest management.

Once constraints, in the form of sustained yield, are in place, the effects on volume and value flows are dramatic. In the case of biological forest management (III-2), the option for silviculture has increased both the harvest level and the net present value. During the conversion period, decadal harvests have gone up by 2.14 million cubic metres and accrued NPV has increased by $191 million dollars. Considering that the true biological effect of intensive forest management was to increase the average decadal harvest by 532,000 cubic metres and reduce the total NPV by $77 million dollars, the effect of the sustained yield constraint is extremely significant. The reason for the apparently large increase in both volume and value is the allowable cut effect. The combination of volume maximization and sustained yield has altered the biologically efficient pattern (recall Tables 12 and 13) of investment so as to increase harvests during the first one hundred years. In accounting for an accurate value measure of biological investments, the presence of the ACE creates additional NPV in the amount of $268 million dollars ($191 + $77) and requires average harvest levels to be 1.61 million cubic metres above their proper levels.

There is also an ACE contained within the apparent volume and value increases of the constrained economic scenario (IV-2). Silvicultural investments have appeared to increase the total NPV during the constraint period by $79 million dollars as well as increase the average decadal harvest by 1.02 million cubic metres. From Table 16, the true value of economically efficient silvicultural investments during this period is $12.5 million dollars with an increase in average decadal harvest of 380,000 cubic metres. The allowable cut effect has therefore generated an additional $66.5 million dollars of NPV from the increase in periodic harvest of 640,000 cubic metres. The ACE is, therefore, much lower than in the case of volume maximization. For a large ACE to be generated, there must be flexibility in rotations coupled with large volume effects which can be transferred back into the period of constraint. The objective in this case being value, not volume, investment decisions are solely a function of the returns generated. Thus, only in situations where increased volumes are a secondary effect to an increment in value, can a volume transfer into the constraint period be made.

To obtain the opportunity cost of biological forest management in the presence of the sustained yield constraint, the difference in values, net of the allowable cut effects, received from scenarios III-2 and IV-2 are identified. For III-2, the accrued NPV during the period of constraint is $1.465 billion dollars. Subtracting the ACE ($268 million) leaves $1.197 billion. The value of IV-2, net of the ACE, is $1.405 billion dollars. The difference, $208 million, is the opportunity cost of biological forest management in the presence of sustained yield. The inclusion of silvicultural investments has therefore increased the opportunity costs of constrained biological maximization by $90 million dollars, from the $118 million dollars calculated previously.

Provincial constraints requiring sustained yield and biological forest management have been shown to have dramatic effects, when the opportunity for silvicultural investment occurs. Where the true value of investment for volume maximization, as shown by the unconstrained II-2, is to reduce net present value by $77 million, the incorporation of sustained yield creates a dramatic allowable cut effect. The constrained volume maximization case was shown to list an apparent increase in NPV of $191 million dollars. Thus, the sustained yield constraint has shown there to be an additional $268 million dollars available through investing in silviculture when there is an ACE. This large ACE is a direct result of biological forest management. By investing in those silvicultural alternatives which generate the largest biological return in the least amount of time, greater amounts of volume can be transferred back into the period of constraint. The increase in today's NPV more than makes up for future discounted losses.

When the forest is managed for economic objectives, the effects of the sustained yield constraint, while still present, are much less severe. The ACE in the case of constrained value maximization was shown to be $66.5 million dollars. The allowable cut effect under economic objectives is, therefore, much lower than in the case of biological maximization.

The possibility of silvicultural investment has been shown to increase the opportunity costs of constrained biological forest management. The comparisons of III-2 and IV-2 suggest that a further misallocation of resources has increased the cost of volume maximization by 76%, to $208 million dollars.

4.2.4 Implications for Forest Managers

The preceding sections have identified several inconsistencies between stand level optimization and forest level management. While some of these inconsistencies are embedded in forest modeling techniques, they are in large part tied to the operational constraints put in place by provincial policy. In attempting to determine allowable harvests via the timber supply guidelines, the results suggest that by following harvest scheduling prescriptions for allowable cuts, without taking the allowable cut effect into consideration, will lead to a dramatic misallocation of resources.

The initial stock of old growth is so large in proportion to the whole forest that it almost entirely overshadows any benefit which can be received through silviculture, treatments. In the case of volume maximization, silvicultural treatments are actually a cost to society. Under a policy of sustained yield, volume maximization is designed to provide community stability, indications of employment effects are calculated in Appendix VI. The results of these effects are that they do not provide enough justification in value terms to offset the opportunity costs of biological forest management. In fact, by taking the allowable cut effect and the resultant increase in employment into consideration, sustained yield forest management based on economic maximization provides much greater returns to employment. This is due to shorter, more frequent, rotations and the resultant larger areas of land being constantly used and treated.

By requiring the allowable harvest to be based on biological criteria, the incentive for the firm is to invest in economically inefficient silvicultural alternatives which provide the best combination of volume and rotation length. As a firm operating within the forest, the ACE is then designed to alleviate the economic inefficiencies of silvicultural investments. However, if the justification for operation is, in any way, dependant upon the increased harvests and returns available through the ACE, then the long term profitability of the operation is in jeopardy. As updates occur to forest level plans, reductions in overmature timber, allowable harvest, and consequently the ACE are made. The decision to invest in uneconomical silviculture cannot then be mitigated, to the same extent, by increased returns available through the ACE. As this occurs, firms will be unable to invest in opportunities which can satisfy their volume requirements. In that the present policy was designed to provide long term community stability, it must also be designed to provide long term industrial profitability. The justification of projects which include the ACE will not provide for either in the long run.

The owners of the resource, by allowing the firm to capture the ACE, are creating a dual cost to society. In the short term, society loses on the revenues it could have received from an increase in rents to capture the ACE. In effect, the revenues the firm withdraws through the ACE are actually the rents society could have collected on the future timber harvest. Thus, society is exchanging value for additional volume and short term employment. In the long term society must also bear the cost arising out of the loss of the forest dependant community.

If one then considers the age class distribution of Alberta's current forested land it would be difficult to justify the total costs of performing silvicultural treatments which maximize volume. These costs are more than just treatment application costs as they must also include costs relating to research and development, information collection, transaction costs, and the long term effects of the ACE.

5.0 SIGNIFICANT RESULTS AND CONCLUSIONS

There is increasing concern that annual timber harvests for Canada as a whole and certainly for a number of regions will decline in the future as the Canadian industry makes the transition from harvesting the mature forest base to relying increasingly on regrowth. In all but the Prairie provinces, shortages of timber have been predicted. While the forest sector is of vital regional importance in many areas, it is still relatively young in Alberta. The recent surge of investment into Alberta's forest base will therefore enhance this shift from overmature forests to second growth. Thus, a high degree of economic intervention may be required to prevent the timber falldowns predicted for the remainder of the country.

The focus of this thesis has been to investigate the magnitude of potential tradeoffs that timber supply policies create between the flows of volume and value from the forest. The requirement for sustained yield and volume maximization, while ensuring large consistent harvests, is not without costs. These constraints create resource misallocations as firms respond to policy signals by investing in forest management treatments which are not efficient. Where the primary unit of investment for the forest manager is at the stand, the primary planning unit is at the forest level. The amalgamation of these levels under policy constraints does not allow optimal stand investment to occur.

To facilitate research into these questions, a case study was developed within the policy framework set out in Alberta's annual allowable cut guidelines. The intial stand characteristics of two Forest Management Units southeast of Hinton, Alberta, were modified to present an operable forest landbase. In order to simulate silvicultural investment and its effect on the stand level, the Tait model was adapted to provide measures of merchantable volume. The benefits and costs of forest operations were then attached to derive a set of forty-two biological and economic yield tables for three site classes and a range of treatments from natural regeneration to a variety of intensive management regimes.

Once the benefits and costs of stand management had been estimated, optimal biological and economic rotation ages, and their associated values, were determined using the mean annual increment and soil expectation value criteria, respectively. Optimal stand level treatment regimes for each site class were then identified. In order to maximize the MAI from individual stands the following treatments were prescribed: thin the naturally regenerated stand to a 2.5 metre spacing at age 20 then fertilize at age 50 on good sites; medium sites would require the naturally regenerated stand to be fertilized at age 70; and poor sites would have the naturally regenerated stand thinned to a 1.5 metre spacing at age age 20 and fertilized at age 50. Rotation ages on these sites would be 110, 160, and 160 years respectively. In order to maximize the SEV from individual stands the following treatments were prescribed: thin the naturally regenerated stand to a 2.5 metre spacing and fertilize at age 20 on good sites; fertilize the naturally regenerated stand at age 70 on medium site; and as no positive SEV's were attached to any poor site treatments, the least cost treatment was found to be a fertilization of the naturally regenerated stand at age 80. Optimal rotation ages for these sites were 50, 80, and 100 years, respectively. The difference in treatments and treatment ages between sites and optimization criteria showed there to be opportunity costs associated with volume maximization. By investing in alternatives which maximize biological charteristics, the costs associated with each site class were: $603.84 per hectare on good sites, $274.53 per hectare on medium sites, and $428.04 on poor sites. The management of poor site areas to maximize SEV was shown to retain an opportunity cost of $76.46 per hectare.

To assess the limitations of implementing optimal stand level treatments into forest level planning, four forest management regimes were developed and examined using the harvest scheduling model MUSYC. It was found that deviations from the optimal set of stand management alternatives was caused by two effects. Minor deviations were created by the limitations of forest level modeling techniques. The inability to adequately model the infinite time horizon required by rotation theory caused shifts from the optimal stand treatment to occur near the end of the planning horizon. These deviations were shown to encompass relatively minor resource allocations.

Policy constraints, in the form of sustained yield, were shown to create much larger resource misallocations. This inconsistency was caused by an allowable cut effect which sought to increase volumes and values during the period of constraint by selecting investments which combined increments of volume, value, and rotation reduction.

The flows of volume and value from the forest management regimes were then examined to quantify these inefficiencies, and identify the potential tradeoffs between policies which espouse volume maximization over value maximization.

By examining the harvest and value schedules of regimes unconstrained by policy, the opportunity cost of biological forest management was estimated. Management for economic objectives was shown to generate an additional $1.546 billion dollars over the unconstrained volume maximization scenario. The primary contributor to this opportunity cost was the stock of timber which was economically overmature but not yet biologically overmature. Maximization of economic objectives allowed a first period harvest in excess of the volume maximization scenario of approximately 50 million cubic metres. As the results of the unconstrained regimes do not account for processing capacity, they must be taken as upper bounds only. A true evaluation of the unconstrained scenario would have to consider the costs of added capacity to accomodate the estimated harvest.

The impact of the sustained yield constraint on biological and economic objectives in the absence of intensive management was then estimated. This constraint was shown to provide an additional $607 million dollars under an objective of volume maximization because of the requirement to increase the flow of harvest at the beginning of the planning horizon. The effect of sustained yield on the objective of economic maximization was to reduce the accrued net present value by $770 million dollars. This was due to the previously large harvest within the first period being smoothed out over the period of constraint and subjecting it to the effects of discounting. The sustained yield requirement has, therefore, significantly reduced the opportunity cost of biological forest management. Management for volume objectives in the presence of sustained yield was found to create an opportunity cost of $118 million dollars. Thus, the total costs of biological management and sustained yield were estimated to be $888 million dollars, almost half the associated opportunity costs of unconstrained biological forest management.

The inclusion of silvicultural investment opportunities was found to effect both the flow of volume and value from the forest. By proceeding with investments into economically efficient alternatives, it was found that total net present value could be increased by $15 million dollars. Investments which were biologically efficient, while increasing harvest volume by 11.5 million cubic metres, were found to reduce the obtainable NPV by approximately $77 million dollars. Thus, the inclusion of silvicultural investment possibilities increases the opportunity cost of biological management to $1.637 billion dollars in the unconstrained case.

The presence of the sustained yield constraint significantly altered the pattern of biologically efficent silvicultural investment. Cursory examination showed intensive management to increase the obtainable NPV by approximately $191 million dollars during the period of constraint. This apparent increase was due to the allowable cut effect. The ACE was determined to have generated an additional $268 million dollars in net present values through investing in treatments which could provide a reduction in rotation age while retaining an increased increment of volume.

The ACE was also shown to alter the pattern of economically efficient investments. The value of the ACE was not, however, as large as was demonstrated for the volume maximization scenario. The sustained yield constraint was shown to have generated an additional $66.5 million dollars in NPV when value maximization was the objective. The reduction in the ACE under this scenario was due to the objective function requiring investment decisions to be made according to generated returns. Thus, only in situations where increased volumes were a secondary affect to an increment in value, could a volume transfer be made into the constraint period. Nevertheless, the policy constraint did create an allocation of resources not in line with efficient distribution.

In examining competing economic and biological objectives and investments under sustained yield, a quantification of the costs to volume maximization was made. After accounting for their respective allowable cut effects, it was determined that the inclusion of silvicultural investments had increased the opportunity costs of biological forest management by $90 million dollars to $208 million dollars. As would be expected, this is equivalent to the increase in opportunity costs coming from the difference between the unconstrained economic and biological regimes.

The premise of forest level constraints are to provide both industry and community stability. Thus, an accounting was made of the value associated with the employment generated and maintained by the scenarios. The presence of the sustained yield constraint served to increase the value of employment between the constrained and unconstrained volume maximization regimes by $17.742 million dollars. As before, this is a direct result of the harvest flow being reallocated and smoothed out at the beginning of the planning horizon. The value of employment was reduced by $11.802 million dollars when the sustained yield constraint was implemented under economic maximization. However, constrained economic maximization in the absence of silvicultural investments still retained greater employment values, $3.234 million dollars, than its volume maximization counterpart. While the inclusion of silvicultural alternatives will create employment as treatments are established, not all of the additional employment is a direct result of efficient resource allocation. The allowable cut effect, through treatments designed to increase current volume and value will generate employment. In that the true value of employment associated with silvicultural investments is described by the unconstrained scenarios, the allowable cut effect was netted out of the constrained scenarios. The results showed that silvicultural investments within a policy regime of economic maximization retained the largest incremental employment benefit.

The results of this research show there to be several implications for forest managers. The primary conclusion being that a shift in government policy to one which espouses economic maximization will provide much greater benefit to the Province. The shorter, and more frequent, rotations which are documented via economic maximization, create increases in both sustainable volume and sustainable value from the forest landbase. The objective of economic maximization also provides for a more efficient allocation of resources. Investments based on biological criteria have been shown to retain much less net present value than those based on economic criteria. As well, once the sustained yield constraint is in place, the allowable cut effect is greatly reduced under conditions of economic maximization. The ability to generate and maintain employment under conditions of constrained economic maximization have also been shown to retain greater benefits than that of volume maximization. These benefits arise primarily out of the larger amounts of land that are constantly in use when economic criteria are employed.

A further conclusion of this research involves the allocation of resources to silvicultural investment alternatives. This research has shown that while conditions can exist for profitable silviculture investment, the increment in net present value over what would have been there regardless is quite small. If minor fluctuations (i.e.10%) in the cost of treatment or the price received for the final product occur, the optimal treatment regime may alter dramatically. As well, the costs of intensive management are more than just treatment application costs and must include related research, data collection, and transaction costs. These costs were not accounted for in this research. The initial age class distribution of the forest also effects the scale of silvicultural investments. When there is an abundance of economically overmature timber, as is the case for many of Alberta's forests, the relative benefit of any additional silvicultural investment is completely overshadowed by the initial forest stock. Thus, in relation to the gross value obtained from the forest, silvicultural benefits account for very little.

When the stock of overmature forest is large, the allowable cut effect plays an important role in resource misallocation. This research has shown that the ACE significantly alters investments decisions when volume maximization is the goal. As the stock of overmature forests dwindles the ACE will also diminish. Once the ACE is no longer available to offset non-profitable investments, forest companies will have to make several difficult decisions regarding future operations. This research has shown there to be very few silvicultural alternatives which provide positive net benefits. Thus, as the timber supply constricts, so will industrial profitability.

5.1 Research Limitations

As is usually the case, the limitations of this research are a function of the scope of work and the assumptions required to achieve the results.

At the stand level, all prices and costs were assumed to be known and constant. While this was a necessary requirement, the data used limit the numeric conclusions to the market conditions which existed in 1987. In addition, the determination of the optimal silvicultural treatment response required assumptions regarding future conditions. As such, there was no incorporation of treatment failure within the possible stand level outcomes. The provision of additional treatment cost for failure may increase the incremental benefit of the treatment case over the no treatment case.

At the forest level, the inability of the MUSYC model to account for spatial relationships limits the applicability of the conclusions. The values received from the forest would be lessened if operational considerations were accounted for. Also, the data used for this research focused on the provision of wood for pulp products only. In normal operations both sawlogs and pulplogs would be required. Given the price differential between pulp and dimension lumber this assumption served to enhance the profitability of silvicultural treatments.

5.2 Future Research Needs

The future needs in this area of research should address several of the above limitations. In determining optimal stand level treatments, the incorporation of an additional cost to account for treatment failure should be made. Already some indication of natural and artificial regeneration success rates are available and given the total expenditures relating to silvicultural treatments, an accumulation of data regarding the outcomes of these events can begin. The provision of these results would almost assuredly alter the rankings of investment possibilities. These results would also attach an increase in cost to each treatment, making them even less profitable but more realistic.

The ability to link spatial considerations into an optimization framework is another area requiring further research. While much work is currently being done in this area, using geographic information system technologies, operable systems are still several years away.

A linkage is also required between the optimal stand and forest level treatment regime. This research has shown there to be several inconsistencies in amalgamating these levels of management. Research in this area has focused on the implementation of decompostion frameworks and the movement of shadow prices between the stand and forest levels.

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APPENDICES

APPENDIX I

Site Class Distribution for the Forest

Table 18

Original Species and Site Combinations* of Forest Management Units E1 and R4

	E1			R4		
Species/Site	Good	Med	Poor	Good	Med	Poor
Pine	7644	41094	2372	1582	59322	1120
White Spruce	659	1647	--	--	2702	--
Black Spruce	1384	1120	--	--	4613	--
Mixed	6129	20390	--	2043	31704	--
Uncomm.	--	--	15618	--	--	14498

* adapted from Beck et.al., 1989, pg 28

APPENDIX II

Biological and Economic Yield Tables

The following is a legend outlining the terms used in the yield tables contained in this Appendix:

Age = age of the stand in years

Tree = average gross volume per tree in cubic metres

Density = gross number of stems per hectare

TotVol = total gross volume per hectare of the stand

Mer Vol = predicted merchantable volume in cubic metres per hectare based on 15cm/10cm utilization standards

Mer Stems = predicted number of merchantable stems per hectare

Mer Vol/Stem = predicted merchantable volume per stem

Diam = predicted average quadratic diameter of the merchantable stems

Tr/Mill Costs = predicted truck to mill costs in dollars per cubic metre

Tr/Truck Costs = predicted tree to truck costs in dollars per cubic metre

Tot Costs = the total costs per cubic metre of the harvesting phases

Prod'tn Costs = the total costs of converting 1 cubic metre in the forest to product

NPV = the net present value per hectare of the treatment type

SEV = the soil expectation value per hectare of the treatment type

MAI = the mean annual increment of the treatment type

GOOD SITES

Table 19

Economic and Biological Yields from Unmanaged Stands
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Tot Costs	Prod'tn Costs	NPV	SEV	MAI
0														
10								Average Cost =		18.25				
20														
30	0.01	10868	92.42											
40	0.03	4959	154.99											
50	0.05	3797	207.43											
60	0.08	3001	253.89	99.93	709	0.14	17.11	7.99	14.10	22.09	92.91	329.60	372.71	1.82
70	0.12	2432	294.98	163.55	961	0.17	17.42	7.99	13.60	21.59	92.41	389.79	422.82	2.52
80	0.16	2009	331.37	221.83	1030	0.22	18.68	7.99	12.98	20.97	91.79	349.34	368.80	2.96
90	0.22	1686	363.65	274.04	1015	0.27	20.22	6.89	12.39	19.28	90.10	278.27	288.56	3.22
100	0.27	1433	392.31	320.22	964	0.33	21.88	6.89	11.84	18.74	89.56	185.98	190.57	3.37
110	0.34	1232	417.74	360.73	897	0.40	23.62	6.89	11.34	18.23	89.05	101.47	103.15	3.44
120	0.41	1068	440.29	396.03	826	0.48	25.40	6.89	10.88	17.77	88.59	30.77	31.11	3.44
130	0.49	933	460.24	426.62	756	0.56	27.22	6.89	10.45	17.35	88.17	-25.26	-25.45	3.41
140	0.58	[illegible]	477.83	452.98	691	0.66	29.06	6.89	10.06	16.95	87.77	-68.11	-68.45	3.36
150	0.68	[illegible]	493.27	475.54	630	0.75	30.93	6.89	9.69	16.58	87.40	-100.05	-100.39	3.28
160	0.78	646	506.74	494.69	575	0.86	32.81	6.89	9.34	16.24	87.06	-123.42	-123.71	3.19
170	0.90	577	518.41	510.80	525	0.97	34.72	6.89	9.02	15.91	86.73	-140.28	-140.49	3.10
180	1.02	518	528.41	524.18	480	[illegible]	36.64	6.89	8.71	15.61	86.43	-152.29	-152.45	3.00

Table 20

Economic and Biological Yields from Unmanaged Stands
Fertilized at 60 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20													
30	0.01	10868	92.42										
40	0.03	4959	154.99										
50	0.05	3797	207.43										
60	0.08	3001	253.89	99.93	709	0.14	17.11	7.99	14.10	92.91	329.60	372.71	1.82
70	0.13	2380	303.32	172.76	975	0.18	17.62	7.99	13.50	92.31	406.16	440.58	2.66
80	0.18	1914	350.83	244.06	1033	0.24	19.27	6.89	12.74	90.45	402.53	424.96	3.25
90	0.24	1614	380.83	294.18	1004	0.29	20.82	6.89	12.17	89.89	297.10	308.08	3.46
100	0.30	1377	407.50	338.24	947	0.36	22.49	6.89	11.65	89.37	191.02	195.73	3.56
110	0.36	1187	431.19	376.73	878	0.43	24.22	6.89	11.17	88.89	97.87	99.49	3.59
120	0.44	1032	452.21	410.15	808	0.51	25.99	6.89	10.73	88.44	21.86	22.10	3.57
130	0.52	904	470.80	439.04	739	0.59	27.80	6.89	10.32	88.03	-37.43	-37.71	3.51
140	0.61	796	487.19	463.85	675	0.69	29.64	6.89	9.93	87.65	-82.24	-82.66	3.44
150	0.71	706	501.55	485.02	616	0.79	31.50	6.89	9.57	87.29	-115.38	-115.77	3.34
160	0.82	629	514.05	502.94	562	0.89	33.38	6.89	9.24	86.95	-139.47	-139.79	3.24
170	0.93	562	524.85	517.94	513	1.01	35.28	6.89	8.92	86.64	-156.76	-157.00	3.14
180	1.06	505	534.07	530.32	469	1.13	37.20	6.89	8.62	86.34	-169.03	-169.21	3.03

Table 21

Economic and Biological Yields on Managed Stands Thinned to 1.5 x 1.5m Spacing at 20 Years of Age Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	28.80										
30	0.01	3960	52.90										
40	0.03	3160	109.14										
50	0.06	2573	166.60	79.39	781	0.10	15.04	7.99	14.96	93.77	156.58	188.92	1.76
60	0.10	2138	220.83	135.21	935	0.14	16.54	7.99	14.03	92.84	259.55	293.49	2.46
70	0.15	1808	270.65	191.99	972	0.20	18.30	7.99	13.21	92.02	243.72	264.38	2.95
80	0.20	1552	315.96	246.57	955	0.26	20.11	6.89	12.51	90.22	177.83	187.74	3.29
90	0.26	1349	357.01	297.47	913	0.33	21.93	6.89	11.89	89.61	71.68	74.33	3.50
100	0.33	1185	394.16	344.10	861	0.40	23.72	6.89	11.36	89.07	-33.72	-34.55	3.62
110	0.41	1050	427.76	386.35	806	0.48	25.50	6.89	10.88	88.59	-126.66	-128.75	3.68
120	0.49	937	458.16	424.35	752	0.56	27.25	6.89	10.45	88.16	-203.17	-205.43	3.69
130	0.58	842	485.64	458.34	700	0.65	28.98	6.89	10.06	87.78	-263.44	-265.41	3.67
140	0.67	761	510.46	488.62	652	0.75	30.68	6.89	9.71	87.42	-309.46	-311.02	3.62
150	0.77	691	532.87	515.47	608	0.85	32.37	6.89	9.38	87.09	-343.81	-344.98	3.55
160	0.88	630	553.07	539.21	567	0.95	34.04	6.89	9.08	86.79	-369.01	-369.86	3.48
170	0.99	577	571.24	560.11	529	1.06	35.68	6.89	8.80	86.51	-387.26	-387.86	3.39
180	1.11	530	587.55	578.44	494	1.17	37.32	6.89	8.53	86.25	-400.33	-400.75	3.31

Table 22

Economic and Biological Yields on Managed Stands Thinned to 2.5 x 2.5m Spacing at 20 Years of Age Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	19.60										
30	0.02	1502	35.78										
40	0.06	1316	78.38										
50	0.11	1155	127.93	102.95	707	0.15	17.30	7.99	14.01	92.82	324.79	391.88	2.29
60	0.18	1020	179.09	154.41	686	0.23	20.21	6.89	12.87	90.58	375.15	424.21	2.81
70	0.25	908	229.07	207.00	654	0.32	22.89	6.89	11.97	89.69	311.39	337.78	3.18
80	0.34	815	276.56	258.22	619	0.42	25.38	6.89	11.24	88.96	200.98	212.18	3.44
90	0.44	736	320.99	306.70	583	0.53	27.73	6.89	10.63	88.35	78.26	81.15	3.61
100	0.54	670	362.20	351.76	548	0.64	29.95	6.89	10.11	87.83	-37.15	-38.06	3.70
110	0.65	612	400.20	393.13	516	0.76	32.06	6.89	9.66	87.37	-136.33	-138.59	3.74
120	0.77	563	435.12	430.77	485	0.89	34.09	6.89	9.26	86.97	-216.91	-219.32	3.75
130	0.90	519	467.13	464.82	457	1.02	36.03	6.89	8.90	86.62	-279.90	-281.99	3.72
140	1.03	481	496.42	495.46	432	1.15	37.89	6.89	8.58	86.30	-327.79	-329.44	3.67
150	1.17	447	523.16	522.91	408	1.28	39.70	6.89	8.29	86.01	-363.45	-364.68	3.61
160	1.31	417	547.54	547.43	386	1.42	41.44	6.89	8.03	85.74	-389.58	-390.47	3.53
170	1.46	390	569.74	569.24	366	1.56	43.13	6.89	7.78	85.50	-408.48	-409.11	3.45
180	1.61	366	589.90	588.60	347	1.70	44.78	6.89	7.56	85.27	-422.01	-422.45	3.36

Table 23

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	816	7.60										
30	0.02	788	16.06										
40	0.06	727	43.08										
50	0.12	666	80.41	68.85	446	0.15	18.92	7.99	13.86	92.67	45.89	55.37	1.53
60	0.20	611	123.74	111.90	439	0.26	22.61	6.89	12.54	90.25	128.37	145.16	2.03
70	0.30	561	169.69	159.25	425	0.37	25.96	6.89	11.53	89.24	117.62	127.59	2.45
80	0.42	518	216.04	208.01	408	0.51	29.03	6.89	10.72	88.43	56.61	59.76	2.77
90	0.54	480	261.43	256.23	391	0.66	31.86	6.89	10.06	87.77	-26.84	-27.84	3.01
100	0.68	446	305.07	302.65	373	0.81	34.48	6.89	9.50	87.21	-113.67	-116.48	3.19
110	0.83	417	346.53	346.53	357	0.97	36.93	6.89	9.02	86.74	-193.20	-196.40	3.30
120	0.99	391	385.61	385.61	341	1.13	39.16	6.89	8.63	86.34	-261.88	-264.79	3.35
130	1.15	367	422.24	422.24	327	1.29	41.28	6.89	8.27	85.99	-316.66	-319.03	3.38
140	1.32	345	456.44	456.44	313	1.46	43.29	6.89	7.95	85.67	-359.09	-360.90	3.38
150	1.49	328	488.28	488.28	300	1.63	45.22	6.89	7.67	85.38	-391.22	-392.55	3.37
160	1.67	310	517.84	517.84	288	1.80	47.07	6.89	7.41	85.12	-415.13	-416.08	3.34
170	1.85	295	545.23	545.23	277	1.97	48.84	6.89	7.17	84.88	-432.69	-433.36	3.30
180	2.03	281	570.57	570.57	267	2.14	50.54	6.89	6.95	84.66	-445.44	-445.91	3.26

Table 24

Economic and Biological Yields on Managed Stands
Thinned to 1.5 x 1.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	28.80										
30	0.02	3881	58.47										
40	0.04	2984	128.63	44.27	523	0.08	14.94	7.99	15.44	94.25	-33.55	-44.94	1.26
50	0.08	2443	185.34	96.25	838	0.11	15.53	7.99	14.64	93.45	204.50	246.75	2.14
60	0.12	2041	238.18	152.99	951	0.16	17.11	7.99	13.75	92.56	273.16	308.88	2.78
70	0.17	1735	286.48	209.41	970	0.22	18.88	7.99	12.98	91.78	226.65	245.86	3.22
80	0.22	1495	330.33	263.01	944	0.28	20.68	6.89	12.31	90.02	139.04	146.79	3.51
90	0.28	1303	370.03	312.64	898	0.35	22.48	6.89	11.72	89.44	17.11	17.74	3.68
100	0.35	1148	405.94	357.93	845	0.42	24.26	6.89	11.21	88.92	-98.59	-101.02	3.77
110	0.43	1019	438.43	398.85	790	0.50	26.02	6.89	10.74	88.46	-198.08	-201.36	3.80
120	0.51	911	467.81	435.59	737	0.59	27.76	6.89	10.33	88.04	-278.71	-281.81	3.79
130	0.60	820	494.38	468.40	687	0.68	29.48	6.89	9.95	87.67	-341.53	-344.09	3.75
140	0.70	742	518.37	497.59	639	0.78	31.18	6.89	9.61	87.32	-389.13	-391.09	3.69
150	0.80	675	540.03	523.46	596	0.88	32.86	6.89	9.29	87.00	-424.45	-425.89	3.61
160	0.91	616	559.53	546.29	556	0.98	34.51	6.89	8.99	86.71	-450.24	-451.28	3.52
170	1.02	565	577.07	566.37	519	1.09	36.16	6.89	8.72	86.43	-468.85	-469.58	3.43
180	1.14	519	592.80	583.95	485	1.20	37.78	6.89	8.46	86.17	-482.34	-482.65	3.34

Table 25

Economic and Biological Yields on Managed Stands
Thinned to 2.5 x 2.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	19.60										
30	0.03	1487	39.70										
40	0.07	1272	94.44	70.92	709	0.10	15.17	7.99	15.00	93.81	240.22	321.75	2.03
50	0.13	1118	145.07	119.51	704	0.17	18.27	7.99	13.61	92.42	376.16	453.86	2.66
60	0.20	990	196.15	171.78	679	0.25	21.08	6.89	12.56	90.27	392.36	443.67	3.12
70	0.28	883	245.47	224.19	645	0.35	23.69	6.89	11.72	89.44	297.13	322.32	3.45
80	0.37	794	292.03	274.68	609	0.45	26.13	6.89	11.04	88.75	163.53	172.64	3.66
90	0.47	719	335.43	322.14	573	0.56	28.42	6.89	10.46	88.18	24.86	25.78	3.79
100	0.57	655	375.59	366.04	539	0.68	30.61	6.89	9.97	87.68	-101.08	-103.57	3.85
110	0.69	600	412.57	406.22	507	0.80	32.68	6.89	9.53	87.25	-207.06	-210.49	3.87
120	0.81	552	446.52	442.69	478	0.93	34.67	6.89	9.15	86.86	-291.95	-295.20	3.85
130	0.94	510	477.61	475.62	450	1.06	36.59	6.89	8.80	86.52	-357.65	-360.33	3.80
140	1.07	473	506.04	505.21	425	1.19	38.43	6.89	8.49	86.21	-407.23	-409.28	3.74
150	1.21	440	531.99	531.69	402	1.32	40.21	6.89	8.21	85.93	-443.93	-445.44	3.67
160	1.35	410	555.63	555.31	381	1.46	41.94	6.89	7.95	85.67	-470.70	-471.78	3.58
170	1.50	384	577.13	576.32	361	1.60	43.61	6.89	7.72	85.43	-490.00	-490.76	3.49
180	1.66	360	596.66	594.92	343	1.74	45.24	6.89	7.50	85.21	-503.78	-504.31	3.40

Table 26

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	816	7.60										
30	0.02	783	18.21										
40	0.08	711	54.10	43.89	445	0.10	16.14	7.99	15.04	93.85	-78.81	-105.56	1.25
50	0.14	652	93.86	81.94	446	0.18	20.12	6.89	13.40	91.11	84.88	102.41	1.82
60	0.23	598	138.41	126.81	436	0.29	23.70	6.89	12.19	89.91	131.88	149.13	2.31
70	0.34	550	184.76	174.95	421	0.42	26.95	6.89	11.25	88.97	97.77	106.05	2.69
80	0.45	508	230.98	223.77	403	0.55	29.93	6.89	10.50	88.21	17.48	18.45	2.98
90	0.59	471	275.92	271.58	386	0.70	32.69	6.89	9.87	87.58	-80.26	-83.23	3.20
100	0.73	439	318.94	317.30	369	0.86	35.25	6.89	9.34	87.06	-177.05	-181.42	3.34
110	0.88	410	359.68	359.68	353	1.02	37.63	6.89	8.89	86.61	-263.83	-268.20	3.43
120	1.03	385	398.01	398.01	337	1.18	39.82	6.89	8.51	86.23	-336.62	-340.36	3.46
130	1.20	362	433.88	433.88	323	1.34	41.90	6.89	8.17	85.88	-394.08	-397.02	3.47
140	1.37	342	467.33	467.33	309	1.51	43.88	6.89	7.86	85.58	-438.22	-440.43	3.46
150	1.54	323	498.44	498.44	297	1.68	45.78	6.89	7.58	85.30	-471.45	-473.05	3.44
160	1.72	307	527.30	527.30	285	1.85	47.60	6.89	7.33	85.05	-496.07	-497.20	3.40
170	1.90	292	554.04	554.04	274	2.02	49.35	6.89	7.10	84.81	-514.07	-514.87	3.36
180	2.08	278	578.75	578.18	264	2.19	51.02	6.89	6.89	84.60	-527.14	-527.69	3.30

Table 27

Economic and Biological Yields on Managed Stands
Thinned to 1.5 x 1.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	28.80										
30	0.01	3960	52.90										
40	0.03	3160	109.14										
50	0.06	2573	166.60	79.39	781	0.10	15.04	7.99	14.96	93.77	156.58	188.92	1.76
60	0.10	2138	220.83	143.64	944	0.15	16.81	7.99	13.89	92.70	279.55	316.11	2.61
70	0.16	1775	279.34	213.65	971	0.22	19.00	7.99	12.93	91.74	299.25	324.62	3.29
80	0.23	1489	336.57	267.03	944	0.28	20.78	6.89	12.27	89.98	206.40	217.90	3.56
90	0.29	1299	375.68	316.39	898	0.35	22.57	6.89	11.69	89.40	80.65	83.63	3.72
100	0.36	1144	411.07	361.37	845	0.43	24.35	6.89	11.18	88.89	-37.55	-38.48	3.80
110	0.44	1017	443.08	401.99	790	0.51	26.10	6.89	10.72	88.44	-138.63	-140.93	3.83
120	0.52	910	472.04	438.44	737	0.60	27.83	6.89	10.31	88.02	-220.27	-222.71	3.81
130	0.61	819	498.21	470.98	686	0.69	29.55	6.89	9.94	87.65	-283.71	-285.83	3.77
140	0.70	741	521.86	499.92	639	0.78	31.24	6.89	9.59	87.31	-331.69	-333.36	3.70
150	0.81	674	543.20	525.56	596	0.88	32.91	6.89	9.28	86.99	-367.25	-368.50	3.62
160	0.91	615	562.42	548.19	556	0.99	34.56	6.89	8.98	86.70	-393.19	-394.09	3.54
170	1.03	564	579.71	568.09	519	1.10	36.20	6.89	8.71	86.42	-411.89	-412.53	3.44
180	1.15	519	595.20	585.50	485	1.21	37.82	6.89	8.45	86.17	-425.23	-425.68	3.35

Table 26

Economic and Biological Yields on Managed Stands
Thinned to 2.5 x 2.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	19.60										
30	0.02	1502	35.78										
40	0.06	1316	78.38	56.72	703	0.08	14.08	7.99	15.56	94.37	158.83	212.74	1.62
50	0.11	1155	127.97	102.95	707	0.15	17.30	7.99	14.01	92.82	324.79	391.88	2.29
60	0.18	1020	179.09	162.63	683	0.24	20.62	6.89	12.72	90.43	396.71	448.59	2.96
70	0.26	897	237.55	228.25	644	0.35	23.84	6.89	11.68	89.39	369.94	401.29	3.51
80	0.38	791	297.38	278.58	608	0.46	26.27	6.89	11.00	88.71	230.86	243.72	3.71
90	0.48	716	340.45	325.81	573	0.57	28.55	6.89	10.43	88.14	88.45	91.72	3.83
100	0.58	653	380.27	369.45	539	0.69	30.72	6.89	9.94	87.65	-39.96	-40.95	3.89
110	0.70	598	416.91	409.36	507	0.81	32.79	6.89	9.51	87.22	-147.54	-149.98	3.90
120	0.82	550	450.54	445.57	477	0.93	34.77	6.89	9.13	86.84	-233.45	-236.04	3.87
130	0.95	509	481.34	478.25	450	1.06	36.67	6.89	8.79	86.50	-299.78	-302.02	3.83
140	1.08	472	509.49	507.61	425	1.19	38.51	6.89	8.48	86.19	-349.76	-351.52	3.76
150	1.22	439	535.17	533.88	402	1.33	40.28	6.89	8.20	85.91	-386.71	-388.02	3.68
160	1.36	410	558.57	557.30	380	1.47	42.00	6.89	7.94	85.66	-413.64	-414.58	3.60
170	1.51	383	579.86	578.12	361	1.60	43.68	6.89	7.71	85.42	-433.03	-433.70	3.50
180	1.67	360	599.17	596.56	342	1.74	45.30	6.89	7.49	85.20	-446.86	-447.33	3.41

Table 29

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	816	7.60										
30	0.02	788	16.06										
40	0.06	727	43.08	33.90	440	0.08	14.78	7.99	15.69	94.50	-111.54	-149.40	0.97
50	0.12	666	80.41	68.85	446	0.15	18.92	7.99	13.86	92.67	45.89	55.37	1.53
60	0.22	605	130.53	118.78	438	0.27	23.12	6.89	12.37	90.09	142.47	161.10	2.16
70	0.34	549	187.89	178.20	420	0.42	27.13	6.89	11.20	88.92	167.50	181.70	2.74
80	0.46	507	234.08	227.03	403	0.56	30.10	6.89	10.46	88.17	83.18	87.82	3.03
90	0.59	470	278.93	274.75	386	0.71	32.84	6.89	9.84	87.55	-17.51	-18.16	3.23
100	0.73	438	321.83	320.33	368	0.87	35.39	6.89	9.31	87.03	-116.36	-119.23	3.37
110	0.89	409	362.43	362.43	352	1.03	37.75	6.89	8.87	86.59	-204.62	-208.00	3.45
120	1.04	384	400.61	400.61	337	1.19	39.93	6.89	8.49	86.20	-278.26	-281.35	3.48
130	1.21	362	436.33	436.33	322	1.35	42.00	6.89	8.15	85.87	-336.27	-338.78	3.49
140	1.38	341	469.63	469.63	309	1.52	43.98	6.89	7.85	85.56	-380.77	-382.69	3.48
150	1.55	323	500.60	500.60	297	1.69	45.88	6.89	7.57	85.28	-414.22	-415.63	3.45
160	1.73	306	529.32	529.32	285	1.86	47.69	6.89	7.32	85.03	-438.99	-440.00	3.41
170	1.91	291	555.92	555.92	274	2.03	49.43	6.89	7.09	84.80	-457.09	-457.80	3.37
180	2.09	277	580.52	579.81	264	2.20	51.09	6.89	6.88	84.59	-470.22	-470.71	3.31

Table 30

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1572	0.11										
20	0.00	1464	6.74										
30	0.02	1313	30.98										
40	0.06	1161	70.34										
50	0.11	1027	117.53	97.29	650	0.15	17.71	7.99	13.94	92.75	-237.94	-287.09	2.16
60	0.18	913	167.21	148.01	629	0.24	20.81	6.89	12.75	90.46	-178.37	-201.70	2.69
70	0.26	817	216.38	200.91	599	0.34	23.68	6.89	11.82	89.53	-229.88	-249.36	3.09
80	0.36	736	263.51	253.49	566	0.45	26.36	6.89	11.06	88.77	-329.73	-348.10	3.38
90	0.46	668	307.88	304.29	534	0.57	28.89	6.89	10.42	88.14	-444.82	-461.27	3.58
100	0.57	609	349.20	349.20	503	0.69	31.20	6.89	9.90	87.62	-559.59	-573.41	3.68
110	0.69	558	387.43	387.43	473	0.82	33.31	6.89	9.47	87.19	-660.92	-671.86	3.69
120	0.82	514	422.64	422.64	446	0.95	35.33	6.89	9.09	86.80	-741.75	-750.00	3.68
130	0.96	476	454.97	454.97	421	1.08	37.30	6.89	8.74	86.45	-804.20	-810.22	3.64
140	1.10	442	484.57	484.57	397	1.22	39.20	6.89	8.43	86.14	-851.34	-855.63	3.59
150	1.24	411	511.63	511.63	376	1.36	41.05	6.89	8.14	85.85	-886.29	-889.31	3.53
160	1.40	384	536.32	536.32	356	1.51	42.85	6.89	7.87	85.58	-911.85	-913.95	3.46
170	1.55	360	558.79	558.79	338	1.65	44.61	6.89	7.62	85.34	-930.34	-931.78	3.39
180	1.72	338	579.20	579.20	321	1.81	46.33	6.89	7.39	85.11	-943.59	-944.58	3.31

Table 31

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 20 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1572	0.11										
20	0.00	1464	6.74										
30	0.03	1301	34.52										
40	0.08	1126	85.42	66.26	654	0.10	15.42	7.99	14.97	93.78	-331.31	-443.77	1.89
50	0.13	997	134.01	113.48	646	0.18	18.73	7.99	13.52	92.33	-189.29	-228.39	2.52
60	0.21	888	183.87	165.36	622	0.27	21.74	6.89	12.43	90.14	-161.00	-182.06	3.01
70	0.29	796	232.56	218.46	591	0.37	24.54	6.89	11.56	89.28	-242.56	-263.11	3.36
80	0.39	718	278.88	270.66	558	0.49	27.16	6.89	10.85	88.56	-365.14	-385.49	3.61
90	0.49	653	322.30	320.74	526	0.61	29.64	6.89	10.24	87.96	-496.25	-514.60	3.77
100	0.61	596	362.63	362.63	495	0.73	31.85	6.89	9.76	87.48	-624.54	-639.95	3.82
110	0.73	547	399.87	399.87	466	0.86	33.93	6.89	9.35	87.06	-732.18	-744.29	3.81
120	0.86	505	434.13	434.13	439	0.99	35.93	6.89	8.98	86.69	-817.03	-826.11	3.78
130	1.00	467	465.56	465.56	415	1.12	37.87	6.89	8.64	86.36	-882.03	-888.63	3.72
140	1.14	434	494.31	494.31	392	1.26	39.75	6.89	8.34	86.05	-930.78	-935.47	3.66
150	1.29	405	520.58	520.58	371	1.40	41.58	6.89	8.05	85.77	-966.75	-970.03	3.59
160	1.44	378	544.52	544.52	351	1.55	43.36	6.89	7.79	85.51	-992.94	-995.22	3.51
170	1.60	355	566.30	566.30	333	1.70	45.11	6.89	7.55	85.27	-1011.83	-1013.40	3.43
180	1.76	333	586.08	586.08	317	1.85	46.81	6.89	7.33	85.04	-1025.33	-1026.40	3.35

Table 32

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 50 Years of Age
Good Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1572	0.11										
20	0.00	1464	6.74										
30	0.02	1313	30.98										
40	0.06	1161	70.34										
50	0.11	1027	117.53	97.29	650	0.15	17.71	7.99	13.94	92.75	-237.94	-287.09	2.16
60	0.19	902	175.13	156.19	626	0.25	21.25	6.89	12.60	90.31	-156.92	-177.44	2.84
70	0.30	793	236.43	222.58	590	0.38	24.70	6.89	11.51	89.22	-169.49	-183.85	3.42
80	0.39	716	282.58	274.70	557	0.49	27.31	6.89	10.81	88.52	-297.39	-313.97	3.66
90	0.50	651	325.79	324.63	525	0.62	29.78	6.89	10.21	87.92	-432.24	-448.22	3.82
100	0.62	595	365.89	365.89	494	0.74	31.97	6.89	9.74	87.45	-563.59	-577.50	3.85
110	0.74	546	402.91	402.91	465	0.87	34.03	6.89	9.33	87.04	-672.74	-683.87	3.84
120	0.87	504	436.96	436.96	439	1.00	36.02	6.89	8.96	86.67	-758.55	-766.98	3.80
130	1.00	467	468.18	468.18	414	1.13	37.96	6.89	8.62	86.34	-824.16	-830.33	3.75
140	1.15	434	496.74	496.74	391	1.27	39.83	6.89	8.32	86.03	-873.30	-877.70	3.68
150	1.29	404	522.82	522.82	370	1.41	41.66	6.89	8.04	85.75	-909.51	-912.60	3.61
160	1.45	378	546.60	546.60	351	1.56	43.44	6.89	7.78	85.50	-935.86	-938.01	3.53
170	1.60	354	568.22	568.22	333	1.71	45.18	6.89	7.54	85.26	-954.84	-956.32	3.44
180	1.77	333	587.85	587.85	317	1.86	46.88	6.89	7.32	85.03	-968.40	-969.41	3.36

MEDIUM SITES

Table 33

Economic and Biological Yields on Unmanaged Stands
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	Total Costs	NPV	SEV	MAI
0														
10														
20	0.00	30366	36.01					Average Costs		=	19.48			
30	0.00	20109	60.09					Total Average Costs		=	19.59			
40	0.01	7697	107.13											
50	0.03	4678	151.01											
60	0.05	3923	197.06											
70	0.07	3352	239.69	80.86	642	0.13	16.69	7.99	14.39	93.20	22.38	96.72	104.92	1.24
80	0.10	2910	278.96	128.32	862	0.15	16.92	7.99	13.95	92.76	22.02	119.64	126.31	1.71
90	0.12	2560	315.11	176.72	978	0.18	17.73	7.99	13.44	92.25	21.50	101.97	105.74	2.08
100	0.15	2276	348.43	224.95	1035	0.22	18.72	7.99	12.96	91.77	21.00	65.12	66.72	2.37
110	0.19	2043	379.18	272.38	1057	0.26	19.78	7.99	12.51	91.32	20.55	22.49	22.86	2.59
120	0.22	1848	407.60	318.60	1057	0.30	20.85	6.89	12.10	89.81	19.04	-14.72	-14.88	2.77
130	0.26	1683	433.91	363.38	1046	0.35	21.93	6.89	11.72	89.44	18.66	-51.63	-52.02	2.91
140	0.30	1542	458.28	406.58	1026	0.40	22.99	6.89	11.38	89.10	18.31	-82.27	-82.69	3.01
150	0.34	1420	480.89	448.10	1003	0.45	24.03	6.89	11.06	88.78	17.99	-106.76	-107.12	3.09
160	0.38	1314	501.86	487.89	977	0.50	25.05	6.89	10.77	88.49	17.70	-125.80	-126.09	3.15
170	0.43	1221	521.33	521.33	951	0.55	25.97	6.89	10.53	88.24	17.43	-140.67	-140.89	3.16
180	0.47	1139	539.40	539.40	924	0.58	26.65	6.89	10.36	88.08	17.18	-152.42	-152.58	3.08

Table 34

Economic and Biological Yields on Unmanaged Stands
Fertilized at 70 Years of Age
Medium Sites

Age	Tres	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	30366	36.01										
30	0.00	20109	60.09										
40	0.01	7697	107.13										
50	0.03	4678	151.01										
60	0.05	3923	197.06										
70	0.07	3352	239.69	80.86	642	0.13	16.69	7.99	14.39	93.20	96.72	104.92	1.24
80	0.10	2843	287.48	138.15	879	0.16	17.18	7.99	13.81	92.62	132.05	139.41	1.84
90	0.14	2428	335.34	202.63	990	0.20	18.47	7.99	13.12	91.93	134.12	139.07	2.38
100	0.17	2169	367.06	250.67	1031	0.24	19.46	7.99	12.66	91.47	83.35	85.41	2.64
110	0.20	1954	396.36	297.62	1044	0.29	20.50	6.89	12.25	89.96	36.28	36.88	2.83
120	0.24	1774	423.47	343.19	1040	0.33	21.56	6.89	11.86	89.58	-12.62	-12.76	2.98
130	0.28	1621	448.58	387.21	1026	0.38	22.62	6.89	11.51	89.22	-54.15	-54.56	3.10
140	0.32	1489	471.87	429.57	1006	0.43	23.66	6.89	11.18	88.90	-87.88	-88.32	3.18
150	0.36	1375	493.47	470.21	982	0.48	24.68	6.89	10.88	88.60	-114.41	-114.80	3.24
160	0.40	1275	513.53	509.09	957	0.53	25.68	6.89	10.63	88.32	-134.81	-135.12	3.28
170	0.45	1186	532.15	532.15	931	0.57	26.43	6.89	10.42	88.13	-151.33	-151.56	3.23
180	0.50	1108	549.45	549.45	905	0.61	27.10	6.89	10.26	87.97	-163.41	-163.58	3.14

Table 35

Economic and Biological Yields on Managed Stands Thinned to 1.5 x 1.5m Spacing at 20 Years of Age Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	22.80										
30	0.01	4049	40.12										
40	0.02	3362	81.58										
50	0.04	2823	125.36	45.14	600	0.08	14.05	7.99	15.75	94.56	-103.01	-124.28	1.00
60	0.07	2405	167.78	80.50	727	0.11	15.25	7.99	14.87	93.68	-27.68	-31.30	1.46
70	0.10	2075	207.40	119.35	839	0.14	16.72	7.99	14.07	92.88	-19.63	-21.29	1.84
80	0.13	1812	243.80	159.43	861	0.19	18.24	7.99	13.38	92.19	-53.92	-56.92	2.13
90	0.17	1597	276.99	199.36	856	0.23	19.76	7.99	12.78	91.59	-108.16	-112.16	2.35
100	0.22	1420	307.12	238.26	835	0.29	21.26	6.89	12.24	89.96	-161.00	-164.97	2.51
110	0.26	1271	334.42	275.60	806	0.34	22.73	6.89	11.77	89.48	-217.89	-221.49	2.62
120	0.31	1146	359.10	311.04	774	0.40	24.18	6.89	11.34	89.06	-267.06	-270.03	2.70
130	0.37	1038	381.40	344.39	740	0.47	25.59	6.89	10.96	88.67	-307.39	-309.69	2.76
140	0.42	945	401.50	375.54	707	0.53	26.97	6.89	10.61	88.32	-339.29	-341.00	2.78
150	0.49	864	419.59	404.45	674	0.60	28.32	6.89	10.29	88.00	-363.84	-365.08	2.79
160	0.55	793	435.85	431.10	642	0.67	29.64	6.89	9.99	87.71	-382.35	-383.23	2.78
170	0.62	730	450.42	450.42	612	0.74	30.82	6.89	9.75	87.47	-396.50	-397.11	2.73
180	0.69	674	463.44	463.44	583	0.79	31.87	6.89	9.55	87.27	-406.92	-407.35	2.65

Table 36

Economic and Biological Yields on Managed Stands Thinned to 2.5 x 2.5m Spacing at 20 Years of Age Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	12.80										
30	0.02	1522	23.13										
40	0.04	1369	51.40										
50	0.07	1229	85.98	54.34	560	0.10	15.53	7.99	15.08	93.89	-52.75	-63.65	1.21
60	0.11	1106	123.18	84.72	566	0.15	18.07	7.99	13.94	92.75	-20.24	-22.88	1.54
70	0.16	1001	160.66	118.08	560	0.21	20.40	6.89	13.04	90.75	-27.14	-29.44	1.82
80	0.22	910	197.08	153.02	548	0.28	22.55	6.89	12.30	90.01	-74.33	-78.47	2.04
90	0.28	832	231.73	188.53	532	0.35	24.58	6.89	11.67	89.39	-133.75	-138.70	2.22
100	0.35	764	264.26	223.93	515	0.43	26.50	6.89	11.14	88.85	-194.09	-198.88	2.36
110	0.42	705	294.55	258.74	498	0.52	28.32	6.89	10.67	88.38	-249.10	-253.22	2.46
120	0.49	653	322.57	292.58	480	0.61	30.06	6.89	10.25	87.96	-296.09	-299.39	2.54
130	0.57	607	348.40	325.21	463	0.70	31.72	6.89	9.88	87.59	-334.49	-336.99	2.60
140	0.66	566	372.11	356.41	447	0.80	33.31	6.89	9.54	87.26	-364.87	-366.71	2.64
150	0.74	530	393.82	386.06	432	0.89	34.83	6.89	9.24	86.95	-388.34	-389.66	2.66
160	0.83	497	413.65	413.65	417	0.99	36.28	6.89	8.97	86.68	-406.17	-407.10	2.67
170	0.93	467	431.72	431.72	403	1.07	37.44	6.89	8.76	86.48	-420.09	-420.74	2.62
180	1.02	439	448.15	448.15	390	1.15	38.56	6.89	8.58	86.29	-430.08	-430.53	2.56

Table 37

Economic and Biological Yields on Managed Stands Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	3.80										
30	0.01	795	8.32										
40	0.03	747	23.77										
50	0.07	697	46.81	30.87	346	0.09	16.11	7.99	15.30	94.11	-250.00	-301.64	0.69
60	0.12	650	75.25	53.10	355	0.15	19.36	7.99	13.94	92.75	-204.90	-231.69	0.97
70	0.18	606	106.90	79.46	356	0.22	22.28	6.89	12.89	90.60	-188.61	-204.60	1.22
80	0.25	566	140.04	108.65	354	0.31	24.94	6.89	12.05	89.76	-205.76	-217.22	1.45
90	0.33	530	173.43	139.66	349	0.40	27.39	6.89	11.35	89.07	-237.95	-246.75	1.64
100	0.41	497	206.27	171.73	343	0.50	29.66	6.89	10.76	88.48	-275.91	-282.73	1.81
110	0.51	468	238.02	204.32	336	0.61	31.79	6.89	10.26	87.97	-313.62	-318.81	1.95
120	0.61	442	268.38	237.00	329	0.72	33.79	6.89	9.81	87.53	-347.74	-351.61	2.06
130	0.71	418	297.16	269.43	322	0.84	35.67	6.89	9.42	87.13	-376.86	-379.68	2.16
140	0.82	396	324.28	301.36	316	0.95	37.45	6.89	9.07	86.78	-400.72	-402.74	2.23
150	0.93	377	349.72	332.58	309	1.08	39.13	6.89	8.75	86.47	-419.68	-421.11	2.29
160	1.04	359	373.48	362.91	303	1.20	40.73	6.89	8.47	86.18	-434.42	-435.42	2.34
170	1.16	342	395.61	392.21	297	1.32	42.25	6.89	8.21	85.93	-445.66	-446.35	2.38
180	1.27	327	416.17	416.17	291	1.43	43.53	6.89	8.00	85.72	-454.35	-454.82	2.38

Table 38

Economic and Biological Yields on Managed Stands
Thinned to 1.5 x 1.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	22.80										
30	0.01	3971	45.23										
40	0.03	3173	100.17										
50	0.05	2677	143.79	58.30	656	0.09	14.72	7.99	15.31	94.12	-85.19	-102.78	1.30
60	0.08	2291	185.18	95.54	786	0.12	15.99	7.99	14.49	93.30	-30.27	-34.23	1.74
70	0.11	1985	223.50	135.24	841	0.16	17.45	7.99	13.75	92.56	-43.58	-47.27	2.08
80	0.15	1739	258.55	175.52	853	0.21	18.95	7.99	13.10	91.91	-95.43	-100.75	2.34
90	0.19	1538	290.43	215.24	842	0.26	20.44	6.89	12.53	90.25	-154.33	-160.04	2.53
100	0.23	1371	319.35	253.66	819	0.31	21.92	6.89	12.03	89.74	-224.39	-229.93	2.67
110	0.28	1230	345.51	290.36	790	0.37	23.38	6.89	11.58	89.29	-287.73	-292.49	2.77
120	0.33	1111	369.17	325.05	758	0.43	24.80	6.89	11.17	88.89	-341.22	-345.01	2.83
130	0.39	1008	390.51	357.60	725	0.49	26.20	6.89	10.80	88.52	-384.39	-387.27	2.86
140	0.45	919	409.75	387.91	692	0.56	27.56	6.89	10.47	88.18	-418.14	-420.25	2.87
150	0.51	842	427.05	415.96	660	0.63	28.90	6.89	10.16	87.87	-443.89	-445.40	2.87
160	0.57	773	442.59	441.76	629	0.70	30.20	6.89	9.87	87.59	-463.18	-464.24	2.85
170	0.64	713	456.50	456.50	599	0.76	31.28	6.89	9.66	87.38	-478.12	-478.86	2.77
180	0.71	659	468.91	468.91	572	0.82	32.32	6.89	9.47	87.18	-488.75	-489.26	2.68

Table 39

Economic and Biological Yields on Managed Stands
Thinned to 2.5 x 2.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	12.80										
30	0.02	1508	26.32										
40	0.05	1325	65.29										
50	0.09	1190	101.45	66.37	560	0.12	16.68	7.99	14.55	93.36	-40.16	-48.46	1.47
60	0.13	1073	139.09	98.26	561	0.18	19.12	7.99	13.53	92.34	-28.39	-32.11	1.79
70	0.18	972	176.34	132.51	553	0.24	21.36	6.89	12.70	90.41	-53.69	-58.24	2.04
80	0.24	886	212.16	167.87	539	0.31	23.46	6.89	12.01	89.73	-117.12	-123.64	2.24
90	0.30	811	246.01	203.51	523	0.39	25.44	6.89	11.43	89.14	-188.70	-195.68	2.39
100	0.37	746	277.67	238.81	506	0.47	27.32	6.89	10.92	88.64	-257.76	-264.12	2.51
110	0.45	690	307.04	273.35	489	0.56	29.10	6.89	10.48	88.19	-318.86	-324.13	2.60
120	0.52	640	334.17	306.80	472	0.65	30.80	6.89	10.08	87.80	-370.01	-374.13	2.67
130	0.60	595	359.13	338.94	456	0.74	32.43	6.89	9.73	87.44	-411.22	-414.30	2.71
140	0.69	556	382.02	369.59	440	0.84	33.99	6.89	9.41	87.12	-443.48	-445.72	2.74
150	0.77	520	402.95	398.64	425	0.94	35.48	6.89	9.12	86.83	-468.19	-469.78	2.75
160	0.86	488	422.04	422.04	411	1.03	36.92	6.89	8.87	86.59	-487.26	-488.38	2.72
170	0.96	459	439.43	439.43	397	1.11	38.30	6.89	8.68	86.39	-501.58	-502.36	2.66
180	1.05	433	455.21	455.21	384	1.19	39.62	6.89	8.50	86.21	-511.82	-512.36	2.60

Table 40

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	3.80										
30	0.01	791	9.79										
40	0.04	733	32.09										
50	0.08	683	57.62	39.10	348	0.11	17.52	7.99	14.69	93.50	-267.67	-322.96	0.87
60	0.14	637	87.65	63.19	353	0.18	20.63	6.89	13.47	91.19	-223.98	-253.27	1.15
70	0.20	594	120.15	90.88	353	0.26	23.44	6.89	12.52	90.23	-226.71	-245.92	1.40
80	0.28	555	153.58	120.97	350	0.35	26.01	6.89	11.74	89.45	-255.21	-269.44	1.61
90	0.36	520	186.90	152.55	345	0.44	28.39	6.89	11.09	88.81	-296.63	-307.60	1.79
100	0.45	488	219.41	184.97	339	0.55	30.61	6.89	10.54	88.25	-341.59	-350.02	1.95
110	0.54	460	250.69	217.71	332	0.66	32.68	6.89	10.06	87.77	-384.38	-390.74	2.07
120	0.65	435	280.47	250.40	325	0.77	34.63	6.89	9.64	87.35	-422.12	-426.81	2.18
130	0.75	412	308.64	282.73	319	0.89	36.48	6.89	9.26	86.98	-453.75	-457.15	2.26
140	0.86	391	335.11	314.47	312	1.01	38.22	6.89	8.93	86.64	-479.34	-481.76	2.33
150	0.97	372	359.90	345.42	306	1.13	39.87	6.89	8.62	86.34	-499.48	-501.18	2.38
160	1.08	354	383.03	375.42	299	1.25	41.43	6.89	8.35	86.07	-515.01	-516.19	2.42
170	1.20	338	404.55	404.35	293	1.38	42.91	6.89	8.10	85.82	-526.78	-527.60	2.45
180	1.31	323	424.52	424.52	288	1.48	44.06	6.89	7.92	85.64	-536.01	-536.57	2.43

Table 41

Economic and Biological Yields on Managed Stands Thinned to 1.5 x 1.5m Spacing at 20 Years of Age Fertilized at 50 Years of Age Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	4444	22.80										
30	0.01	4049	40.12										
40	0.02	3362	81.53										
50	0.04	2823	125.36	45.14	600	0.08	14.05	7.99	15.75	94.56	-103.01	-124.28	1.00
60	0.07	2355	176.37	87.56	777	0.11	15.61	7.99	14.68	93.49	-15.78	-17.84	1.59
70	0.12	1978	228.17	139.21	842	0.17	17.61	7.99	13.68	92.49	27.50	30.16	2.14
80	0.15	1734	262.85	179.59	853	0.21	19.09	7.99	13.04	91.85	-28.37	-29.95	2.39
90	0.19	1534	294.37	219.30	842	0.26	20.58	6.89	12.48	90.20	-90.34	-93.69	2.58
100	0.24	1368	322.95	257.65	819	0.31	22.05	6.89	11.99	89.70	-162.76	-166.78	2.71
110	0.28	1228	348.80	294.23	789	0.37	23.49	6.89	11.54	89.26	-227.72	-231.49	2.80
120	0.34	1109	372.17	328.78	757	0.43	24.91	6.89	11.14	88.85	-282.31	-285.44	2.86
130	0.39	1007	393.25	361.16	724	0.50	26.29	6.89	10.78	88.49	-326.21	-328.65	2.89
140	0.45	918	412.25	391.29	691	0.57	27.65	6.89	10.44	88.16	-360.44	-362.26	2.90
150	0.51	841	429.34	419.16	659	0.64	28.98	6.89	10.14	87.85	-386.51	-387.82	2.89
160	0.58	772	444.68	444.68	628	0.71	30.28	6.89	9.86	87.57	-406.01	-406.94	2.87
170	0.64	712	458.41	458.41	599	0.77	31.33	6.89	9.65	87.36	-421.14	-421.79	2.78
180	0.71	658	470.66	470.66	571	0.82	32.37	6.89	9.46	87.17	-431.83	-432.28	2.69

Table 42

Economic and Biological Yields on Managed Stands
Thinned to 2.5 x 2.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.01	1600	12.80										
30	0.02	1522	23.13										
40	0.04	1369	51.40										
50	0.07	1229	85.98	54.34	560	0.10	15.53	7.99	15.08	93.89	-52.75	-63.65	1.21
60	0.12	1092	130.67	91.01	564	0.16	18.56	7.99	13.74	92.55	-11.30	-12.78	1.65
70	0.19	969	179.96	135.80	552	0.25	21.55	7.99	12.63	91.44	4.21	4.57	2.09
80	0.24	883	215.65	171.27	539	0.32	23.64	6.89	11.96	89.67	-51.31	-54.17	2.28
90	0.31	809	249.33	206.95	523	0.40	25.60	6.89	11.38	89.10	-125.66	-130.30	2.43
100	0.38	745	280.80	242.25	506	0.48	27.46	6.89	10.88	88.60	-196.69	-201.55	2.55
110	0.45	688	309.98	276.74	489	0.57	29.24	6.89	10.44	88.16	-259.18	-263.47	2.64
120	0.53	638	336.92	310.13	472	0.66	30.93	6.89	10.05	87.76	-311.28	-314.74	2.70
130	0.61	594	361.68	342.18	455	0.75	32.55	6.89	9.70	87.41	-353.13	-355.78	2.74
140	0.69	555	384.39	372.73	440	0.85	34.10	6.89	9.38	87.09	-385.83	-387.77	2.76
150	0.78	519	405.15	401.66	425	0.95	35.59	6.89	9.09	86.81	-410.82	-412.22	2.77
160	0.87	487	424.09	424.09	410	1.03	36.88	6.89	8.86	86.57	-430.19	-431.18	2.74
170	0.96	458	441.32	441.32	397	1.11	38.02	6.89	8.67	86.38	-444.60	-445.29	2.67
180	1.06	432	456.97	456.97	384	1.19	39.11	6.89	8.49	86.20	-454.90	-455.38	2.61

Table 43

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	3.80										
30	0.01	795	8.32										
40	0.03	747	23.77										
50	0.07	697	46.81	30.87	346	0.09	16.11	7.99	15.30	94.11	-250.00	-301.64	0.69
60	0.13	644	80.90	57.67	354	0.16	19.95	7.99	13.72	92.53	-205.37	-232.23	1.05
70	0.21	592	122.77	93.16	353	0.26	23.65	6.89	12.45	90.16	-161.07	-174.72	1.43
80	0.28	553	156.25	123.42	350	0.35	26.21	6.89	11.68	89.40	-191.88	-202.58	1.65
90	0.37	519	189.55	155.12	345	0.45	28.57	6.89	11.04	88.76	-235.14	-243.84	1.82
100	0.46	487	222.00	187.60	338	0.55	30.77	6.89	10.50	88.21	-281.49	-288.44	1.97
110	0.55	459	253.19	220.38	332	0.66	32.84	6.89	10.02	87.74	-325.30	-330.68	2.10
120	0.65	434	282.87	253.07	325	0.78	34.78	6.89	9.60	87.32	-363.75	-367.79	2.20
130	0.76	411	310.91	285.40	318	0.90	36.61	6.89	9.23	86.95	-395.88	-398.84	2.28
140	0.86	390	337.27	317.10	312	1.02	38.35	6.89	8.90	86.62	-421.81	-423.94	2.35
150	0.98	371	361.94	348.01	305	1.14	39.99	6.89	8.60	86.32	-442.19	-443.69	2.40
160	1.09	354	384.95	377.96	299	1.26	41.55	6.89	8.33	86.05	-457.88	-458.93	2.44
170	1.20	338	406.35	406.35	293	1.39	43.01	6.89	8.09	85.80	-469.79	-470.52	2.46
180	1.32	323	426.21	426.21	287	1.48	44.14	6.89	7.91	85.62	-479.10	-479.60	2.44

Table 44

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1573	0.07										
20	0.00	1485	3.76										
30	0.01	1364	18.01										
40	0.03	1236	43.06										
50	0.07	1116	75.19	48.03	519	0.09	15.44	7.99	15.20	94.01	-621.51	-749.89	1.07
60	0.11	1009	110.76	76.69	525	0.15	18.13	7.99	14.00	92.81	-583.08	-659.34	1.39
70	0.16	916	147.26	108.58	519	0.21	20.58	6.89	13.06	90.77	-582.82	-632.21	1.67
80	0.22	836	183.18	142.27	508	0.28	22.84	6.89	12.29	90.01	-622.08	-656.75	1.90
90	0.28	766	217.64	176.74	494	0.36	24.96	6.89	11.65	89.36	-674.77	-699.72	2.08
100	0.35	705	250.22	211.25	478	0.44	26.96	6.89	11.09	88.81	-729.76	-747.77	2.22
110	0.43	652	280.68	245.30	462	0.53	28.86	6.89	10.61	88.33	-780.69	-793.61	2.34
120	0.51	605	308.98	278.50	446	0.62	30.66	6.89	10.19	87.90	-824.66	-833.83	2.42
130	0.60	563	335.12	310.59	431	0.72	32.38	6.89	9.81	87.52	-860.86	-867.30	2.48
140	0.68	526	359.18	341.35	416	0.82	34.02	6.89	9.47	87.18	-889.67	-894.16	2.53
150	0.77	492	381.25	370.63	402	0.92	35.60	6.89	9.16	86.87	-912.03	-915.13	2.56
160	0.87	462	401.44	398.32	389	1.03	37.10	6.89	8.88	86.60	-929.02	-931.16	2.57
170	0.97	435	419.85	419.85	376	1.12	38.41	6.89	8.65	86.37	-942.11	-943.57	2.54
180	1.07	410	436.61	436.61	363	1.20	39.57	6.89	8.46	86.18	-951.81	-952.81	2.49

Table 45

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 20 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1573	0.07										
20	0.00	1485	3.76										
30	0.02	1353	20.72										
40	0.05	1200	55.65										
50	0.08	1083	89.69	59.21	519	0.11	16.63	7.99	14.65	93.46	-615.85	-743.06	1.32
60	0.13	981	126.00	89.48	520	0.17	19.21	7.99	13.57	92.38	-595.45	-673.32	1.63
70	0.18	892	162.50	122.35	513	0.24	21.58	6.89	12.71	90.43	-611.95	-663.82	1.88
80	0.24	815	197.98	156.55	501	0.31	23.78	6.89	12.00	89.72	-666.42	-703.56	2.09
90	0.31	748	231.77	191.21	486	0.39	25.84	6.89	11.40	89.11	-730.65	-757.66	2.25
100	0.38	689	263.55	225.68	471	0.48	27.80	6.89	10.88	88.59	-793.98	-813.58	2.38
110	0.46	638	293.16	259.52	455	0.57	29.65	6.89	10.42	88.14	-850.77	-864.85	2.47
120	0.54	593	320.60	292.39	439	0.67	31.42	6.89	10.02	87.73	-898.77	-908.76	2.54
130	0.63	552	345.91	324.04	424	0.76	33.11	6.89	9.66	87.37	-937.70	-944.72	2.59
140	0.72	516	369.16	354.29	410	0.86	34.72	6.89	9.33	87.04	-968.34	-973.23	2.62
150	0.81	484	390.46	383.01	396	0.97	36.26	6.89	9.03	86.75	-991.91	-995.28	2.64
160	0.90	454	409.92	409.92	383	1.07	37.74	6.89	8.77	86.48	-1009.73	-1012.04	2.64
170	1.00	428	427.65	427.65	370	1.15	38.93	6.89	8.57	86.28	-1023.60	-1025.18	2.59
180	1.10	404	443.77	443.77	358	1.24	40.06	6.89	8.39	86.10	-1033.54	-1034.62	2.54

Table 46

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 50 Years of Age
Medium Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1573	0.07										
20	0.00	1485	3.76										
30	0.01	1364	18.01										
40	0.03	1236	43.06										
50	0.07	1116	75.19	48.03	519	0.09	15.44	7.99	15.20	94.01	-621.51	-749.89	1.07
60	0.12	997	117.90	82.61	523	0.16	18.63	7.99	13.80	92.61	-576.21	-651.57	1.50
70	0.19	889	165.95	125.45	513	0.24	21.77	6.89	12.65	90.36	-543.18	-589.22	1.93
80	0.25	812	201.33	159.78	500	0.32	23.95	6.89	11.95	89.66	-601.09	-634.58	2.13
90	0.32	746	234.98	194.48	486	0.40	26.01	6.89	11.35	89.07	-667.90	-692.60	2.29
100	0.39	688	266.59	228.96	470	0.49	27.95	6.89	10.84	88.55	-733.10	-751.20	2.41
110	0.46	637	296.03	262.77	454	0.58	29.80	6.89	10.39	88.10	-791.21	-804.30	2.50
120	0.55	591	323.29	295.58	439	0.67	31.55	6.89	9.99	87.70	-840.12	-849.46	2.57
130	0.63	551	348.42	327.15	424	0.77	33.23	6.89	9.63	87.34	-879.66	-886.25	2.62
140	0.72	515	371.50	357.31	409	0.87	34.84	6.89	9.30	87.02	-910.72	-915.31	2.65
150	0.81	483	392.64	385.92	396	0.98	36.37	6.89	9.01	86.73	-934.56	-937.74	2.66
160	0.91	454	411.95	411.95	383	1.08	37.82	6.89	8.75	86.47	-952.66	-954.84	2.66
170	1.01	427	429.53	429.53	370	1.16	39.00	6.89	8.55	86.27	-966.62	-968.12	2.60
180	1.11	403	445.51	445.51	358	1.24	40.13	6.89	8.37	86.09	-976.62	-977.64	2.55

POOR SITES

Table 47

Economic and Biological Yields on Unmanaged Stands
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	Tot Costs	NPV	SEV	MAI
0														
10														
20	0.00	68585	19.66											
30	0.00	44059	34.91											
40	0.00	15017	65.17											
50	0.01	8768	94.42											
60	0.02	6153	121.89											
70	0.03	4748	147.27											
80	0.04	3882	170.51	30.86	393	0.08	15.12	7.99	15.64	94.45	23.63	-110.69	-116.86	0.41
90	0.06	3322	192.13	59.31	612	0.10	15.32	7.99	15.08	93.89	23.07	-88.82	-92.11	0.70
100	0.07	2872	211.28	87.08	735	0.12	16.01	7.99	14.55	93.36	22.54	-88.46	-90.64	0.92
110	0.09	2504	228.19	113.44	799	0.14	16.84	7.99	14.08	92.89	22.07	-98.56	-100.19	1.08
120	0.11	2200	243.08	138.00	825	0.17	17.73	7.99	13.65	92.46	21.64	-112.42	-113.67	1.20
130	0.13	1945	256.16	160.57	829	0.19	18.63	7.99	13.26	92.07	21.25	-126.42	-127.37	1.28
140	0.15	1729	267.59	181.06	819	0.22	19.54	7.99	12.91	91.72	20.90	-138.87	-139.57	1.34
150	0.18	1544	277.53	199.47	799	0.25	20.45	6.89	12.60	90.31	19.49	-148.43	-148.94	1.36
160	0.21	1385	286.13	215.86	774	0.28	21.34	6.89	12.30	90.02	19.20	-156.78	-157.14	1.38
170	0.24	1247	293.50	230.29	746	0.31	22.23	6.89	12.04	89.75	18.93	-163.17	-163.43	1.39
180	0.27	1127	299.75	242.86	716	0.34	23.11	6.89	11.79	89.50	18.68	-167.94	-168.12	1.40

Average Cost = 21.04

Table 48

Economic and Biological Yields on Unmanaged Stands Fertilized at 80 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	68585	19.66										
30	0.00	44059	34.91										
40	0.00	15017	65.17										
50	0.01	8768	94.42										
60	0.02	6153	121.89										
70	0.03	4748	147.27										
80	0.04	3882	170.51	30.86	393	0.08	15.12	7.99	15.64	94.45	-110.69	-116.86	0.41
90	0.07	3177	207.26	72.75	635	0.11	16.18	7.99	14.64	93.45	-74.83	-77.60	0.86
100	0.09	2713	230.61	106.44	740	0.14	17.12	7.99	14.04	92.85	-74.62	-76.46	1.12
110	0.10	2376	245.41	132.21	790	0.17	17.86	7.99	13.64	92.45	-91.97	-93.49	1.26
120	0.12	2094	258.42	155.85	809	0.19	18.67	7.99	13.28	92.09	-110.85	-112.08	1.36
130	0.15	1857	269.80	177.30	809	0.22	19.52	7 99	12.94	91.75	-128.22	-129.18	1.42
140	0.17	1655	279.72	196.58	797	0.25	20.38	6.89	12.63	90.34	-141.79	-142.50	1.46
150	0.19	1482	288.31	213.74	777	0.28	21.24	6.89	12.34	90.05	-153.79	-154.32	1.47
160	0.22	1332	295.69	228.88	752	0.30	22.10	6.89	12.07	89.79	-163.06	-163.44	1.48
170	0.25	1201	301.97	242.09	724	0.33	22.95	6.89	11.83	89.54	-170.03	-170.30	1.47
180	0.28	1087	307.24	253.49	695	0.36	23.80	6.89	11.60	89.31	-175.18	-175.36	1.45

Table 49

Economic and Biological Yields on Managed Stands Thinned to 1.5 x 1.5m Spacing at 20 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	4444	6.40										
30	0.00	4173	13.83										
40	0.01	3636	36.18										
50	0.02	3163	64.01										
60	0.03	2767	93.56	29.56	355	0.08	15.66	7.99	15.48	94.29	-284.97	-322.24	0.54
70	0.05	2439	122.72	49.74	467	0.11	16.48	7.99	14.83	93.64	-262.50	-284.75	0.77
80	0.07	2166	150.46	72.35	537	0.13	17.56	7.99	14.22	93.02	-263.08	-277.74	0.96
90	0.09	1938	176.32	96.24	579	0.17	18.68	7.99	13.66	92.47	-278.21	-288.50	1.13
100	0.11	1745	200.17	120.58	603	0.20	19.79	7.99	13.18	91.99	-300.27	-307.68	1.27
110	0.14	1580	221.99	144.77	615	0.24	20.88	6.89	12.75	90.46	-321.37	-326.69	1.38
120	0.17	1438	241.85	168.39	619	0.27	21.92	6.89	12.37	90.08	-344.16	-347.98	1.46
130	0.20	1315	259.87	191.13	617	0.31	22.93	6.89	12.03	89.74	-363.93	-366.65	1.53
140	0.23	1207	276.15	212.77	611	0.35	23.90	6.89	11.72	89.44	-380.23	-382.15	1.58
150	0.26	1112	290.83	233.17	603	0.39	24.83	6.89	11.44	89.16	-393.20	-394.54	1.61
160	0.30	1027	304.01	252.24	593	0.43	25.72	6.89	11.19	88.91	-403.23	-404.16	1.63
170	0.33	952	315.83	269.92	581	0.46	26.58	6.89	10.96	88.68	-410.83	-411.47	1.64
180	0.37	884	326.37	286.19	569	0.50	27.41	6.89	10.75	88.47	-416.50	-416.93	1.64

Table 50

Economic and Biological Yields on Managed Stands Thinned to 2.5 x 2.5m Spacing at 20 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	1600	0.60										
30	0.00	1557	2.18										
40	0.01	1457	9.86										
50	0.02	1350	23.88										
60	0.03	1244	42.88	21.99	311	0.07	14.99	7.99	15.91	94.72	-346.31	-391.60	0.40
70	0.06	1146	65.03	36.48	337	0.11	17.36	7.99	14.79	93.60	-330.14	-358.13	0.56
80	0.08	1058	88.74	53.40	354	0.15	19.42	7.99	13.92	92.73	-329.05	-347.39	0.71
90	0.12	979	112.86	71.98	365	0.20	21.26	6.89	13.21	90.93	-335.57	-347.98	0.85
100	0.15	908	136.64	91.61	371	0.25	22.93	6.89	12.63	90.34	-350.86	-359.52	0.96
110	0.19	844	159.59	111.81	375	0.30	24.45	6.89	12.13	89.84	-368.02	-374.11	1.06
120	0.23	788	181.42	132.20	377	0.35	25.86	6.89	11.70	89.41	-384.67	-388.95	1.15
130	0.27	737	201.98	152.47	376	0.40	27.17	6.89	11.32	89.04	-399.51	-402.50	1.22
140	0.32	691	221.18	172.41	375	0.46	28.39	6.89	10.99	88.71	-412.05	-414.13	1.28
150	0.37	650	239.01	191.82	373	0.51	29.53	6.89	10.70	88.41	-422.24	-423.67	1.32
160	0.42	612	255.48	210.54	370	0.57	30.60	6.89	10.43	88.15	-430.28	-431.27	1.36
170	0.47	578	270.64	228.47	367	0.62	31.60	6.89	10.19	87.91	-436.48	-437.16	1.38
180	0.52	547	284.54	245.50	364	0.68	32.54	6.89	9.98	87.69	-441.18	-441.64	1.40

Table 51

Economic and Biological Yields on Managed Stands Thinned to 3.5 x 3.5m Spacing at 20 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	0.30										
30	0.00	803	1.12										
40	0.01	772	5.40										
50	0.02	736	13.96										
60	0.04	699	26.71										
70	0.06	663	42.87	25.31	214	0.12	19.05	7.99	14.56	93.37	-348.92	-394.55	0.46
80	0.10	628	61.49	38.28	226	0.17	21.58	6.89	13.61	91.33	-340.05	-368.87	0.59
90	0.14	595	81.64	53.10	235	0.23	23.80	6.89	12.85	90.57	-346.52	-365.83	0.71
100	0.18	564	102.57	69.28	242	0.29	25.78	6.89	12.23	89.94	-360.40	-373.73	0.82
110	0.23	536	123.70	86.44	247	0.35	27.56	6.89	11.70	89.42	-377.57	-386.89	0.91
120	0.28	510	144.61	104.24	251	0.42	29.18	6.89	11.26	88.97	-395.17	-401.71	0.99
130	0.34	485	165.00	122.42	254	0.48	30.66	6.89	10.87	88.58	-411.48	-416.05	1.06
140	0.40	463	184.65	140.77	257	0.55	32.02	6.89	10.52	88.24	-425.67	-428.85	1.13
150	0.46	443	203.43	159.10	258	0.62	33.28	6.89	10.22	87.94	-437.48	-439.69	1.18
160	0.52	424	221.26	177.26	260	0.68	34.44	6.89	9.95	87.67	-447.01	-448.53	1.22
170	0.59	406	238.10	195.13	261	0.75	35.52	6.89	9.71	87.42	-454.50	-455.54	1.26
180	0.65	390	253.93	212.58	262	0.81	36.52	6.89	9.49	87.21	-460.28	-460.99	1.29

Table 52

Economic and Biological Yields on Managed Stands
Thinned to 1.5 x 1.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	4444	6.40										
30	0.00	4108	17.04										
40	0.01	3446	50.93										
50	0.03	3001	80.20										
60	0.04	2633	109.83	39.24	380	0.10	16.79	7.99	14.91	93.72	-316.76	-358.18	0.71
70	0.06	2329	138.40	60.94	476	0.13	17.56	7.99	14.35	93.16	-304.40	-330.20	0.94
80	0.08	2075	165.22	84.45	536	0.16	18.56	7.99	13.80	92.61	-315.29	-332.86	1.13
90	0.10	1862	190.05	108.79	572	0.19	19.61	7.99	13.31	92.12	-339.06	-351.60	1.28
100	0.13	1681	212.83	133.24	593	0.22	20.67	6.89	12.87	90.59	-364.19	-373.18	1.40
110	0.15	1525	233.60	157.29	603	0.26	21.70	6.89	12.48	90.19	-393.35	-399.86	1.50
120	0.18	1391	252.47	180.59	606	0.30	22.70	6.89	12.13	89.84	-419.53	-424.20	1.57
130	0.21	1274	269.54	202.88	603	0.34	23.67	6.89	11.81	89.53	-441.63	-444.93	1.62
140	0.24	1171	284.95	223.99	598	0.37	24.60	6.89	11.53	89.24	-459.49	-461.80	1.66
150	0.28	1080	298.82	243.79	589	0.41	25.50	6.89	11.27	88.98	-473.48	-475.09	1.68
160	0.31	999	311.26	262.22	580	0.45	26.36	6.89	11.03	88.75	-484.19	-485.30	1.69
170	0.35	927	322.38	279.24	568	0.49	27.20	6.89	10.81	88.53	-492.22	-492.99	1.69
180	0.39	862	332.29	294.84	557	0.53	28.00	6.89	10.62	88.33	-498.17	-498.69	1.68

Table 53

Economic and Biological Yields on Managed Stands Thinned to 2.5 x 2.5m Spacing at 20 Years of Age Fertilized at 20 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	1600	0.60										
30	0.00	1550	2.95										
40	0.01	1425	[illegible]										
50	0.03	1315	33.02										
60	0.04	1211	53.93	28.90	312	0.09	16.56	7.99	15.20	94.01	-392.31	-539.72	0.53
70	0.07	1116	77.15	44.77	335	0.13	18.75	7.99	14.24	93.05	-382.23	-504.45	0.69
80	0.10	1030	101.29	62.69	350	0.18	20.67	6.89	13.47	91.18	-384.38	-493.71	0.84
90	0.13	954	125.41	81.95	360	0.23	22.41	6.89	12.84	90.55	-400.25	-504.97	0.96
100	0.17	886	148.90	102.00	366	0.28	23.99	6.89	12.30	90.02	-420.54	-524.28	1.07
110	0.21	825	171.38	122.42	369	0.33	25.44	6.89	11.85	89.56	-441.47	-546.00	1.17
120	0.25	771	192.64	142.88	370	0.39	26.78	6.89	11.45	89.16	-460.84	-566.92	1.24
130	0.29	722	212.56	163.10	370	0.44	28.04	6.89	11.10	88.82	-477.61	-585.44	1.30
140	0.34	678	231.10	182.88	369	0.50	29.21	6.89	10.79	88.51	-491.48	-600.98	1.35
150	0.39	638	248.28	202.04	367	0.55	30.30	6.89	10.52	88.23	-502.58	-613.55	1.39
160	0.44	601	264.11	220.45	365	0.60	31.33	6.89	10.27	87.98	-511.24	-623.42	1.42
170	0.49	568	278.65	238.02	362	0.66	32.29	6.89	10.05	87.76	-517.85	-631.02	1.44
180	0.54	538	291.95	254.64	358	0.71	33.20	6.89	9.84	87.56	-522.82	-636.76	1.46

Table 54

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 20 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	0.30										
30	0.00	801	1.53										
40	0.01	762	9.09										
50	0.03	725	19.83										
60	0.05	688	34.45										
70	0.08	651	52.02	31.09	213	0.15	20.57	6.89	14.01	91.73	-448.81	-486.85	0.48
80	0.12	617	71.58	45.03	224	0.20	22.95	6.89	13.17	90.88	-449.19	-474.22	0.60
90	0.16	584	92.27	60.59	233	0.26	25.05	6.89	12.48	90.20	-457.69	-474.61	0.71
100	0.20	555	113.44	77.33	239	0.32	26.93	6.89	11.91	89.63	-470.56	-482.17	0.81
110	0.26	527	134.57	94.88	244	0.39	28.63	6.89	11.43	89.15	-484.91	-492.93	0.90
120	0.31	502	155.31	112.95	248	0.46	30.17	6.89	11.02	88.73	-498.86	-504.40	0.98
130	0.37	478	175.40	131.30	251	0.52	31.59	6.89	10.65	88.37	-511.37	-515.20	1.05
140	0.43	457	194.68	149.73	254	0.59	32.89	6.89	10.33	88.05	-522.02	-524.66	1.11
150	0.49	437	213.03	168.06	256	0.66	34.09	6.89	10.05	87.76	-530.75	-532.56	1.16
160	0.55	418	230.41	186.16	257	0.72	35.21	6.89	9.80	87.51	-537.70	-538.94	1.20
170	0.62	401	246.77	203.90	258	0.79	36.24	6.89	9.57	87.28	-543.12	-543.96	1.24
180	0.68	385	262.12	221.19	259	0.85	37.20	6.89	9.36	87.08	-547.26	-547.83	1.26

Table 55

Economic and Biological Yields on Managed Stands Thinned to 1.5 x 1.5m Spacing at 20 Years of Age Fertilized at 50 Years of Age Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	4444	6.40										
30	0.00	4173	13.88										
40	0.01	3636	36.18										
50	0.02	3163	64.01										
60	0.03	2767	93.56	33.97	367	0.09	16.21	7.99	15.20	94.01	-287.42	-325.01	0.62
70	0.05	2389	130.97	63.64	477	0.13	17.80	7.99	14.24	93.05	-237.83	-257.99	0.98
80	0.08	2064	170.83	87.38	536	0.16	18.77	7.99	13.72	92.53	-251.22	-265.22	1.17
90	0.11	1853	195.29	111.84	572	0.20	19.80	7.99	13.24	92.05	-277.06	-287.31	1.32
100	0.13	1674	217.70	136.34	592	0.23	20.84	6.89	12.81	90.52	-303.69	-311.18	1.44
110	0.16	1520	238.10	160.40	602	0.27	21.86	6.89	12.42	90.14	-334.02	-339.55	1.53
120	0.19	1387	256.62	183.65	605	0.30	22.85	6.89	12.08	89.79	-361.03	-365.04	1.60
130	0.22	1271	273.36	205.86	603	0.34	23.80	6.89	11.77	89.48	-383.69	-386.56	1.65
140	0.25	1168	288.47	226.87	597	0.38	24.72	6.89	11.49	89.20	-401.93	-403.96	1.68
150	0.28	1078	302.05	246.56	589	0.42	25.61	6.89	11.23	88.95	-416.18	-417.60	1.70
160	0.31	998	314.23	264.86	579	0.46	26.47	6.89	11.00	88.72	-427.06	-428.04	1.71
170	0.35	926	325.11	281.75	568	0.50	27.29	6.89	10.79	88.50	-435.20	-435.88	1.71
180	0.39	861	334.79	297.21	556	0.53	28.09	6.89	10.59	88.31	-441.22	-441.68	1.70

Table 56

Economic and Biological Yields on Managed Stands
Thinned to 2.5 x 2.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	1600	0.60										
30	0.00	1557	2.18										
40	0.01	1457	9.86										
50	0.02	1350	23.88										
60	0.03	1244	42.88	25.12	312	0.08	15.73	7.99	15.57	94.38	-332.92	-376.46	0.46
70	0.06	1132	71.04	46.67	335	0.14	19.03	7.99	14.13	92.94	-295.13	-320.15	0.72
80	0.10	1026	105.18	64.79	350	0.19	20.93	6.89	13.38	91.09	-298.16	-314.78	0.86
90	0.14	950	129.29	84.20	359	0.23	22.64	6.89	12.76	90.47	-315.05	-326.70	0.99
100	0.17	883	152.69	104.34	365	0.29	24.20	6.89	12.24	89.95	-336.19	-344.49	1.10
110	0.21	822	175.03	124.82	368	0.34	25.63	6.89	11.79	89.51	-357.77	-363.69	1.19
120	0.26	768	196.12	145.29	370	0.39	26.96	6.89	11.40	89.12	-377.62	-381.82	1.26
130	0.30	720	215.86	165.51	370	0.45	28.20	6.89	11.06	88.77	-394.73	-397.69	1.32
140	0.35	676	234.22	185.26	369	0.50	29.36	6.89	10.75	88.47	-408.85	-410.91	1.37
150	0.39	636	251.20	204.38	367	0.56	30.45	6.89	10.48	88.20	-420.11	-421.54	1.41
160	0.44	600	266.85	222.74	364	0.61	31.46	6.89	10.24	87.95	-428.87	-429.86	1.44
170	0.50	567	281.21	240.23	361	0.67	32.42	6.89	10.02	87.73	-435.56	-436.24	1.46
180	0.55	537	294.34	256.78	358	0.72	33.32	6.89	9.82	87.53	-440.58	-441.04	1.47

Table 57

Economic and Biological Yields on Managed Stands
Thinned to 3.5 x 3.5m Spacing at 20 Years of Age
Fertilized at 50 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0													
10													
20	0.00	816	0.30										
30	0.00	803	1.12										
40	0.01	772	5.40										
50	0.02	736	13.96										
60	0.04	699	26.71										
70	0.07	657	47.27	32.86	213	0.15	20.99	6.89	13.87	91.58	-385.37	-418.03	0.51
80	0.12	615	74.34	47.06	224	0.21	23.33	6.89	13.05	90.76	-387.13	-408.70	0.63
90	0.16	583	95.16	62.82	232	0.27	25.39	6.89	12.38	90.10	-396.91	-411.59	0.74
100	0.21	553	116.38	79.71	239	0.33	27.25	6.89	11.83	89.54	-410.85	-420.99	0.84
110	0.26	525	137.50	97.38	244	0.40	28.92	6.89	11.36	89.07	-426.03	-433.07	0.93
120	0.32	500	158.19	115.52	248	0.47	30.44	6.89	10.95	88.66	-440.59	-445.49	1.00
130	0.37	477	178.20	133.92	251	0.53	31.84	6.89	10.59	88.31	-453.55	-456.94	1.07
140	0.43	455	197.38	152.36	253	0.60	33.13	6.89	10.28	87.99	-464.52	-466.86	1.13
150	0.50	436	215.63	170.70	255	0.67	34.32	6.89	10.00	87.72	-473.46	-475.07	1.18
160	0.56	417	232.88	188.78	257	0.74	35.42	6.89	9.75	87.47	-480.57	-481.67	1.22
170	0.62	400	249.13	206.49	258	0.80	36.44	6.89	9.53	87.24	-486.08	-486.84	1.25
180	0.69	384	264.35	223.73	259	0.87	37.39	6.89	9.33	87.04	-490.30	-490.81	1.28

Table 58

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1574	0.03										
20	0.00	1503	1.75										
30	0.01	1410	8.66										
40	0.02	1308	21.79										
50	0.03	1208	40.02	20.53	272	0.08	15.63	7.99	15.74	94.55	-825.77	-996.34	0.46
60	0.06	1115	61.56	34.54	299	0.12	18.05	7.99	14.62	93.43	-800.97	-905.72	0.63
70	0.08	1029	84.84	51.03	318	0.16	20.15	6.89	13.76	91.47	-793.46	-860.71	0.79
80	0.11	953	108.68	69.24	331	0.21	22.02	6.89	13.06	90.77	-806.04	-850.96	0.92
90	0.15	885	132.29	88.55	339	0.26	23.70	6.89	12.48	90.19	-827.21	-857.80	1.04
100	0.19	823	155.16	108.45	345	0.31	25.25	6.89	11.99	89.70	-851.42	-872.44	1.14
110	0.23	769	176.97	128.59	348	0.37	26.67	6.89	11.56	89.27	-875.12	-889.60	1.22
120	0.27	719	197.55	148.65	349	0.43	27.98	6.89	11.19	88.90	-896.39	-906.36	1.29
130	0.32	675	216.80	168.40	349	0.48	29.21	6.89	10.86	88.57	-914.43	-921.27	1.35
140	0.37	635	234.70	187.65	348	0.54	30.35	6.89	10.57	88.28	-929.13	-933.82	1.39
150	0.42	598	251.27	206.24	346	0.60	31.43	6.89	10.31	88.02	-940.76	-943.96	1.42
160	0.47	565	266.52	224.05	344	0.65	32.43	6.89	10.07	87.79	-949.75	-951.93	1.45
170	0.52	534	280.52	240.99	341	0.71	33.38	6.89	9.86	87.58	-956.57	-958.06	1.46
180	0.58	506	293.32	257.00	338	0.76	34.27	6.89	9.67	87.38	-961.67	-962.68	1.47

Table 59

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 20 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1574	0.03										
20	0.00	1503	1.75										
30	0.01	1400	10.48										
40	0.02	1274	31.19										
50	0.04	1175	51.55	27.72	274	0.10	17.41	7.99	14.97	93.78	-852.06	-1028.07	0.62
60	0.07	1084	74.33	43.23	298	0.14	19.61	7.99	14.02	92.83	-836.31	-945.69	0.79
70	0.10	1002	98.15	60.82	315	0.19	21.56	6.89	13.27	90.98	-838.49	-909.55	0.94
80	0.13	928	122.05	79.78	327	0.24	23.30	6.89	12.65	90.37	-860.77	-908.74	1.06
90	0.17	863	145.40	99.56	334	0.30	24.88	6.89	12.13	89.84	-889.74	-922.64	1.17
100	0.21	804	167.80	119.73	339	0.35	26.34	6.89	11.68	89.40	-919.85	-942.56	1.26
110	0.25	751	189.03	139.96	342	0.41	27.69	6.89	11.29	89.01	-947.84	-963.52	1.33
120	0.30	704	208.95	159.98	343	0.47	28.94	6.89	10.95	88.67	-972.14	-982.94	1.39
130	0.34	661	227.51	179.57	343	0.52	30.11	6.89	10.65	88.36	-992.28	-999.70	1.44
140	0.39	622	244.73	198.58	342	0.58	31.20	6.89	10.38	88.09	-1008.42	-1013.50	1.47
150	0.44	587	260.61	216.85	341	0.64	32.23	6.89	10.13	87.85	-1021.02	-1024.49	1.50
160	0.50	555	275.20	234.29	339	0.69	33.19	6.89	9.91	87.63	-1030.66	-1033.03	1.51
170	0.55	525	288.56	250.81	336	0.75	34.10	6.89	9.72	87.43	-1037.92	-1039.52	1.52
180	0.60	498	300.75	266.36	333	0.80	34.95	6.89	9.54	87.25	-1043.30	-1044.39	1.52

Table 60

Economic and Biological Yields on Managed Stands
Planted to 2.5 x 2.5m Spacing
Fertilized at 50 Years of Age
Poor Sites

Age	Tree	Density	TotVol	Mer Vol	Mer Stems	Mer Vol/Stem	Diam	Tr/Mill Costs	Tr/Truck Costs	Prod'tn Costs	NPV	SEV	MAI
0	0.00	1600	0.00										
10	0.00	1574	0.03										
20	0.00	1503	1.75										
30	0.01	1410	8.66										
40	0.02	1308	21.79										
50	0.03	1208	40.02	20.53	272	0.08	15.63	7.99	15.74	94.55	-825.77	-996.34	0.46
60	0.06	1101	67.40	38.46	299	0.13	18.78	7.99	14.34	93.15	-805.26	-910.57	0.70
70	0.10	999	100.95	62.88	315	0.20	21.81	6.89	13.18	90.90	-773.81	-839.39	0.97
80	0.13	926	124.86	81.99	326	0.25	23.53	6.89	12.58	90.29	-798.18	-842.66	1.09
90	0.17	861	148.15	101.87	334	0.31	25.10	6.89	12.07	89.78	-828.80	-859.45	1.20
100	0.21	802	170.46	122.10	339	0.36	26.54	6.89	11.63	89.34	-860.15	-881.38	1.29
110	0.26	750	191.57	142.36	341	0.42	27.87	6.89	11.24	88.96	-889.03	-903.74	1.36
120	0.30	703	211.36	162.38	342	0.47	29.11	6.89	10.91	88.62	-913.96	-924.12	1.41
130	0.35	660	229.80	181.95	343	0.53	30.27	6.89	10.61	88.32	-934.55	-941.54	1.46
140	0.40	621	246.87	200.92	342	0.59	31.35	6.89	10.34	88.06	-950.99	-955.78	1.49
150	0.45	586	262.62	219.14	340	0.64	32.36	6.89	10.10	87.82	-963.79	-967.07	1.51
160	0.50	554	277.08	236.51	338	0.70	33.32	6.89	9.89	87.60	-973.57	-975.81	1.53
170	0.55	525	290.32	252.96	336	0.75	34.22	6.89	9.69	87.40	-980.92	-982.44	1.53
180	0.61	497	302.39	268.42	333	0.81	35.06	6.89	9.51	87.23	-986.37	-987.40	1.53

APPENDIX III

This Appendix serves to provide and explain the input files required for the MUSYC model. The following example is from Regime IV, Scenario 2, economic maximization without silvicultural options under conditions of even flow and regenerated harvests occurring at the optimal soil expectation value.

To proceed with this scenario, the policy and forest management parameters of the MUSYC model were altered. The objective function was set to maximize present net value for 25 decades. The first 10 periods of harvest was constrained to be perfect even flow while the remaining 15 periods of harvest were allowed to fluctuate +/-95%. No management alternatives other than natural regeneration were allowed and the harvest of regenerated areas were constrained to occur at the maximum soil expectation value age.

```
TITLE
  MUSYC : CONSTRAINED ECONOMIC MAXIMIZATION
          SILVICULTURAL TREATMENTS NOT INCLUDED
PRINT OUT DATA AND GENERATE MATRIX
PARAMETER
    2 25 10  1 10  1   45.        15.       15.
 UNITS  HECRS.CUBIC METERS
THRU 25 DECADES, MAXIMIZE PNW
HARVEST CONSTRAINTS
 SEQUENTIAL LOWER AND UPPER BOUNDS
   10     0.00      0.00
   25     0.95      0.95
IDENTIFIERS
 WORK. GROUP
  PL
 LAND CLASS
  GOOD                                 MEDIUM
  POOR
 CONDITION CLASS FOR EXISTING STANDS
  A - R4.GOOD                          B - R4.MEDIUM
  C - R4.FAIR                          D - E1.GOOD
  E - E1.MEDIUM                        F - E1.FAIR
 CONDITION CLASS FOR REGENERATED STANDS
  REGEN (A)                            REGEN (B)
  REGEN (C)
TIMBER CLASS DATA
   1 1 1 1   E   5     0.264    1.0
   1 1 1 1   E   9     3.034    1.0
   1 1 1 1   E  11     3.562    1.0
   1 1 1 1   E  13     0.396    1.0
   1 2 2 2   E   1     3.068    1.0
   1 2 2 2   E   3     0.264    1.0
   1 2 2 2   E   5    11.074    1.0
   1 2 2 2   E   7     7.908    1.0
   1 2 2 2   E   9    97.136    1.0
   1 2 2 2   E  10     0.528    1.0
   1 2 2 2   E  11    54.146    1.0
   1 2 2 2   E  13     5.800    1.0
   1 2 2 2   E  17     0.132    1.0
   1 3 3 3   E   5     0.396    1.0
   1 3 3 3   E   9     1.054    1.0
   1 3 3 3   E  11     0.660    1.0
   1 3 3 3   E  13     0.132    1.0
   1 1 4 1   E   5     0.132    1.0
   1 1 4 1   E   6     0.132    1.0
   1 1 4 1   E   7     0.792    1.0
   1 1 4 1   E   8     3.428    1.0
   1 1 4 1   E   9    13.444    1.0
   1 1 4 1   E  10     0.924    1.0
   1 1 4 1   E  11     4.744    1.0
   1 1 4 1   E  12     3.428    1.0
   1 1 4 1   E  13     0.264    1.0
   1 1 4 1   E  14     0.264    1.0
   1 2 5 2   E   1     9.226    1.0
```

```
    1 2 5 2   E   2     2.638    1.0
    1 2 5 2   E   3    29.260    1.0
    1 2 5 2   E   4     3.560    1.0
    1 2 5 2   E   5     2.768    1.0
    1 2 5 2   E   6     2.770    1.0
    1 2 5 2   E   7    15.158    1.0
    1 2 5 2   E   8     7.908    1.0
    1 2 5 2   E   9    33.080    1.0
    1 2 5 2   E  10    10.546    1.0
    1 2 5 2   E  11     4.218    1.0
    1 2 5 2   E  12     1.318    1.0
    1 2 5 2   E  14     0.396    1.0
    1 2 5 2   E  16     0.132    1.0
    1 3 6 3   E   3     0.132    1.0
    1 3 6 3   E   5     1.186    1.0
    1 3 6 3   E   7     1.450    1.0
    1 3 6 3   E   8     1.188    1.0
    1 3 6 3   E   9     0.396    1.0
    1 3 6 3   E  10     0.132    1.0
    1 3 6 3   E  11     0.132    1.0
    1 3 6 3   E  12     0.132    1.0
MANAGEMENT ALTERNATIVES A
 EXIST ALTERNATIVES
    1 1 1  5  1  1  0  0  1 14  1 14  1  1              A
    1 1 1  5 10  7  0  0  1 14  1 14  1  1     2        B
    1 1 1  9  1  1  0  0  1 10  1 10  1  1              A
    1 1 1 11  1  1  0  0  1  8  1  8  1  1              A
    1 1 1 13  1  1  0  0  1  6  1  6  1  1              A
    1 2 2  1  2  2  0  0  1 18  1 18  1  1              A
    1 2 2  1 11  8  0  0  1 18  1 18  1  1     7        B
    1 2 2  1  7  4  0  0  1 18  1 18  1  1  2           C
    1 2 2  1  8  5  0  0  1 18  1 18  1  1  2           D
    1 2 2  1  9  6  0  0  1 18  1 18  1  1  2           E
    1 2 2  1 13 10  0  0  1 18  1 18  1  1  2           F
    1 2 2  1 15 12  0  0  1 18  1 18  1  1  2           G
    1 2 2  1 17 14  0  0  1 18  1 18  1  1  2           H
    1 2 2  1 14 11  0  0  1 18  1 18  1  1  2  5        I
    1 2 2  1 16 13  0  0  1 18  1 18  1  1  2  5        J
    1 2 2  1 18 15  0  0  1 18  1 18  1  1  2  5        K
    1 2 2  3  2  2  0  0  1 16  1 16  1  1              A
    1 2 2  3 11  8  0  0  1 16  1 16  1  1     5        B
    1 2 2  5  2  2  0  0  1 14  1 14  1  1              A
    1 2 2  5 11  8  0  0  1 14  1 14  1  1     3        B
    1 2 2  7  2  2  0  0  1 12  1 12  1  1              A
    1 2 2  7 11  8  0  0  1 12  1 12  1  1     1        B
    1 2 2  9  2  2  0  0  1 10  1 10  1  1              A
    1 2 2 10  2  2  0  0  1  9  1  9  1  1              A
    1 2 2 11  2  2  0  0  1  8  1  8  1  1              A
    1 2 2 13  2  2  0  0  1  6  1  6  1  1              A
    1 2 2 17  2  2  0  0  1  2  1  2  1  1              A
    1 3 3  5  3  3  0  0  1 14  1 14  1  1              A
    1 3 3  5 12  9  0  0  1 14  1 14  1  1     4        B
    1 3 3  9  3  3  0  0  1 10  1 10  1  1              A
    1 3 3 11  3  3  0  0  1  8  1  8  1  1              A
```

1	3	3	13	3	3	0	0	1	6	1	6	1	1			A
1	1	4	5	4	1	0	0	1	14	1	14	1	1			A
1	1	4	5	10	7	0	0	1	14	1	14	1	1		2	B
1	1	4	6	4	1	0	0	1	13	1	13	1	1			A
1	1	4	6	10	7	0	0	1	13	1	13	1	1		1	B
1	1	4	7	4	1	0	0	1	12	1	12	1	1			A
1	1	4	8	4	1	0	0	1	11	1	11	1	1			A
1	1	4	9	4	1	0	0	1	10	1	10	1	1			A
1	1	4	10	4	1	0	0	1	9	1	9	1	1			A
1	1	4	11	4	1	0	0	1	8	1	8	1	1			A
1	1	4	12	4	1	0	0	1	7	1	7	1	1			A
1	1	4	13	4	1	0	0	1	6	1	6	1	1			A
1	1	4	14	4	1	0	0	1	5	1	5	1	1			A
1	2	5	1	5	2	0	0	1	18	1	18	1	1			A
1	2	5	1	11	8	0	0	1	18	1	18	1	1		7	B
1	2	5	1	7	4	0	0	1	18	1	18	1	1	2		C
1	2	5	1	8	5	0	0	1	18	1	18	1	1	2		D
1	2	5	1	9	6	0	0	1	18	1	18	1	1	2		E
1	2	5	1	13	10	0	0	1	18	1	18	1	1	2		F
1	2	5	1	15	12	0	0	1	18	1	18	1	1	2		G
1	2	5	1	17	14	0	0	1	18	1	18	1	1	2		H
1	2	5	1	14	11	0	0	1	18	1	18	1	1	2	5	I
1	2	5	1	16	13	0	0	1	18	1	18	1	1	2	5	J
1	2	5	1	18	15	0	0	1	18	1	18	1	1	2	5	K
1	2	5	2	5	2	0	0	1	17	1	17	1	1			A
1	2	5	2	11	8	0	0	1	17	1	17	1	1		6	B
1	2	5	2	7	4	0	0	1	17	1	17	1	1	1		C
1	2	5	2	8	5	0	0	1	18	1	18	1	1	1		D
1	2	5	2	9	6	0	0	1	19	1	19	1	1	1		E
1	2	5	2	13	10	0	0	1	18	1	18	1	1	1		F
1	2	5	2	15	12	0	0	1	17	1	17	1	1	1		G
1	2	5	2	17	14	0	0	1	17	1	17	1	1	1		H
1	2	5	2	14	11	0	0	1	17	1	17	1	1	1	4	I
1	2	5	2	16	13	0	0	1	17	1	17	1	1	1	4	J
1	2	5	2	18	15	0	0	1	17	1	17	1	1	1	4	K
1	2	5	3	5	2	0	0	1	16	1	16	1	1			A
1	2	5	3	11	8	0	0	1	16	1	16	1	1		5	B
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1	2	5	4	11	8	0	0	1	15	1	15	1	1		4	B
1	2	5	5	5	2	0	0	1	14	1	14	1	1			A
1	2	5	5	11	8	0	0	1	14	1	14	1	1		3	B
1	2	5	6	5	2	0	0	1	13	1	13	1	1			A
1	2	5	6	11	8	0	0	1	13	1	13	1	1		2	B
1	2	5	7	5	2	0	0	1	12	1	12	1	1			A
1	2	5	7	11	8	0	0	1	12	1	12	1	1		1	B
1	2	5	8	5	2	0	0	1	11	1	11	1	1			A
1	2	5	9	5	2	0	0	1	10	1	10	1	1			A
1	2	5	10	5	2	0	0	1	9	1	9	1	1			A
1	2	5	11	5	2	0	0	1	8	1	8	1	1			A
1	2	5	12	5	2	0	0	1	7	1	7	1	1			A
1	2	5	14	5	2	0	0	1	5	1	5	1	1			A
1	2	5	16	5	2	0	0	1	3	1	3	1	1			A
1	3	6	3	6	3	0	0	1	16	1	16	1	1			A
1	3	6	3	12	9	0	0	1	16	1	16	1	1		6	B

```
 1 3 6  5  6  3  0  0  1 14  1 14  1  1               A
 1 3 6  5 12  9  0  0  1 14  1 14  1  1     4         B
 1 3 6  7  6  3  0  0  1 12  1 12  1  1               A
 1 3 6  7 12  9  0  0  1 12  1 12  1  1     2         B
 1 3 6  8  6  3  0  0  1 11  1 11  1  1               A
 1 3 6  8 12  9  0  0  1 11  1 11  1  1     1         B
 1 3 6  9  6  3  0  0  1 10  1 10  1  1               A
 1 3 6 10  6  3  0  0  1  9  1  9  1  1               A
 1 3 6 11  6  3  0  0  1  8  1  8  1  1               A
 1 3 6 12  6  3  0  0  1  7  1  7  1  1               A
REGEN ALTERNATIVES
 1 1 1 NOR  1  1  0  0  0  7  7  7  7  1  1         A
 1 1 1 NOR 16 13  0  0  0  7  7  7  7  1  1     6   B
 1 1 1 NOR  7  4  0  0  0  6  6  6  6  1  1  2      C
 1 1 1 NOR  8  5  0  0  0  6  6  6  6  1  1  2      D
 1 1 1 NOR  9  6  0  0  0  6  6  6  6  1  1  2      E
 1 1 1 NOR 19 16  0  0  0  6  6  6  6  1  1  2      F
 1 1 1 NOR 21 18  0  0  0  5  5  5  5  1  1  2      G
 1 1 1 NOR 23 20  0  0  0  6  6  6  6  1  1  2      H
 1 1 1 NOR 20 17  0  0  0  5  5  5  5  1  1  2  5   I
 1 1 1 NOR 22 19  0  0  0  5  5  5  5  1  1  2  5   J
 1 1 1 NOR 24 21  0  0  0  7  7  7  7  1  1  2  5   K
 1 1 1 NOR  4 34  0  0  0  6  6  6  6  1  1         L
 1 1 1 NOR  5 35  0  0  0  6  6  6  6  1  1  2      M
 1 1 1 NOR  6 36  0  0  0  5  5  5  5  1  1     5   N
 1 2 2 NOR  2  2  0  0  0  8  8  8  8  1  1         A
 1 2 2 NOR 17 14  0  0  0  8  8  8  8  1  1     7   B
 1 2 2 NOR 10  7  0  0  0  7  7  7  7  1  1  2      C
 1 2 2 NOR 11  8  0  0  0  6  6  6  6  1  1  2      D
 1 2 2 NOR 12  9  0  0  0  7  7  7  7  1  1  2      E
 1 2 2 NOR 25 22  0  0  0  6  6  6  6  1  1  2      F
 1 2 2 NOR 27 24  0  0  0  6  6  6  6  1  1  2      G
 1 2 2 NOR 29 26  0  0  0  7  7  7  7  1  1  2      H
 1 2 2 NOR 26 23  0  0  0  7  7  7  7  1  1  2  5   I
 1 2 2 NOR 28 25  0  0  0  7  7  7  7  1  1  2  5   J
 1 2 2 NOR 30 27  0  0  0  7  7  7  7  1  1  2  5   K
 1 2 2 NOR 37 37  0  0  0  7  7  7  7  1  1         L
 1 2 2 NOR 38 38  0  0  0  7  7  7  7  1  1  2      M
 1 2 2 NOR 39 39  0  0  0  7  7  7  7  1  1     5   N
 1 3 3 NOR  3  3  0  0  0 10 10 10 10  1  1         A
 1 3 3 NOR 18 15  0  0  0 10 10 10 10  1  1     8   B
 1 3 3 NOR 13 10  0  0  0  8  8  8  8  1  1  2      C
 1 3 3 NOR 14 11  0  0  0  8  8  8  8  1  1  2      D
 1 3 3 NOR 15 12  0  0  0  9  9  9  9  1  1  2      E
 1 3 3 NOR 31 28  0  0  0  7  7  7  7  1  1  2      F
 1 3 3 NOR 33 30  0  0  0  8  8  8  8  1  1  2      G
 1 3 3 NOR 35 32  0  0  0  9  9  9  9  1  1  2      H
 1 3 3 NOR 32 29  0  0  0  7  7  7  7  1  1  2  5   I
 1 3 3 NOR 34 31  0  0  0  8  8  8  8  1  1  2  5   J
 1 3 3 NOR 36 33  0  0  0  8  8  8  8  1  1  2  5   K
 1 3 3 NOR 40 40  0  0  0  8  8  8  8  1  1         L
 1 3 3 NOR 41 41  0  0  0  8  8  8  8  1  1  2      M
 1 3 3 NOR 42 42  0  0  0  7  7  7  7  1  1     5   N
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APPENDIX IV

Forest Employment

The primary objective of Alberta's sustained yield policy is to ensure the stability of forest-dependant communities. Approximately 1 job in 65 was dependant on Alberta's forest sector in 1987 (Forestry Canada, 1990). Recent announcements of expansions and greenfield projects will increase this ratio as workers are required not only for the processing facilities and forest management but for service orientated industries as well. Differing methods of forest management will have differing effects on the base of labour required to carry them out. The effects of alternative forest management strategies on employment levels must therefore be evaluated.

Two schools of thought surround the issue of evaluating the effects of employment. The neoclassical approach dictates that the world operates at levels of full employment. Therefore, a project which requires an additional unit of labour would be required to draw that unit of labour from an outside source. The net effect would be zero since the unit of labour was already employed and any benefit would be offset by the cost of foregone employment elsewhere Thus, no benefit can be assigned to the incremental employment a project will generate in a given area.

Alternatively, the Keynsian approach is characterized by a world of fixed wages and unemployment. In such a case, any increase in employment which can be attributed to the project could be counted as a net benefit. Realistically, the actual situation would lie somewhere between these two views.

As Fraser(1981) points out, even in times of extreme unemployment, a one-to-one relationship between jobs created and reduced unemployment is not always possible as there can still exist shortages for specific skill categories and equipment items. The ability of a project to increase employment must therefore be measured cautiously.

Employment Estimation

While projects will require employees to carry them out, not all labour will have been unemployed otherwise. The direct and indirect benefits of forest investments on employment must therefore be weighted by some factor which will adequately reflect the employment climate. As this research uses figures based in 1987, absolute unemployment rates in Alberta's forest industry for this year were used to determine any employment effects. This assumes that forest investments requiring additional employees will obtain them from the labour market in the same proportion as there is unemployment.

In 1987, absolute forestry related unemployment in Alberta was approximately 0.121 (Statistics Canada, 71-201). By establishing a base rate or average level of employment required to maintain forestry operations, increases in gross employment levels can be weighted by a factor u, where u = 0.121, to determine the absolute effects of investments.

Base Rate

To establish a base rate of permanent employment for the case study forest (/1000m^3 of harvest), an average of the projected employment from current and future pulp mill projects was taken[2]. Using three projects as the data base, the number of direct jobs per quantity of pulp produced was transformed into permanent jobs/1000m3 of greenwood:

$$\frac{D}{(Ay/Am)} * 1000 = \frac{\text{Direct Jobs}}{1000\text{m}3}$$

where: D = number of direct jobs associated with the project.
Ay = air dry metric tonnes of pulp produced each year.
Am = the ratio of ADMT and m^3 of greenwood

Average values from the projects were:

D = 435 Direct Jobs
Ay = 358,000 ADMT/yr.
Am = .1786 ADMT/m^3 of greenwood

Substitution yields a value of 0.22 direct, permanent jobs/1000m^3 of harvest. Indirect employment effects averaged from the projects equaled an approximate ratio of 2.0. This estimate is not out of line with those used by other agencies (White et.al, 1989; B.C. Ministry of Forests, 1990; Alta. Forestry Lands and Wildlife, 1990).

Silviculture Employment

Silvicultural treatments will generate additional short term employment. The following estimates were used to evaluate the the overall job creation impact of forest management:

ACTIVITY	EMPLOYMENT GENERATED[3]
Surveys and Prescriptions	0.1 days per hectare
Seeds and Seedlings	1.0 days per hectare
Site Preparation	0.5 days per hectare
Planting	2.0 days per hectare
Juvenile Spacing	4.0 days per hectare
Fertilization	0.1 days per hectare

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[2] Source: Alberta Forest, Lands and Wildlife, Forest Industry and Development, Edmonton

[3] The per hectare estimates are those used throughout the Canada - B.C. Forest Resource Development Agreement

To bring the employment created by these treatments to the same scale as the base rate, they must be converted to a yearly basis. In evaluating silvicultural treatment employment, it was assumed that there are approximately 180 days in the working year. This number is lower than the usual 220 days in a normal working year because silvicultural employment can be a seasonal activity.

Employment Valuation

It was assumed that the value of an additional job is its market price, i.e. the annual wage paid to that employee. As little of this type of estimation work has been done for Alberta, values for British Columbia are assumed to be proxies. White et.al. (1989) provide income characteristics for forest specialized communities for the year 1986. By updating the average income for incorporated communities through the consumer price index (Statistics Canada, 62-001), 1987 average wage rates are obtained. Average annual income was determined to be $20,688 in 1987. This value not only incorporates all direct jobs associated with the forest industry, but the indirect employment as well. Therefore, higher paying jobs within the forest sector are offset by service orientated indirect employment.

Employment Effects

As has been previously mentioned, allowable cut policy is based on the need for community stability. Labour is required to harvest the timber as well as process it. Also, to properly estimate the value of silvicultural treatments employment effects must also be accounted for. The following Tables summarize the effects of the aforementioned regimes on employment. In Table 61, values relate to direct person-years of employment required for each scenario per decade. Table 62 compares the shadow priced increase(decrease) in net present value of the total employment from each scenario over the first 100 years of the planning horizon.

Table 61

Summary of Decadal Flows of Gross Person-Years of Direct Employment

Decade	I-1	I-2	II-1	II-2	III-1	III-2	IV-1	IV-2
1	12980	13119	1111	1118	2707	3222	2960	3218
2	752	1653	76	365	2707	4222	2960	3910
3	127	146	1353	1384	2711	4240	2960	4235
4	460	495	340	706	2702	4268	2961	4264
5	111	156	58	154	2693	4204	2947	4200
6	950	2053	712	773	2688	4072	2941	4042
7	81	880	7066	181	2678	3967	2935	3460
8	1713	567	15720	8476	2682	4174	2966	3266
9	6682	7590	998	18878	2684	3930	3026	3817
10	730	836	4205	1745	2708	4270	3053	3513
11	112	1173	2776	2957	269	869	712	198
12	430	1301	1114	1340	523	538	1260	204
13	136	157	1233	1381	1014	218	1128	630
14	947	1078	1662	2173	206	1622	950	962
15	1411	99	10	600	402	600	1359	1405
16	421	1570	0	123	785	717	1205	1890
17	6694	8366	0	12	1525	986	2341	2892
18	715	824	0	18	2963	2284	1774	4903
19	86	107	0	8	4043	3303	782	312
20	429	522	0	8	3917	7487	1260	352
21	136	1231	0	0	3091	381	1154	443
22	2276	1842	0	0	2798	750	1441	887
23	113	98	48	0	3423	1432	1215	1343
24	648	592	712	779	3104	2859	1536	2600
25	7177	8880	36365	36893	156	5595	1706	5199

where: units are person-years of employment
scenario abbreviaitons are as before

Table 62

Summary of Inter Regime Shadow Values of Employment

	I-1	I-2	II-1	II-2	III-1	III-2	IV-1
I-1	-	-	-	-	-	-	-
I-2	4.104	-	-	-	-	-	-
II-1	-42.502	-46.606	-	-	-	-	-
II-2	-42.739	-46.844	-0.238	-	-	-	-
III-1	-24.770	-28.874	17.732	17.970	-	-	-
III-2	-10.321	-14.425	32.180	32.418	14.448	-	-
IV-1	-21.535	-25.639	20.966	21.204	3.234	-11.214	-
IV-2	-11.803	-15.907	30.699	30.936	12.967	-1.482	9.732

where: shadow price of employment = .121
values are in millions of dollars
scenario abbreviations are as before

The previous Tables allow for an examination into community stability and employment creation. In examining Table 61, I-1, the extremely large harvests and harvest areas noted previously also create periods of substantial employment. Just as with the harvests, these periods of great employment are then followed by extended periods of idleness. Such is also the case for II-1, unconstrained volume maximization. The additional value of employment of I-1 over II-1 is $98.012 million dollars however. The large gains in employment are due to economic rotations allowing the large harvest in the first period. Just as with evaluating the NPV from the timber harvest, discounting values employment created today more than employment created tomorrow. The option for silvicultural treatments has created additional employment for the unconstrained economic maximization scenario. In comparison to I-1 the increase in employment NPV from I-2 is approximately $4.104 million dollars. Of interest is that the option for silvicultural treatmetns has actually reduced the value of employment for the unconstrained volume maximization scenario. The readjustment of periodic harvest levels has effected the labour requirement, specifically in periods 7 to 10 (Table 61). The result is that scenario II-2 retains $0.238 million dollars less employment value than II-1.

Employment is directly related to the harvest of timber and the total area needed to meet the volume requirements. For scenario III-1, approximately 260 persons are needed to harvest and mill the first 100 years cut, annually. As the area harvested changes from year to year, based on the volume per hectare of each given stand, so do employees required to treat it. Average annual employment for the first 100 years is approximately 9 persons. The inclusion of silvicultural treatment options (III-2) has increased employment levels through the additional harvest as well as the additional treatments. The shadow priced NPV of this additional employment is approximately $14.448 million when compared to scenario III-1 . The number of labour intensive thinning treatments serves to provide the majority of this benefit.

The additional employment benefit to value based rotations (IV-1) is evident as larger areas of harvest translate into greater employment levels. Treatment employment levels are much more stable in the instance of economic rotations as larger amounts land are constantly being used. When compared to scenario III-1, the additional employment generated here accrues a net present value of $3.234 million dollars. There was no additional value attached to the evident stability. The inclusion of silvicultural treatment options (IV-2) has caused employment levels to increase significantly during the first ten periods. While average employment generated solely from site preparation has gone up by approximately 28 person-years. incremental employment obtained through silvicultural treatments is substantial. Although sometimes subject to fluctuation, additional employment averaged 291 person-years per period for the entire planning horizon. The increases in NPV which can be associated with silviculture amount to $9.732 million over IV-1.

Of interest when comparisons are made between regimes III and IV, are the differences in areas treated versus employment generated. As one would expect, shorter rotations and more frequent harvests create larger treatment areas for IV-1 and thus greater employment over III-1. However, when silvicultural options are examined, we find that while scenario IV-2 treats 942,383 hectares and scenario III-2 treats only 679,703 hectares, III-2 creates an additional $1.482 million dollars worth of employment. The mixture of treatments has changed substantially with IV-2 opting for "less" intensive, thus lower cost, silvicultural options such as fertilization.

Employment levels resulting from sustained yield, biological forest management are represented by regime III scenario 1 (III-1). Even though harvest levels are equal, employment levels differ from decade to decade. This is due to the varying areas of harvest required to maintain sustained yield. Average periodic employment is 2696 person-years (py's) or approximately 267 persons directly employed each year. To examine the cost, in py terms, of management based on MAI instead of SEV, comparison is made to IV-1. Average periodic employment for IV-1 is 2971 py's. In taking the difference, the total gross opportunity costs in py terms is 275 years of employment each decade. This value must be subject to shadow pricing however as not all of the additional employment will result from newly created jobs. The resultant value lost to biological management can be viewed in Table 15. The opportunity cost of lost direct and indirect employment is therefore $3.234 million dollars.

Sustained yield policies are designed with community stability in mind. To evaluate this policy in employment terms is difficult. While the unconstrained economic maximization scenario retains a much larger net present value of employment, there is no resemblance of stability. If labour is perfectly mobile, as in the neoclassical sense, the entire present value decrease can be attributable to sustained yield policies. Thus, the opportunity cost is established by comparing IV-1 and I-1 and is found in Table 15. The costs of flow constraints on employment is $11.802 million dollars. This is a direct result of the extremely large employment effects during the first decade of I-1. However, in a Keynsian sense, not all labour is mobile and there is unemployment in the market place. There would then be an associated cost to not maintaining community stability. As wild swings in the labour force would occur, costs to society for support programs such as unemployment insurance and welfare would also increase greatly. This then would be a cost associated with the unconstrained scenarios and one which is not estimated within the scope of this research.

In examining biological forest management, however, the presence of the sustained yield constraint greatly increases the value of employment. The constrained volume maximization scenario generates an additional $17.742 million dollars of employment when compared to the unconstrained scenario. This is a direct result of the smoothing effect created by the sustained yield policy. Harvests, and thus employment, which would be realized later in the planning horizon under II-1 are pushed forward to achieve sustained yield under III-1. This additional employment earlier in the planning horizon retains greater value through discounting.

When the flow of harvest is constrained by sustained yield there is also an employment allowable cut effect which must be estimated. While the inclusion of silvicultural alternatives will create employment as treatments are established, not all of the additional jobs are created as a direct result of efficient resource allocation. The ACE, through treatments designed to increase the current harvest, will generate employment. As would be expected, silvicultural treatments designed to maximize volume (III-2) appear to generate the greatest increase in employment. The shadow value of this increased employment over III-1 is approximately $14.448 million dollars. This compares to increases of $9.732 million dollars for IV-2 over IV-1, $4.104 million dollars for I-2 over I-1, and a $0.238 million dollar reduction for II-2 over II-1. Comparing IV-2 with III-2 shows an additional $1.481 million dollars accruing to the volume maximization scenario.

Assuming the true employment value of silvicultural investments are described by the unconstrained scenarios, the allowable cut effect can be netted out. The associated employment ACE within the constrained economic maximization regime is $5.628 million dollars ($9.732 - $4.104) and the ACE within the constrained volume maximization regime is $14.686 million dollars ($14.448 + $0.238).

These results show silvicultural investments within a policy regime of economic maximization to retain the largest incremental employment benefit. Also, that silvicultural investments based on biological maximization have adverse effects on employment because of the shifts which occur in the harvest patterns during periods 7 to 10. These results are primarily a function of the age class distribution of the forest. As was noted previously, for the unconstrained regimes, the existence of economically overmature stands allows for much larger initial harvests and thus greater values for employment.

The constrained economic maximization scenarios have been shown to be the better of the two constrained maximization regimes for employment valuation. Shorter rotations and much larger areas of land being constantly used for harvesting and treatment serve to increase the labour required to maintain operations. As well, the ACE is much less severe under conditions of economic maximization, showing a much more effecient allocation of resources.

As was seen in previous results, silvicultural treatments provide very little added benefit when compared to the values extracted from the forest as a whole. Again, this is a function of the forest and as the forest approaches normality, investment allocations would provide benefits in greater proportion to the overall forest value.

APPENDIX V

Allowable Cut Effect

When examining the period of time a seedling requires to reach an optimal age for harvest, it becomes obvious that investments in forest management, over and above minimum requirements, are rare when based solely on the discounted values of future benefits. As an incentive for firms to intensify their forestry investments, it has been suggested that expenditures made to increase future growth should allow an increase in current harvests. These prompt elevations in annual harvests and allow for an extremely high rate of return on timber investments, making investments into future growth appear very attractive. This "allowable cut effect" (Schweitzer et.al., 1972) has created enthusiasm among foresters but uncertainty among many economists.

The allowable cut effect (ACE) has been defined as the "prospective increase in future inventory due to an increase in inputs, which will be harvested in equal annual amounts beginning now and extending over the period of one rotation." (Teeguarden, 1973) Thus, a firm, through the intensification of management practices, can realize an uplift in annual allowable cut. This is not to say that ACE has applications throughout the forest industry as Schweitzer et.al.(1972) have described the characteristics of the management decision-making situation necessary for an ACE to occur:

1. An allowable cut is calculated, sold, and harvested.
2. The allowable cut is based on volume regulation.
3. The allowable cut varies with the rate of forest growth
4. There is a reserve of merchantable timber available for immediate harvest.

The reasons for these are quite clear. if a firm is not already harvesting its calculated allowable cut, then it will not required the extra merchantable timber available to it through the ACE. This condition will have implications over the long run. Once harvest levels have reached the long run sustained yield average, the amount of cut will be equal to the amount of growth for the forest. In such a scenario, there will no longer be an excess of merchantable growing stock and the ACE will be invalid. As well, if an excess supply of harvestable timber is not available, then there is no incentive for the firm to intensify its management practices so as to increase its cut through an ACE. The model used to estimate annual allowable cut (AAC) must include in it, some measure of forest growth. This is because the ACE bases itself upon averaging out an increase in forest growth over the even flow constraint period. By making use of the Hanzlik formula for allowable cut estimation, this criteria can easily be seen.

$$AAC = (V/R) + I$$

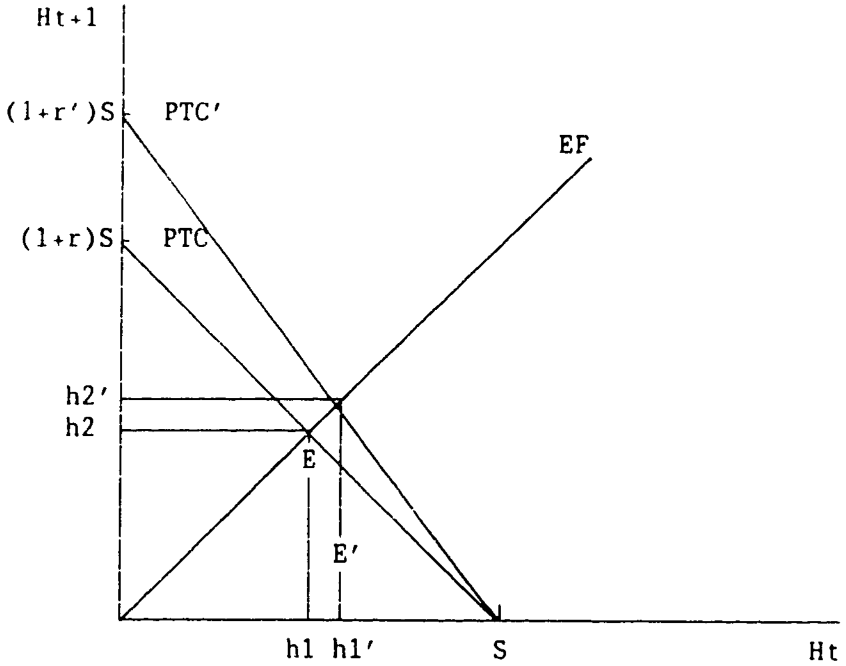
where: AAC = annual allowable cut
V = volume of mature timber
R = length of constraint period or rotation length
I = mean annual increment

The Hanzlik formula allows its users to liquidate rotation age timber while cutting the current annual growth. Thus, by increasing I through more intensive management practices, an increase in AAC would be immediately realized. The final criterion is that of volume regulation or flow constraints. For the ACE to occur, there must be limits placed on the temporal allocation of timber harvest. If there were no constraints on harvest flow, a firm could autonomously decide to increase their cut instead of doing so through an ACE.

As was previously mentioned, any type of investment which increase the quantity of timber in future time periods qualifies for consideration under the allowable cut effect. Binkley (1980) has graphically demonstrated how such an investment would lead to an elevation in allowable cut. In referring to Figure 1, a two period harvest scheduling model is depicted. There is an inventory (S) which can be harvested now (Ht) or next period (Ht+1). The tradeoff between the harvests in these two periods is shown by the product transformation curve (PTC), which is linear with a slope -(1+r), where r is the rate of growth of the current forest. Assuming all of the criteria required for an ACE to occur are met, the evenflow constraint (EF) extends out from the origin at a 45 degree angle and the harvest for each period will be at the intersection of EF and PTC (h1 and h2). Once an investment is made which increases future growth rates, the slope of the PTC will increase to -(1+r′) and a new PTC will be formed (PTC′). The level of maximum sustained yield will shift from E to E′ and the level of harvest will increase in both periods to h1′ and h2′. The allowable cut effect is the difference between h1 and h1′.

Figure 1

The Allowable Cut Effect



There have been many arguments against the use of the ACE in evaluating timber investments. These arguments are primarily rooted in the fact that the ACE goes against basic economic investment theory. Such theory maintains that good investment opportunities must be based solely on their individual merits. The ACE greatly overestimates the return on investments by attributing to the investment, returns which are the joint products of the capital held in surplus merchantable growing stock and the investment itself (Teeguarden, 1973). Teeguarden(1973) and Walker(1975) have both pointed out that the ACE may perform poorly as an investment guide because of the ACE;s requirement for a reserve of merchantable timber. The ACE can lead to investing in areas with lower growth potential but larger reserves of merchantable as opposed to sites with higher growth potential. Aside from Walker's feeling that ACE ignores the growth potential of the site, he has also noted that ACE gives rise to a sort of "perverse economics". In realizing the ACE, the larger the inventory of merchantable timber on a site, the greater the incentive to invest in producing more inventory on that site. This is total reversal to economic theory which states that as supply becomes increasing limited, the price will rise, making it more attractive to invest in the process of creating additional supplies.

A further shortcoming of the ACE is that it promotes investments which increase the quantity of timber not investments which increase timber quality. In a study performed by Fraser(1985), two forest investment alternatives were examined, a spacing/fertilization project and a backlog reforestation project. Benefit-cost analyses were done at various rates of interest and the net benefits from the spacing/fertilization project were consistently higher that those of the reforestation project. When investments were no longer judged according to their own merits and the ACE was incorporated, the results of the analyses changed drastically. Besides both project's returns increasingly significantly, both had positive net benefits at a 10% level of interest for the first time. As well, the net benefits of the reforestation project now continually exceeded those of the spacing/fertilization project. The ACF therefore slants investment decisions towards those with greater physical impacts. Fraser noted that this could potentially lead to serious distortions if it were to result in the rejection of more lucrative alternatives because of lesser impacts on physical volumes.

Since the vast majority of the forested land base is owned by the

Crown. Teeguarden(1973) has criticized the ACE for not being in the best interests of public welfare. He questions whether it should be the goal of public agencies to promote increases in cash flow as opposed to the maximization of real wealth. If a firm does, however, increase production due to ACE, increases in employment and other external effects may also be realized by the local community. As well, Teeguarden suggested that the ACE inherently overestimated the real wealth effect of a new investment by: 1) failing to account for the opportunity costs associated with the merchantable timber reserve needed to obtain it and; 2) averaging current and future output effects. It must be noted however, that it is not the ACE which creates the opportunity cost but the even flow policy associated with it. The ACE does not occur without constraints placed on harvest flow. Also that future output effects are averaged back to increase current production levels is what has drawn many organizations, including government agencies, toward it. Attempts by government to encourage intensive management, without legislation, have not been well received because of the lacking incentive to invest in areas which show low returns. The ACE alleviates this problem by allowing firms to realize high rates of return on their investments. The use of and consequences of using this tool must, however, be understood by those who interpret its results.

APPENDIX VI

The following table represents a summary of statistics obtain through the MUSYC runs

Regime I Scenario 1

TABLE 63

Periodic Flows for the Unconstrained Economic Maximization Regime, No Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Harvest (py's)	Generated Treatment (py's)
1	55.832	250.808	1975.271	12283	697
2	3.107	24.648	73.062	684	68
3	0.524	4.354	8.290	115	12
4	1.902	15.292	20.394	418	42
5	0.457	3.560	3.315	101	10
6	3.926	31.106	19.228	864	86
7	0.338	2.638	1.121	74	7
8	7.197	46.706	16.281	1583	130
9	27.650	215.472	41.802	6083	599
10	3.024	23.462	3.090	665	65
11	0.459	3.958	0.314	101	11
12	1.902	15.292	0.885	418	42
13	0.560	4.748	0.175	123	13
14	3.914	30.974	0.832	861	86
15	5.947	36.918	0.866	1308	103
16	1.737	14.008	0.168	382	39
17	27.701	215.868	1.817	6094	600
18	2.959	23.066	0.131	651	64
19	0.355	2.770	0.011	78	8
20	1.776	13.842	0.036	391	38
21	0.560	4.748	0.008	123	13
22	9.522	65.254	0.089	2095	181
23	0.464	3.958	0.003	102	11
24	2.768	14.140	0.007	609	39
25	29.592	240.120	0.084	6510	667

Regime I Scenario 2

TABLE 64

Periodic Flows for the Unconstrained Economic Maximization Regime, Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Generated Harvest (py's)	Treatment (py's)	Silvic (py's)
1	55.832	250.808	1971.663	12283	697	139
2	3.571	25.836	83.525	786	72	795
3	0.575	4.616	0.457	127	13	6
4	2.002	13.842	21.270	440	38	17
5	0.630	5.142	3.599	139	14	3
6	8.366	63.804	41.302	1841	177	35
7	0.407	2.902	1.176	90	8	782
8	1.825	12.690	0.958	402	35	130
9	31.138	215.340	46.959	6850	598	142
10	3.422	24.254	3.466	753	67	16
11	4.689	39.688	3.232	1032	110	31
12	2.123	15.424	0.982	467	43	791
13	0.562	3.956	-0.017	124	11	22
14	4.384	31.106	0.930	964	86	28
15	0.381	2.638	0.046	84	7	8
16	5.884	46.706	0.489	1294	130	146
17	31.154	215.472	2.039	6854	599	913
18	3.383	23.462	0.128	744	65	15
19	0.401	2.770	0.010	88	8	11
20	2.128	15.030	0.043	468	42	12
21	4.892	40.478	0.065	1076	112	43
22	4.423	30.974	0.039	973	86	783
23	0.381	2.638	-0.001	84	7	7
24	1.969	14.008	0.004	433	39	120
25	36.704	289.826	0.104	8075	805	0

Regime II Scenario 1

Table 65

Periodic Flows for the Unconstrained Volume Maximization Regime, No Silvicultural Options Scenario

Period Volume (decades)	Harvest Area (MMm3)	Harvest Value (Mha)	Present Harvest (MM$)	Employment Treatment (py's)	Generated (py's)
1	4.888	12.922	175.185	1075	36
2	0.333	0.924	8.067	73	3
3	5.944	16.478	97.188	1308	46
4	1.490	4.220	16.456	328	12
5	0.256	0.528	1.904	56	1
6	3.161	5.932	15.885	695	16
7	31.351	60.606	106.425	6897	168
8	69.649	142.872	159.653	15323	397
9	4.404	10.546	6.797	969	29
10	18.589	41.656	19.430	4090	116
11	12.198	33.216	8.597	2684	92
12	4.876	14.932	2.318	1073	41
13	5.430	13.846	1.759	1195	38
14	7.295	20.698	1.595	1605	57
15	0.042	0.132	0.006	9	0
16	0.000	0.000	0.000	0	0
17	0.000	0.000	0.000	0	0
18	0.000	0.000	0.000	0	0
19	0.000	0.000	0.000	0	0
20	0.000	0.000	0.000	0	0
21	0.000	0.000	0.000	0	0
22	0.000	0.000	0.000	0	0
23	0.214	0.396	0.001	47	1
24	3.161	5.932	0.014	695	16
25	161.020	338.504	0.469	35424	940

Regime II Scenario 2

Table 66

Periodic Flows for the Unconstrained Volume Maximization Regime, Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Generated Harvest (py's)	Treatment (py's)	Silvic (py's)
1	4.888	12.922	171.577	1075	36	7
2	0.333	0.924	7.606	73	3	289
3	5.944	16.478	93.405	1308	46	30
4	1.443	3.824	15.557	317	11	377
5	0.330	0.924	- 0.138	73	3	79
6	3.295	6.328	16.236	725	18	30
7	0.743	1.450	2.304	163	4	14
8	37.447	70.230	85.881	8238	195	42
9	83.307	164.356	128.999	18328	457	94
10	7.658	18.062	7.978	1685	50	10
11	12.941	33.084	9.102	2847	92	18
12	5.689	16.514	2.690	1252	46	42
13	6.069	13.846	1.983	1335	38	8
14	7.986	20.038	1.763	1757	56	360
15	0.466	1.320	- 0.001	103	4	494
16	0.000	0.000	- 0.094	0	0	123
17	0.000	0.000	- 0.007	0	0	12
18	0.000	0.000	- 0.006	0	0	18
19	0.000	0.000	- 0.002	0	0	8
20	0.000	0.000	0.000	0	0	0
21	0.000	0.000	0.000	0	0	0
22	0.000	0.000	0.000	0	0	0
23	0.000	0.000	0.000	0	0	0
24	3.455	6.724	0.015	760	19	0
25	163.428	338.108	0.477	35954	939	0

TABLE 67

Periodic Flows for the Constrained Volume Maximization Regime, No Silvicultural Options Scenario

Period Volume (decades)	Harvest Area (MMm3)	Harvest Value (Mha)	Present Harvest (MM$)	Employment Treatment (py's)	Generated (py's)
1	11.843	36.662	421.912	2605	102
2	11.843	36.715	284.494	2605	102
3	11.843	38.327	192.128	2605	106
4	11.843	35.049	130.105	2605	97
5	11.843	31.832	87.980	2605	88
6	11.843	29.930	59.348	2605	83
7	11.843	26.429	40.170	2605	73
8	11.843	27.743	27.098	2605	77
9	11.843	28.577	18.313	2605	79
10	11.843	36.924	12.334	2605	103
11	1.175	3.444	0.827	259	10
12	2.292	6.997	1.090	504	19
13	4.469	11.285	1.448	983	31
14	0.910	2.297	0.199	200	6
15	1.774	4.479	0.262	390	12
16	3.459	8.734	0.346	761	24
17	6.745	14.864	0.454	1484	41
18	13.152	25.377	0.597	2893	70
19	17.942	34.418	0.550	3947	96
20	17.376	33.848	0.360	3823	94
21	13.718	26.315	0.192	3018	73
22	12.417	23.820	0.117	2732	66
23	15.181	29.930	0.097	3340	83
24	13.777	26.429	0.059	3031	73
25	0.689	1.322	0.002	152	4

Regime III Scenario 2

TABLE 68

Periodic Flows for the Constrained Volume Maximization Regime, Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Generated Harvest (py's)	Employment Generated Treatment (py's)	Employment Generated Silvic (py's)
1	13.983	43.814	494.356	3076	122	24
2	13.983	44.368	331.567	3076	123	1023
3	13.983	45.926	216.084	3076	128	1036
4	13.983	43.898	146.741	3076	122	1070
5	13.983	38.477	98.422	3076	107	1021
6	13.983	36.076	67.016	3076	100	896
7	13.983	40.196	45.350	3076	112	779
8	13.983	57.790	30.920	3076	161	937
9	13.983	77.470	20.418	3076	215	639
10	13.983	133.619	13.921	3076	371	823
11	1.207	20.703	0.476	266	58	545
12	0.262	2.666	-0.026	58	7	473
13	0.511	3.780	-0.002	112	11	95
14	0.997	5.679	0.204	219	16	1387
15	1.943	11.312	0.166	427	31	142
16	1.927	11.801	0.178	424	33	260
17	3.757	29.148	0.207	827	81	78
18	7.327	2.826	0.331	1612	8	664
19	14.288	48.529	0.431	3143	135	25
20	27.861	114.955	0.564	6129	319	1039
21	1.666	4.863	0.015	367	14	0
22	3.249	12.714	0.017	715	35	0
23	6.336	13.855	0.040	1394	38	0
24	12.354	50.646	0.052	2718	141	0
25	24.091	106.347	0.068	5300	295	0

TABLE 69

Periodic Flows for the Constrained Economic Maximization Regime, No Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Harvest (py's)	Generated Treatment (py's)
1	12.947	40.153	461.306	2848	112
2	12.947	40.494	311.125	2848	112
3	12.947	40.399	210.572	2848	112
4	12.947	40.639	141.858	2848	113
5	12.947	35.629	95.988	2848	99
6	12.947	33.433	64.854	2848	93
7	12.947	31.210	43.870	2848	87
8	12.947	42.300	29.563	2848	118
9	12.947	63.973	19.809	2848	178
10	12.947	73.770	13.361	2848	205
11	2.946	22.965	2.033	648	64
12	5.214	40.639	2.430	1147	113
13	4.663	36.685	1.467	1026	102
14	3.934	30.663	0.837	865	85
15	6.075	43.868	0.877	1337	122
16	4.995	38.235	0.468	1099	106
17	9.741	71.415	0.641	2143	198
18	7.339	57.199	0.320	1615	159
19	3.222	26.129	0.096	709	73
20	5.214	40.639	0.105	1147	113
21	4.751	35.629	0.062	1045	99
22	6.005	43.321	0.056	1321	120
23	5.041	38.038	0.031	1109	106
24	6.489	46.070	0.027	1428	128
25	7.061	55.037	0.020	1553	153

Regime IV Scenario 2

TABLE 70

Periodic Flows for the Constrained Economic Maximization Regime, Silvicultural Options Scenario

Period (decades)	Harvest Volume (MMm3)	Harvest Area (Mha)	Present Value (MM$)	Employment Generated Harvest (py's)	Treatment (py's)	Silvic (py's)
1	[illegible]	43.697	495.064	3073	121	24
2	[illegible]	44.323	334.979	3073	123	714
3	13.968	45.856	218.825	3073	127	1035
4	13.968	43.843	146.588	3073	122	1069
5	[illegible]	38.438	98.322	3073	107	1020
6	13.968	36.073	66.701	3073	100	869
7	13.968	40.027	44.432	3073	111	276
8	13.968	57.358	31.068	3073	159	34
9	13.968	79.736	21.261	3073	221	523
10	13.968	132.033	13.960	3073	367	73
11	0.699	10.522	0.477	154	29	15
12	0.764	10.799	0.351	168	30	6
13	1.490	13.528	0.447	328	38	264
14	2.906	20.097	0.550	639	56	267
15	5.667	39.177	0.764	1247	109	49
16	7.609	51.149	0.715	1674	142	74
17	10.789	77.269	0.672	2374	215	303
18	20.127	140.969	0.886	4428	392	83
19	1.248	9.031	0.037	275	25	12
20	0.744	4.281	0.012	164	12	176
21	1.450	11.448	0.017	319	32	92
22	2.828	19.566	0.024	622	54	211
23	5.514	37.919	0.032	1213	105	25
24	10.753	70.603	0.045	2366	196	38
25	20.968	211.104	0.059	4613	586	0