UNIVERSITY OF ALBERTA

A FOREST PLANNING SIMULATION MODEL: INTEGRATION OF TRANSPORTATION AND SILVICULTURAL DECISIONS

BY

GLEN WILLIAM ARMSTRONG ©

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

FALL 1990

ISBN 0-315-65106-7

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: GLEN WILLIAM ARMSTRONG

TITLE OF THESIS: A FOREST PLANNING SIMULATION MODEL: INTEGRATION OF TRANSPORTATION AND SILVICULTURAL DECISIONS

DEGREE: MASTER OF SCIENCE IN FOREST ECONOMICS

YEAR THIS DEGREE GRANTED: 1990

Glen William Armstrong

13024 - 72 Street

Edmonton, Alberta

T5C 0P9

Date: 12 October 1990

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

THE UNDERSIGNED CERTIFY THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH FOR ACCEPTANCE, A THESIS ENTITLED A FOREST PLANNING SIMULATION MODEL: INTEGRATION OF TRANSPORTATION AND SILVICULTURAL DECISIONS SUBMITTED BY GLEN WILLIAM ARMSTRONG IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST ECONOMICS.

William E. Phillips

W.E. Phillips

James Beck Jr

J.A. Beck, Jr.

Luis Constantino

L.F. Constantino

[illegible]

D.S. Gill

Date: 11 October 1990

ABSTRACT

A simulation based forest planning model is developed and tested in this thesis. The model is designed to help a forest manager choose the schedule of harvesting, other silvicultural, and road building activities that maximize the contribution of a forest area to the present net worth of the manager's employer. It is assumed that the forest products company faces rigid mill capacity constraints.

The theory of forest rotation is used to identify the costs and benefits of delaying the harvest of forest stand aggregates. The costs of delay are the interest costs of holding forest inventory and delaying future rotations. The benefits of a delayed harvest are those associated with stand growth. In each period, stand aggregates are sorted by descending net cost of delay per cubic metre. Harvest proceeds down this harvest priority list until the volume request for the period is satisfied. Harvested stands are assigned to the management regime that maximizes the present net worth of the next rotation.

Stand aggregates in inaccessible areas are not harvested, but the net costs of delaying harvest and regeneration for these aggregates are used to provide the analyst with an indication of priority areas for access development. The analyst chooses a number of roading projects to evaluate for each period: the project where the difference between the costs of delay avoided by harvest and the interest costs of the roading project is the greatest is selected as the best roading project for the period.

The model is applied to a forest management licence agreement area in Saskatchewan. The study demonstrates the application of the model to a forest planning problem. The sensitivity of the model to changes in discount rate and period length is examined. The importance of sorting the harvest priority list by net cost of delay per cubic metre and not cost per hectare is demonstrated. The model developed here is useful for forest planning under a wide variety of institutional and market structures related to the harvesting and processing of wood fibre.

ACKNOWLEDGEMENTS

A number of people and organizations contributed to the development of this thesis, and I would like to take this opportunity to thank them. Steve Smith and Jack Spencer of Weyerhaeuser Canada Ltd. and Jamie Benson of Saskatchewan Parks, Recreation, and Culture provided the data necessary to undertake this study. Ray Fautley and Diana Boylen of Forestry Canada acted as financial authority and scientific authority for the project. Funding for the project was provided through the Canada-Saskatchewan Forest Resource Development Agreement. Frank Novak of the University of Alberta listened to many derailed trains of thought, and helped put them back on track. Thank you all.

The members of my supervisory committee deserve special acknowledgement for their contributions. Dhara Gill chaired the examination committee and helped make the thesis defence a pleasant chore. Jim Beck sparked my interest in this area of research and played a big role in the development of the research proposal. Many of the ideas in this thesis developed out of conversations with Luis Constantino. My supervisor, Bill Phillips, has my gratitude for his advice, his endless patience, and his accessibility. The suggestions of all four committee members are appreciated and make this thesis better than it would have been without their help.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHIC PLATES

CHAPTER 1: INTRODUCTION

The economics of timber supply is a topic that commands a great deal of interest in the Canadian forestry community. The national timber supply study being undertaken by Forestry Canada, the efforts of the Forest Economics and Policy Analysis Research Unit at the University of British Columbia (*e.g.* Williams and Gasson, 1986), and the Alberta Economic Timber Supply Study (Beck *et al.*, 1989) are evidence of the importance of this topic to foresters and government policy makers.

An important aspect of economic timber supply modeling that has received little attention in Canada is the interrelationship between transportation and silvicultural activities in forest management. Timber harvesting and many other silvicultural activities simply cannot take place unless there is a developed transportation system providing access to the part of the forest to be treated. The development of a road system is a costly undertaking, so the timing and extent of road development will influence the profitability of forest management.[1]

The purpose of this research is to develop a forest planning model incorporating both silvicultural and transportation activities to help determine the combination of these activities over time and space that best meet the objectives of a forest manager. The specific objectives of this study are:

a. to build a model of the decision making environment of industrial forest managers;
b. to implement the model as a computer program running on a personal computer;
c. to develop a set of cost and response functions for silvicultural and transportation activities applicable to a case study area; and
d. to apply the model in a case study in order to evaluate its performance and investigate the sensitivity of the model to changes in assumptions.

This chapter presents an introduction to the study including background information about the study area and brief descriptions of some other models that can been used to model the development

---

1 In some areas, modes of transportation other than roads are important means of moving wood from stump to mill. For simplicity, and because the case study focuses on road construction, the discussion will centre on the development of access through road construction.

of access into forest areas. Desirable qualities in the model to be built for this study are identified based on the strengths and weaknesses of the reviewed models and specific characteristics of the planning problem for the case study area.

Chapter 2 describes the theoretical basis and computer implementation of the model. Chapter 3 describes the data collected and developed for this study. Chapter 4 presents the results of case study runs. The study is summarized in Chapter 5 and suggestions for further development are made.

The model developed in this thesis is based on the assumption that the objective of industrial forest management is to maximize the contribution of forest management activities to the present net worth (PNW) of the firm owning or managing a forest. In this study, forests are viewed primarily as a source of timber. It is recognized, however, that forests provide a number of other goods and services outside the scope of the present study. The manager can influence the PNW by making decisions with respect to:

- the timing of harvest of individual stands within the forest,
- the timing and location of any road construction projects, and
- the type and intensity of other silvicultural treatments to be applied to stands regenerated after harvest.

In this study, timber is treated as an input to the pulp production process: the demand for timber, therefore, is derived from the demand for pulp. The firm is assumed to be constrained by rigid mill capacity constraints. The forest manager's problem is to develop a cost minimizing timber supply schedule over the length of the planning horizon. The economics underlying the model developed here comes from the theories of production and finance.

The model developed in this thesis is used in a case study using data from the Weyerhaeuser Canada Ltd. forest management licence agreement (FMLA) area north of Prince Albert, Saskatchewan. The structure of the model and the data requirements of the computer implementation were developed in order to take advantage of the available data and to fit the planning situation facing Weyerhaeuser.

Weyerhaeuser operates a bleached kraft pulp mill near Prince Albert producing softwood and hardwood pulp and a lumber mill near Big River. The FMLA gives Weyerhaeuser the right

> ... to enter upon the Agreement area for the purposes of managing, growing, cutting and removing the timber thereon, conducting forest management and all other purposes incidental thereto and for the purposes of construction, operation and maintenance of, camps, roads, wood yards, mills and other installations necessary and incidental to its operations[2]

for a period of 20 years. The agreement contains an "evergreen clause" allowing for renewal of the agreement every five years subject to acceptable performance by the firm. The agreement area is an area of forest north of Prince Albert.

1.1 Description of Other Models

There are existing forest planning models that have been or could be used to model both silviculture and the development of access to the forest. These models can be classified as simulation or optimization models and can be further classified as to whether road construction is modeled internally or completely controlled by the user.

Optimization models directly determine the combination of activities that will optimize an objective function subject to constraints. These models are presented with a set of possible activities, and set of constraints, and an objective function from which the best combination of activities is mathematically determined.

Simulation models project forest inventories in response to some specified actions. They do not determine the optimal combination of activities. The simulation models usually contain a harvest priority rule which determines the order in which stands are to be harvested.

Road construction can be modeled internally or can be externally specified. In an optimization model, the internal specification would allow the model to determine the best time to build a particular road. In a simulation model, an internal specification would trigger the construction of roads under certain conditions. External specification of access development imposes changing periodic constraints on available wood supply.

1.1.1 Optimization Models - External Access Development

The most commonly used mathematical technique for optimization based forest planning models is linear programming (LP). Several LP models have been developed. The most commonly used in Canada are Timber RAM (Navon, 1971) and MUSYC (Johnson and Jones, 1979). The matrix generators for these models allow the user to specify possible forest management activities and

---

2 "Forest Management Licence Agreement" between Weyerhaeuser Canada Ltd. and the Province of Saskatchewan. Unsigned draft dated 9 September 1986.

constraints in a convenient form. A computerized linear programming algorithm determines the combination of forest management activities that optimizes the objective function while satisfying the constraints.

Access development must be modeled externally using Timber RAM or MUSYC. The user can specify the proportion of the area of a timber class that is accessible in each of the first five periods of analysis. In this formulation, access development acts as a constraint rather than as an activity. This approach ensures that inaccessible timber is not scheduled for harvest but provides no guidance as to when roads should be built. There is no ability to directly include road construction and maintenance costs in the solution or reporting procedures for either model.

Lougheed (1988) develops a forest planning modeling system combining the capabilities of Timber RAM and a geographic information system (GIS). The timing of road construction is determined outside the model. The GIS is used to digitize road networks for each of the first five periods, to determine minimum haul cost routes to each stand, and to attach haul cost attributes ($\$/m^3$) to stands for each of the first five periods. Stands are considered accessible when the haul cost per cubic metre first reaches a minimum. This information is used to formulate the periodic accessibility constraints for Timber RAM.

These models can be used to determine the combination of silvicultural activities that optimize an objective function subject to a series of constraints. Unfortunately, the timing of access development is determined externally and modeled as a constraint, so there is a real possibility that roads will be built at a non-optimal time. The models could be run as simulators to model the effect of building sections of road at different times, but the amount of work involved in running these simulations could be tremendous.

1.1.2 Optimization Models - Internal Access Development

Mixed integer programming (MIP) is an extension of LP that forces some variables in the problem to assume integer values. This technique has been used in some forest planning models to incorporate access development. It is useful to think of potential roads as a number of road segments that you can choose to build or not build in a particular time period. These segments start and end with a node. Areas in the forest are assigned a node or nodes from which they can be accessed. If there is a continuous path of constructed road between a node accessing a stand and a destination for the timber, the stand is considered accessible and harvest can occur. Models incorporating this technique include an extended version of Timber RAM called Roading RAM (Weintraub and Navon, 1976) and the Integrated Resource Planning Model (IRPM) (Jones *et al.*, 1988).

One of the capabilities developed in the FORPLAN model used by the United States Forest Service is aggregate emphasis. Aggregate emphasis is a technique that allows for some spatial analysis of forest planning problems (Iverson and Alston, 1986). This technique also requires the use of MIP. It allows the model to choose one of several possible management emphases for an area, each of which has a set of alternative prescriptions. Alternative emphases can be created to reflect the timing of road development.

A model that can simultaneously optimize silviculture and access development like these MIP based models would be the ideal product of this study. However MIP solution procedures require a great deal of computing power: successful implementation of one of these procedures (for any usefully sized problem) on the current generation of microcomputers is unlikely.

1.1.3 Simulation Models - External Access Development

External access development in simulation models is accomplished in much the same way as in optimization models. For example, access development in the Timber Resource Inventory Model (TRIM) (Tedder *et al.*, 1984) can be modeled using TRIM's capability to shift areas from outside the accessible land base to the accessible land base.

1.1.4 Simulation Models - Internal Access Development

Williams (1987) uses a modified version of the Ontario Wood Supply and Forest Planning Model (OWOSFOP) to simulate forest growth, harvest, and road construction for a case study in Ontario. The study used a number of different harvest priority rules to order stands for harvest: the opportunity cost rule is the one of interest here.

In each period, the stands are ranked on the basis of decreasing opportunity cost (*i.e.* the cost of not harvesting in the current period).[3] The model harvests from the sorted list of stands until the harvest request for the period is met. A model parameter specifies the proportion of the total harvest volume that should come from accessible stands with an opportunity cost at least as great as a

---

3 This concept is discussed in detail in chapter 3.

specified amount. If this specified proportion cannot be harvested, road construction is triggered and continues until the specified proportion can be harvested. It is not clear how the model chooses which roads to construct in which period.

The structure of the problem suggests several features that would be desirable to incorporate in the model. Because Weyerhaeuser produces both softwood and hardwood pulp at the Prince Albert mill, the model should be able to discriminate between requests for softwood and hardwood timber. The emphasis on access development requires that the model be able to handle a large number of spatially distinct forest inventory records. Because the model's main purpose is to provide guidance for road construction decisions, access development would be best modeled internally.

The manager's problem has been stated as a constrained maximization problem: choose the combination of harvest, silvicultural, and road building activities that maximize present net worth subject to a number of constraints. Because the problem is one of constrained optimization, the natural way to solve it would be to use constrained optimization techniques. With the use of optimization, the analyst would be sure of determining the "best" silvicultural and transportation schedule given the problem specification. However, one of the objectives of the study is to implement the model on a personal computer. Computing limitations therefore prohibit the use of mixed integer programming and restrict the use of linear programming to small problems.

The model developed here will be a simulation model using a highest opportunity cost first harvest priority rule and will allow for the development and comparison of several roading projects each period. Road construction will be externally specified in the sense that the analyst will create and choose the roading options, but will be internally specified in the sense that the road construction schedule will be developed based on information provided by the model each period.

CHAPTER 2: MODEL FORMULATION AND IMPLEMENTATION

The basic assumption of this model is that the objective of industrial forest management is to maximize the present net worth of the financial contribution of a forest area to the firm managing it. The firm faces a positive discount rate reflecting the firm's cost of capital, a fixed forest land base, and fixed mill capacity constraints. This chapter presents the theoretical basis for the model developed in this thesis and describes how it was implemented as a computer program.

2.1 Theoretical Basis

The model developed for this study uses as its basis results from the theory of optimal forest rotation. This theory is used to identify the costs and benefits of a delay in the harvest of a stand, and to identify the costs and benefits associated with the delay of the development of access to an unaccessed stand. These costs and benefits are then used to help determine whether to harvest stands now or delay harvest until later, and to determine whether to build a section of road now or to delay construction.

Rotation theory was developed to determine the harvest age for a single timber stand that maximizes the return to forest land. This optimal harvest age is the age where the marginal increase in stand value (due to growth) is exactly offset by the marginal costs of retaining an inventory of standing timber and delaying reforestation (Davis and Johnson, 1987). Any stand for which the costs of a marginal delay in harvest exceed the benefits should be harvested immediately.

The introduction of a maximum harvest volume constraint and a forest level focus changes the nature of the problem. The problem becomes one of cost minimization subject to the volume harvest constraint. The net costs of a delay in harvest of a stand identified using rotation theory are a close approximation of the costs that should be minimized in the forest level problem. These net costs will be used to determine harvest priority.

2.1.1 Harvest Priority

For now, assume that the entire forest is accessible and that the optimal silvicultural regime (except for the final harvest age) is known. The value of bare land to be used for a perpetual series of timber rotations can be expressed as

$$F(T) = \frac{H(T)e^{-rT} - E}{1 - e^{-rT}}$$

where $H(T)$ is a function expressing the value of timber ($/ha) at different stand ages (T), r is the appropriate discount rate, and E represents the establishment costs for regenerated stands, including the present value of all silvicultural costs.

Given a strictly concave function for bare land value ($F''(T) < 0$), the optimal harvest age T^* is the age where the first order condition for maximization

$$F'(T^*) = H'(T^*) - \left(rH(T^*) + r\frac{H(T^*)e^{-rT^*} - E}{1 - e^{-rT^*}} \right) = 0$$

or

$$F'(T^*) = H'(T^*) - r(H(T^*) + F(T^*)) = 0$$

is satisfied. The optimal harvest age is the age where the marginal rate of value growth is just offset by the interest costs incurred by not liquidating the existing forest inventory and starting a new timber stand. The decision rule is to choose T^* such that

$$H'(T^*) = r(H(T^*) + F(T^*))$$

The net cost of a marginal delay in the harvest of a cubic metre of timber, $D(T)$, is

$$D(T) = \frac{rH(T) + rF(T^*) - H'(T)}{V(T)}$$

where $V(T)$ is the stand volume (m^3/ha) at T years of age. The term $rH(T)$ is the interest cost of holding forest inventory; $rF(T^*)$ is the interest cost of holding land; and $H'(T)$ is the net value growth rate of the timber.

A profit maximizing forest manager facing fixed product prices and no harvest volume constraints would choose to harvest every stand where $D(T)$ is positive. If $D(T)$ is negative, the forest manager would be better off to delay the harvest; if $D(T)$ is 0, the forest manager would be indifferent. The manager is choosing stands to harvest so as to minimize the net opportunity cost of not harvesting.

If the forest manager faces harvest volume constraints, the harvest/delay decision becomes more complicated. The harvest of any stand where $D(T) < 0$ should be delayed. If the total volume of stands where $D(T) > 0$ exceeds the plant capacity some choices must be made as to which stands to harvest. The harvest rule consistent with opportunity cost minimization is to harvest the stands with the highest $D(T)$ until the harvest request is met. With harvest volume constraints, the formula for

$D(T)$ presented above is a close approximation to the net costs of delayed harvest but is not entirely correct. It is not likely that future stands will be harvested at the optimal rotation age, so the land holding costs will be overestimated. However, the effect of this overestimate will be small because inventory holding costs are typically much larger than land holding costs.

In the example presented in Figure 2.1, the costs of delaying harvest outweigh the benefits (*i.e.* $D(T) > 0$) for half of the total forest inventory volume. However, the mill can process only 20 percent of the inventory volume. The total net cost of delayed harvest is minimized by harvesting the stands to the left of the capacity constraint. The sum of costs avoided by harvesting this period is the area *ABCD*.

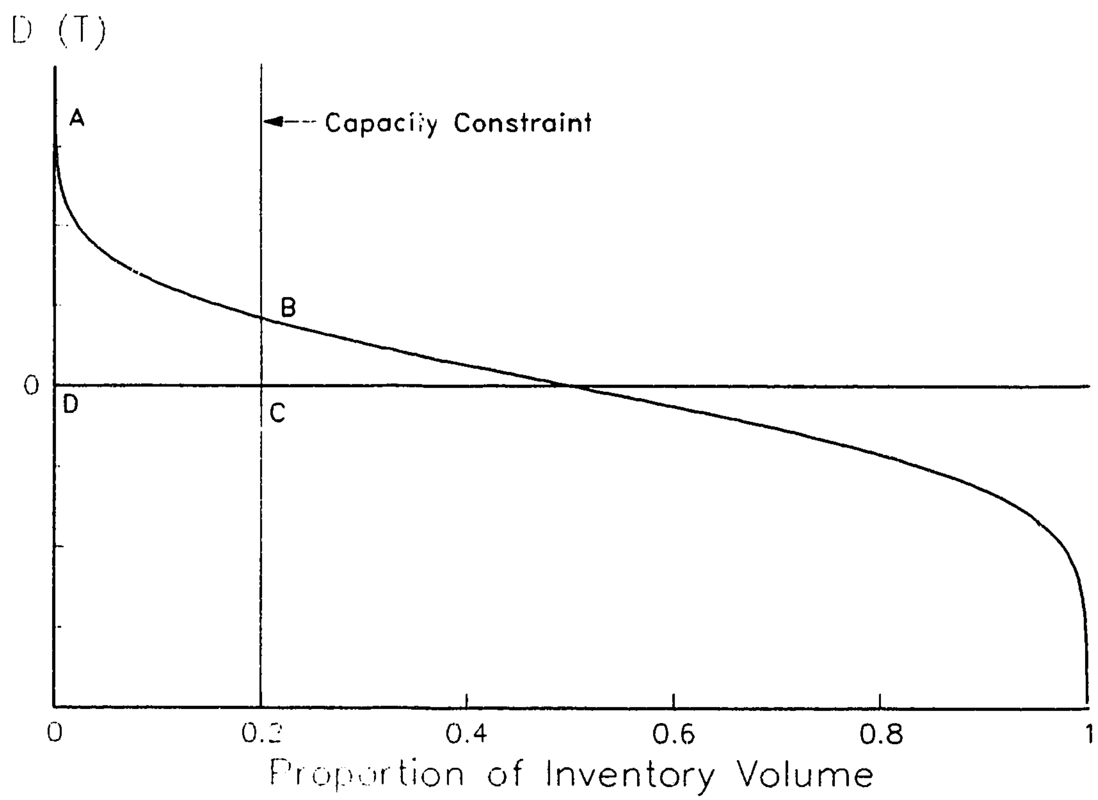

Figure 2.1. Effect of an introduction of a capacity constraint on optimal harvest selection.

2.1.2 Development of Access

In section 2.1.1, a simple single stand model was used to identify the costs and benefits of a marginal delay in the harvest. A similar procedure will be used here to identify the costs and benefits of a marginal delay in access development. The first harvest can only take place after the stand is accessed at a cost of R $/ha. The net present value of the bare land for timber production is

$$F(T_a) = [H(T_a) + F(T^*) - R]e^{-rT_a}$$

where $F(T_a)$ is the value of the forested land if access is developed and harvest taken at age T_a. $F(T^*)$ is the value of forested land once access has been developed. This is the $F(T^*)$ developed in section 2.1.1.

The optimal age of development of access T_a^* occurs where

$$F'(T_a^*) = H'(T_a^*) - r(H(T_a^*) + F(T^*) - R) = 0$$

The net cost per cubic metre of a marginal delay in access development can be determined to be

$$D(T) = \frac{rH(T) + rF(T^*) - rR - H'(T)}{V(T)}$$

In this case the benefits of a marginal delay in the first harvest include the interest charges on the road development costs. All other costs and benefits are the same as in the case where road development is not considered.

Accounting for roads is more complicated than suggested by the simple model above. A section of road may help access several stands. It may be worthwhile to access a stand before the optimal time indicated by the single stand model in order to develop access to stands further down the road. Therefore, evaluating the costs and benefits of a segment of road on a stand by stand basis is not appropriate. The approach used here is to select a number of road segments to build and group them as a roading project for the period. A number of roading projects (including a no road option) will be considered in each period and the one with the greatest difference between the costs and benefits of delaying road construction will be selected as the best option for the period.

Figure 2.2 displays the net costs of delayed harvest (excluding the benefits of delayed road construction) that can be avoided under complete and partial accessibility. If roads required to develop the inaccessible areas are not built, the maximum avoidable costs of delay are represented by the area $ABCD$. If access to the entire forest was developed through road construction, the costs of delay that would be avoided by harvesting are represented by the area $ AB'CD$ By developing access, the forest manager is able to avoid additional costs of delay represented by the area ABB'. If these additional avoidable costs exceed the interest costs of the roads ($r\ R$), the project is better than building no roads at all. If not, the project should not be implemented this period. The roading project where $ABB' - rR$ is the greatest is the best roading project for the period.

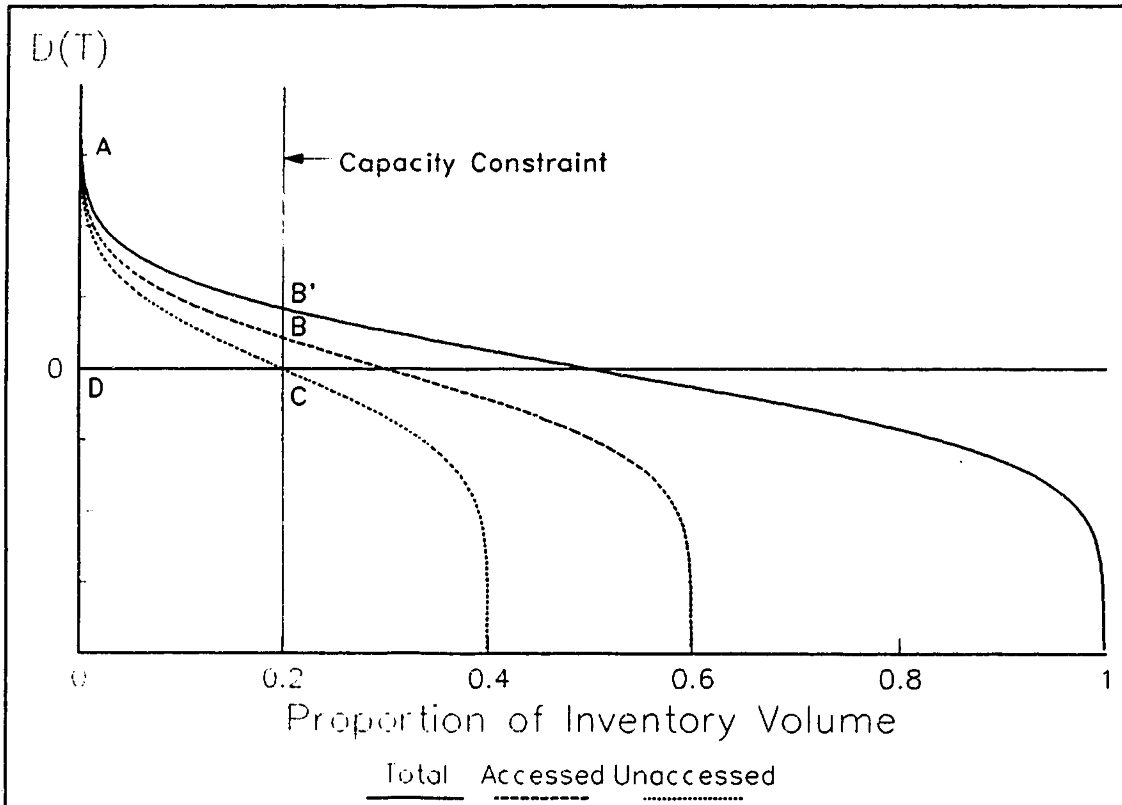

Figure 2.2. Effect of development of new access on optimal harvest.

2.1.3 Timber Value

The value of timber is a necessary input to the opportunity cost calculations and therefore central to the analysis. Because Weyerhaeuser meets most of its mill's requirement for timber from its own forestry operations, there is no direct market evidence for the value of timber on the study area. The conversion return approach to timber valuation (Davis and Johnson, 1987) is used for this study. Using this approach, the value of a cubic metre of a timber at any point in the production process is the selling price the final product that can be made from that cubic metre, less all costs associated with further processing of that cubic metre. The conversion return for a cubic metre of standing timber, for example, assuming that pulp is the final product, is the selling price of the pulp that can be produced from that cubic metre, less all costs associated with harvesting, transporting, milling, and marketing[4].

2.2 Computer Implementation

The model is written for IBM compatible personal computers using the Turbo Pascal language (Borland International, 1989). Figure 2.3 shows the general structure using a stripped down version of the main routine. In the verbal description of the general algorithm below, relevant locations in the program are indicated by square brackets. The general description here is followed by more specific descriptions for some of the sections.

The program begins with an initialization section [Initialize] which sets the control parameters for the program and identifies and reads data files. After this initialization, the program flows through three nested loops: the time period loop, the road option loop, and the inventory loop. The period loop is the outermost loop in the program. It controls the program for the passage of time and everything in the period loop is repeated for each period to be considered.

Several roading projects can be considered in each period. For all periods except the first, the inventory, map, road, and other relevant files for the best road option in the previous period are copied to provide the basis for the actions considered for a roading option [CopyPrevFiles]. For the first period, the initial data files are copied. The first road construction option considered in each period is option "0": the option of constructing no roads in the period. For all other options, an access priority map is displayed and roads are constructed if desired [Access].

The inventory loop is used to assign attributes to inventory records. For each inventory record, current period and next period volumes [GetVolume], woodlands and transportation costs [AssignLogCosts], pulp conversion returns in the mill yard [CalcValue], silvicultural regimes and the

4 The theoretically correct measure of timber value for decision making in this model would be conversion surplus (revenue less variable costs) not conversion return (revenue less total costs) because the investments in mill capacity and forestry equipment (and therefore overhead and depreciation) are sunk costs. Preliminary indications suggest that the use of conversion return in this analysis did not introduce any appreciable bias in the results. However, in instances where fixed costs represent a large proportion of the total costs, the bias could be significant as the inventory holding costs of all inventory aggregates would increase, possibly resulting in accelerated road construction.

```
program RoadSilv;
begin

  Initialize;
  BestPrevRoad := 0;
  ThruPeriods := false;
  PeriodCounter :=1;

  repeat {until ThruPeriods}
    if PeriodCounter > Control.NumberOfPeriods then
      ThruPeriods := true
    else
    begin
      RoadOption := 0;
      ThruRoadOptions := false;

      repeat {until ThruRoadOptions}
        CopyPrevFiles;
        if RoadOption > 0 then
        begin
          Access
        end;

        repeat {until ThruInventory}
          begin
            GetVolume;
            AssignLogCost;
            CalcValue;
            CalcRegenNetValue;
            CalcOpportunityCost;
          end;
        until ThruInventory;

        SortInventory;
        HarvestAndRegeneration;
        DisplaySummary;
        if RoadOption > 0 then
        begin
          SelectOption;
        end;
        RoadOption := RoadOption + 1;
        if RoadOption > Control.NumberOfRoadOptions then
        begin
          ThruRoadOptions := true;
        end;
      until ThruRoadOptions;

      SelectBestRoadOption;
      PurgeFiles;
      PeriodCounter := PeriodCounter + 1;
    end;
  until ThruPeriods;

end.
```

Figure 2.3. Generalized algorithm for RoadSilv model.

present net value of the next rotation [CalcRegenNetValue] are determined. From this information, opportunity costs per cubic metre are calculated [CalcOpportunityCost]. Records with a positive opportunity cost (*i.e.* records that would be harvested if no harvest volume constraints existed) are written to a file for sorting. Once all inventory records have been read and have additional information attached to them, the inventory loop is finished.

The inventory records are sorted by descending opportunity costs [SortInventory], and the harvest algorithm is executed for this time period and road option [HarvestAndRegeneration]. After the harvest is taken, a summary of for all road options considered for the period so far is displayed [DisplaySummary]. If the road option is greater than 0, the user is given the opportunity to select from a menu of options to control the further actions of the program [SelectOption]. These options allow the user to examine another roading project for the period, to select the best road option for the period, to automate the remaining periods, or to end the run.

Once all the road options that will be considered for the period have been evaluated, (*i.e.* the road option loop is finished) the best road option is selected [SelectBestRoadOption]. The work files for the other options are deleted [PurgeFiles], the period counter is incremented, and the program proceeds for the next period. The program ends once all periods have been considered.

2.2.1 Initialization

The program requires a great deal of input information. The initialization stage of the program reads information from a control file to provide control for the analysis. The files containing the starting inventory, the coefficients for yield curves, management options for timber types and the timing of treatments required for the management options, logging costs, costs of silvicultural treatments, and rotation ages are specified as well as the starting year for the analysis, the number of periods to be analyzed, the period length, road construction and annual maintenance costs, and softwood and hardwood volume requirements by period, and hardwood and softwood conversion returns per cubic metre by period.

2.2.2 Inventory Attributes

For determination of harvest priority and reporting purposes it is necessary to attach certain information to the inventory records. Much of this additional information will be determined for both the current period and the next period to allow for opportunity cost calculations.

The softwood and hardwood volume per ha for each combination of unit, species association, site class, yield level, and access is determined using the yield curves discussed earlier. The woodlands and transportation costs for softwood and hardwood timber ($\$/m^3$) are determined using the cost tables presented in chapter 3. Costs per ha are determined by multiplying the total cost per m^3 by the volume per ha determined with the yield curves. The conversion return per m^3 is given in the information read in the initialization section. This is calculated for hardwood and softwood for the current and subsequent periods on a per ha basis by multiplying it by the volume per ha.

Weyerhaeuser provided data on the timing and cost of treatments and resulting timber yields for three silvicultural regimes: basic management, intensive hardwood management, and intensive softwood management. Basic management represents the treatments necessary to maintain the long term sustained yield of the forest (as required by the FMLA), and the intensive management regimes are designed to increase the future yields from the forest. Rotation ages for each of the species associations, site classes, and yield levels were also provided by Weyerhaeuser.

Theoretically, the best silvicultural regime would be the one that gives the highest soil expectation value (SEV), reflecting a perpetual stream of costs and benefits. The final harvest age in this theoretically correct specification would be determined endogenously. However, the regime selected in this model is the one that gives the highest present net worth for the next rotation given an exogenously specified rotation age. This approximation was chosen in order to simplify the implementation of the model. A silvicultural regime usually results in more than one species association - yield level combination because some proportion of the harvest area is not satisfactorily regenerated and must be retreated. In order to correctly determine the SEV of a regime for a particular inventory record, the present net worth (PNW) of an infinite stream of projects with multiple outcomes must be calculated. The extra computations required for calculation of the true soil expectation value with multiple outcomes would be difficult to implement so the PNW of one rotation was used to approximate the SEV for the harvest priority calculations.

[illegible] opportunity costs in the theoretical model presented in section 2.1 are developed using [illegible]s time. Discrete time periods are used in the computer implementation of the model. All [illegible] this study used period lengths of five or ten years. All activities are assumed to be evenly distributed among each of the years in a period. For example, if 100 km of road is built in a five year period, it is assumed that 20 km of road are built in each of the five years in the period.

The discrete time model uses the following equations for the determination of the net costs of delayed harvest. The inventory holding costs per hectare for one period are calculated as

$$IHC_T = \frac{(1+i)^n - 1}{i(1+i)^n} \frac{1}{n} (H_T(1+i)^n - H_T)$$

where i is the discrete discount rate n is the period length, and H_T is the stumpage value per ha of the record at time T. The land holding costs per hectare for one period are approximated as

$$LHC_T = \frac{(1+i)^n - 1}{i(1+i)^n} \frac{1}{n} (PNW_R(1+i)^n - PNW_R)$$

where PNW_R is the present net worth of the activities undertaken for the next rotation. The value of growth per hectare for one period is calculated as

$$VG_T = \frac{(1+i)^n - 1}{i(1+i)^n} \frac{1}{n} (H_{T+1} - H_T)$$

For each inventory record, the net cost per cubic metre of delaying harvest until the next period is

$$D_T = \frac{IHC_T + LHC_T - VG_T}{V_T}$$

where V_T is the stand volume (m^3/ha) at age T.

The benefit of delaying road construction until the next period (the cost of not delaying road construction) is given by

$$RC_T = \frac{(1+i)^n - 1}{i(1+i)^n} \frac{1}{n} \left(\left(RB + \frac{M}{i} \right)(1+i)^n - \left(RB + \frac{M}{i} \right) \right)$$

where RB are the road construction costs and M are the annual road maintenance costs. Road maintenance costs are assumed to occur annually in perpetuity.

In the above equations, the factor

$$\frac{(1+i)^n - 1}{i(1+i)^n} \frac{1}{n}$$

is used to calculate the present value of costs or benefits spread evenly through each year of a period.

2.2.3 Harvest and Regeneration

The rule of harvest in this model is that accessible inventory records with the highest opportunity cost per cubic metre are to be cut first. This requires sorting the inventory on the basis of descending opportunity costs. Inventory records with negative opportunity costs are not considered for harvest as it is more profitable to delay harvest of these inventory records for at least one period.

The harvest algorithm proceeds down this sorted inventory list, accumulating softwood and hardwood volume from accessible inventory records until the volume request for the period is met or no more records with a positive opportunity cost are available for harvest. If the request is exceeded the last inventory record harvested is split into harvested and unharvested portions so that the request is met exactly. If the volume request cannot be met from the available inventory, all wood with a positive opportunity cost will be harvested. The opportunity costs for inventory records not harvested because of inaccessibility are accumulated for each unit. Harvested inventory records are regenerated using the management regime determined as discussed in section 2.2.2.

Two models were built for this study. One ignores the possibility of wood type discrimination and harvests from the sorted inventory list until the total volume request is satisfied. The model that allows for wood type discrimination operates in the following manner. The harvest algorithm proceeds down the sorted inventory list until the request for one of the wood types is satisfied. The remaining records in the sorted list are updated to reflect that additional wood volume of a specific type has no value in the current period once the request for that type of wood has been satisfied. Opportunity costs are recalculated and the remaining inventory is re-sorted to reflect the new opportunity costs. Harvest proceeds down the re-sorted inventory list until the request for the other wood type is satisfied or the opportunity cost reaches 0.

The silvicultural regime determined as discussed in section 2.2.2 is applied to all harvested areas. A silvicultural regime for a species association - site class consists of the timing for the treatments to be considered, the proportion of the harvested area to be treated, and the species association - yield level that will result from the treatments. The proportion of the area that is not satisfactorily regenerated (NSR) given the treatment is also specified, and the timing of treatments for the NSR area and the proportion of the NSR treatment to be treated with a treatment are given.

2.2.4 Access Construction

The forest inventory is aggregated by unit, species association, site class, origin, yield level, and accessibility. Each unit is made up of a number of 10 km by 10 km map sheets. The map sheets are the basic unit of access: each map sheet is either accessible or not. The total productive area of each unit is the sum of the productive area of the map sheets contained within it. The inaccessible area is the sum of the area of inaccessible map sheets and the accessible area is the sum of the area of accessible map sheets.

For the no road option of each period, the harvest algorithm accumulates opportunity costs, $D_T \times V_T \times Area$, for inventory records not harvested because of inaccessibility. Avoidable costs for each map sheet are calculated by apportioning the unit costs to map sheets as follows

$$AC_m = AC_u \frac{UA_m}{UA_u}$$

where AC represents the avoidable costs of inventory skipped over because of no access, UA is unaccessed area and the subscripts u and m represent unit and map sheet respectively.

Map sheet records are sorted on the basis of descending AC_m. Map sheets are assigned colors by progressing down this sorted list. If, for the kth map sheet in the sorted list,

$$\sum_{i=1}^{k} AC_{m_i} < \frac{1}{4} \sum_{j=1}^{t} AC_{m_j}$$

where t is the total number of map sheets, the map sheet is to be colored bright red in order to indicate the costliest map sheets to leave unaccessed. The map sheets containing the next quarter of total costs are to be colored dark red, the next quarter blue, and the last quarter light gray. This is illustrated in Plate 2.1.

This colouring scheme provides the analyst with some visual information as to which map sheets are the costliest to leave unaccessed in the current period. This should help the analyst formulate roading projects to consider in a time period.

After each roading option is complete the analyst has the choice of examining another road option for the period (unless the maximum number of road options has been reached), selecting the best road option for the period and continuing with the next period as before, selecting the best road option for the current period and automating the run for the next period (*i.e.* no roads will be built in subsequent periods), or stopping the analysis at the current period.

In each period, the analyst has the choice of up to 10 different roading projects, one of which is not building any roads at all in the current period. When roads are developed, their class changes from potential to existing, and map sheets are examined to see if the development of new roads makes any close enough to a road to be considered accessed.

If a map sheet becomes newly accessed, inventory records must be updated. Remember that the inventory is aggregated by unit and that the unit of access is the map sheet. The area of each of those combinations of unaccessed inventory records is reduced by UA_m / UA_u and the area of those combinations in the accessed portion of the inventory is increased accordingly.

Harvest is taken from the new inventory and information such as that in Figure 2.4 is presented after the harvest. After each road option, the analyst has the opportunity to examine another road option, to select what the analyst considers to be the best road option for the period and start the next period, or select the best road option and quit the analysis. The "automate" option allows the analyst to select the best road option for this period, and proceed through the rest of the analysis without building any more roads.

The column headed "Opt" contains a number used to identify the road option. The road option "0" always represents the option of building no roads this period. The column "OCReduct" represents the opportunity costs avoided by harvesting with a road option, "SoftHarv" is the total volume of softwood harvested, "HardHarv" is the total volume of hardwood harvested, "RoadBilt" is the amount of road built (km) in the period, "RoadCost" is the interest costs of the roading project, "OCDiffer" is the difference between "OCReduct" for the current road option and the no road option, and "NetBenef" is the difference between "OCReduct" and "RoadCost".

In general, the road option with the greatest "NetBenef" will be the one the analyst will select as the best road option for the period. In this example, road option 3 is the best for the current period. Appendix D contains a detailed example of the process used to identify the best road option for a period.

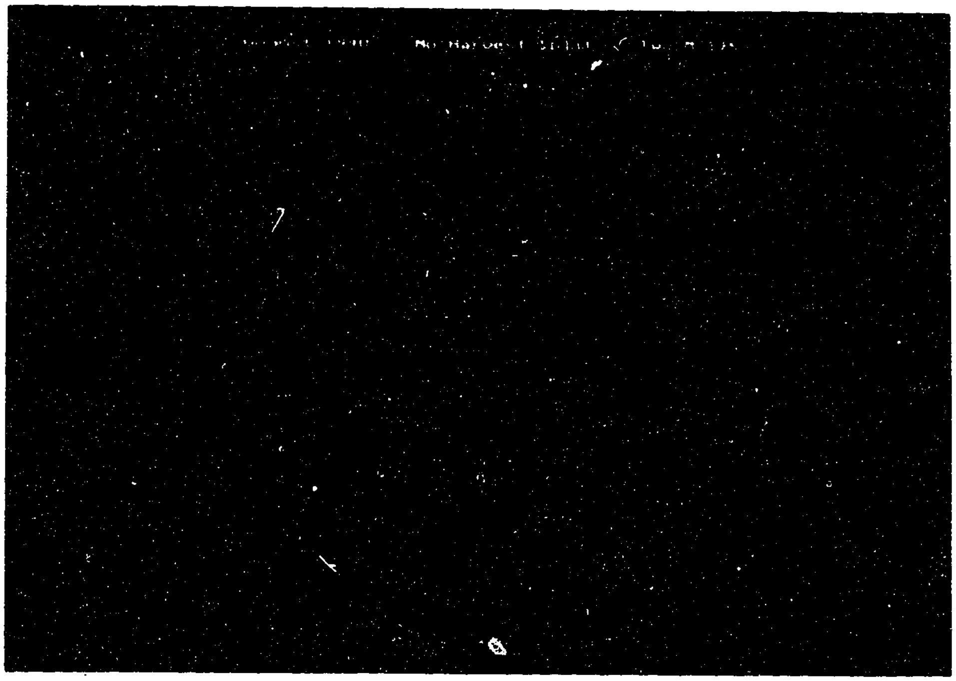

Plate 2.1. Screen display of study area indicating priority areas for access development.

Summary of road options for period 3. 2000-2005.
Softwood Request: 8781475 Hardwood Request: 6446330

Opt	OCReduct	SoftHarv	HardHarv	RoadBilt	RoadCost	OCDiffer	NetBenef
0	161189793	9991280	5236525	0	0	0	0
1	161620736	10135110	5092695	12	244750	430943	186193
2	162988010	10353518	4874287	54	1054746	1798217	743471
3	163339528	10360581	4867224	64	1252395	2149735	897340
4	163477190	10312554	4915251	75	1464960	2287397	822438
5	163507790	10224930	5002875	76	1488497	2317997	829500

What do you want to do now?
E)xamine another road option for this period.
S)elect the best road option and start the next period.
A)utomate future periods after selecting best road option.
Q)uit after selecting best road option for this period.
Best Road Option? 3_

Figure 2.4. Screen used to compare roading options for a period.

2.2.5 Reporting

All activities undertaken are written to an action file detailing the year they were done, the area harvested or treated, softwood and hardwood volumes harvested, the km of road built, and the inventory type associated with the treatment, and the cost or benefit of doing so. The reporting feature is very flexible as reports can be generated for any combination of inventory attributes, treatment types, and time periods using an external report generator.

CHAPTER 3: DATA DESCRIPTION

A large amount and variety of data are required by the model developed in this thesis. Spatial data representing the road network and geographical attributes of the forest inventory are required to determine the accessibility of different parts of the FMLA area. Forest inventory information describing the area of cover types in different units is necessary. Timber yield curves are needed to determine the volume of wood in cover types now and in the future. Descriptions of silvicultural options and returns are necessary to determine which silvicultural prescription should be undertaken. Costs of treatments, prices of products, and discount rates are required to model the economic aspects of the problem.

Most of the data used in this study have been provided by Weyerhaeuser and the Forestry Branch of Saskatchewan Parks Recreation and Culture (SPRC). All financial information provided by Weyerhaeuser has been slightly perturbed using random numbers to preserve confidentiality.

3.1 Road Network

Existing class 1 (numbered provincial highway) and class 2 (main haul road) roads were electronically digitized from 1:250,000 forest road inventory maps provided by SPRC. Future roads identified by Weyerhaeuser staff were drawn on these maps and digitized as well. These maps use Universal Transverse Mercator (UTM) projections and coordinates. UTM coordinates are expressed as metres north of the equator and east of a reference meridian. The UTM system is a convenient way of expressing location of map features and makes approximate calculation of distances between any two points straightforward.

The 10 km by 10 km forest inventory map sheets provided by SPRC are the basic unit of access for the model: each map sheet is either accessible or not at any point in time. In order to provide connections from the map sheet to the road network, a grid of imaginary roads connecting the centre of each map sheet to the centres of the map sheets to the north, south, east, and west was created. An imaginary road is simply a device to allow for a connection between the centre of a map sheet and the road network. Nodes in the road network were created at road segment end points and at any intersection between existing, future, or imaginary roads.

The haul cost minimizing route from the Prince Albert mill to the centre of each map sheet was determined using the Dijkstra algorithm as described by Dykstra (1984). For the purposes of the Dijkstra algorithm, haul along class 1 roads was assumed to cost \$0.0144 m^3/km, along class 2 \$0.0181 m^3/km, along future roads \$0.0608 m^3/km and along imaginary roads \$1.0 m^3/km.

The inventory in a map sheet is considered accessible if the haul cost minimizing route between the mill and the centre of the map sheet involves less than 15 km of future and imaginary roads. Distances less than 15 km are assumed to be spanned by roads of class 3 or lower. The 15 km limit was determined by examination of the existing road network in relation to the forest inventory.

In order to evaluate the net economic benefits of road construction, construction and maintenance costs are required. Class 2 roads cost \$50,000/km to build and \$1,600/km/year to maintain.[5] All the future roads identified by Weyerhaeuser are assumed to be constructed to Class 2 standards.

3.2 Inventory Data

SPRC's forest inventory system identifies individual stands within 10 by 10 km forest inventory map sheets. Associated with each stand are a number of inventory attributes including species composition, height and density codes, soil drainage and texture codes, year of origin, and area. Computer tapes containing the forest inventory data for the area were provided by SPRC.

For purposes of growth projection, Weyerhaeuser identifies the productivity of sites using site capability classes. The company assigns site capability classes to stands on the basis of soil texture, soil drainage, and the primary species of the stand. The table used to make the site capability class assignment is in Appendix A. Stands in site capability class 4 and non-treed cover types (*e.g.* open, scrub, burn, or cut) were excluded from the analysis.

For planning and operational purposes, Weyerhaeuser divides its FMLA area into a number of units as illustrated in Figure 3.1 . Unit boundaries within the FMLA area correspond with inventory map sheet boundaries; determining the unit containing a map sheet was therefore straightforward. These units represent the finest spatial detail for the forest inventory in the model.

---

5 Pers. comm. Jack Spencer, Weyerhaeuser Canada Ltd., 15 February 1989.

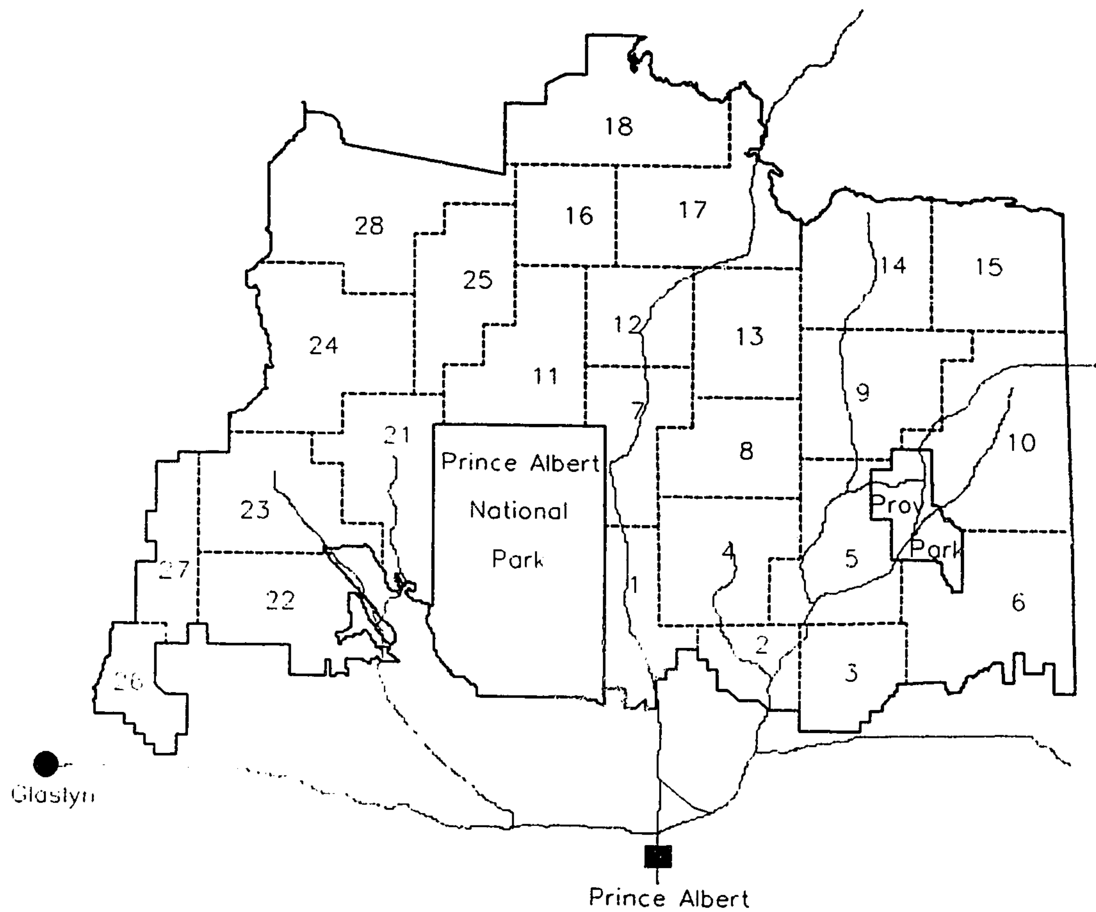

Figure 3.1. Map of study area indicating planning unit boundaries.

Nine species associations are used for modeling growth and yield and reporting purposes. These describe a stand as to whether it is softwood, hardwood, softwood-hardwood mixedwood, or hardwood-softwood mixedwood, and the primary softwood species except in pure hardwood types. The codes used to identify species associations are defined in Table 3.1.

The inventory used by the model is aggregated on the basis of unit, species association, site capability class, year of origin, accessibility, and yield level. Tables 3.2 and 3.3 provide some summary statistics for the forest inventory. An external report generator can be used to provide inventory summaries using any combination of inventory attributes.

Table 3.1. Species association codes and descriptions.

Identifier	Description
SJP	Softwood, jack pine
SBS	Softwood, black spruce
SWS	Softwood, white spruce
SJPBS	Softwood, jack pine and black spruce
HTA	Hardwood, trembling aspen
HSJP	Hardwood-Softwood, trembling aspen and jack pine
HSSP	Hardwood-Softwood, trembling aspen and white or black spruce
SHJP	Softwood-Hardwood, jack pine and trembling aspen
SHSP	Softwood-Hardwood, white or black spruce and trembling aspen

Table 3.2. Productive forest area (ha) by unit and site capability class.

	Site Capability Class			
Unit	1	2	3	Total
1	14,850	19,307	8,711	42,867
2	11,386	15,778	4,827	31,991
3	12,019	17,167	8,354	37,540
4	33,976	19,777	10,851	64,604
5	29,575	26,478	17,340	73,393
6	10,527	36,182	27,971	74,679
7	10,514	23,998	4,123	38,634
8	10,064	27,335	5,459	42,857
9	21,929	40,220	14,409	76,558
10	20,789	30,503	25,126	76,418
11	31,048	34,582	9,585	75,216
12	9,242	16,231	8,399	33,872
13	326	27,478	7,408	35,212
14	2,918	53,632	17,725	74,276
15	14,254	44,185	14,844	73,284
16	55	10,704	8,713	19,471
17	4,006	37,103	17,102	58,210
18	14,726	41,751	15,034	71,510
21	14,306	46,232	2,687	63,225
22	16,263	60,117	5,717	82,097
23	18,665	59,305	3,932	81,901
24	18,565	42,279	5,750	66,594
25	12,673	38,273	12,052	62,998
26	4,524	43,984	563	49,070
27	3,158	40,098	5,632	48,888
28	16,392	38,573	15,124	70,089
Total	356,745	891,272	277,438	1,525,456

Table 3.3. Productive forest area (ha) by unit and accessibility.

Unit	Inaccessible	Accessible	Total
1	0	42,867	42,867
2	414	31,577	31,991
3	9,216	28,323	37,540
4	0	64,604	64,604
5	0	73,393	73,393
6	13,972	60,707	74,679
7	0	38,634	38,634
8	30,732	12,125	42,857
9	22,151	54,407	76,558
10	4,575	71,843	76,418
11	13,216	62,000	75,216
12	0	33,872	33,872
13	12,737	22,475	35,212
14	2,105	72,170	74,276
15	39,405	33,879	73,284
16	2,325	17,146	19,471
17	0	58,210	58,210
18	952	70,558	71,510
21	6,432	56,793	63,225
22	39,085	43,012	82,097
23	37,021	44,881	81,901
24	6,631	59,963	66,594
25	13,594	49,404	62,998
26	11,574	37,496	49,070
27	38,961	9,928	48,888
28	56,077	14,012	70,089
Total	361,175	1,164,281	1,525,456

3.3 Yield Data

Up to four different yield levels for a species association - site class combination are permitted: natural (NAT), S1, S2, and intensively managed (MGD). The S1 and S2 yield levels are for regenerated timber under basic management. These yield levels reflect yields resulting from different treatments under the basic management regime. Yield tables for hardwood and softwood timber by species association, site class, and yield level were provided by Weyerhaeuser. These were converted to yield functions of the form:

$$v = \begin{cases} 0 & (if\ a < a_{min}) \\ b_0 + b_1 a + b_2 a^2 + b_3 a^3 & (if\ a_{min} \le a \le a_{max}) \\ c_0 + c_1 a & (if\ a > a_{max}) \end{cases}$$

where v is stand volume (m^3/ha), a is stand age (years), a_{min} is the minimum age for the cubic equation, a_{max} is the maximum age for the cubic equation, the b's are coefficients for the cubic equation, and the c's are coefficients for the linear equation for ages above a_{max}. These functions were created by using ordinary least squares regression to fit a cubic equation to the tabulated yields between α_{min} and α_{max}, and a linear equation for ages above α_{max}. The ages α_{min} and α_{max} were determined by inspection of the yield tables. The coefficients determined for the yield functions are presented in Appendix B.

3.4 Silvicultural Data

In order to determine the best silvicultural prescription for an area after harvest, a number of pieces of information are required. The schedule of treatments for alternative prescriptions is needed, the response of the forest to treatment must be specified, and the costs of the treatments must be known.

Three silvicultural options are considered for all harvested areas. Basic silviculture is the assumed minimum silvicultural activity necessary to maintain the long run sustained yield (LRSY) of the FMLA area. Maintenance of the LRSY is a requirement of the forest management licence agreement. The management activities are similar to those currently undertaken. Intensive softwood management will result in the establishment of softwood on all sites. The sites are to be managed in order to result in the optimum softwood stocking of 2000 to 2500 seedlings per ha. Intensive hardwood management will result in the establishment of 2000 to 2500 hardwood seedlings per ha on all sites.

The schedule of treatments is specified for each silvicultural option, existing species association, and site class. Appendix C details the timing of treatments and the resulting species associations and yield levels.

Silvicultural treatment costs used in this study are based on costs provided by Weyerhaeuser. Scarification costs $225/ha treated, site preparation costs $245/ha, planting costs $670/ha, fill-in planting costs $460/ha, precommercial thinning costs $470/ha, mechanical cleaning costs $620/ha, and chemical cleaning costs $325/ha.

3.5 Rotation Ages

Volume maximizing rotation ages were provided by Weyerhaeuser for species association, site class, and yield level combinations. The rotation ages identified by Weyerhaeuser are displayed in Table 3.4. Any combination not found in this table is assigned a rotation age of 80 years. These rotation ages are used solely for the determination of the present value of silvicultural activities and affect actual harvest age only through the calculation of the land holding costs. The calculated land holding cost will be an approximation of the actual land holding cost as the actual harvest age for inventory aggregates is not known until harvest occurs. However, compared with the costs of holding inventory, land holding costs are relatively small. The error introduced through the approximation will affect the results only slightly.

Table 3.4. Rotation ages by species association, yield level, and site.

Species	Yield	Site Class		
Association	Level	1	2	3
SJP	S1	67	73	77
	S2	55	70	77
	MGD	45	65	77
SBS	S1	75	95	130
	S2	75	95	130
	MGD	75	95	130
SWS	MGD	40	50	60
SJPBS	S1	75	95	130
HTA	S1	65	71	77
	MGD	48	65	77
SHJP	S1	67	73	77
	S2	55	70	77
SHSP	S2	69	74	79
HSJP	S1	67	73	77

3.6 Woodlands and Transportation Costs

Tables 3.5 and 3.6 detail the per m^3 woodland and transportation costs for softwood and hardwood timber respectively. The haul cost represents the cost of hauling timber from the landing to the Prince Albert mill. Logging costs represent the cost of falling and transporting the timber to the landing. Loading costs are the costs of loading the timber onto the trucks. Dues are the Crown dues that are paid to the province. Fixed costs are administration costs. Semi-variable costs include construction and maintenance of improved bush roads. All variation in the total costs per cubic metre result from variation in cost of hauling, and hauling costs vary only by unit and wood type.

Table 3.5. Woodlands and transportation costs for softwood timber.

Unit	Haul ($/m³)	Logging ($/m³)	Loading ($/m³)	Dues ($/m³)	Fixed ($/m³)	Semi-Variable ($/m³)	Total ($/m³)
1	3.25	10.15	0.94	0.85	0.66	1.88	17.72
2	2.92	10.15	0.94	0.85	0.66	1.88	17.38
3	3.39	10.15	0.94	0.85	0.66	1.88	17.86
4	4.31	10.15	0.94	0.85	0.66	1.88	18.78
5	3.91	10.15	0.94	0.85	0.66	1.88	18.38
6	5.01	10.15	0.94	0.85	0.66	1.88	19.48
7	5.25	10.15	0.94	0.85	0.66	1.88	19.72
8	5.09	10.15	0.94	0.85	0.66	1.88	19.56
9	6.00	10.15	0.94	0.85	0.66	1.88	20.47
10	5.94	10.15	0.94	0.85	0.66	1.88	20.41
11	6.34	10.15	0.94	0.85	0.66	1.88	20.81
12	6.11	10.15	0.94	0.85	0.66	1.88	20.57
13	6.34	10.15	0.94	0.85	0.66	1.88	20.81
14	7.38	10.15	0.94	0.85	0.66	1.88	21.85
15	8.54	10.15	0.94	0.85	0.66	1.88	23.01
16	7.54	10.15	0.94	0.85	0.66	1.88	22.01
17	7.62	10.15	0.94	0.85	0.66	1.88	22.09
18	8.53	10.15	0.94	0.85	0.66	1.88	22.99
21	7.06	10.15	0.94	0.85	0.66	1.88	21.53
22	6.92	10.15	0.94	0.85	0.66	1.88	21.39
23	6.91	10.15	0.94	0.85	0.66	1.88	21.37
24	9.22	10.15	0.94	0.85	0.66	1.88	23.69
25	8.42	10.15	0.94	0.85	0.66	1.88	22.89
26	7.15	10.15	0.94	0.85	0.66	1.88	21.61
27	7.70	10.15	0.94	0.85	0.66	1.88	22.17
28	10.54	10.15	0.94	0.85	0.66	1.88	25.01
Avg.	6.44	10.15	0.94	0.85	0.66	1.88	20.91

Table 3.6. Woodlands and transportation costs for hardwood timber.

Unit	Haul ($/m^3)	Logging ($/m^3)	Loading ($/m^3)	Dues ($/m^3)	Fixed ($/m^3)	Semi-Variable ($/m^3)	Total ($/m^3)
1	4.26	9.08	1.11	0.31	0.66	1.88	17.30
2	3.82	9.08	1.11	0.31	0.66	1.88	16.85
3	4.45	9.08	1.11	0.31	0.66	1.88	17.48
4	5.66	9.08	1.11	0.31	0.66	1.88	18.69
5	5.13	9.08	1.11	0.31	0.66	1.88	18.17
6	6.59	9.08	1.11	0.31	0.66	1.88	19.62
7	6.89	9.08	1.11	0.31	0.66	1.88	19.92
8	6.68	9.08	1.11	0.31	0.66	1.88	19.71
9	7.88	9.08	1.11	0.31	0.66	1.88	20.91
10	7.80	9.08	1.11	0.31	0.66	1.88	20.83
11	8.32	9.08	1.11	0.31	0.66	1.88	21.35
12	8.02	9.08	1.11	0.31	0.66	1.88	21.05
13	8.33	9.08	1.11	0.31	0.66	1.88	21.36
14	9.70	9.08	1.11	0.31	0.66	1.88	22.73
15	11.22	9.08	1.11	0.31	0.66	1.88	24.25
16	9.89	9.08	1.11	0.31	0.66	1.88	22.92
17	10.01	9.08	1.11	0.31	0.66	1.88	23.04
18	11.19	9.08	1.11	0.31	0.66	1.88	24.22
21	9.27	9.08	1.11	0.31	0.66	1.88	22.30
22	9.09	9.08	1.11	0.31	0.66	1.88	22.12
23	9.06	9.08	1.11	0.31	0.66	1.88	22.10
24	12.10	9.08	1.11	0.31	0.66	1.88	25.13
25	11.06	9.08	1.11	0.31	0.66	1.88	24.09
26	9.38	9.08	1.11	0.31	0.66	1.88	22.41
27	10.10	9.08	1.11	0.31	0.66	1.88	23.14
28	13.83	9.08	1.11	0.31	0.66	1.88	26.86
Avg.	8.45	9.08	1.11	0.31	0.66	1.88	21.48

3.7 Conversion Return

The costs of getting wood from the stump to the mill yard are detailed in section 3.6. The costs of milling the wood to produce a product and marketing it, and the returns from marketing it must also be taken into account. The conversion return for a cubic metre of timber in the mill yard is the selling price of the product produced from that cubic metre less all costs associated with getting the timber from the mill yard to selling the product.

The conversion return for timber in the mill yard is derived from price and cost projections in the RISI Pulp and Paper Review (Resource Information Systems Inc., 1989). Constant 1990 conversion returns are calculated assuming a five percent annual rate of inflation. RISI expresses costs and prices in $/t. These figures are converted into roundwood equivalents using conversion factors of 4.712 m^3 of roundwood per tonne of hardwood pulp and 5.6175 m^3 of roundwood per tonne of softwood pulp. The softwood conversion factor assumes an equal mix of spruce and pine pulpwood in the furnish for softwood pulp. These factors are developed from the forest products conversion factors used by the Alberta Forest Service (Alberta Energy and Natural Resources, 1985).

The data used to calculate the conversion returns for hardwood and softwood timber are presented in Tables 3.7 and 3.8. The average conversion return for softwood timber in the mill yard is \$66.9/m^3 and for hardwood timber is \$68.8/m^3. These average values will be used in the analysis. The existing model could be used to analyze problems where timber value is increasing or decreasing at a constant rate. Some modification of the program would be necessary to accommodate fluctuating timber values between periods.

Table 3.7. Determination of conversion return for softwood timber in the mill yard.

Year	Exchange (\$/US\$)	Price (US\$/t)	Price (\$/t)	Total Cost (\$/t)	Wood Cost (\$/t)	C.R. (\$/t)	C.R. (\$/m^3)	C.R. (1990 \$/m^3)
1990	1.23	796	979	643	243	579	103.1	103.1
1991	1.23	682	839	647	234	426	75.8	72.2
1992	1.23	703	865	670	240	435	77.4	70.2
1993	1.22	779	950	709	261	502	89.4	77.3
1994	1.22	800	976	737	275	514	91.5	75.3
1995	1.21	726	878	756	278	400	71.3	55.9
1996	1.21	697	843	781	284	346	61.7	46.0
1997	1.20	846	1015	827	309	497	88.5	62.9
1998	1.20	976	1171	862	326	635	113.1	76.5
1999	1.19	924	1100	883	328	545	96.9	62.5
2000	1.18	876	1034	913	334	455	80.9	49.7
2001	1.18	1034	1220	966	361	615	109.5	64.0
2002	1.17	1199	1403	1009	382	776	138.1	76.9
2003	1.18	1118	1319	1038	387	668	119.0	63.1
2004	1.18	1035	1221	1078	398	541	96.4	48.7

The total cost column reflects all costs of producing pulp, including overhead and depreciation. The price of pulp (\$/t) is determined by multiplying the price of pulp (US\$/t) by the exchange rate (\$/US\$). The conversion return (\$/t of pulp) for timber in the mill yard is the price (\$/t) less total cost (\$/t) plus wood cost (\$/t). The conversion return per cubic metre of wood is calculated by dividing the conversion return per tonne by the cubic metres of wood required to produce a tonne of pulp. These nominal values are converted to real 1990 dollars using the formula

$$CR_{1990} = \frac{CR_{year}}{1.05^{(year-1990)}}$$

to reflect the assumed five percent annual rate of inflation.

Table 3.8. Determination of conversion return for hardwood timber in the mill yard.

Year	Exchange ($/US$)	Price (US$/t)	Price ($/t)	Total Cost ($/t)	Wood Cost ($/t)	C.R. ($/t)	C.R. ($/m^3)	C.R. (1990 $/m^3)
1990	1.23	725	892	588	187	491	104.1	104.1
1991	1.23	623	766	606	192	352	74.8	71.2
1992	1.23	649	798	631	200	367	77.9	70.7
1993	1.22	724	883	657	209	435	92.4	79.8
1994	1.22	737	899	679	216	436	92.6	76.1
1995	1.21	659	797	703	224	318	67.6	52.9
1996	1.21	634	767	732	233	268	56.9	42.5
1997	1.20	799	959	763	244	440	93.3	66.3
1998	1.20	928	1114	789	252	577	122.4	82.8
1999	1.19	868	1033	816	260	477	101.2	65.2
2000	1.18	823	971	852	272	391	83.0	51.0
2001	1.18	983	1160	892	287	555	117.8	68.9
2002	1.17	1147	1342	925	298	715	151.7	84.5
2003	1.18	1053	1243	960	309	592	125.5	66.6
2004	1.18	961	1134	1003	324	455	96.6	48.8

3.8 Discount Rate

The real discount rate chosen for the analysis should approximate Weyerhaeuser's real cost of capital for forestry investments. The capital asset pricing model (CAPM) (Brealey *et al.*, 1986) was used to help determine a reasonable range for the real discount rates used in the analysis. The CAPM and estimation of the appropriate discount rate is discussed below.

The CAPM states that in an efficient capital market, the risk premium that must be paid on an investment varies directly with the sensitivity of the return on that investment to variability in the market. An essential assumption of the CAPM is that risk is made up of two components: unique risk and market risk. Unique risks are risks specific to the project in question. Market risk is risk associated with fluctuation in stock market returns. The effect of unique risks can be eliminated through diversifying an investment portfolio. The CAPM determines the risk premium necessary for an investment to be undertaken based on the sensitivity of the return of an investment to fluctuations in the stock market.

The CAPM has the mathematical form

$$r = r_f + \beta(r_m - r_f)$$

where r is the discount rate for the analysis, r_f is rate of return associated with a riskless investment, r_m is the rate of return associated with the market portfolio, and β is a measure of the sensitivity of the return on an investment to changes in the return to the market portfolio.

The rate of return for riskless investments will be approximated by the rate of return on 90 day treasury bills and the rate of return of the market portfolio will be based on the performance of the TSE 300 Composite Index including dividend and reinvestment returns.

Two approaches are used here to estimate the discount rate. The first will be to estimate β for the returns of the pulp and paper industry to give some estimate of the average cost of capital for companies in the pulp and paper industry. The second approach will be to estimate β for pulp prices to estimate the average cost of capital for the pulp operations of pulp and paper companies. This assumes that all of the real variation in returns to pulping operations can be explained by changes in the price of pulp.

The data used to determine the two βs is from the CANSIM data base of Statistics Canada. All data is monthly for the period January 1956 to January 1989. The data retrieved were the TSE 300 stock price index, the TSE stock price index for companies in paper and allied industries, TSE dividend yields, treasury bill rates, and the implicit price index for bleached pulp. The annual rates of return for dividend yields and treasury bill yields were converted to monthly returns using the formula

$$r_{monthly} = (1 + r_{yearly})^{\frac{1}{12}} - 1$$

The monthly rates of return for the two stock price indices and the implicit price index for pulp were determined from the index for the current month and the previous month as

$$r_k = \frac{p_t}{p_{t-1}} - 1$$

where p represents the price index and the subscripts t and $t-1$ represent the current and previous periods respectively.

The total monthly rate of return for investments in the market portfolio and paper companies was calculated as the sum of the monthly returns calculated from the price index, the monthly dividend yields, and monthly reinvestment returns. Reinvestment returns are the returns gained from reinvesting dividend payments in the stock market. These reinvestment returns are calculated as the product of the previous month's dividend yields and the current month's return calculated from the price indices.

The βs for the two models were be estimated using ordinary least squares regression to fit the equation

$$r - r_f = \alpha + \beta(r_m - r_f)$$

The resulting equation for the monthly risk premium required for investments in pulp and paper companies is

$$(r - r_f) = \underset{(-0.22937)}{-3.5964 \times 10^{-4}} + \underset{(32.992)}{1.1209}(r_m - r_f)$$

The equation for investment in the pulp operations of companies is

$$(r - r_f) = \underset{(-0.48032)}{-4.4748 \times 10^{-4}} - \underset{(-2.0984)}{4.2363 \times 10^{-2}}(r_m - r_f)$$

The t statistics for the coefficients of both equations are in parentheses underneath the coefficients. Neither α is significantly different from 0 at the 95% level. The industry β is significantly positive and the divisional β is slightly but significantly negative.

Brealey *et al.* state that 0.5% was the average annual real rate of return for riskless investments and 8.1% was the average annual real risk premium paid for investments in the market portfolio of stocks in Canada for the period 1924 - 1983[6]. The monthly risk free rate of return is $\left(1.005^{\frac{1}{12}} - 1\right)$. The monthly risk premium for the market portfolio of stocks is $\left(1.081^{\frac{1}{12}} - 1\right)$.

Inserting these values into the CAPM produces a required monthly rate of return of 0.7715% for industry investment and 0.01399% for pulp investment. These equate to annual rates of 9.66% $(1.007715^{12} - 1)$ and 0.168% $(1.0001399^{12} - 1)$ respectively. For the base analysis, a 5% real discount rate (approximately half way between the two extremes) was chosen. A set of runs using a 10% real discount rate was used to examine the sensitivity of the model results to changes in the discount rate.

---

6 Brealey *et al.* develop these estimates from data presented in P.P. Boyle, H.H. Panjer, and K.P. Sharp, "Report on Canadian Economic Statistics: 1924-1983", Canadian Institute of Actuaries, Ottawa, 1984.

3.9 Harvest Levels

Required harvest levels for hardwood and softwood timber were provided by Weyerhaeuser. The FMLA needs to produce 555,258 m^3 of hardwood pulpwood, 477,485 m^3 of softwood pulpwood, and 346,000 m^3 of softwood sawlogs each year. This is a total requirement of 555,258 m^3 of hardwood and 823,485 m^3 of softwood each year. If another mill of the same size as the current one is built softwood pulpwood harvest would increase by 932,810 m^3 and hardwood pulpwood harvest would need to increase by 734,008 m^3. The total annual softwood harvest requirements would then be 1,756,295 m^3 and the total annual hardwood requirements would be 1,289,266 m^3.

The requirements for both types of wood more than double when an identical mill is constructed. The current mill is supplied to a certain extent from purchases of roundwood and chips from operators not on the FMLA, and from chips derived from sawmilling of harvest from the FMLA area. Certain small operators also require wood from the FMLA, so the FMLA is modeled in order to take this into account. We assume here that additional pulp mill requirements are satisfied entirely by company harvest on the FMLA area, so doubling pulp mill capacity more than doubles roundwood requirements.

CHAPTER 4: RESULTS AND DISCUSSION

The results of several runs used to test the operation of the model and evaluate the effects of different assumptions are presented and discussed in this chapter. The effects of determining harvest priority using opportunity cost calculated on an area basis and on a volume basis are compared. The unsuitability of the model in situations where specific volumes of different types of wood are required is demonstrated. The effects of changing volume requests, period lengths, and discount rates are examined.

4.1 Harvest Priority Determination

The harvest priority for inventory records should be determined by sorting the inventory by descending opportunity costs per cubic metre. The model harvests from this sorted inventory list until the volume request is met or the opportunity cost becomes negative. This approach minimizes the total opportunity cost incurred in a period when maximum harvest volume constraints must be satisfied. However, forest managers make decisions as to which stands or parts of stands to harvest: real decisions are area based decisions.

Because most harvest decisions are area based, it is tempting to determine the harvest priority using the opportunity cost per hectare. This is incorrect, because the harvest constraint is a volume constraint[7], but leads to some interesting results. Figures 4.1 and 4.2 show the net opportunity cost curves for the harvested inventory sorted by opportunity cost per hectare and opportunity cost per cubic metre respectively. Each graph also shows the opportunity cost measured in the other units calculated by multiplying or dividing by the stand volume (m^3/ha) as appropriate. These curves display the opportunity cost (\$/m^3 and \$/ha) that are avoided with each incremental cubic metre harvested in a period. They can be thought of as inverted supply curves.

---

7 The example that follows should help to explain this. Suppose you have a mill that will process 1000 m^3 of timber per year and two stands from which you can take this year's harvest. Your objective is to minimize the opportunity cost for this year. Stand A is 4 ha in area and supports 200 m^3/ha with an opportunity cost of \$400/ha/year (\$2/m^3/year). Stand B is also 4 ha in area and supports 100 m^3/ha with an opportunity cost of \$250/ha/year (\$2.5/m^3/year). If an area based sort was used to determine harvest priority, all 4 ha of stand A and 2 ha of stand B would be harvested. The opportunity cost reduction would be \$2,100. If a volume based sort was used, all 4 ha of stand B and 3 ha of stand A would be harvested. The opportunity cost reduction would be \$2,200. The volume based sort clearly allows for a greater reduction in opportunity cost when there are constraints on maximum harvest volume.

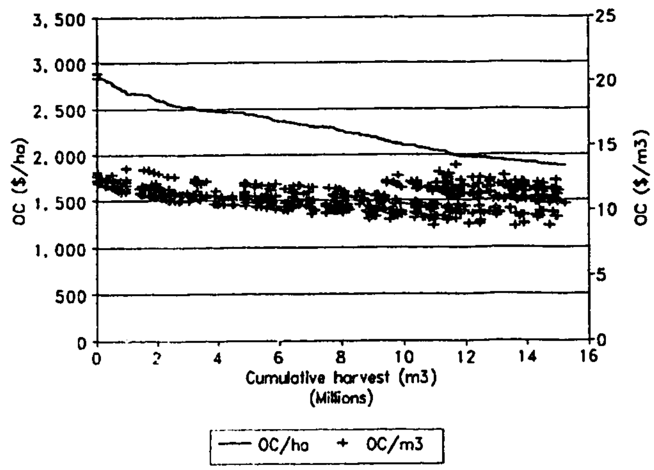

Figure 4.1. Incremental benefit curve for harvested inventory sorted by opportunity cost per ha.

If the inventory is sorted by opportunity cost per ha, the opportunity cost per cubic metre is much more tightly distributed than the opportunity cost per ha when the inventory is sorted by the opportunity cost per cubic metre (Figures 4.1 and 4.2). This indicates that there is much more variation in the type of stands scheduled for harvest under the opportunity cost per cubic metre sorting scheme. This is confirmed by the distribution of harvested area by site class (Figures 4.3 and 4.4) and distribution of harvested area by species association (Figures 4.5 and 4.6).

Under the area based sorting scheme, 80 percent of the harvested area is from site class 1, the remaining 20 percent is from site class 2. When inventory is sorted by opportunity cost per cubic metre, 56 percent of the harvested area is from site class 1, 41 percent from site class 2, and 2 percent from site class 3. The area harvested is also much more distributed across species associations when the inventory is sorted by opportunity cost per cubic metre. With the area based sort, nearly half the harvested area is from the HSSP species association. With the volume based sort, the harvest area is fairly evenly distributed across species associations.

Harvests are more evenly distributed across site classes and species associations when the inventory is sorted by opportunity cost per cubic metre because of the dominance of the inventory holding cost in harvest priority determination. Because the conversion return for a cubic metre of timber is nearly constant across species associations and site classes, the inventory holding cost per cubic metre is nearly constant across species associations and site classes. The inventory holding cost per hectare is greatest for areas with a large volume per hectare. Sorting by opportunity cost per hectare would tend to schedule large volume, site class 1 stands for harvest first.

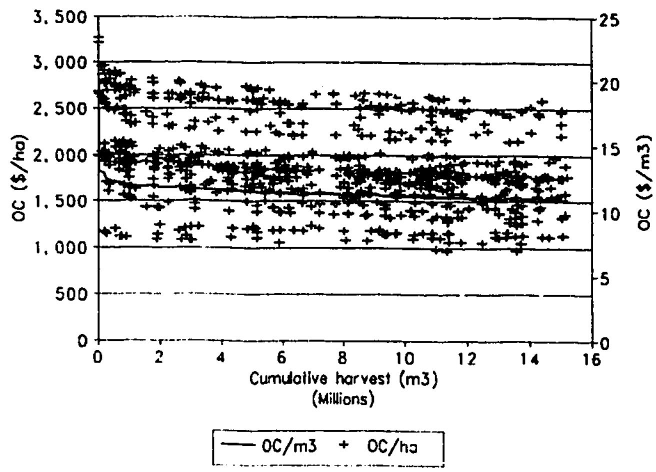

Figure 4.2. Incremental benefit curve for harvested inventory sorted by opportunity cost per m^3.

With the area based sorting scheme, many inventory records with opportunity costs less than $10/$m^3$ are harvested. None are under $10/$m^3$ with the volume based sorting scheme. This means that the total opportunity cost avoided should be greater under the volume based sorting scheme. In fact, harvest with the volume based sorting scheme reduces opportunity cost by $173.3 million while harvest with the area based sorting scheme reduces opportunity cost by only $165.9 million.

Economic theory suggests that the best natural resources should be extracted first (Pearse, 1989). It has been observed that forest products companies in Canada harvest from a wide variety of sites and cover types (*e.g.* Beck *et al.* 1988) which, at first glance, would seem to contradict this principle. Why would a company harvest a low volume black spruce stand instead of a high volume white spruce stand? It has been suggested that this mix of harvested cover types occurs because of government requirements that firms harvest the bad with the good. The results discussed here suggest that much of this is simply economically rational (opportunity cost minimizing) behaviour when companies are facing harvest volume constraints. The problem comes with the definition of best: in our case, the best cubic metres are those which, when harvested, will reduce the opportunity cost the most. Best, in this context, is not the same as greatest timber volume or highest site productivity.

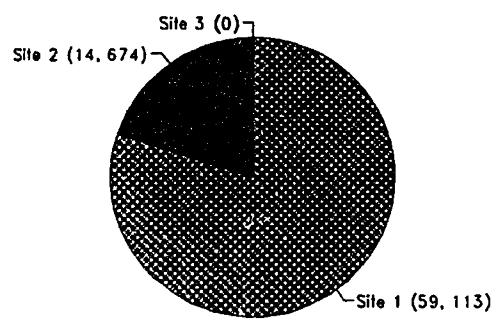

Figure 4.3. Harvest area distribution by site class for inventory sorted by opportunity cost per ha.

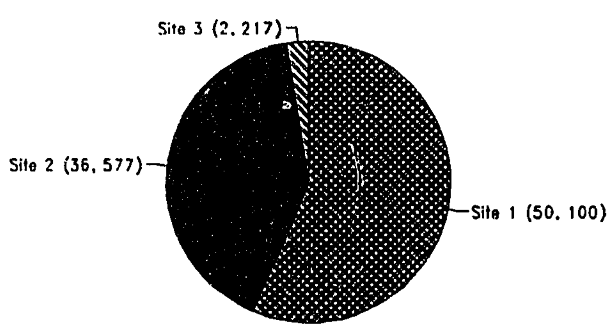

Figure 4.4. Harvest area distribution by site class for inventory sorted by opportunity cost per m^3.

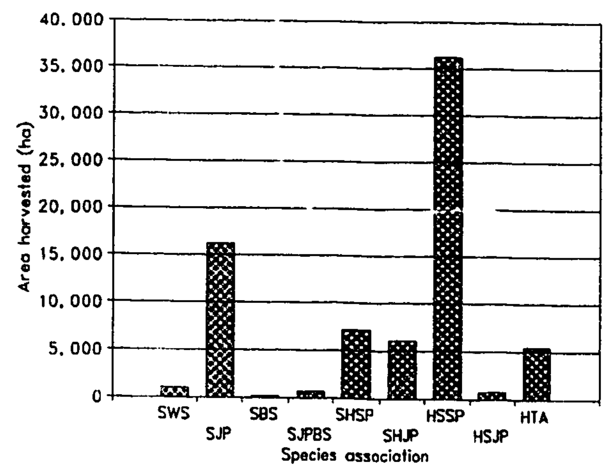

Figure 4.5. Harvest area distribution by species association for inventory sorted by opportunity cost per ha.

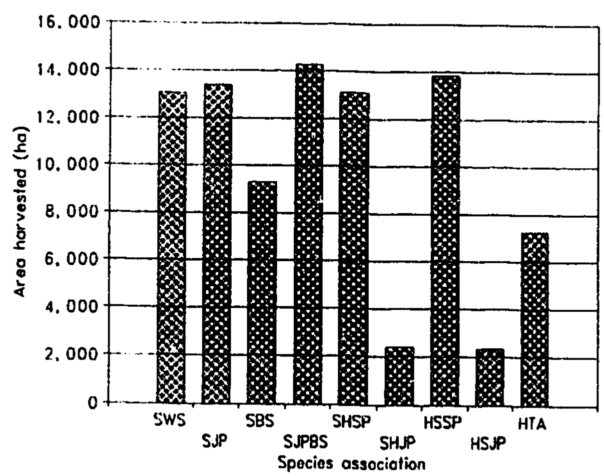

Figure 4.6. Harvest area distribution by species association for inventory sorted by opportunity cost per m^3.

4.2 Wood Type Discrimination

Initially, the model was constructed to allow for discrimination between softwood and hardwood timber. The first complete run attempted with the model was a two mill run requiring specified volumes of each type of timber. The screen display for the second period of this run (Figure

4.7) shows some counter-intuitive results. Developing access to new areas should allow for a greater reduction in opportunity costs or, at worst, no reduction in opportunity costs. Both of the road options examined here showed an increase in opportunity costs as a result of access development (indicated by negative numbers in the OCDiffer column in Figure 4.7).

```
Summary of road options for period 2.  1995-2000.
Softwood Request:  8781475  Hardwood Request:  6446330

Opt   OCReduct  SoftHarv  HardHarv  RoadBilt  RoadCost  OCDiffer  NetBenef
---------------------------------------------------------------------------
  0 153225583   8958195   6446330         0         0         0         0
  1 151547043   8968805   6446330        12    244750  -1678539  -1923290
  2 151480907   8969593   6446330        11    214917  -1744676  -1959592
---------------------------------------------------------------------------
What do you want to do now?
  E)xamine another road option for this period.
  S)elect the best road option and start the next period.
  A)utomate future periods after selecting best road option.
  Q)uit after selecting best road option for this period.
```

Figure 4.7. End of period summary screen for period 2 of run F2.

Figure 4.8 shows the reduction in opportunity costs with incremental harvest volume for the base run and road option 1 for period 2. By building the roads for option 1, proportionally more high opportunity cost softwood timber is accessed than hardwood timber, causing the softwood requirement to be met earlier for road option 1 than for the base run. Once the softwood requirement is met, the opportunity costs for the remaining inventory are recalculated to reflect the fact that additional softwood volume is of no value for the current period and the inventory is re-sorted. The sudden dip in marginal opportunity cost reduction from about $10.80/m^3 to about $6.50/m^3 occurs where the softwood volume request is met.

The total reduction in opportunity cost for each of the road options is the area under the appropriate curve. Because the curves are very similar over most of their range, the area of the gap between the vertical drops accounts for most of the discrepancy. This behaviour makes the scheme used to indicate priority areas for access development unreliable for situation where specified volumes of more than one type of wood are required. Better access should never result in a negative

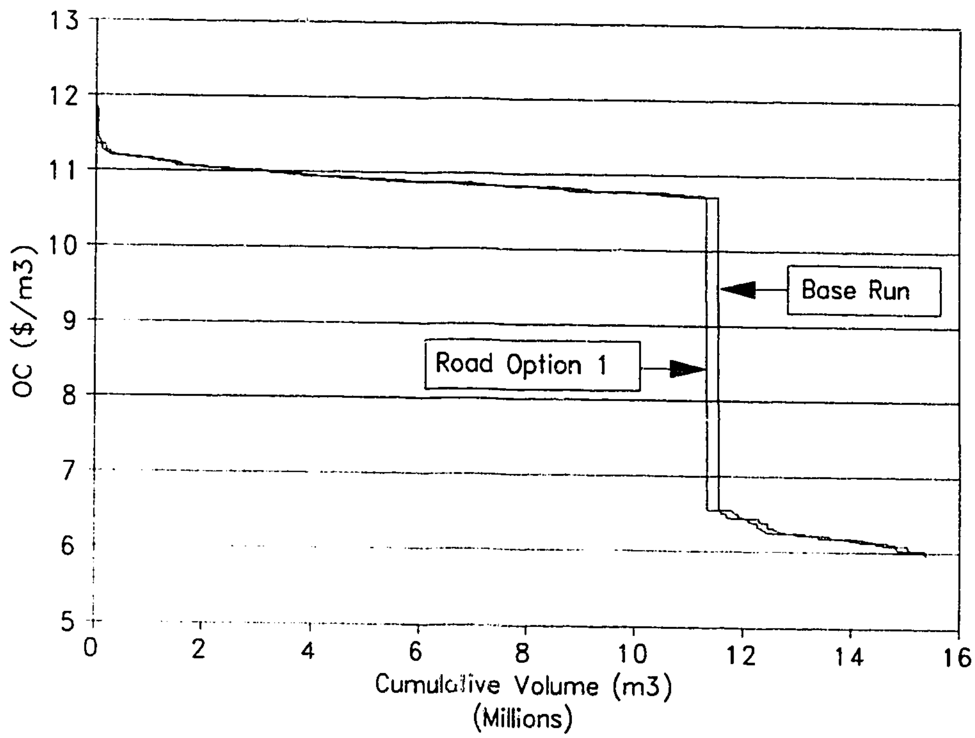

Figure 4.8. Incremental benefit curves showing effect of wood type discrimination.

difference in opportunity costs. Because of this, the series of runs for specific quantities of hardwood and softwood were abandoned although the model does report the volumes harvested by wood type each period.

4.3 Results of the Base Set of Runs

Six runs were conducted using an annual real discount rate of five percent and a planning horizon comprising 10 five year periods. Runs were conducted assuming that the FMLA provided fibre for one or two mills of the size of the existing mill, and assuming that no further road construction would take place, that all roads would be built in the first period, or that road construction would be guided by information provided by the model. These runs represent the base set of runs used for the analysis. These runs are identified by the codes defined in Table 4.1.

Table 4.1. Identification codes for the base set of runs.

	One Mill	Two Mills
No roads built	N1A	N2A
All roads built first period	A1A	A2A
Guided construction	F1A	F2A

The management level for future stands and the present net worth (PNW) of the next rotation are important pieces of information for the model. They determine future yields from the land base and influence the harvest decision through effects on the cost of holding land. The management level for newly harvested forest land is determined in this model to be the one which gives the highest PNW for the next rotation assuming the next harvest occurs at the previously specified rotation age.

The management level is determined using the treatments and responses for different management levels, harvest costs and returns, rotation ages, yield curves, and real discount rate specified in the input. It is not dependent on shortages or surpluses of timber in future periods or on the actual age of harvest. Table 4.2 presents the average PNW/ha of the next rotation for the species associations and site classes harvested in run F2A. There will be slight variation in these figures between runs reflecting different haul costs but these figures can be taken as representative for the base set of runs.

Table 4.2. Average PNW ($/ha) and management level for next rotation by species association and site class for run F2A. The management level code (H) indicates intensive hardwood, (S) indicates intensive softwood, and (B) indicates basic management.

Species Association	Site 1	Site 2	Site 3
HSJP	991 (H)	228 (B)	104 (B)
HSSP	983 (H)	217 (B)	100 (B)
HTA	1,097 (H)	219 (B)	102 (B)
SBS	296 (H)	-206 (B)	-314 (B)
SHJP	704 (H)	-55 (B)	-184 (B)
SHSP	697 (H)	118 (B)	24 (B)
SJP	178 (S)	-99 (B)	-223 (B)
SJPBS	164 (B)	-98 (B)	-272 (B)
SWS	496 (H)	108 (B)	14 (B)

All site class 1 land except for that currently in the SJP and SJPBS species associations will be managed intensively for hardwood production after harvest. All site class 2 and 3 land will be managed under basic management. The most profitable management level for site classes 2 and 3 of the SBS, SHJP, SJP, and SJPBS species association show negative returns for the next rotation. The negative PNWs indicate that no money is to be made managing those species association and site class combinations under the best option considered. Barring government regulation, this land would be most profitably left idle after harvest.

Table 4.3 shows the area by unit accessed in the first period by building 391 km of road for runs A1A and A2A. A total of 283,224 ha of previously inaccessible land becomes available for harvest. Table 4.4 shows the area accessed by unit and period in run F1A and Table 4.5 shows the same for run F2A. A total of 63 km of road built periods 5 and 9 of run F1A accesses 54,125 ha. The 198 km built in periods 3, 4, 5, 9, and 10 of run F2A accesses 180,445 ha.

Table 4.3. New area accessed (ha) and road built (km) in period 1 for runs A1A and A2A.

Unit	Area Accessed (ha)
8	30,732
9	22,151
11	13,216
13	10,113
15	39,405
21	6,432
22	30,832
23	37,020
24	4,656
25	9,376
26	11,574
27	33,047
28	34,670
Total	283,224
Road built (km)	391

Table 4.4. New area accessed (ha) and road built (km) by unit and period for run F1A.

Unit	Period 5	9	Total
8	30,732	0	30,732
9	3,390	13,967	17,357
13	6,036	0	6,036
Total	40,158	13,967	54,125
Road built (km)	51	12	63

Table 4.5. New area accessed (ha) and road built (km) by unit and period for run F2A.

Unit	Period 3	4	5	9	10	Total
8	30,732	0	0	0	0	30,732
9	17,357	0	4,794	0	0	22,151
11	0	0	9,275	0	3,941	13,216
13	6,036	0	0	0	0	6,036
21	0	0	6,432	0	0	6,432
22	0	0	27,105	3,727	0	30,832
23	0	19,354	17,666	0	0	37,020
26	0	0	0	0	11,574	11,574
27	0	0	0	22,420	0	22,420
Total	54,125	19,354	65,272	26,149	15,515	180,415
Road built (km)	64	12	72	20	30	198

Tables 4.6 and 4.7 summarize the softwood and hardwood volumes harvested by period for each of the runs in the base set. The total volume request is met in all instances indicating that there is no absolute shortage of timber in the FMLA area over the fifty year planning horizon. In most periods of all runs more softwood and less hardwood than requested is harvested. This could indicate that there is a relative shortage of hardwood in the FMLA area.

Table 4.6. Volume harvested and requested (thousand m^3) by period and wood type for runs N1A, A1A, and F1A.

	Softwood				Hardwood			
Period	Request	N1A	A1A	F1A	Request	N1A	A1A	F1A
1	4,117	4,609	4,639	4,609	2,776	2,285	2,255	2,285
2	4,117	4,637	4,678	4,637	2,776	2,257	2,215	2,257
3	4,117	4,543	4,800	4,543	2,776	2,350	2,094	2,350
4	4,117	4,574	4,178	4,574	2,776	2,320	2,716	2,320
5	4,117	4,575	4,641	4,713	2,776	2,318	2,252	2,181
6	4,117	4,285	4,000	4,190	2,776	2,609	2,894	2,704
7	4,117	3,513	3,930	3,539	2,776	3,381	2,963	3,354
8	4,117	4,833	4,630	5,208	2,776	2,061	2,264	1,686
9	4,117	4,647	5,550	4,898	2,776	2,247	1,344	1,996
10	4,117	5,498	5,000	5,075	2,776	1,396	1,893	1,819

Table 4.7. Volume harvested and requested (thousand m^3) by period and wood type for runs N2A, A2A, and F2A.

	Softwood				Hardwood			
Period	Request	N2A	A2A	F2A	Request	N2A	A2A	F2A
1	8,781	10,506	10,623	10,506	6,446	4,722	4,605	4,722
2	8,781	10,599	10,757	10,599	6,446	4,628	4,470	4,628
3	8,781	9,991	9,969	10,361	6,446	5,237	5,259	4,867
4	8,781	9,549	8,890	9,373	6,446	5,679	6,338	5,855
5	8,781	8,740	9,770	8,980	6,446	6,488	5,458	6,248
6	8,781	10,799	9,258	9,882	6,446	4,429	5,970	5,345
7	8,781	10,882	9,824	9,722	6,446	4,345	5,404	5,506
8	8,781	8,194	11,372	10,008	6,446	7,034	3,856	5,220
9	8,781	11,001	6,411	8,462	6,446	4,227	8,817	6,766
10	8,781	8,738	10,783	9,434	6,446	6,489	4,445	5,794

The present net worth of activities in each of the units for each of the runs in the base set is presented in table 4.8. This present net worth is calculated from all of the activities reported in the action output file. Road maintenance costs for roads existing at the start of the planning horizon are not reported. This value is constant between runs and is not needed for comparative purposes. Road maintenance costs for roads constructed during the run are included until the end of the planning horizon. Any silvicultural activities scheduled after the end of the planning horizon, for land

In both the one mill and two mill sets of runs, building all roads in the first period is clearly less profitable than building no roads at all. In the two mill runs, the guided construction run shows a present net worth $2.5 million dollars greater than the no road construction run. This is an increase in PNW of about 0.1 percent over the no road construction run. Run F1A (the guided construction run for one mill) shows a decrease of 0.05 percent over the no construction run (N1A).

Table 4.8. Present net worth of activities (million $) by unit and run.

Unit	N1A	A1A	F1A	N2A	A2A	F2A
1	91.2	86.2	89.9	127.8	123.6	125.3
2	57.6	54.3	56.0	85.3	80.0	82.1
3	27.8	25.4	26.6	49.6	47.0	47.8
4	163.7	154.5	161.3	221.6	212.9	217.5
5	190.2	183.0	188.2	261.2	253.2	259.0
6	46.9	42.4	45.0	98.4	89.3	92.5
7	64.4	57.5	63.3	115.3	108.6	111.5
8	16.5	63.2	45.0	29.0	109.2	93.6
9	61.9	77.5	66.5	134.5	171.0	166.6
10	92.5	79.0	89.0	185.8	167.5	176.7
11	63.4	53.5	58.6	165.9	167.1	167.3
12	21.5	17.0	19.2	65.2	53.6	58.3
13	9.7	11.6	10.6	27.7	32.2	29.5
14	16.2	14.2	15.8	79.3	53.7	58.5
15	2.3	5.6	2.2	29.3	41.2	18.1
16	5.4	4.8	5.0	18.9	12.2	14.2
17	32.1	30.5	30.9	99.9	77.3	83.6
18	27.7	22.7	27.2	107.8	84.1	90.5
21	54.9	45.5	51.0	143.9	128.7	140.6
22	11.2	16.3	10.6	61.9	80.5	77.5
23	38.4	50.2	37.7	112.3	153.6	155.5
24	10.9	6.9	7.8	90.2	68.4	68.8
25	17.9	17.3	17.9	87.8	69.6	71.5
26	10.8	11.6	10.6	50.9	50.9	48.0
27	1.3	3.9	1.3	4.4	20.2	11.0
28	0.4	2.4	0.4	9.9	14.4	6.5
Roads		-28.1	-1.4		-28.1	-5.2
Total	1,136.8	1,109.1	1,136.2	2,464.2	2,442.1	2,466.7

Theoretically, such a decrease should not occur because the economic criteria used to guide road construction should increase PNW. The information used to guide road construction considers the present value of future harvests of regenerated timber. The reporting procedures, however, do not incorporate the value of unharvested timber in the present value calculations. Longer planning horizons or larger discount rates would reduce the effect of this bias. In any case, the effect of road construction on the PNW in both the one mill and two mill runs is negligible. This indicates that for foreseeable demands on the timber base, the FMLA is well accessed now and that future road construction will have a small impact on profitability of the operation.

4.4 Discount Rate Change

A s[illegible] runs was conducted with a real 10 percent annual discount rate in order to determine the ef[illegible]ange in the discount rate on the results. The set of runs included one for no road construc[illegible] (N2C), one for complete road construction in the first period (A2C), and a guided construction run (F2C). All the runs in this set assume that the FMLA area will be supplying two pulp mills with timber.

The most noticeable effect of a change in discount rates is the change in management levels and the PNW of future rotations. Table 4.9 presents the average PNW/ha of the next rotation for the species associations and site classes harvested in run F2C. All harvested stands will be managed under basic management in this set of runs. The best management regimes for all of the species associations and site classes (except HSJP, HSSP, and HTA site class 1) have negative present net worth. The difference in PNW between site classes is much smaller than in the base set of runs.

Table 4.9. Average PNW ($/ha) for next rotation by species association and site class for run F2C.

Species Association	Site 1	Site 2	Site 3
HSJP	3	-15	-20
HSSP	0	-15	-21
HTA	0	-15	-21
SBS	-265	-242	-268
SHJP	-212	-220	-259
SHSP	-54	-65	-69
SJP	-210	-246	-262
SJPBS	-210	-246	-263
SWS	-69	-81	-85

Much more site class 2 land is scheduled for harvest in the runs with the 10 percent discount rate than in the base set of runs (compare Figures 4.9 and 4.4). This difference can be attributed to a much smaller effect of the land holding cost on the determination of harvest priority. This smaller effect results from the smaller difference in PNWs between sites. The distribution of area of species associations harvested is very similar between the base set and the 10 percent set of runs (compare Figures 4.10 and 4.6).

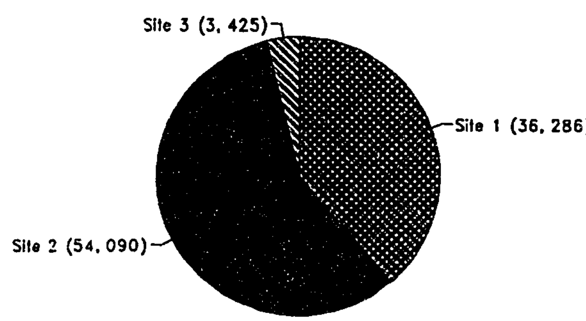

Figure 4.9. Harvest area distribution by site class harvested in period 1 of run F2C.

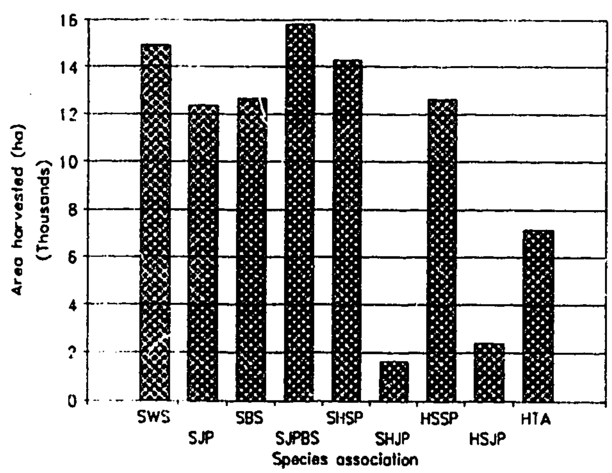

Figure 4.10. Harvest area distribution by species association harvested in period 1 of run F2C.

Table 4.10 summarizes the timing of road construction and amount of newly accessible area for run F2C. The total amount of road built and area accessed in this run is slightly greater than that in run F2A. The difference is that more of unit 13 is accessed here. The timing of access between the two runs also differs slightly. Nearly 75 percent of the area scheduled for access in period 3 of F2A is accessed in period 2 of F2C. Area scheduled for access in period 5 of F2A is spread across periods 5,6, and 7 in F2C. All of the area scheduled for access in period 9 of F2A is accessed in period 10 of F2C. Some of the area scheduled for access in period 10 of F2C is accessed in period 9 of F2A.

Table 4.10. New area accessed (ha) and road built (km) by unit and period for run F2C.

Unit	Period								Total
	2	3	4	5	6	7	9	10	
8	30,732	0	0	0	0	0	0	0	30,732
9	3,390	13,967	0	0	4,794	0	0	0	22,151
11	0	0	0	0	9,275	0	3,942	0	13,216
13	6,036	0	0	0	0	0	0	4,077	10,113
21	0	0	0	6,432	0	0	0	0	6,432
22	0	0	0	0	0	27,105	0	3,727	30,832
23	0	0	19,354	10,243	0	7,423	0	0	37,020
26	0	0	0	0	0	0	0	11,574	11,574
27	0	0	0	0	0	0	0	22,420	22,420
Total	40,158	13,967	19,354	16,675	14,069	34,528	3,942	41,798	184,491
Road Built (km)	51	12	12	17	22	32	10	54	210

The change in access schedule between the runs is interesting in that in some instances access is delayed and in others it is accelerated. Part of the change in the access schedule results from the change is the harvest priority resulting from change in the PNW of the next rotation and the relative importance of the growth rate. A more important factor is that the lower PNW of future harvests decrease the opportunity cost of land, and makes road construction less profitable. However, an increase in discount rate will also have the effect of making the annual costs of roads relatively less expensive (because of the inclusion of maintenance costs) than inventory holding costs. This would make roads relatively less expensive to build and would therefore tend to accelerate road construction. It would be very difficult to make an *a priori* prediction of the effect of interest rates on the road construction schedule.

Table 4.11 displays the present net worth by unit for the 10 percent series of runs. The guided construction run shows a slightly greater present net worth than the no road construction run. In all cases the present net worth is less than that in the base set of runs. This is because of the higher discount rate.

Table 4.11. Present net worth of activities (million $) by unit for runs N2C, A2C, and F2C.

Unit	N2C	A2C	F2C
1	97.7	96.0	96.5
2	60.9	56.5	58.8
3	28.2	25.7	26.5
4	165.7	159.0	163.7
5	218.6	213.1	216.8
6	62.6	56.2	59.6
7	85.7	76.7	79.8
8	17.3	74.6	66.9
9	84.8	102.6	98.5
10	122.6	108.0	114.0
11	88.3	86.4	86.5
12	34.2	27.9	30.9
13	14.8	18.6	17.3
14	28.5	18.7	22.5
15	4.1	6.0	2.0
16	6.8	4.6	4.8
17	39.9	30.2	32.2
18	26.5	15.9	20.9
21	70.6	68.9	67.5
22	17.6	25.6	18.5
23	49.1	68.9	60.2
24	16.3	7.6	8.6
25	23.6	15.5	15.7
26	18.3	18.6	16.8
27	1.9	5.1	2.2
28	0.2	0.4	0.0
Roads		-21.0	-2.5
Total	1,384.7	1,366.4	1,385.2

4.5 Period Length Change

A two mill run using a 5% discount rate and 10 10-year periods (Run F2B) was conducted to examine the behaviour of the model using longer periods. Table 4.12 displays the present net worth by unit for run F2B. Because the planning horizon is twice as long as that for run F2A, the present net worth of this run should be about 1.0872 times that of run F2A assuming that the flow of costs and benefits in the first five decades is similar to that in the last five decades[8]. It turns out that the PNW of run F2B is 1.0869 times that of run F2A. This is extremely close to the expected value of 1.0872.

[8] The present value of one dollar received today and one dollar received 50 years from now, assuming a 5% rate of discount, is $1 + 1.05^{-50} = 1.0872$.

Table 4.12. Present net worth of activities (million $) by unit for run F2B.

Unit	PNW
1	134.4
2	94.1
3	50.7
4	218.7
5	241.9
6	97.1
7	114.6
8	89.0
9	153.3
10	166.3
11	155.0
12	53.0
13	31.9
14	68.1
15	28.8
16	12.0
17	90.1
18	99.0
21	158.8
22	131.8
23	203.0
24	94.1
25	92.0
26	70.9
27	30.3
28	9.8
Roads	-7.6
Total	2,681.0

Table 4.13 shows the area accessed as a result of road building for run F2B. When making comparisons with run F2A, keep in mind that the periods in run F2B are twice as long as those in F2A. The end of period 5 in run F2B is the end of the planning horizon for run F2A. At the end of fifty years (5 periods) 248 km of road were built developing access to an additional 199,969 ha. This compares with 198 km and 180,415 ha after fifty years in run F2A (Table 4.5). Access development is somewhat accelerated in run F2B compared with run F2A and the order of units for access development is somewhat shuffled. The accelerated development can be partially explained by the fact that the choice becomes to develop access now or wait 10 years as opposed to 5 years.

The shuffling can be explained by a change in ordering of stands for harvest. The curve used to determine harvest priority is very flat (Figure 4.2), so slight changes in the calculated opportunity cost can make for a large changes in harvest priority. Several changes occur with a move from 5 year periods to 10 year periods. Volumes are calculated at ages at the middle of each period. A change in period length makes for changes in volumes. Average growth over a 10 year period will be different from average growth over a 5 year period.

Table 4.13. New area accessed (ha) and road built (km) by unit and period for run F2B.

	Period							
Unit	2	3	4	5	6	7	8	Total
8	24,861	5,871	0	0	0	0	0	30,732
9	17,357	4,794	0	0	0	0	0	22,151
11	0	13,216	0	0	0	0	0	13,216
13	0	6,036	0	0	4,077	0	0	10,113
15	0	0	0	0	39,405	0	0	39,405
21	0	6,432	0	0	0	0	0	6,432
22	27,104	3,728	0	0	0	0	0	30,832
23	26,778	10,242	0	0	0	0	0	37,020
24	0	0	0	0	4,656	0	0	4,656
25	0	5,428	0	0	3,948	0	0	9,376
26	0	0	11,574	0	0	0	0	11,574
27	0	6,044	16,844	7,646	0	2,513	0	33,047
28	0	6,014	0	0	0	0	28,656	34,670
Total	96,100	67,805	28,418	7,646	52,086	2,513	28,656	283,224
Road Built (km)	98	85	36	29	79	10	34	371

Table 4.14 summarizes the volume harvested by period and wood type in run F2B. This also demonstrates the shuffling of harvest priority. In the first 40 years of the planning horizon, more hardwood volume than requested is harvested. In run F2A, there was an apparent shortage of hardwood timber. In periods 7 through 10 of run F2B, considerably more hardwood than requested is harvested. This reflects that much of site class 1 stands harvested were put into intensive hardwood management. A great deal of second growth hardwood timber is harvested in these periods.

Changing period length has little unexpected effect on the present net value of the stream of costs and benefits of the activities undertaken but does have a noticeable effect on the timing and mix of road construction activities and on the mix of wood types harvested. This indicates that the construction schedule and harvest schedule is quite sensitive to period length. Determining the best period length to use for this model involves some trade-offs.

Table 4.14. Volume harvested (thousand m^3) by period and wood type for run F2B.

	Softwood		Hardwood	
Period	Request	Harvest	Request	Harvest
1	17,563	17,073	12,893	13,383
2	17,563	16,275	12,893	14,181
3	17,563	18,203	12,893	12,252
4	17,563	16,284	12,893	14,172
5	17,563	18,526	12,893	11,930
6	17,563	22,092	12,893	8,364
7	17,563	5,950	12,893	24,506
8	17,563	7,902	12,893	22,554
9	17,563	8,000	12,893	22,456
10	17,563	11,940	12,893	18,515

Analytically, the best period length would be one that corresponds to periods for which actual decisions are made (probably one year or shorter). Results using shorter periods are probably more trustworthy. However shorter periods imply more periods need to be analyzed. Because the model takes a great deal of time (computer and analyst) and computer disk space for each period, practical limitations would favour longer periods.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In the traditional single stand models of forest economics, the standard objective is to maximize the economic return to forest land. The opportunity cost minimizing objective used in the model developed here results from distortions introduced by institutions related to forest management in Saskatchewan and in other parts of Canada. Because the company manages a large forest area to provide a pulp mill with a specific volume of timber each year, because the company is unable to sell timber to other operators, and because the timber base is more than large enough to supply the mill, cost minimization becomes the appropriate objective. This means that maximization of economic returns to forest land under existing institutional arrangements is not applicable to the case study. An interesting area for research would be evaluation of the different degrees of economic efficiency introduced under alternative institutional arrangements including forest management licence agreements.

This thesis develops a forest planning model integrating decisions related to timber harvest, other silvicultural activities, and transportation. The central assumption of the model is that a forest manager will choose to undertake harvest, other silvicultural, and road construction activities that minimize the net opportunity cost incurred in a period. The net opportunity cost is defined as the costs of holding forest inventory and land less the value growth of the forest and the benefits of delaying road construction for one period.

The model presented here allows an analyst to evaluate and compare several different roading options in each period of a planning horizon. The analyst is presented with information that will allow for the choice of the cost minimizing roading option for the period. By choosing a roading option, the analyst is also implicitly choosing the set of harvest and other silvicultural activities that will be undertaken for the period. The model is designed to provide a forest planner with useful information about priority areas for access development and the net benefit of developing access to those areas.

The model is applied and tested using data developed for a forest management licence area in Saskatchewan. The effects of changing the annual harvest request, period length, and discount rate were examined. Increasing the annual harvest request leads to the unsurprising result that road construction is accelerated. A more surprising result is that a harvest request more than double the original does not appear to lead to any timber supply shortage on the FMLA area and that the volume harvested is always much less than the volume with a positive opportunity cost.

Changes in period length have the effect that a noticeably different mix of stand types is scheduled for harvest. This occurs because of the sensitivity of the harvest mix to slight changes in the calculated opportunity cost. Changing the period length leads to large enough changes in the harvest priority list to be noticeable. The implication of this is that the period length should be carefully chosen to reflect the time period used by the company for making harvest and roading decisions and the computer and analytical resources available.

An increase in the discount rate used for the analysis has several counteracting effects, so the overall effect is not easily predicted. It does have the effect of reducing the present net worth of future rotations and therefore the opportunity cost of land. As well, in the case examined here, the difference in the PNW of future rotations between site classes becomes much smaller. This smaller difference between the PNW of different site classes leads to less site class 1 land being harvested in a period. Because of the inclusion of annual maintenance costs, road construction becomes relatively cheaper than delaying harvest, so some roads are built earlier. But because of the smaller PNW, the costs of holding land decrease, leading to delay of road construction in some instances.

An interesting byproduct of the study was a comparison between the stands scheduled for harvest when they were sorted by opportunity cost per ha or opportunity cost per m^3. Because a specific volume of wood was to be harvested each period, the opportunity cost per m^3 is the correct value to use as the sort key. The variety of stand types scheduled for harvest when sorted by opportunity cost per m^3 is much more diverse than what happens with the opportunity cost per ha. This may go some way towards explaining why an economically rational company would harvest what appears to be, at first glance, economically unattractive timber.

The model developed is a simulation model using single stand optimization techniques to guide forest level decisions. As such, the solutions developed using this model will be an approximation of the optimal solution. In order to evaluate just how far from optimal the solution actually is would require the construction of an intertemporal mixed integer programming model to solve the problem.

The present net worth of the solution of the MIP formulation could be compared to that resulting from the application of the model developed here. This would be an interesting and useful extension of this work.

A limitation of the model is its inability to handle requests for more than one wood type because the harvest priority ranking scheme is inappropriate when a mix of wood types is required. One solution to this problem is to use constrained optimization techniques within each period (perhaps mixed integer or dynamic programming) to determine the opportunity cost minimizing mix of harvest, other silvicultural, and transportation activities subject to constraints on the volume of different wood types harvested. The resulting model would be a series of single period optimization models within a multi-period growth and yield simulator. This is an intriguing possibility for further development of the model.

LITERATURE CITED

Alberta Energy and Natural Resources, 1985: "Forest Products Conversion Factors: Background to the Various Forest Product Conversion Factors Used by the Alberta Forest Service", ENR Technical Report No. T/90, Edmonton.

Beck, J.A, R.G. Anderson, G.W. Armstrong, and G.H. Farrow, 1989: "Alberta Economic Timber Supply Study. Final Report", Forestry Canada, Edmonton.

Borland International, 1989: "Turbo Pascal Reference Guide", vers. 5.0, Scotts Valley.

Brealey, R., S. Myers, G. Sick, and R. Whaley, 1986: "Principles of Corporate Finance", 1st Canadian ed., McGraw-Hill Ryerson, Toronto.

Davis, L.S. and K.N. Johnson, 1987: "Forest Management", 3d ed., McGraw-Hill, Toronto.

Dykstra, D.P., 1984: "Mathematical Programming for Natural Resource Management", McGraw-Hill, Toronto.

Iverson, D.C. and R.M. Alston, 1986: "The Genesis of FORPLAN: A Historical and Analytical Review of Forest Service Planning Models". USDA Forest Service General Technical Report INT-214.

Johnson, K.N. and D.B. Jones, 1979: "Timber Harvest Scheduling Model. User's Guide and Operations Manual". Unpublished mimeo. USDA Forest Service.

Jones, J.G., J.F.C Hyde III, and M.L. Meacham, 1986: "Four Analytical Approaches for Integrating Land Management and Transportation Planning on Forest Lands", U.S. Forest Service Research Paper INT-361.

Jones, J.G., A. Weintraub, M.L. Meacham, A. Magendzo, and R. Cahoon, 1988: "An Automated Heuristic Process For Solving Integrated Resource Analysis System (IRAS) Models: User's Guide (Draft)". Unpublished mimeo. Intermountain Research Station, U.S. Forest Service.

Lougheed, W.H, 1988: "Spatial Analysis in Timber Management Planning", Canada-Ontario Forest Resource Development Agreement.

Navon, D.I., 1971: "Timber RAM Users' Manual Part II: Forester's Guide", U.S. Forest Service, Berkeley.

Pearse, P.H., 1989: "Introduction to Forestry Economics", UBC Press, Vancouver.

Resource Information Systems, Inc., 1989: Pulp and Paper Review 13(2).

Tedder, P.L., J.C. Gourley, and R.N. LaMont, 1984: "The Timber Resource Inventory Model (TRIM): A Timber Inventory Projection Model For National Timber Supply Projections and Policy Analysis", Unpublished mimeo. Oregon State University.

Weintraub, A. and D. Navon, 1976: A Forest Management Planning Model Integrating Silvicultural and Transportation Activities. *Manage. Sci.* 22(12):1299-1309.

Williams, D.H., and R. Gasson, 1986: The Economic Stock of Timber in the Coastal Region of British Columbia", Report 86-11, Forest Economics and Policy Analysis Project, University of British Columbia, Vancouver.

Williams, J., 1987: "Forest Management and Access: Harvest Allocation Options and Their Impact on Road Expenditures", Ontario MNR Sci. and Tech. Series, Vol 2.

APPENDIX A: SITE CAPABILITY CLASS ASSIGNMENTS

The following table shows the site capability classes assigned to stands on the basis of soil texture, soil drainage, and leading species.

Texture	Drainage	JP	WS	BS	TA
C, C-MC	VR, VR-R	3	4	4	4
	RD, RD-WD	3	3	4	3
	WD, WD-MWD	2	2	3	2
	MWD, MWD-ID	2	2	2	2
	ID, ID-PD	3	2	2	2
	PD, PD-VPD	3	3	3	3
	VPD	4	4	4	4
MC, MC-MF	VR, VR-R	3	4	4	4
	RD, RD-WD	3	3	4	2
	WD, WD-MWD	1	2	2	2
	MWD, MWD-ID	1	2	1	1
	ID, ID-PD	2	2	2	2
	PD, PD-VPD	3	3	3	3
	VPD	4	4	4	4
MF, MF-F	VR, VR-R	4	4	4	4
	RD, RD-WD	3	4	4	4
	WD, WD-MWD	2	2	2	2
	MWD, MWD-ID	1	1	1	1
	ID, ID-PD	3	1	1	1
	PD, PD-VPD	3	3	3	3
	VPD	4	4	4	4
F	VR, VR-R	4	4	4	4
	RD, RD-WD	4	4	4	4
	WD, WD-MWD	2	2	2	2
	MWD, MWD-ID	1	1	1	1
	ID, ID-PD	3	2	2	1
	PD, PD-VPD	3	3	3	4
	VPD	4	4	4	4
O	VR, VR-R	4	4	4	4
	RD, RD-WD	4	4	4	4
	WD, WD-MWD	4	4	4	4
	MWD, MWD-ID	4	4	4	4
	ID, ID-PD	4	4	3	4
	PD, PD-VPD	4	4	3	4
	VPD	4	4	4	4

Soil texture is recorded as coarse (C), coarse to moderately coarse (C-MC), moderately coarse (MC), moderately coarse to moderately fine (MC-MF), moderately fine (MF), moderately fine to fine (MF-F), fine (F), and organic (O). Soil drainage is recorded as very rapid (VR), very rapid to rapid (VR-R), rapidly drained (RD), rapidly drained to well drained (RD-WD), well drained (WD), well drained to moderately well drained (WD-MWD), moderately well drained (MWD), moderately well drained to imperfectly drained (MWD-ID), imperfectly drained (ID), imperfectly drained to poorly drained (ID-PD), poorly drained (PD), poorly drained to very poorly drained (PD-VPD), and very poorly drained (VPD). Leading species codes are JP for jack pine, WS for white spruce and balsam fir, BS for black spruce and larch, and TA for trembling aspen and black poplar.

APPENDIX B: TIMBER YIELD CURVE COEFFICIENTS

Spp. Ass.	Site	Yld Lvl	Wood Type	a_{min}	a_{max}	b_0	b_1	b_2	b_3	c_0	c_1
SJP	1	NAT	S	30	120	-2.6698E+1	2.4087E+0	1.3321E-2	-1.5969E-4	1.7822E+2	0.0000E+0
SJP	1	S1	S	20	80	-1.3121E+2	7.9175E+0	-2.2500E-2	-1.3889E-4	2.8707E+2	0.0000E+0
SJP	1	S2	S	20	70	-1.0757E+2	3.3135E+0	1.5905E-1	-1.6111E-3	3.5110E+2	0.0000E+0
SJP	1	MGD	S	20	80	-1.0389E+2	5.6036E+0	0.0000E+0	0.0000E+0	3.5348E+2	0.0000E+0
SJP	1	NAT	H	30	140	-1.5381E+0	1.0103E-1	2.6264E-3	-1.7262E-5	1.6716E+1	0.0000E+0
SJP	2	NAT	S	30	140	-8.3765E+1	4.3849E+0	-2.7426E-2	4.7306E-5	1.2238E+2	0.0000E+0
SJP	2	S1	S	30	80	-1.1681E+2	5.2489E+0	-2.2679E-2	0.0000E+0	1.5796E+2	0.0000E+0
SJP	2	S2	S	30	80	-1.2257E+2	6.2655E+0	-3.0833E-2	0.0000E+0	1.8133E+2	0.0000E+0
SJP	2	MGD	S	20	80	-5.7964E+1	2.8821E+0	0.0000E+0	0.0000E+0	1.7261E+2	0.0000E+0
SJP	2	NAT	H	30	140	-3.1692E+0	1.3640E-1	1.1060E-3	-9.3499E-6	1.1948E+1	0.0000E+0
SJP	3	NAT	S	30	120	-5.7403E+1	2.4508E+0	-5.3193E-3	-4.6173E-5	8.0312E+1	0.0000E+0
SJP	3	S1	S	30	80	-4.3762E+1	1.4714E+0	0.0000E+0	0.0000E+0	7.3952E+1	0.0000E+0
SJP	3	S2	S	30	80	-6.7024E+1	2.1454E+0	9.0873E-3	-1.4815E-4	8.6913E+1	0.0000E+0
SJP	3	MGD	S	30	80	1.2786E+1	-1.7290E+0	5.8095E-2	-3.0556E-4	8.9833E+1	0.0000E+0
SJP	3	NAT	H	30	140	-4.0973E+0	1.5549E-1	1.6162E-4	-4.8433E-6	7.5487E+0	0.0000E+0
SBS	1	NAT	S	30	77	2.4471E+2	-1.7362E+1	3.8437E-1	-2.3278E-3	8.9451E+1	4.4972E-1
SBS	1	S1	S	30	100	-3.1905E+1	-8.6126E-1	9.2045E-2	-5.6818E-4	2.3424E+2	0.0000E+0
SBS	1	S2	S	30	100	6.1952E+1	-2.0696E+0	7.3593E-2	-4.0152E-4	1.8941E+2	0.0000E+0
SBS	1	MGD	S	30	100	4.0452E+1	-9.3452E-1	7.9167E-2	-5.0000E-4	2.3867E+2	0.0000E+0
SBS	1	NAT	H	30	180	-1.8836E+1	7.6511E-1	-5.8208E-3	1.2212E-5	0.0000E+0	0.0000E+0
SBS	2	NAT	S	30	90	7.0207E+1	-5.3463E+0	1.2736E-1	-7.0833E-4	7.6814E+1	3.0492E-1
SBS	2	S1	S	40	100	-9.7786E+1	2.3643E+0	0.0000E+0	0.0000E+0	1.3864E+2	0.0000E+0
SBS	2	S2	S	30	100	-5.8798E+1	1.7488E+0	0.0000E+0	0.0000E+0	1.1608E+2	0.0000E+0
SBS	2	MGD	S	30	100	-9.0905E+1	3.0524E+0	0.0000E+0	0.0000E+0	2.1433E+2	0.0000E+0
SBS	2	NAT	H	30	180	-1.3158E+1	5.2467E-1	-3.7604E-3	7.1181E-6	0.0000E+0	0.0000E+0
SBS	3	NAT	S	30	120	4.0501E+1	-2.3643E+0	4.1153E-2	-1.5989E-4	5.2686E+1	1.7008E-1
SBS	3	S1	S	40	130	6.5014E+1	-3.9466E+0	7.1387E-2	-3.1099E-4	7.5136E+1	0.0000E+0
SBS	3	S2	S	40	130	2.0310E+1	-1.6130E+0	3.6620E-2	-1.6336E-4	7.0583E+1	0.0000E+0
SBS	3	MGD	S	40	120	-8.1897E+1	2.3309E+0	-2.9196E-3	-3.5936E-5	9.3675E+1	0.0000E+0
SBS	3	NAT	H	30	180	-2.3250E+0	5.1542E-2	5.5049E-4	-4.2219E-6	0.0000E+0	0.0000E+0
SWS	1	NAT	S	30	86	-2.3002E+2	1.4591E+1	-1.7018E-1	6.5631E-4	1.9410E+2	-1.2165E-1
SWS	1	MGD	S	30	80	-3.9500E+1	-8.7976E-1	3.0310E-1	-2.5833E-3	5.0726E+2	0.0000E+0
SWS	1	NAT	H	30	180	-1.2462E+1	9.9075E-1	-5.8778E-3	1.1279E-5	0.0000E+0	0.0000E+0
SWS	2	NAT	S	30	84	-1.6345E+2	9.9261E+0	-1.0866E-1	3.9024E-4	1.4147E+2	-7.7613E-2
SWS	2	MGD	S	20	80	7.0714E+1	-8.7238E+0	3.7357E-1	-2.8333E-3	3.1300E+2	0.0000E+0
SWS	2	NAT	H	30	180	-1.0665E+1	7.4666E-1	-4.3445E-3	8.1491E-6	0.0000E+0	0.0000E+0
SWS	3	NAT	S	30	100	-1.0861E+2	5.8587E+0	-5.7315E-2	1.8232E-4	9.3739E+1	-7.2992E-2
SWS	3	MGD	S	20	80	2.4143E+1	-3.7607E+0	1.6631E-1	-1.1667E-3	1.9033E+2	0.0000E+0
SWS	3	NAT	H	30	180	-1.1082E+1	5.8284E-1	-3.6034E-3	7.2382E-6	0.0000E+0	0.0000E+0
SJPBS	1	NAT	S	30	76	3.0182E+2	-2.1437E+1	4.7602E-1	-2.9315E-3	1.1201E+2	3.0607E-1
SJPBS	1	S1	S	20	80	-3.6571E+1	4.7500E-1	9.0595E-2	-6.6667E-4	2.3990E+2	0.0000E+0
SJPBS	1	NAT	H	30	160	-3.1330E+0	1.0715E-2	3.0905E-3	-1.8401E-5	1.1104E+0	0.0000E+0
SJPBS	2	NAT	S	30	88	7.1074E+1	-5.5977E+0	1.3814E-1	-7.9722E-4	8.7826E+1	1.9485E-1
SJPBS	2	S1	S	30	100	-6.0012E+1	2.0310E+0	0.0000E+0	0.0000E+0	1.4308E+2	0.0000E+0
SJPBS	2	NAT	H	30	160	-8.6891E-1	-5.9195E-2	3.1128E-3	-1.6559E-5	1.1104E+0	0.0000E+0
SJPBS	3	NAT	S	40	120	2.3325E+1	-1.5015E+0	2.9202E-2	-1.1280E-4	3.9010E+1	2.4772E-1
SJPBS	3	S1	S	40	130	-1.2055E+1	-4.6084E-1	2.5839E-2	-1.2005E-4	1.0097E+2	0.0000E+0
SJPBS	3	NAT	H	40	160	5.8349E+0	-2.9976E-1	4.6633E-3	-1.8590E-5	1.1104E+0	0.0000E+0
HTA	1	NAT	S	30	80	-9.5190E+0	3.9373E-1	-2.0119E-3	-2.7778E-6	7.0257E+0	8.1905E-3
HTA	1	NAT	H	30	100	-2.9746E+2	1.3846E+1	-1.3463E-1	4.2744E-4	1.9091E+2	-2.2617E-1
HTA	1	S1	H	20	80	-1.0564E+2	6.5817E+0	1.5000E-2	-3.8889E-4	3.1779E+2	0.0000E+0
HTA	1	MGD	H	20	60	1.2860E+2	-1.3608E+1	5.8500E-1	-4.4167E-3	4.6410E+2	0.0000E+0

Spp. Ass.	Site	Yld Lvl	Wood Type	α_{min}	α_{max}	b_0	b_1	b_2	b_3	c_0	c_1
HTA	2	NAT	S	30	100	-6.3297E+0	2.3147E-1	-6.3925E-4	-3.6195E-6	6.8056E+0	0.0000E+0
HTA	2	NAT	H	30	140	-2.0075E+2	8.3800E+0	-6.4011E-2	1.4619E-4	1.1898E+2	0.0000E+0
HTA	2	S1	H	20	80	-4.8036E+1	3.2179E+0	0.0000E+0	0.0000E+0	2.0939E+2	0.0000E+0
HTA	2	MGD	H	20	77	7.9786E+1	-8.7377E+0	3.2012E-1	-2.2778E-3	2.6509E+2	0.0000E+0
HTA	3	NAT	S	40	100	-9.9190E+0	3.5513E-1	-2.5595E-3	5.5556E-6	5.3548E+0	0.0000E+0
HTA	3	NAT	H	40	140	-2.4514E+2	8.9794E+0	-7.2005E-2	1.8013E-4	9.4938E+1	0.0000E+0
HTA	3	S1	H	30	80	1.0943E+2	-8.7698E+0	2.1548E-1	-1.2778E-3	1.3267E+2	0.0000E+0
HTA	3	MGD	H	30	80	3.2095E+1	-4.2410E+0	1.4829E-1	-9.9074E-4	1.3463E+2	0.0000E+0
HSJP	1	NAT	S	30	120	-1.7816E+1	1.4416E+0	-6.7203E-3	-4.2735E-6	5.1016E+1	0.0000E+0
HSJP	1	S1	S	20	80	-6.2857E+0	-5.6429E-1	5.9167E-2	-4.1667E-4	1.1390E+2	0.0000E+0
HSJP	1	NAT	H	30	140	-4.4313E+1	3.1759E+0	-1.9497E-2	2.7480E-5	9.3579E+1	0.0000E+0
HSJP	1	S1	H	30	80	-2.3857E+1	1.4163E+0	1.3214E-2	-5.5556E-5	1.4557E+2	0.0000E+0
HSJP	2	NAT	S	30	120	-1.5718E+1	1.1914E+0	-5.7611E-3	-8.5470E-7	4.7117E+1	-3.5653E-2
HSJP	2	S1	S	30	80	[illegible]	[illegible]	6.1310E-2	-3.8889E-4	7.5690E+1	0.0000E+0
HSJP	2	NAT	H	30	140	-3.3081E+1	2.3407E+0	-1.1960E-2	5.5297E-6	7.5376E+1	0.0000E+0
HSJP	2	S1	H	20	80	-3.5643E+1	1.5943E+0	0.0000E+0	0.0000E+0	8.9500E+1	0.0000E+0
HSJP	3	NAT	S	30	120	[illegible]	6.9290E-1	2.1154E-4	-2.4476E-5	3.2127E+1	0.0000E+0
HSJP	3	S1	S	30	80	2.2143E+0	-6.8690E-1	2.9643E-2	-1.6667E-4	5.1643E+1	0.0000E+0
HSJP	3	NAT	H	30	140	-3.5024E+1	1.9319E+0	-9.1721E-3	8.8060E-7	5.8090E+1	0.0000E+0
HSJP	3	S1	H	30	80	3.0524E+1	-2.3053E+0	5.2937E-2	-2.4074E-4	6.1635E+1	0.0000E+0
HSSP	1	NAT	S	30	150	-4.0892E+1	2.4429E+0	-1.2187E-2	1.8959E-5	1.1533E+2	0.0000E+0
HSSP	1	NAT	H	30	140	-1.2488E+2	5.9897E+0	-4.2231E-2	8.1663E-5	1.1003E+2	0.0000E+0
HSSP	2	NAT	S	30	180	-4.0461E+1	2.2393E+0	-1.3284E-2	2.5980E-5	8.3707E+1	0.0000E+0
HSSP	2	NAT	H	30	140	-9.9922E+1	4.6933E+0	-3.2227E-2	5.5802E-5	7.8615E+1	0.0000E+0
HSSP	3	NAT	S	30	180	-4.0513E+1	1.9370E+0	-1.2242E-2	2.5649E-5	6.1088E+1	0.0000E+0
HSSP	3	NAT	H	30	140	-8.4419E+1	3.7086E+0	-2.5457E-2	4.4069E-5	5.6762E+1	0.0000E+0
SHJP	1	NAT	S	30	120	-8.1357E+0	1.2807E+0	1.5423E-2	-1.1323E-4	1.7198E+2	0.0000E+0
SHJP	1	S1	S	30	80	-6.0786E+1	2.8071E+0	0.0000E+0	0.0000E+0	1.6379E+2	0.0000E+0
SHJP	1	S2	S	30	80	-8.8071E+1	2.6960E+0	1.3762E-1	-1.2222E-3	3.8260E+2	0.0000E+0
SHJP	1	NAT	H	30	140	-2.6475E+1	1.8382E+0	-1.0934E-2	9.6089E-6	4.2934E+1	0.0000E+0
SHJP	1	S1	H	30	80	1.5357E+1	-1.8242E+0	7.4167E-2	-3.8889E-4	1.4498E+2	0.0000E+0
SHJP	1	S2	H	30	80	-4.0214E+1	2.1071E+0	0.0000E+0	0.0000E+0	1.2836E+2	0.0000E+0
SHJP	2	NAT	S	30	130	-3.0083E+1	1.6429E+0	3.5431E-3	-5.8411E-5	1.1505E+2	0.0000E+0
SHJP	2	S1	S	20	80	-1.4286E+1	2.3690E-1	4.2500E-2	-3.3333E-4	1.0600E+2	0.0000E+0
SHJP	2	S2	S	20	80	2.1786E+1	-4.2452E+0	1.8571E-1	-1.3333E-3	1.8807E+2	0.0000E+0
SHJP	2	NAT	H	30	140	-3.1095E+1	1.6840E+0	-1.1711E-2	1.9632E-5	2.9004E+1	0.0000E+0
SHJP	2	S1	H	30	80	-3.6429E+0	-4.8492E-1	4.5119E-2	-3.0556E-4	8.9881E+1	0.0000E+0
SHJP	2	S2	H	30	80	-2.7607E+1	1.2750E+0	0.0000E+0	0.0000E+0	7.4393E+1	0.0000E+0
SHJP	3	NAT	S	30	130	-3.9990E+1	1.7423E+0	-3.4557E-3	-2.4476E-5	7.4338E+1	0.0000E+0
SHJP	3	S1	S	30	80	1.6048E+1	-1.3534E+0	4.0516E-2	-2.3148E-4	4.8556E+1	0.0000E+0
SHJP	3	S2	S	30	80	-4.6548E+1	1.2205E+0	1.7103E-2	-1.2963E-4	9.4183E+1	0.0000E+0
SHJP	3	NAT	H	30	140	-3.1154E+1	1.4824E+0	-1.1451E-2	2.4333E-5	1.8712E+1	0.0000E+0
SHJP	3	S1	H	30	80	-4.0276E+1	1.2171E+0	0.0000E+0	0.0000E+0	5.7095E+1	0.0000E+0
SHJP	3	S2	H	30	80	-2.7952E+1	9.1429E-1	0.0000E+0	0.0000E+0	4.5190E+1	0.0000E+0
HSSP	1	NAT	S	30	110	-1.2364E+2	6.4220E+0	-4.5492E-2	8.2576E-5	1.4223E+2	0.0000E+0
HSSP	1	S2	S	30	80	-3.3714E+1	2.6619E+0	-9.0476E-3	0.0000E+0	1.2133E+2	0.0000E+0
HSSP	1	NAT	H	30	140	-3.1184E+1	1.1869E+0	5.1310E-3	-5.9596E-5	7.2025E+1	0.0000E+0
HSSP	1	S2	H	20	80	-2.7964E+1	1.3821E+0	0.0000E+0	0.0000E+0	8.2607E+1	0.0000E+0
HSSP	2	NAT	S	30	110	-9.7934E+1	4.7619E+0	-3.1239E-2	4.1835E-5	1.0714E+2	-3.2439E-2
HSSP	2	S2	S	20	80	-3.6429E+0	3.7698E-2	3.0595E-2	-2.2222E-4	8.1405E+1	0.0000E+0
HSSP	2	NAT	H	30	140	-2.7453E+1	1.0059E+0	2.6395E-3	-4.1401E-5	5.1503E+1	0.0000E+0
HSSP	2	S2	H	20	80	-2.1964E+1	9.5357E-1	0.0000E+0	0.0000E+0	5.4321E+1	0.0000E+0
HSSP	3	NAT	S	30	130	-7.8341E+1	3.6466E+0	-2.9464E-2	7.6832E-5	6.6568E+1	0.0000E+0
HSSP	3	S2	S	20	80	-1.2321E+1	8.0357E-1	0.0000E+0	0.0000E+0	5.1964E+1	0.0000E+0
HSSP	3	NAT	H	30	140	-1.5296E+1	4.6770E-1	4.1638E-3	-3.5897E-5	3.3290E+1	0.0000E+0
HSSP	3	S2	H	30	80	-2.6295E+1	8.1143E-1	0.0000E+0	0.0000E+0	3.8619E+1	0.0000E+0

APPENDIX C: SILVICULTURAL TREATMENTS

This appendix contains a copy of the input file used to define the treatments for the silvicultural options. The format of the file is somewhat cryptic, so it will be explained based on the following example for the intensive softwood management option for the HSSP species association on site class 1.

```
INTSOFT HSSP   1 TREAT1     0 1.00 SITEPREP
INTSOFT HSSP   1 TREAT2     0 1.00 PLANT
INTSOFT HSSP   1 TREAT3     5 1.00 CHEMCLEAN
INTSOFT HSSP   1 TREAT4     6 0.30 FILLIN
INTSOFT HSSP   1 REGLAG     5
INTSOFT HSSP   1 YLDCRV            SWS      MGD
INTSOFT HSSP   1 NSR          0.25
INTSOFT HSSP   1 NSRTREAT1  6 1.00 SITEPREP
INTSOFT HSSP   1 NSRTREAT2  7 1.00 PLANT
INTSOFT HSSP   1 NSRYLDCRV         SWS      MGD
```

Up to four basic treatments are permitted in a silvicultural regime. Two more treatments can be used for not satisfactorily regenerated (NSR) areas. In this example, the first treatment (site preparation) occurs 0 years after harvest on 100% of the harvested area. The second treatment (planting) also occurs 0 years after harvest on 100% of the harvested area. The third treatment (chemical cleaning) occurs 5 years after harvest on 100% of the harvested area, and the fourth treatment (fill-in planting) occurs 6 years after harvest on 30% of the harvested area. There is a regeneration lag of 5 years, and the satisfactorily regenerated area will follow the MGD yield curve for the SWS species association. Twenty-five percent of the area is NSR after these treatments. All of the NSR area is site prepared six years after harvest, and planted seven years after harvest. The area that was NSR will then follow the MGD yield curve for the SWS species association.

Silvcultural Treatment Regimes

```
BASIC  SJP  1 TREAT1     0 1.00 SCARIFY
BASIC  SJP  1 REGLAG     3
BASIC  SJP  1 YLDCRV            SJP     S1
BASIC  SJP  1 NSR          0.00

BASIC  SJP  2 TREAT1     0 1.00 SCARIFY
BASIC  SJP  2 REGLAG     3
BASIC  SJP  2 YLDCRV            SJP     S1
BASIC  SJP  2 NSR          0.10
BASIC  SJP  2 NSRTREAT1  6 1.00 SITEPREP
BASIC  SJP  2 NSRTREAT2  7 1.00 PLANT
BASIC  SJP  2 NSRYLDCRV         SJP     S2

BASIC  SJP  3 TREAT1     0 1.00 SCARIFY
BASIC  SJP  3 REGLAG     3
BASIC  SJP  3 YLDCRV            SJP     S1
BASIC  SJP  3 NSR          0.15
BASIC  SJP  3 NSRTREAT1  6 1.00 SITEPREP
BASIC  SJP  3 NSRTREAT2  7 1.00 PLANT
BASIC  SJP  3 NSRYLDCRV         SJP     S2

BASIC  SBS  1 TREAT1     0 1.00 SCARIFY
BASIC  SBS  1 REGLAG     7
BASIC  SBS  1 YLDCRV            SBS     S1
BASIC  SBS  1 NSR          0.25
BASIC  SBS  1 NSRTREAT1  8 1.00 SITEPREP
BASIC  SBS  1 NSRTREAT2  9 1.00 PLANT
BASIC  SBS  1 NSRYLDCRV         SBS     S2

BASIC  SBS  2 TREAT1     0 1.00 SCARIFY
BASIC  SBS  2 REGLAG     7
BASIC  SBS  2 YLDCRV            SJPBS   S1
```

```
BASIC   SBS     2 NSR              0.10
BASIC   SBS     2 NSRTREAT1    8 1.00 SITEPREP
BASIC   SBS     2 NSRTREAT2    9 1.00 PLANT
BASIC   SBS     2 NSRYLDCRV           SJP       S2

BASIC   SBS     3 TREAT1       0 1.00 SCARIFY
BASIC   SBS     3 REGLAG       7
BASIC   SBS     3 YLDCRV              SBS       S1
BASIC   SBS     3 NSR              0.25
BASIC   SBS     3 NSRTREAT1    8 1.00 SITEPREP
BASIC   SBS     3 NSRTREAT2    9 1.00 PLANT
BASIC   SBS     3 NSRYLDCRV           SBS       S2

BASIC   SJPBS   1 TREAT1       0 1.00 SCARIFY
BASIC   SJPBS   1 REGLAG       3
BASIC   SJPBS   1 YLDCRV              SJP       S1
BASIC   SJPBS   1 NSR              0.00

BASIC   SJPBS   2 TREAT1       0 1.00 SCARIFY
BASIC   SJPBS   2 REGLAG       3
BASIC   SJPBS   2 YLDCRV              SJP       S1
BASIC   SJPBS   2 NSR              0.10
BASIC   SJPBS   2 NSRTREAT1    6 1.00 SITEPREP
BASIC   SJPBS   2 NSRTREAT2    7 1.00 PLANT
BASIC   SJPBS   2 NSRYLDCRV           SJP       S2

BASIC   SJPBS   3 TREAT1       0 1.00 SCARIFY
BASIC   SJPBS   3 REGLAG       3
BASIC   SJPBS   3 YLDCRV              SJPBS     S1
BASIC   SJPBS   3 NSR              0.15
BASIC   SJPBS   3 NSRTREAT1    6 1.00 SITEPREP
BASIC   SJPBS   3 NSRTREAT2    7 1.00 PLANT
BASIC   SJPBS   3 NSRYLDCRV           SJP       S2

BASIC   SWS     1 TREAT1       0 1.00 NOTHING
BASIC   SWS     1 REGLAG       3
BASIC   SWS     1 YLDCRV              HTA       S1
BASIC   SWS     1 NSR              0.15
BASIC   SWS     1 NSRTREAT1    4 1.00 SITEPREP
BASIC   SWS     1 NSRTREAT2    5 1.00 PLANT
BASIC   SWS     1 NSRYLDCRV           SHSP      S2

BASIC   SWS     2 TREAT1       0 1.00 NOTHING
BASIC   SWS     2 REGLAG       3
BASIC   SWS     2 YLDCRV              HTA       S1
BASIC   SWS     2 NSR              0.15
BASIC   SWS     2 NSRTREAT1    4 1.00 SITEPREP
BASIC   SWS     2 NSRTREAT2    5 1.00 PLANT
BASIC   SWS     2 NSRYLDCRV           SHSP      S2

BASIC   SWS     3 TREAT1       0 1.00 NOTHING
BASIC   SWS     3 REGLAG       3
BASIC   SWS     3 YLDCRV              HTA       S1
BASIC   SWS     3 NSR              0.15
BASIC   SWS     3 NSRTREAT1    4 1.00 SITEPREP
BASIC   SWS     3 NSRTREAT2    5 1.00 PLANT
BASIC   SWS     3 NSRYLDCRV           SHJP      S2

BASIC   SHJP    1 TREAT1       0 1.00 SCARIFY
BASIC   SHJP    1 REGLAG       3
BASIC   SHJP    1 YLDCRV              HSJP      S1
BASIC   SHJP    1 NSR              0.00

BASIC   SHJP    2 TREAT1       0 1.00 SCARIFY
BASIC   SHJP    2 REGLAG       3
BASIC   SHJP    2 YLDCRV              HSJP      S1
BASIC   SHJP    2 NSR              0.00

BASIC   SHJP    3 TREAT1       0 1.00 SCARIFY
BASIC   SHJP    3 REGLAG       3
BASIC   SHJP    3 YLDCRV              HSJP      S1
BASIC   SHJP    3 NSR              0.15
BASIC   SHJP    3 NSRTREAT1    6 1.00 SCARIFY
BASIC   SHJP    3 NSRTREAT2    7 1.00 PLANT
BASIC   SHJP    3 NSRYLDCRV           SHJP      S2

BASIC   SHSP    1 TREAT1       0 1.00 NOTHING
BASIC   SHSP    1 REGLAG       3
BASIC   SHSP    1 YLDCRV              HTA       S1
BASIC   SHSP    1 NSR              0.15
BASIC   SHSP    1 NSRTREAT1    6 1.00 SITEPREP
BASIC   SHSP    1 NSRTREAT2    7 1.00 PLANT
BASIC   SHSP    1 NSRYLDCRV           SHSP      S2

BASIC   SHSP    2 TREAT1       0 1.00 NOTHING
BASIC   SHSP    2 REGLAG       3
BASIC   SHSP    2 YLDCRV              HTA       S1
BASIC   SHSP    2 NSR              0.15
BASIC   SHSP    2 NSRTREAT1    6 1.00 SITEPREP
BASIC   SHSP    2 NSRTREAT2    7 1.00 PLANT
BASIC   SHSP    2 NSRYLDCRV           SHSP      S2

BASIC   SHSP    3 TREAT1       0 1.00 NOTHING
BASIC   SHSP    3 REGLAG       3
BASIC   SHSP    3 YLDCRV              HTA       S1
BASIC   SHSP    3 NSR              0.15
BASIC   SHSP    3 NSRTREAT1    6 1.00 SITEPREP
BASIC   SHSP    3 NSRTREAT2    7 1.00 PLANT
BASIC   SHSP    3 NSRYLDCRV           SHJP      S2

BASIC   HSJP    1 TREAT1       0 1.00 NOTHING
BASIC   HSJP    1 REGLAG       1
BASIC   HSJP    1 YLDCRV              HTA       S1
BASIC   HSJP    1 NSR              0.05
BASIC   HSJP    1 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSJP    1 NSRTREAT2    7 1.00 PLANT
BASIC   HSJP    1 NSRYLDCRV           SHJP      S2

BASIC   HSJP    2 TREAT1       0 1.00 NOTHING
BASIC   HSJP    2 REGLAG       1
BASIC   HSJP    2 YLDCRV              HTA       S1
BASIC   HSJP    2 NSR              0.05
BASIC   HSJP    2 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSJP    2 NSRTREAT2    7 1.00 PLANT
BASIC   HSJP    2 NSRYLDCRV           SHJP      S2

BASIC   HSJP    3 TREAT1       0 1.00 NOTHING
BASIC   HSJP    3 REGLAG       1
BASIC   HSJP    3 YLDCRV              HTA       S1
BASIC   HSJP    3 NSR              0.05
BASIC   HSJP    3 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSJP    3 NSRTREAT2    7 1.00 PLANT
BASIC   HSJP    3 NSRYLDCRV           SHJP      S2

BASIC   HSSP    1 TREAT1       0 1.00 NOTHING
BASIC   HSSP    1 REGLAG       1
BASIC   HSSP    1 YLDCRV              HTA       S1
BASIC   HSSP    1 NSR              0.05
BASIC   HSSP    1 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSSP    1 NSRTREAT2    7 1.00 PLANT
BASIC   HSSP    1 NSRYLDCRV           SHSP      S2

BASIC   HSSP    2 TREAT1       0 1.00 NOTHING
BASIC   HSSP    2 REGLAG       1
BASIC   HSSP    2 YLDCRV              HTA       S1
BASIC   HSSP    2 NSR              0.05
BASIC   HSSP    2 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSSP    2 NSRTREAT2    7 1.00 PLANT
BASIC   HSSP    2 NSRYLDCRV           SHSP      S2

BASIC   HSSP    3 TREAT1       0 1.00 NOTHING
BASIC   HSSP    3 REGLAG       1
BASIC   HSSP    3 YLDCRV              HTA       S1
BASIC   HSSP    3 NSR              0.05
BASIC   HSSP    3 NSRTREAT1    6 1.00 SITEPREP
BASIC   HSSP    3 NSRTREAT2    7 1.00 PLANT
BASIC   HSSP    3 NSRYLDCRV           SHSP      S2
```

BASIC	HTA	1	TREAT1	0	1.00	NOTHING	
BASIC	HTA	1	REGLAG	1			
BASIC	HTA	1	YLDCRV			HTA	S1
BASIC	HTA	1	NSR		0.05		
BASIC	HTA	1	NSRTREAT1	6	1.00	SITEPREP	
BASIC	HTA	1	NSRTREAT2	7	1.00	PLANT	
BASIC	HTA	1	NSRYLDCRV			SHSP	S2
BASIC	HTA	2	TREAT1	0	1.00	NOTHING	
BASIC	HTA	2	REGLAG	1			
BASIC	HTA	2	YLDCRV			HTA	S1
BASIC	HTA	2	NSR		0.05		
BASIC	HTA	2	NSRTREAT1	6	1.00	SITEPREP	
BASIC	HTA	2	NSRTREAT2	7	1.00	PLANT	
BASIC	HTA	2	NSRYLDCRV			SHSP	S2
BASIC	HTA	3	TREAT1	0	1.00	NOTHING	
BASIC	HTA	3	REGLAG	1			
BASIC	HTA	3	YLDCRV			HTA	S1
BASIC	HTA	3	NSR		0.05		
BASIC	HTA	3	NSRTREAT1	6	1.00	SITEPREP	
BASIC	HTA	3	NSRTREAT2	7	1.00	PLANT	
BASIC	HTA	3	NSRYLDCRV			SHSP	S2
INTSOFT	SJP	1	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJP	1	TREAT2	13	0.70	THIN	
INTSOFT	SJP	1	TREAT3	7	0.25	FILLIN	
INTSOFT	SJP	1	REGLAG	3			
INTSOFT	SJP	1	YLDCRV			SJP	MGD
INTSOFT	SJP	1	NSR		0.00		
INTSOFT	SJP	2	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJP	2	TREAT2	13	0.70	THIN	
INTSOFT	SJP	2	TREAT3	7	0.25	FILLIN	
INTSOFT	SJP	2	REGLAG	3			
INTSOFT	SJP	2	YLDCRV			SJP	MGD
INTSOFT	SJP	2	NSR		0.10		
INTSOFT	SJP	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SJP	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SJP	2	NSRYLDCRV			SJP	MGD
INTSOFT	SJP	3	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJP	3	TREAT2	13	0.70	THIN	
INTSOFT	SJP	3	TREAT3	7	0.25	FILLIN	
INTSOFT	SJP	3	REGLAG	3			
INTSOFT	SJP	3	YLDCRV			SJP	MGD
INTSOFT	SJP	3	NSR		0.15		
INTSOFT	SJP	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SJP	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SJP	3	NSRYLDCRV			SJP	MGD
INTSOFT	SBS	1	TREAT1	0	1.00	SCARIFY	
INTSOFT	SBS	1	TREAT2	22	0.40	THIN	
INTSOFT	SBS	1	TREAT3	7	0.40	FILLIN	
INTSOFT	SBS	1	REGLAG	7			
INTSOFT	SBS	1	YLDCRV			SBS	MGD
INTSOFT	SBS	1	NSR		0.25		
INTSOFT	SBS	1	NSRTREAT1	8	1.00	SITEPREP	
INTSOFT	SBS	1	NSRTREAT2	9	1.00	PLANT	
INTSOFT	SBS	1	NSRYLDCRV			SBS	MGD
INTSOFT	SBS	2	TREAT1	0	1.00	SCARIFY	
INTSOFT	SBS	2	TREAT2	22	0.50	THIN	
INTSOFT	SBS	2	TREAT3	7	0.25	FILLIN	
INTSOFT	SBS	2	REGLAG	7			
INTSOFT	SBS	2	YLDCRV			SJP	MGD
INTSOFT	SBS	2	NSR		0.10		
INTSOFT	SBS	2	NSRTREAT1	8	1.00	SITEPREP	
INTSOFT	SBS	2	NSRTREAT2	9	1.00	PLANT	
INTSOFT	SBS	2	NSRYLDCRV			SJP	MGD
INTSOFT	SBS	3	TREAT1	0	1.00	SCARIFY	
INTSOFT	SBS	3	TREAT2	22	0.25	THIN	
INTSOFT	SBS	3	TREAT3	7	0.60	FILLIN	
INTSOFT	SBS	3	REGLAG	7			
INTSOFT	SBS	3	YLDCRV			SBS	MGD
INTSOFT	SBS	3	NSR		0.20		
INTSOFT	SBS	3	NSRTREAT1	8	1.00	SITEPREP	
INTSOFT	SBS	3	NSRTREAT2	9	1.00	PLANT	
INTSOFT	SBS	3	NSRYLDCRV			SBS	MGD
INTSOFT	SJPBS	1	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJPBS	1	TREAT2	15	0.60	THIN	
INTSOFT	SJPBS	1	TREAT3	5	0.40	FILLIN	
INTSOFT	SJPBS	1	REGLAG	5			
INTSOFT	SJPBS	1	YLDCRV			SJP	MGD
INTSOFT	SJPBS	1	NSR		0.00		
INTSOFT	SJPBS	2	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJPBS	2	TREAT2	15	0.60	THIN	
INTSOFT	SJPBS	2	TREAT3	5	0.40	FILLIN	
INTSOFT	SJPBS	2	REGLAG	5			
INTSOFT	SJPBS	2	YLDCRV			SJP	MGD
INTSOFT	SJPBS	2	NSR		0.10		
INTSOFT	SJPBS	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SJPBS	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SJPBS	2	NSRYLDCRV			SJP	MGD
INTSOFT	SJPBS	3	TREAT1	0	1.00	SCARIFY	
INTSOFT	SJPBS	3	TREAT2	15	0.40	THIN	
INTSOFT	SJPBS	3	TREAT3	5	0.40	FILLIN	
INTSOFT	SJPBS	3	REGLAG	5			
INTSOFT	SJPBS	3	YLDCRV			SJP	MGD
INTSOFT	SJPBS	3	NSR		0.10		
INTSOFT	SJPBS	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SJPBS	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SJPBS	3	NSRYLDCRV			SBS	MGD
INTSOFT	SWS	1	TREAT1	0	1.00	SITEPREP	
INTSOFT	SWS	1	TREAT2	0	1.00	PLANT	
INTSOFT	SWS	1	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SWS	1	TREAT4	6	0.20	FILLIN	
INTSOFT	SWS	1	REGLAG	5			
INTSOFT	SWS	1	YLDCRV			SWS	MGD
INTSOFT	SWS	1	NSR		0.25		
INTSOFT	SWS	1	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SWS	1	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SWS	1	NSRYLDCRV			SWS	MGD
INTSOFT	SWS	2	TREAT1	0	1.00	SITEPREP	
INTSOFT	SWS	2	TREAT2	0	1.00	PLANT	
INTSOFT	SWS	2	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SWS	2	TREAT4	6	0.20	FILLIN	
INTSOFT	SWS	2	REGLAG	5			
INTSOFT	SWS	2	YLDCRV			SWS	MGD
INTSOFT	SWS	2	NSR		0.25		
INTSOFT	SWS	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SWS	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SWS	2	NSRYLDCRV			SWS	MGD
INTSOFT	SWS	3	TREAT1	0	1.00	SITEPREP	
INTSOFT	SWS	3	TREAT2	0	1.00	PLANT	
INTSOFT	SWS	3	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SWS	3	TREAT4	6	0.20	FILLIN	
INTSOFT	SWS	3	REGLAG	5			
INTSOFT	SWS	3	YLDCRV			SWS	MGD
INTSOFT	SWS	3	NSR		0.25		
INTSOFT	SWS	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SWS	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SWS	3	NSRYLDCRV			SWS	MGD

INTSOFT	SHJP	1	TREAT1	0	1.00	SCARIFY	
INTSOFT	SHJP	1	TREAT2	5	1.00	MECHCLEAN	
INTSOFT	SHJP	1	TREAT3	5	0.40	FILLIN	
INTSOFT	SHJP	1	REGLAG	5			
INTSOFT	SHJP	1	YLDCRV			SJP	MGD
INTSOFT	SHJP	1	NSR		0.00		
INTSOFT	SHJP	2	TREAT1	0	1.00	SCARIFY	
INTSOFT	SHJP	2	TREAT2	5	1.00	MECHCLEAN	
INTSOFT	SHJP	2	TREAT3	5	0.40	FILLIN	
INTSOFT	SHJP	2	REGLAG	5			
INTSOFT	SHJP	2	YLDCRV			SJP	MGD
INTSOFT	SHJP	2	NSR		0.00		
INTSOFT	SHJP	3	TREAT1	0	1.00	SCARIFY	
INTSOFT	SHJP	3	TREAT2	5	1.00	MECHCLEAN	
INTSOFT	SHJP	3	TREAT3	5	0.25	FILLIN	
INTSOFT	SHJP	3	REGLAG	5			
INTSOFT	SHJP	3	YLDCRV			SJP	MGD
INTSOFT	SHJP	3	NSR		0.10		
INTSOFT	SHJP	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SHJP	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SHJP	3	NSRYLDCRV			SJP	MGD
INTSOFT	SHSP	1	TREAT1	0	1.00	SITEPREP	
INTSOFT	SHSP	1	TREAT2	0	1.00	PLANT	
INTSOFT	SHSP	1	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SHSP	1	TREAT4	6	0.20	FILLIN	
INTSOFT	SHSP	1	REGLAG	5			
INTSOFT	SHSP	1	YLDCRV			SWS	MGD
INTSOFT	SHSP	1	NSR		0.25		
INTSOFT	SHSP	1	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SHSP	1	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SHSP	1	NSRYLDCRV			SWS	MGD
INTSOFT	SHSP	2	TREAT1	0	1.00	SITEPREP	
INTSOFT	SHSP	2	TREAT2	0	1.00	PLANT	
INTSOFT	SHSP	2	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SHSP	2	TREAT4	6	0.20	FILLIN	
INTSOFT	SHSP	2	REGLAG	5			
INTSOFT	SHSP	2	YLDCRV			SWS	MGD
INTSOFT	SHSP	2	NSR		0.25		
INTSOFT	SHSP	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SHSP	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SHSP	2	NSRYLDCRV			SWS	MGD
INTSOFT	SHSP	3	TREAT1	0	1.00	SITEPREP	
INTSOFT	SHSP	3	TREAT2	0	1.00	PLANT	
INTSOFT	SHSP	3	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	SHSP	3	TREAT4	6	0.20	FILLIN	
INTSOFT	SHSP	3	REGLAG	5			
INTSOFT	SHSP	3	YLDCRV			SWS	MGD
INTSOFT	SHSP	3	NSR		0.25		
INTSOFT	SHSP	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	SHSP	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	SHSP	3	NSRYLDCRV			SWS	MGD
INTSOFT	HSJP	1	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSJP	1	TREAT2	0	1.00	PLANT	
INTSOFT	HSJP	1	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSJP	1	TREAT4	6	0.30	FILLIN	
INTSOFT	HSJP	1	REGLAG	5			
INTSOFT	HSJP	1	YLDCRV			SJP	MGD
INTSOFT	HSJP	1	NSR		0.25		
INTSOFT	HSJP	1	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSJP	1	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSJP	1	NSRYLDCRV			SJP	MGD
INTSOFT	HSJP	2	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSJP	2	TREAT2	0	1.00	PLANT	
INTSOFT	HSJP	2	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSJP	2	TREAT4	6	0.30	FILLIN	
INTSOFT	HSJP	2	REGLAG	5			
INTSOFT	HSJP	2	YLDCRV			SJP	MGD
INTSOFT	HSJP	2	NSR		0.25		
INTSOFT	HSJP	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSJP	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSJP	2	NSRYLDCRV			SJP	MGD
INTSOFT	HSJP	3	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSJP	3	TREAT2	0	1.00	PLANT	
INTSOFT	HSJP	3	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSJP	3	TREAT4	6	0.30	FILLIN	
INTSOFT	HSJP	3	REGLAG	5			
INTSOFT	HSJP	3	YLDCRV			SJP	MGD
INTSOFT	HSJP	3	NSR		0.25		
INTSOFT	HSJP	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSJP	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSJP	3	NSRYLDCRV			SJP	MGD
INTSOFT	HSSP	1	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSSP	1	TREAT2	0	1.00	PLANT	
INTSOFT	HSSP	1	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSSP	1	TREAT4	6	0.30	FILLIN	
INTSOFT	HSSP	1	REGLAG	5			
INTSOFT	HSSP	1	YLDCRV			SWS	MGD
INTSOFT	HSSP	1	NSR		0.25		
INTSOFT	HSSP	1	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSSP	1	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSSP	1	NSRYLDCRV			SWS	MGD
INTSOFT	HSSP	2	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSSP	2	TREAT2	0	1.00	PLANT	
INTSOFT	HSSP	2	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSSP	2	TREAT4	6	0.30	FILLIN	
INTSOFT	HSSP	2	REGLAG	5			
INTSOFT	HSSP	2	YLDCRV			SWS	MGD
INTSOFT	HSSP	2	NSR		0.25		
INTSOFT	HSSP	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSSP	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSSP	2	NSRYLDCRV			SWS	MGD
INTSOFT	HSSP	3	TREAT1	0	1.00	SITEPREP	
INTSOFT	HSSP	3	TREAT2	0	1.00	PLANT	
INTSOFT	HSSP	3	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HSSP	3	TREAT4	6	0.30	FILLIN	
INTSOFT	HSSP	3	REGLAG	5			
INTSOFT	HSSP	3	YLDCRV			SWS	MGD
INTSOFT	HSSP	3	NSR		0.25		
INTSOFT	HSSP	3	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HSSP	3	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HSSP	3	NSRYLDCRV			SWS	MGD
INTSOFT	HTA	1	TREAT1	0	1.00	SITEPREP	
INTSOFT	HTA	1	TREAT2	0	1.00	PLANT	
INTSOFT	HTA	1	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HTA	1	TREAT4	6	0.30	FILLIN	
INTSOFT	HTA	1	REGLAG	5			
INTSOFT	HTA	1	YLDCRV			SJP	MGD
INTSOFT	HTA	1	NSR		0.25		
INTSOFT	HTA	1	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HTA	1	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HTA	1	NSRYLDCRV			SJP	MGD
INTSOFT	HTA	2	TREAT1	0	1.00	SITEPREP	
INTSOFT	HTA	2	TREAT2	0	1.00	PLANT	
INTSOFT	HTA	2	TREAT3	5	1.00	CHEMCLEAN	
INTSOFT	HTA	2	TREAT4	6	0.30	FILLIN	
INTSOFT	HTA	2	REGLAG	5			
INTSOFT	HTA	2	YLDCRV			SJP	MGD
INTSOFT	HTA	2	NSR		0.25		
INTSOFT	HTA	2	NSRTREAT1	6	1.00	SITEPREP	
INTSOFT	HTA	2	NSRTREAT2	7	1.00	PLANT	
INTSOFT	HTA	2	NSRYLDCRV			SJP	MGD

```
INTSOFT HTA    3 TREAT1      0 1.00 SITEPREP
INTSOFT HTA    3 TREAT2      0 1.00 PLANT
INTSOFT HTA    3 TREAT3      5 1.00 CHEMCLEAN
INTSOFT HTA    3 TREAT4      6 0.30 FILLIN
INTSOFT HTA    3 REGLAG      5
INTSOFT HTA    3 YLDCRV             [illegible]        MGD
INTSOFT HTA    3 NSR           0.25
INTSOFT HTA    3 NSRTREAT1   6 1.00 SITEPREP
INTSOFT HTA    3 NSRTREAT2   7 1.00 PLANT
INTSOFT HTA    3 NSRYLDCRV          SWS        MGD

INTHARD SJP    1 TREAT1      0 1.00 SITEPREP
INTHARD SJP    1 TREAT2      0 1.00 PLANT
INTHARD SJP    1 TREAT3      6 1.00 MECHCLEAN
INTHARD SJP    1 TREAT4      6 0.20 FILLIN
INTHARD SJP    1 REGLAG      5
INTHARD SJP    1 YLDCRV             HTA        MGD
INTHARD SJP    1 NSR           0.25
INTHARD SJP    1 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJP    1 NSRTREAT2   7 1.00 PLANT
INTHARD SJP    1 NSRYLDCRV          HTA        MGD

INTHARD SJP    2 TREAT1      0 1.00 SITEPREP
INTHARD SJP    2 TREAT2      0 1.00 PLANT
INTHARD SJP    2 TREAT3      6 1.00 MECHCLEAN
INTHARD SJP    2 TREAT4      6 0.20 FILLIN
INTHARD SJP    2 REGLAG      5
INTHARD SJP    2 YLDCRV             HTA        MGD
INTHARD SJP    2 NSR           0.25
INTHARD SJP    2 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJP    2 NSRTREAT2   7 1.00 PLANT
INTHARD SJP    2 NSRYLDCRV          HTA        MGD

INTHARD SJP    3 TREAT1      0 1.00 SITEPREP
INTHARD SJP    3 TREAT2      0 1.00 PLANT
INTHARD SJP    3 TREAT3      6 1.00 MECHCLEAN
INTHARD SJP    3 TREAT4      6 0.20 FILLIN
INTHARD SJP    3 REGLAG      5
INTHARD SJP    3 YLDCRV             HTA        MGD
INTHARD SJP    3 NSR           0.25
INTHARD SJP    3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJP    3 NSRTREAT2   7 1.00 PLANT
INTHARD SJP    3 NSRYLDCRV          HTA        MGD

INTHARD SBS    1 TREAT1      0 1.00 SITEPREP
INTHARD SBS    1 TREAT2      0 1.00 PLANT
INTHARD SBS    1 TREAT3      6 0.20 FILLIN
INTHARD SBS    1 REGLAG      5
INTHARD SBS    1 YLDCRV             HTA        MGD
INTHARD SBS    1 NSR           0.25
INTHARD SBS    1 NSRTREAT1   6 1.00 SITEPREP
INTHARD SBS    1 NSRTREAT2   7 1.00 PLANT
INTHARD SBS    1 NSRYLDCRV          HTA        MGD

INTHARD SBS    2 TREAT1      0 1.00 SITEPREP
INTHARD SBS    2 TREAT2      0 1.00 PLANT
INTHARD SBS    2 TREAT3      6 1.00 MECHCLEAN
INTHARD SBS    2 TREAT4      6 0.20 FILLIN
INTHARD SBS    2 REGLAG      5
INTHARD SBS    2 YLDCRV             HTA        MGD
INTHARD SBS    2 NSR           0.25
INTHARD SBS    2 NSRTREAT1   6 1.00 SITEPREP
INTHARD SBS    2 NSRTREAT2   7 1.00 PLANT
INTHARD SBS    2 NSRYLDCRV          HTA        MGD

INTHARD SBS    3 TREAT1      0 1.00 SITEPREP
INTHARD SBS    3 TREAT2      0 1.00 PLANT
INTHARD SBS    3 TREAT3      6 0.20 FILLIN
INTHARD SBS    3 REGLAG      5
INTHARD SBS    3 YLDCRV             HTA        MGD
INTHARD SBS    3 NSR           0.25
INTHARD SBS    3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SBS    3 NSRTREAT2   7 1.00 PLANT
INTHARD SBS    3 NSRYLDCRV          HTA        MGD
```

```
INTHARD SJPBS  1 TREAT1      0 1.00 SITEPREP
INTHARD SJPBS  1 TREAT2      0 1.00 PLANT
INTHARD SJPBS  1 TREAT3      6 1.00 MECHCLEAN
INTHARD SJPBS  1 TREAT4      6 0.20 FILLIN
INTHARD SJPBS  1 REGLAG      5
INTHARD SJPBS  1 YLDCRV             HTA        MGD
INTHARD SJPBS  1 NSR           0.25
INTHARD SJPBS  1 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJPBS  1 NSRTREAT2   7 1.00 PLANT
INTHARD SJPBS  1 NSRYLDCRV          HTA        MGD

INTHARD SJPBS  2 TREAT1      0 1.00 SITEPREP
INTHARD SJPBS  2 TREAT2      0 1.00 PLANT
INTHARD SJPBS  2 TREAT3      6 1.00 MECHCLEAN
INTHARD SJPBS  2 TREAT4      6 0.20 FILLIN
INTHARD SJPBS  2 REGLAG      5
INTHARD SJPBS  2 YLDCRV             HTA        MGD
INTHARD SJPBS  2 NSR           0.25
INTHARD SJPBS  2 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJPBS  2 NSRTREAT2   7 1.00 PLANT
INTHARD SJPBS  2 NSRYLDCRV          HTA        MGD

INTHARD SJPBS  3 TREAT1      0 1.00 SITEPREP
INTHARD SJPBS  3 TREAT2      0 1.00 PLANT
INTHARD SJPBS  3 TREAT3      6 1.00 MECHCLEAN
INTHARD SJPBS  3 TREAT4      6 0.20 FILLIN
INTHARD SJPBS  3 REGLAG      5
INTHARD SJPBS  3 YLDCRV             HTA        MGD
INTHARD SJPBS  3 NSR           0.25
INTHARD SJPBS  3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SJPBS  3 NSRTREAT2   7 1.00 PLANT
INTHARD SJPBS  3 NSRYLDCRV          HTA        MGD

INTHARD SWS    1 TREAT1      0 1.00 SCARIFY
INTHARD SWS    1 TREAT2      0 1.00 THIN
INTHARD SWS    1 REGLAG      5
INTHARD SWS    1 YLDCRV             HTA        MGD
INTHARD SWS    1 NSR           0.15
INTHARD SWS    1 NSRTREAT1   6 1.00 SITEPREP
INTHARD SWS    1 NSRTREAT2   7 1.00 PLANT
INTHARD SWS    1 NSRYLDCRV          HTA        MGD

INTHARD SWS    2 TREAT1      0 1.00 SCARIFY
INTHARD SWS    2 TREAT2      0 1.00 THIN
INTHARD SWS    2 REGLAG      5
INTHARD SWS    2 YLDCRV             HTA        MGD
INTHARD SWS    2 NSR           0.15
INTHARD SWS    2 NSRTREAT1   6 1.00 SITEPREP
INTHARD SWS    2 NSRTREAT2   7 1.00 PLANT
INTHARD SWS    2 NSRYLDCRV          HTA        MGD

INTHARD SWS    3 TREAT1      0 1.00 SCARIFY
INTHARD SWS    3 TREAT2      0 1.00 THIN
INTHARD SWS    3 REGLAG      5
INTHARD SWS    3 YLDCRV             HTA        MGD
INTHARD SWS    3 NSR           0.15
INTHARD SWS    3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SWS    3 NSRTREAT2   7 1.00 PLANT
INTHARD SWS    3 NSRYLDCRV          HTA        MGD

INTHARD SHJP   1 TREAT1      0 1.00 SCARIFY
INTHARD SHJP   1 TREAT2      6 1.00 MECHCLEAN
INTHARD SHJP   1 REGLAG      2
INTHARD SHJP   1 YLDCRV             HTA        MGD
INTHARD SHJP   1 NSR           0.00

INTHARD SHJP   2 TREAT1      0 1.00 SCARIFY
INTHARD SHJP   2 TREAT2      6 1.00 MECHCLEAN
INTHARD SHJP   2 REGLAG      2
INTHARD SHJP   2 YLDCRV             HTA        MGD
INTHARD SHJP   2 NSR           0.00
```

```
INTHARD SHJP   3 TREAT1      0 1.00 SCARIFY
INTHARD SHJP   3 TREAT2      6 1.00 MECHCLEAN
INTHARD SHJP   3 REGLAG      2
INTHARD SHJP   3 YLDCRV             HTA       MGD
INTHARD SHJP   3 NSR           0.15
INTHARD SHJP   3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SHJP   3 NSRTREAT2   7 1.00 PLANT
INTHARD SHJP   3 NSRYLDCRV          HTA       MGD

INTHARD SHSP   1 TREAT1      0 1.00 SCARIFY
INTHARD SHSP   1 TREAT2      6 1.00 MECHCLEAN
INTHARD SHSP   1 REGLAG      2
INTHARD SHSP   1 YLDCRV             HTA       MGD
INTHARD SHSP   1 NSR           0.00

INTHARD SHSP   2 TREAT1      0 1.00 SCARIFY
INTHARD SHSP   2 TREAT2      6 1.00 MECHCLEAN
INTHARD SHSP   2 REGLAG      2
INTHARD SHSP   2 YLDCRV             HTA       MGD
INTHARD SHSP   2 NSR           0.00

INTHARD SHSP   3 TREAT1      0 1.00 SCARIFY
INTHARD SHSP   3 TREAT2      6 1.00 MECHCLEAN
INTHARD SHSP   3 REGLAG      2
INTHARD SHSP   3 YLDCRV             HTA       MGD
INTHARD SHSP   3 NSR           0.15
INTHARD SHSP   3 NSRTREAT1   6 1.00 SITEPREP
INTHARD SHSP   3 NSRTREAT2   7 1.00 PLANT
INTHARD SHSP   3 NSRYLDCRV          HTA       MGD

INTHARD HSJP   1 TREAT1      0 1.00 NOTHING
INTHARD HSJP   1 TREAT2      6 1.00 MECHCLEAN
INTHARD HSJP   1 REGLAG      1
INTHARD HSJP   1 YLDCRV             HTA       MGD
INTHARD HSJP   1 NSR           0.05
INTHARD HSJP   1 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSJP   1 NSRTREAT2   7 1.00 PLANT
INTHARD HSJP   1 NSRYLDCRV          HTA       MGD

INTHARD HSJP   2 TREAT1      0 1.00 NOTHING
INTHARD HSJP   2 TREAT2      6 1.00 MECHCLEAN
INTHARD HSJP   2 REGLAG      1
INTHARD HSJP   2 YLDCRV             HTA       MGD
INTHARD HSJP   2 NSR           0.05
INTHARD HSJP   2 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSJP   2 NSRTREAT2   7 1.00 PLANT
INTHARD HSJP   2 NSRYLDCRV          HTA       MGD

INTHARD HSJP   3 TREAT1      0 1.00 NOTHING
INTHARD HSJP   3 TREAT2      6 1.00 MECHCLEAN
INTHARD HSJP   3 REGLAG      1
INTHARD HSJP   3 YLDCRV             HTA       MGD
INTHARD HSJP   3 NSR           0.05
INTHARD HSJP   3 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSJP   3 NSRTREAT2   7 1.00 PLANT
INTHARD HSJP   3 NSRYLDCRV          HTA       MGD

INTHARD HSSP   1 TREAT1      0 1.00 NOTHING
INTHARD HSSP   1 TREAT2      6 1.00 MECHCLEAN
INTHARD HSSP   1 REGLAG      1
INTHARD HSSP   1 YLDCRV             HTA       MGD
INTHARD HSSP   1 NSR           0.05
INTHARD HSSP   1 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSSP   1 NSRTREAT2   7 1.00 PLANT
INTHARD HSSP   1 NSRYLDCRV          HTA       MGD

INTHARD HSSP   2 TREAT1      0 1.00 NOTHING
INTHARD HSSP   2 TREAT2      6 1.00 MECHCLEAN
INTHARD HSSP   2 REGLAG      1
INTHARD HSSP   2 YLDCRV             HTA       MGD
INTHARD HSSP   2 NSR           0.05
INTHARD HSSP   2 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSSP   2 NSRTREAT2   7 1.00 PLANT
INTHARD HSSP   2 NSRYLDCRV          HTA       MGD

INTHARD HSSP   3 TREAT1      0 1.00 NOTHING
INTHARD HSSP   3 TREAT2      6 1.00 MECHCLEAN
INTHARD HSSP   3 REGLAG      1
INTHARD HSSP   3 YLDCRV             HTA       MGD
INTHARD HSSP   3 NSR           0.05
INTHARD HSSP   3 NSRTREAT1   6 1.00 SITEPREP
INTHARD HSSP   3 NSRTREAT2   7 1.00 PLANT
INTHARD HSSP   3 NSRYLDCRV          HTA       MGD

INTHARD HTA    1 TREAT1      0 1.00 NOTHING
INTHARD HTA    1 TREAT2      6 1.00 THIN
INTHARD HTA    1 REGLAG      1
INTHARD HTA    1 YLDCRV             HTA       MGD
INTHARD HTA    1 NSR           0.05
INTHARD HTA    1 NSRTREAT1   6 1.00 SITEPREP
INTHARD HTA    1 NSRTREAT2   7 1.00 PLANT
INTHARD HTA    1 NSRYLDCRV          HTA       MGD

INTHARD HTA    2 TREAT1      0 1.00 NOTHING
INTHARD HTA    2 TREAT2      6 1.00 THIN
INTHARD HTA    2 REGLAG      1
INTHARD HTA    2 YLDCRV             HTA       MGD
INTHARD HTA    2 NSR           0.05
INTHARD HTA    2 NSRTREAT1   6 1.00 SITEPREP
INTHARD HTA    2 NSRTREAT2   7 1.00 PLANT
INTHARD HTA    2 NSRYLDCRV          HTA       MGD

INTHARD HTA    3 TREAT1      0 1.00 NOTHING
INTHARD HTA    3 TREAT2      6 1.00 THIN
INTHARD HTA    3 REGLAG      1
INTHARD HTA    3 YLDCRV             HTA       MGD
INTHARD HTA    3 NSR           0.05
INTHARD HTA    3 NSRTREAT1   6 1.00 SITEPREP
INTHARD HTA    3 NSRTREAT2   7 1.00 PLANT
INTHARD HTA    3 NSRYLDCRV          HTA       MGD
```

APPENDIX D: PROGRAM OPERATION

This model requires the operator to make decisions as to which of several road building projects should be undertaken in a period. The operator is presented with information to help make the decision. The process of deciding the best road option is illustrated here with an example. The example is for period 3 of run F2A. Figure D.1 is the summary screen presented by the model after all the road options for period 3 have been examined. After each road option, a similar table for the current road option and all the preceding road options is presented.

A map for each road option is projected on the computer monitor. The map for the first road option of the third period is presented in plate D.1. Existing roads are represented by white lines, proposed roads are represented by green lines, and the roads selected by the operator to be built for this road option are represented by dark blue lines. Each of the coloured squares in the map represents a 10 by 10 km inventory map sheet. These map sheets are colour coded by the opportunity cost that could potentially be avoided by developing access to the map sheet. The map sheets coloured bright red are the most profitable to develop access to, dark red the next, blue the next, and light grey the next. The dark grey map sheets are either currently accessed, or will not allow for any further reduction in opportunity cost if accessed this period.

The 12 km of new road examined for the first road option will allow access to the two bright red "hot spots" in unit 9. By constructing this road with interest costs of $244,750, the model is able to avoid $430,943 of opportunity cost in this period for a net benefit of $186,193.

Road option 2 considers the effect of building the roads shown in plate D.2. This option accesses the same area accessed in option 1 and also much of the currently inaccessible area in unit 8. This road option costs $1,054,746 in interest costs and results in the avoidance of $1,798,217 of opportunity costs for a net benefit of $743,471.

Road option 3 adds another 10 km of road to that built in road option 2 accessing unit 8 completely and some of unit 13. The roads built are shown in plate D.3. The interest costs of the option are $1,252,395 and the opportunity cost reduction is $2,149,735. The net benefit is $897,340.

Road options 4 (Plate D.4) and 5 (Plate D.5) consider the building of additional road to option 3. Option 4 completely accesses unit 9 and option 5 accesses some of unit 23. In both cases the net benefit of these road options is less than that of option 3. Because it has the highest net benefit of the road options considered, option 3 is selected as the best road option for this period.

Summary of road options for period 3. 2000-2005.
Softwood Request: 8781475 Hardwood Request: 6446330

Opt	OCReduct	SoftHarv	HardHarv	RoadBilt	RoadCost	OCDiffer	NetBenef
0	161189793	9991280	5236525	0	0	0	0
1	161620736	10135110	5092695	12	244750	430943	186193
2	162988010	10353518	4874287	54	1054746	1798217	743471
3	163339528	10360581	4867224	64	1252395	2149735	897340
4	163477190	10312554	4915251	75	1464960	2287397	822438
5	163507790	10224930	5002875	76	1488497	2317997	829500

What do you want to do now?
E)xamine another road option for this period.
S)elect the best road option and start the next period.
A)utomate future periods after selecting best road option.
Q)uit after selecting best road option for this period.
Best Road Option? 3_

Figure D.1. End of period summary screen for period 3 of run F2A.

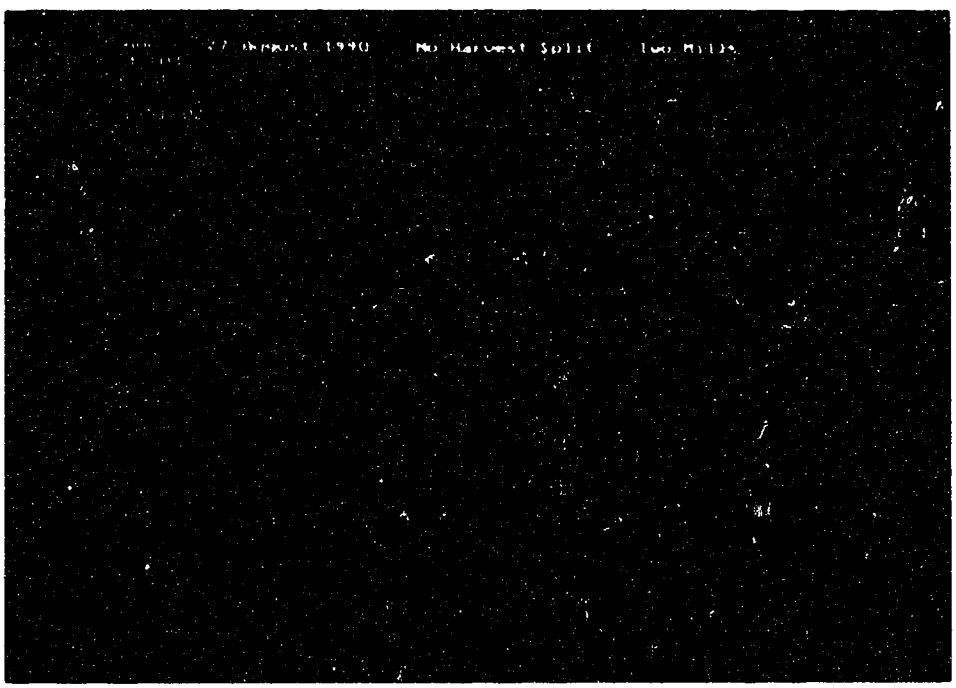

Plate D.1. Screen display of roading option 1 for period 3 of run F2A.

Plate D.2. Screen display of roading option 2 for period 3 of run F2A.

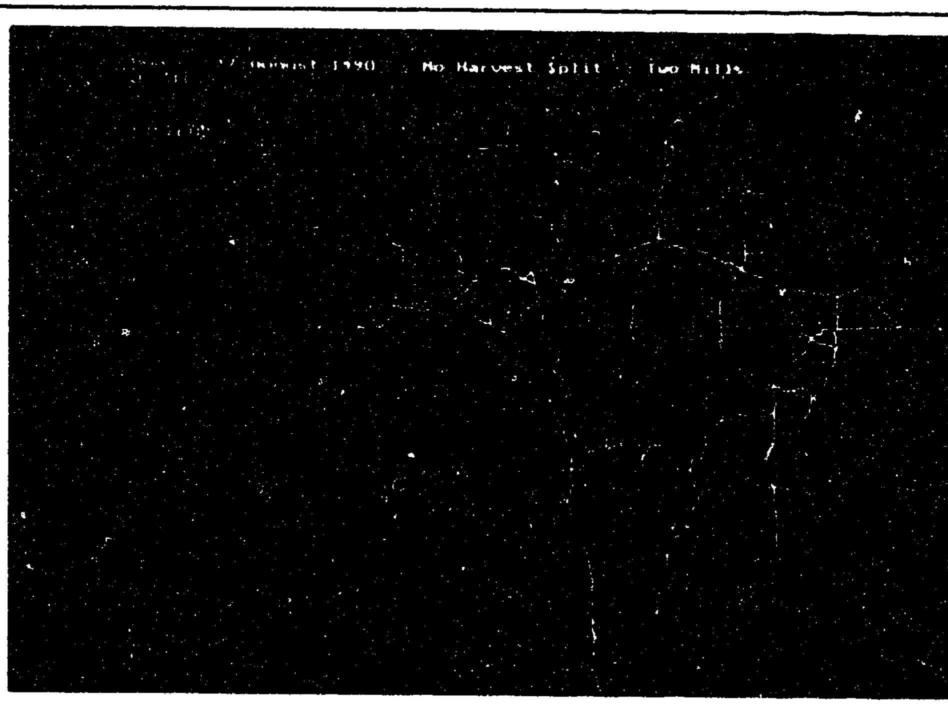

Plate D.3. Screen display of roading option 3 for period 3 of run F2A.

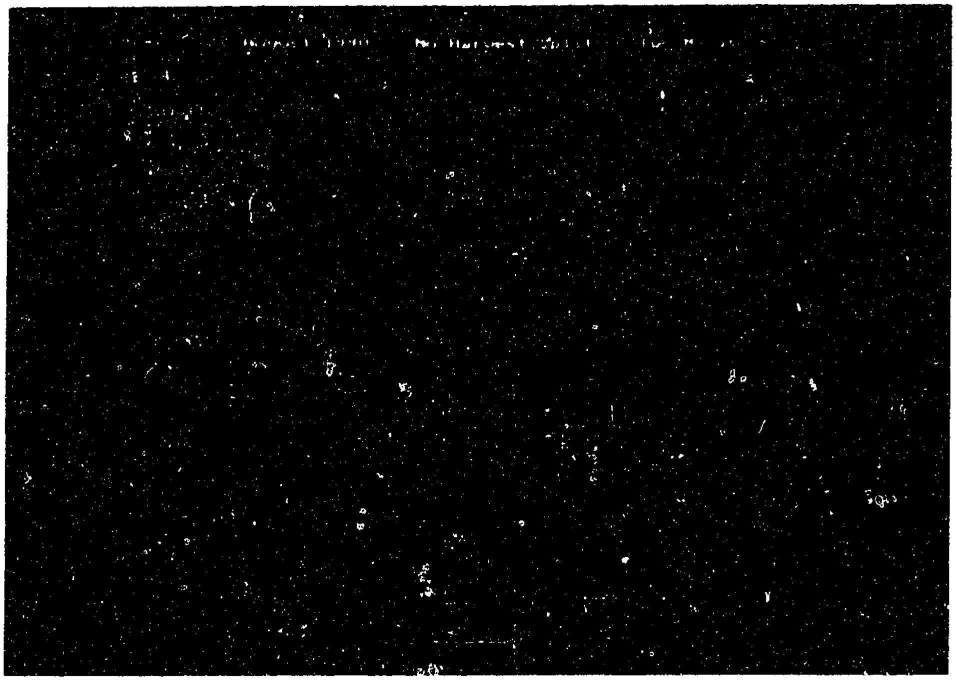

Plate D.4. Screen display of roading option 4 for period 3 of run F2A.

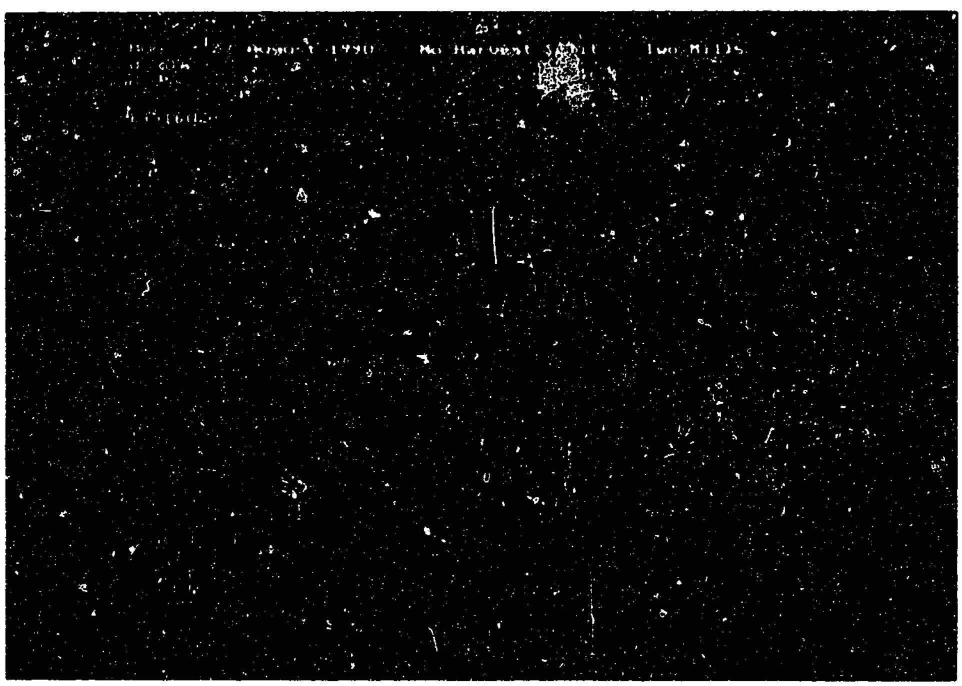

Plate D.5. Screen display of roading option 5 for period 3 of run F2A.