# Comparison of Harvest Scheduling Approaches: Using Woodstock vs. Traditional (Back of the Envelope) Harvest Planning Methods

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 8, 2016

Keywords: Harvest Scheduling, Woodstock, Stanley, GIS, Clear-cut, Thinning



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Abstract

Understanding and managing agricultural or forestry resources can be very difficult for numerous reasons. Methods used to harvest timber vary, and can affect the NPV of a stand. In this study, we compare two approaches: (1) traditional harvest planning (back of the envelope) which includes harvest scheduling that is done by hand (Bettinger et al., 2010). In this approach, final harvest time is determined based on the highest net present value (NPV), and (2) Woodstock and Stanly (Remsoft inc.) harvest scheduling software. Woodstock generates LP matrices using a generalized Model II formulation and produces optimal solutions for the long-term. Using the harvest schedule from Woodstock, Stanley allocates forest stands to harvest blocks according to adjacency, maximum opening size, and harvest flow constraints. The initial study area for this research is the Mary Olive Thomas Demonstration Forest, which is located five miles southeast of Auburn University, with access from Lee County Highway 146. The hypothesis, tested in this study, is that the Woodstock and Stanley approach will improve the profitability and sustainability of the forested area as compared to previous harvest scheduling approaches. Both Woodstock and Stanley are harvest scheduling software; however, they differ in several respects, which will be explained in this study. The main objective of this study is to compare the Woodstock approach and the traditional (back of the envelope) harvest planning methods in terms of economic and ecological benefits. To meet our objective, we will try to answer the following questions;

- How will the Woodstock approach affect the forest's economic and ecological benefits?
- How well does the Woodstock and Stanley approach perform relative to the Traditional Harvest Planning Method?
- What are the pros and cons of using the Woodstock approaches?

# Acknowledgements

I would like to thank Dr. Larry Teeter for serving as my major professor and for his instruction, guidance and commitment. I also would like to thank Dr. Becky Barlow and Dr. Yaoqi Zhang for participating in my thesis examining committee.

Thanks to the Turkish Government for providing me the opportunity and funding to study at Auburn University. Thanks to the technical support of Auburn University, School of Forestry and Wildlife Science.

I would like to thank to my family and my friends who encouraged me during my research.

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# Chapter 1

# Introduction

## 1.1 Background

Understanding and managing systems based on agricultural or forestry resources is very difficult for numerous reasons. First of all, we need to study the sustainability of the underlying natural system. For forestry resources, sustainability involves imposing constraints on the model to guarantee that the harvest rate of the resource does not surpass its natural regenerative capacity and that we sustain the economic rate of growth. Also, we need to take into account the underlying difficulty of the growth and harvesting processes. What's more, the relationship between production processes and general environmental, economic and, at times, social issues need to be taken care of. The complexity is challenging, contributing opportunities to use operational research (OR) methods, principally as globalized economies increase organizations' needs for capability (Weintraub and Romero, 2006).

Operational research (OR) can be considered long term or short term based on planning approaches and the landowner's objectives. Forest planning problems can exist for forests of 20 to 40 acres in size to huge forests of more than a million acres. Also, forest management activities can be planned for a single year to horizon of 150 to 200 years, which includes decision makers at high managerial levels and on the ground;

and include concerns over biodiversity, species preservation, sustainability, and ecosystem management (Weintraub and Bare, 1996). Planning on the small or large scale can be seen as a hierarchy (Bettinger, 2009) of management decisions. Hierarchical, which is one approach to forest planning, is dependent on  including many constraints at the strategic level and adding other constraints at the tactical level both at spatial and temporal scales ( Baskent and Keles, 2005; Session and Bettinger, 2004). Forest planning is the identification of activities and timing of those activities to reach the land owner's objectives (Sessions and Bettinger, 2004). Bettinger and Boston (2009) described three levels of hierarchy; strategic, tactical, and operational.

Several studies have shown that mathematical programming is very applicable to harvest scheduling in forestry. Mathematical programming can be defined as a set of management science methods used to optimize an objective in light of constraints (Bettinger et al. 2011; Field, 1973). Mathematical programming is used to solve many types of certain management science problems. Mathematical programming models differ from simple to complex (Dykstra, 1984). Forestry organizations have used many mathematical programming techniques in their efforts for fifty years to contribute decision-making processes related to forest management activities. Many authors have provided examples of these techniques in their articles (Bettinger and Chung, 2004; Weintraub and Bare, 1996).

Linear Programming (LP), which is commonly used in forestry, is one of the mathematical programming techniques (Bettinger et al., 2010). Natural resource management plans take notice of sustainability of resources. Ecologic value or constraints such as stands in the streamside management zone can be modeled using

LP. Linear programming is used to solve these sustainable forest management problems. Because of the fact that natural resources are used efficiently, and computerizing mathematical programming is growing, linear programming has played a large part natural resource planning (Bettinger et al., 2010; Weintraub and Romero, 2006).

Traditional harvest planning (back of the envelope) includes harvest scheduling that is done by hand (Bettinger and Boston, 2009). In this approach, final harvest time is determined based on highest net present value (NPV). Many studies have indicated that spatial relationships are ignored in this approach.

Since about 1990, Remsoft has been conducting original research and development of two forest management tools, Woodstock and Stanley, as an integrated spatial forest management system (Congswell, 1997). Woodstock generates LP matrices using a generalized Model II formulation and produces optimal solutions for the long-term, strategic portion of the harvest scheduling problem (Walters, 1999). Using the harvest schedule from Woodstock, Stanley allocates forest stands to harvest blocks according to adjacency, maximum opening size, and harvest flow constraints.

The initial study area for this research is the Mary Olive Thomas Demonstration Forest, which is located just five miles southeast of the Auburn University main campus with access from Lee County Highway 146. The hypothesis, which will be tested in this study is that “Woodstock and Stanley are applicable and make the forested area profitable, and sustainable comparing to previous harvest scheduling approaches”. Both Woodstock and Stanley are harvest scheduling software; however, they differ in several respects. Their common and different goals will be explained in this study. The main objective of this study is to compare Woodstock and the traditional (back of the envelope) harvest planning methods in terms of economic and ecological benefits. To meet our objective, we will try to answer the following questions;

- How will Woodstock affect forest's economic and ecological benefits?
- How well do Woodstock and Stanley perform relative to the Traditional Harvest Planning Method?
- What are the weakness and strengths of using Woodstock?

### 1.2 Rationale

Forest ecosystems are primary sources of values such as timber, fuel wood, fodder, water protection, soil conservation, and habitat for wildlife species. A desired flow of these values are affected by forest ecosystem characteristics. Ecosystem characteristics are changed by interventions which are determined in the forest management plans (Baskent et al., 2010). Although forest management plans are mainly about harvest scheduling, harvest scheduling affects the forest in both economic and ecological ways. Optimization or simulation techniques are helpful in solving harvest scheduling problems. They can yield workable and efficient solutions (Nelson and Brodie, 1991).

Our main goal and research question (mentioned above) are important. Each research question's justification is basically defined.

**Research Question 1: How will Woodstock affect forest's economic and ecological benefits?**

Forest management plans have considered just traditional timber production in the past. They have extended their scope of the management system to include complex and sustainable production of multiple values such as soil conservation and non-timber forest products (Baskent and Jordan, 1995). Binary search and linear programing have become the most common management science methods adapted for harvest scheduling once computer use became widespread (Session et al., 2000). Woodstock is a combination of binary search, linear programing, and Monte Carlo simulation (Walter, 1996). Stanly is a tactical plan which acquires a Woodstock solution in order to allocate the area treated and products produced to specific ground units (Bettinger et al., 2010). Many studies have shown that the main goal of new harvest scheduling approaches is to contribute to the management conservation and sustainable development of forests and to provide for their multiple and complementary functions and uses. This goal is not only about economic values such as getting the highest harvest volume or value or increasing the total inventory of a stand by applying the best management actions, but it is also it is related to ecological values, for example, water protection. In this study, we want to track how well Woodstock and Stanley does this job.

**Research Question 2: How well do Woodstock and Stanley perform relative to the Traditional Harvest Planning Method?**

In this study, we collected the data to schedule harvests. We first had to estimate volume for each stand using basal area, average DBH, tree counts and age by using PTAEDA and PCWthin software. Then, we simulated volume growth for 20 years which is the planning horizon for the plan. Scheduling harvests using the traditional method was complex in many ways. In this study, we want to see how well we take advantage software advances to address these difficulties using Woodstock and Stanley.

**Research Question 3: What are the weakness and strengths of using Woodstock and Stanley?**

There is a huge range of variation in forest management planning models. We see the most comprehensive models especially in the USA. For instance, TimberRAM (Navon, 1971) and FORPLAN (Johnson and Jones, 1980) are the most common (Keles and Baskent, 2011). These models are very good models but they are not applicable for some countries or some areas. Also, many companies prefer one of them or they have developed proprietary models for their specific models. That shows that many models have weaknesses behind their advantages. In this study, we will test for weaknesses and strengths using Woodstock and Stanley

# Chapter 2

# Literature Review

## 2.1 Operational Research Model and the Management of Forestry

Understanding and managing systems based on agricultural or forestry resources is very difficult for numerous reasons. First of all, we need to study the sustainability of the underlying natural system. For forestry resources, sustainability involves imposing constraints on the model to guarantee that the harvest rate of the resource does not surpass its natural regenerative capacity and that we sustain the economic rate of growth. Also, we need to take into account the underlying difficulty of the growth and harvesting processes. What's more, the relationship between production processes and general environmental, economic and, at times, social issues need to be taken care of. This complexity is challenging, requiring us to use operations research (OR) methods, principally as globalized economies increase organizations' needs for capability (Weintraub and Romero, 2006).

Presently, forest managers put to use operational research (OR) in their pursuance of drawing out the potential maximization of the forest within a context of accomplishing and surviving natural ecosystem (Weintraub and Bare, 1996). This goal is a multifaceted undertaking because its success is dependent on decisions made at several different levels of spatio-temporal detail. OR, the application of mathematics to decision making problems, compliments these decisions by providing a set of tools that can be used to help forest managers evaluate significantly more of the uncountable factors that contribute to forest policy. For example, Linear programming (LP), which is a technique that can be applied to long-term forestry decisions, allows forest managers to examine the interactions between millions of variables and constraints. To achieve management objectives like getting the highest harvest volume each period, the application of LP and other OR techniques become a modern improvement in forest managers' history of utilizing quantitative methods (Martin, 2013). Plochmann (1989) indicates that forest managers have managed forests since the early nineteenth-century work on Hundeshagen's Forest Rent Theory. Optimal rotation timings for stand harvesting were determined by Faustmann in the mid-nineteenth century (Faustmann, 1849). Faustmann's computational method, which determines age to get the maximum value of a stand, gives a solution in a sustainable harvesting regime over uncountable time horizon (Gunn, 2007). George B. Dantzig discovered the Simplex method in 1963. This discovery supported operational research to professionally find solutions in using Linear Programing (LP) (Martin, 2013). Development of quantitative forest management has been contributed by the Simplex method, an improvement on LP because forest management decisions had to model within an LP framework (Curtis, 1962) enabling the modeling of decisions earlier assumed to be computationally intractable (Martin, 2013).

Many such models are there, the most extensively recognized of which are developed by the United States Department of Agriculture (USDA) Forest Service (Martel et al., 1998). The Timber Resources Allocation Method (Timber RAM) is a computerized method, developed by Navon (1971), for developing long-range forest management plans. Timber RAM calculates a schedule that meets a specific objective. Also, it can develop long-range plans for both private and public forests (Navon, 1971). Timber RAM, however, ignores road constructions and other spatial concerns.  MAX MILLION was developed by Clutter at al. (1968) at the same time (Martel et al., 1998). Besides, the LP model, other OP techniques- for instance, simulation (Robak and Richards, 2001; Baskent and Keles, 2005) - have been put in use to contribute forest management decisions (Martin, 2013).

## 2.2 Hierarchical Planning

Forest planning problems occurs in 20 to 40 acres to entire forests as large as 2,000,000 acres. Also, forests can be planned during one year to the horizon of 150 to 200 years, which includes decision made at high managerial levels and on the ground. This must include concerns over biodiversity, species preservation, sustainability, and ecosystem management. There are also road construction, transportation, and marketing requirements making the plan more complex (Weintraub and Bare, 1996). Planning over small or large scale can be seen as a hierarchy (Bettinger et al., 2010). Hierarchical, which is one approach to forest planning, is dependent on including many constraints at the strategic level and adding another constraint at the tactical level of both spatial and temporal scales ( Baskent and Keles, 2005; Session and Bettinger, 2004). Forest planning is the identification of activities and timing of those activities to reach the land owner’s objectives. Connelly (1996) has defined hierarchical analysis for forest planning as “the organization of information for making decisions at different levels when the quality of the decisions at one level is dependent upon decisions or information at other levels. Levels may be defined temporally or spatially, where the scope of the higher level fully encompasses the scope of the higher level" (Sessions and Bettinger, 2004).

There are three levels of planning hierarchy; strategic, tactical and operational (Weintraub and Bare, 1996). The strategic planning process is the highest level in the hierarchy. It focuses on the long-term achievement of management goals. Some objectives such as the development of wildlife habitat or the production of timber harvest volume are modeled over long time frames and large areas and are general in nature. In strategic planning, spatial aspects such as adjacency of stands are not considered (Bettinger et al., 2010). Strategic planning determines the result of strategic decisions affecting all the forested area in the plan and / or limit how certain lands can be carried up in the plan. With strategic planning, planners focus on how harvest levels answer to some sustainable forest management  initiatives, for example, creating various types of reserve areas and special management zones to deal with the necessities to manage for biodiversity, water quality and wildlife habitat (Gunn, 2010). Baskent and Keles (2005) mention that "the main decisions at this level concern land allocation and aggregate targets for inputs and outputs over the long planning horizon for a large area of land. Therefore, various interest groups or stakeholders can express their opinion for the management of forest ecosystem at the landscape level to activate participation." Linear programing (LP) uses prime areas of application for strategic analysis (Gunn, 2010). Strategic planning schedules activities that maximize the Net Present Value (NPV) of the forest while at the same time maintaining sustainable forest values (Martin, 2013; Gunn, 2010).

At lower levels of planning hierarchy than the strategic plan, spatial relationship is known. In tactical planning, a locational relationship between timber stands and harvest time is recognized (Bettinger et al., 2010). The tactical level considers stands as the spatial resolution in less than 50 years (Martin, 2013; Richard and Gunn, 2000). There are many various approaches have been applied to modeling tactical level decisions (Martin, 2013): Heuristic (Richards and Gunn, 2000; Weintraub et al., 1994), Simulation (Gustafson et al., 2006; Covington et al., 1988), and Integer Programing (Contantino et al., 2008). In tactical level models, some spatial constraints such as maximum opening size and minimum clear cut area are allocated (Martin 2013; Weintraub and Bare, 1996). The tactical level model recognizes actions occurring in the planning area at the specific time to reach the objectives of the plan. On the other hand, action implementations are not enough (Bettinger et al., 2010).

The spatial and temporal resolution goes up from strategic to tactical and similarly from tactical to operational levels (Martin, 2013). Operational planning is the lowest level in the hierarchy. A management action is implemented day-to-day, weekly, monthly, or annually in the plan (Bettinger et al., 2010). Operational level is used to determine land use for the forested area in the plan. Management actions include short-term activities such as harvesting, production, hauling, planting, pest control, fire management, and road construction and maintenance (Baskent and Keles, 2005; Murray and Church, 1995a; Church et al., 1998). Tactical plans guide operational plans, and strategic plans guide tactical plans (Bettinger et al., 2010).

## 2.3 Mathematical Programming and Advanced Planning Techniques in Forestry

Mathematical programming can be defined as a set of methods used in science to optimize an objective in light of constraints (Bettinger et al., 2010; Field, 1973). Mathematical programming is used to solve many types of certain management science problems. Mathematical programing models differ from simple to complex (Dykstra, 1984). Forestry organizations have mostly used many mathematical programming techniques in their efforts for fifty years in order to contribute decision-making processes related to forest management activities. Many authors have examined and given examples of these techniques in their articles (Bettinger and Chung, 2004; Weintraub and Bare, 1996).

### 2.3.1 Linear Programming

Curtis (1962) has described linear programming as "a technique for specifying how to use limited resources or capacities of a business to obtain a particular objective such as least cost, highest margin or least time, when those resources have alternative uses. It is a technique that systematizes for certain conditions the process of selecting the most desirable course of action from others, thereby giving management information for making a more effective decision about the under its control." An optimization technique is used to optimize an objective and linear programming is the most common example of this technique. Linear programming was designed in order to be mainly used for the solution of managerial problems (Buongiorno and Gilless, 2003). Natural resource management plans take notice of sustainability of resources. These plans add constraints about natural resources to make sure that they are considered. Mathematical programing, specifically, linear programming, is used to solve these sustainable forest management problems. Because of the fact that natural resources are used efficiently, and computerizing in mathematical programing is growing, linear programming has been adopted for natural resource planning (Bettinger et al., 2010; Weintraub and Romero, 2006).

A linear programming model for harvest scheduling or another scientific problem includes one objective function, at least one constraint, and probably some accounting rows (Bettinger et al., 2010). Linear programming is very flexible because when an objective is maximized or minimized, many constraints related to the objective are incorporated. For instance, when maximum harvest value is desired, water production and soil conservation are considered to protect nature (Nelson et all, 1991).

### 2.3.2 Binary Search

Binary search is used in forestry. It is a method attempting to find gradually better solution each time. In this case, the binary search finds the optimal value of objective function. For instance, a landowner may want to get highest harvest volume in the light of constraints. We would use binary search. Binary search guesses the harvest volume. Harvest volume can be increased or decreased. When it starts to go down, highest harvest volume is previous step (Bettinger et al., 2010).

Binary search is one of the methods that Woodstock uses to schedule harvesting (Walters, 1993). Outputs can be very different such as expected harvest volume or expected harvest area. One of the output limits can be specified as a binary search citation to determine optimal solution by Woodstock user. In binary search, the citation can be increased or decreased on a run success. Binary search is available to use both area control method and volume control method. In addition, binary search is an optional step for a Woodstock user that the user can turn off and on as needed (Walter, 1993).

### 2.3.3 Monte Carlo Simulation

Monte Carlo simulation contains many sample techniques, and is often used to develop a natural management plan. This technique was named about 65 years ago in Monaco, many fields such as physics, chemistry, and finance have used this technique. Monte Carlo simulation model optimizes an objective (maximize harvest volume, for instance) so the objective function must be determined before we use the technique (Bettinger et al., 2010). Monte Carlo simulation's main idea is to find better choices. This technique randomly selects the best choices from the feasible solution set. In harvest scheduling, this algorithm randomly selects a planning unit such as a stand and assign a treatment type such as clear cut (Li, 2007).

A Woodstock user might want to examine the effects of random variation in the silvicultural application such as thinning or to probabilistic consequences in the yield reply or regeneration. In this problem, Woodstock practices a Monte Carlo simulation to random actions (Walter, 1993).

### 2.3.4 Model One, Model Two and Model Three

There are three classes of the method for defining decision variables in a linear programming; Model One, Model Two, and Model Three (Bettinger et al., 2010). Model one and Model two are the most common models in the science (Martell et al., 1998). In Model One, new generations are attached directly to and recognized by the existing stands to which they are related. In contrast, Model Two separates regenerated stands, after final harvesting, from existing stands that die or harvested completely. Model Two defines a new type of stand in terms of timing and prescription options (Davis et al., 2001).

Remsoft's Woodstock (Cogswell and Feunkes, 1997) is a popular commercial Model Two system. Also, Forplan version II uses Model Two modeling techniques (Martin, 2013; Kent et al., 1991). In the Woodstock model, a theme, for instance, forest type can be transformed to a new theme. For example, a 100 acre Loblolly pine stand can be converted to hardwood or a combination of different forest type with certain assigned respectively after final harvest. Model Two only tracks the stand until final harvest occurs or death of the stands so that we need the define decision variables for a new generation (Davis et al., 2001).

Model Three is not a frequently used method. Model Three aggregates stands that are in same age period from the first year of planning period (Bettinger et al., 2010). Like Model Two, the decision variables in each period are harvested or reach the lifespan so the new regeneration is described or it is allowed to mature for another period in Model Three. The difference is related to initial stand aggregation and tracking of forest state (Martin, 2013; Boychuk and Martell, 1996). The models, FOLPI (Garcia, 1984), and Silvi Plan (Davis and Martell, 1993), are examples using Method Three linear programming methods (Martin, 2013)

## Chapter 3

## Method

### 3.1 Study Area

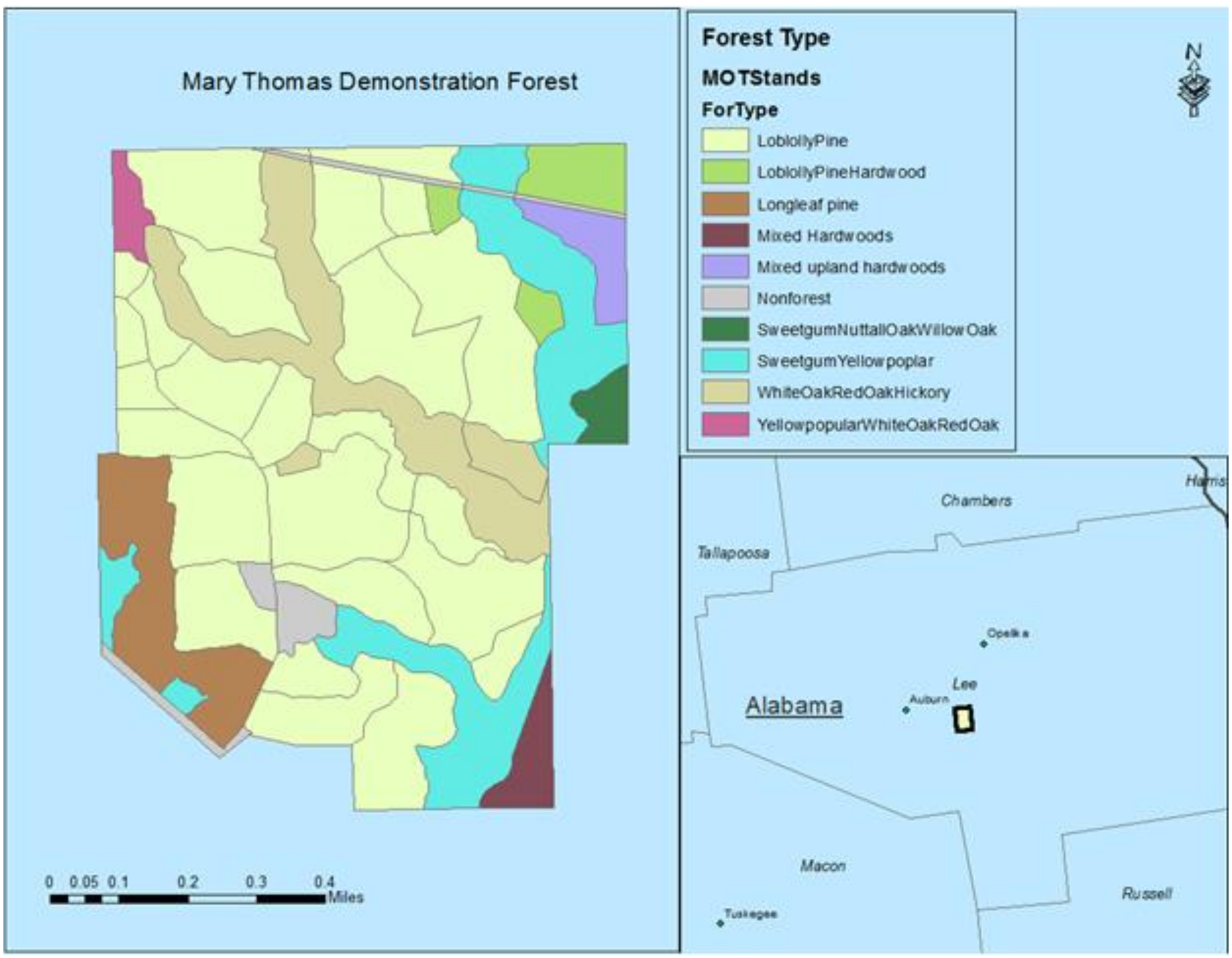


Figure 3.1: Study area; Mary Olive Thomas Demonstration Forest

The initial study area for this research is the Mary Olive Thomas Demonstration Forest, which is located just five miles southeast of the Auburn University main campus with access from Lee County Highway 146 (Figure 3.1).

In the study area, the plan is to manage only loblolly pine (*Pinus taeda*). This species is the main species on the MOT. Other species could also be included in the management plan but their growth is difficult to simulate over the time (research and software limitation). The hardwood stands on the MOT are old and many are near or in the streamside management zone (SMZ) which limits opportunities for harvesting. Twenty-nine loblolly pine stands occupy approximately 240 acre on the MOT.

Loblolly pine accounts for approximately 60% percent of the forest's area (see Table 3.1). In forest management, each species is managed separately because each species has different rotation ages, and growth and yield attribute. The study area is not big but loblolly pine stands differ in site quality, volume, and so on. These parameters make the planning complex.

Table 3.1: Forest type and their total area (acres)

| Forest Type | Area (Acre) |
|---|---|
| Loblolly Pine | 240.44 |
| Other Species | 148.51 |
| Non Forest | 11.04 |

## 3.2 Optimal Rotation Age for Loblolly Pine

In this study, we firstly aimed to find an optimal rotation age for loblolly pine. The definition of rotation age is “A rotation of trees is the number of the years between the establishment of the stand and the final harvest” (Bettinger et al., 2010).From the definition we can understand that optimizing rotation age is to find the best final harvest age to reach the goal. Williams (1988) categorized optimal rotation age according to seven criteria for even-aged stands in 1988.

1. The physical rotation age, or the lifespan of a species of tree. If there are no activities like harvesting the species dies at this age.
2. The technical rotation age or management of stand time to reach desired dimensions by commercial markets.
3. Silvicultural rotation age or getting maximum seed from trees to facilitate new regeneration.
4. The rotation age to get maximum harvest volume. Beyond this age, the inventory starts to decrease.
5. The income generation rotation age, this is used to get maximum income
6. The rotation age maximizing the discounted net revenue. This rotation age provides highest net present value.
7. The value growth rate rotation age. The curve describing the value rate begins to decrease at the final harvest age in this rotation age.

Catastrophic events such as fire, insects or flooding may change the character of a stand in future. These are uncertain events so determining the length of the rotation age has some risks (Bettinger et al., 2009). The seven groups of the rotation age are the subject of when the main goal is unknown.

Bettinger (2010) defined the NPV as “The net present value (NPV) of an investment is the difference between the present value of revenues and the present value of costs over some period of time”. We calculated NPV to find land expectation value (LEV). NPV was calculated according to following formula.

$$NPV = \sum_{t=1}^{T} \frac{(Benefits - cost)_t}{(1+r)^t}$$

Where:

r= discount rate

t= year

Future revenues coming from harvesting, costs such as fertilization and establishment were discounted to now. In this way, their present value is calculated. The Land Expectation Value, introduced by Faustmann (1849), is extensively used to determine the optimal management of even-aged stands. To determine optimal rotation age of a tree in a certain area, Hartman (1976) extended the LEV model. According to the extended model, optimal rotation age is to maximize both timber and amenity values (Nepal et al., 2012). In forestry science, NPV is calculated to find land expectation value (LEV). NPV is not basically taken to determine the optimal rotation age because higher NPV sometimes does not mean a better solution. LEV is the best way to determine optimal rotation age because LEV is calculated based on NPV and management planning horizon. LEV is a typical discounted cash flow (DCF), which is used to calculate to value timber and timberland, so it is frequently applied to several timberland situations. LEV is a practical way to value even-aged pine plantation (Straka and Bullard, 1996).

$$LEV = \left(\frac{NPV * (1+i)^n}{(1+i)^R - 1}\right)$$

Where:

i= discount rate

R= rotation age

n= year

In the study, we aim to find revenues and cost to calculate NPV and LEV. Dooley and Barlow surveyed to costs and cost trends for forestry practices in the South in 2012. From the survey result, we used the price of various timber products and cost of treatments. In Table 3.2, we see the results. We determined the real interest rate (percent) as 5%.

Table 3.2: Costs and prices of actions (Costs and trends of Southern practices, 2014)

| Costs | | | |
|---|---|---|---|
| Timber Product | Price per ton | Treatment Type | Price Per Acre |
| Pulpwood | $9.32 | Establishment | 232.31 |
| Chip-n-Sawtimber | $37.31 | Fertilization | 86.33 |
| Sawtimber | $50.0 | Annual Cost | 3.00 |

In the study area, the main species is loblolly pine. We aimed to find the optimal rotation age for the loblolly pine. Several studies have shown various determinations of the optimal rotation age.

In this study, we assumed that all stands between 15-20 years of age, are subject to thinning and include follow-up fertilization. Thinning target is basal area (residual BA=60). Stands whose age is from 20 years to 25 years might be thinned but there is no follow-up fertilization this late in the rotation. In this case, we might have two thin harvesting and fertilization. Depending on our management actions, we found five different scenarios. For each of them, we calculated the NPV in PTAEDA4.0 (Simulation of tree growth, stand development and economic evaluation in Loblolly Pine plantations). In the study area, we accepted length of the each period as 5 years.

Table 3.3: Calculation of LEV for scenarios

| Scenario Number | Rotation Age | Fertilization Age | Thin Period | NPV Per Acre | LEV Per Acre |
|---|---|---|---|---|---|
| 1 | 20 | - | - | $436 | $699 |
| 2 | 25 | - | - | $570 | 809 |
| 3 | 30 | 15 | 15 and 20 | $635 | $826 |
| 4 | 30 | 15 | 15 | $644 | $838 |
| 5 | 35 | 15 | 15 and 20 | $654 | $799 |

In Table 3.3, we see that scenario 4 gives the best LEV. Stands are thinned and fertilized at age 15 and harvested at age 30. To compare other scenarios, we suggest that thin at age 20 does not increase the LEV because at age 15 stands are already thinned and fertilized. Remaining trees have enough sun light after the thin in period 4 so no additional thin is needed. What's more, thinning does not have any cost. Also, harvesting many trees at age 25 gives the higher net value (NV) instead of harvesting them at age 30. In reality we see that, scenario 4 gives higher LEV comparing to scenario 3 which has only one more thinning at age 25. This is because fertilization, made at age 15, increases the growth of trees slightly. Thin at age 20 cuts this increase short that is why scenario 4 is better than scenario 3. In conclusion, scenario 3 is the best for the study area.  We identified the optimal rotation age as 30 years (6 periods). Also, we are going to thin and fertilize the stands at age 15.

### 3.3 Estimation of Timber Volume for Loblolly Pine

Fast-growing southern pine plantations give more timber than older or natural stands (Clark III and Saucier, 1990). In the study area, trees per acre (TPA) and average diameter at breast height (DBH) have been measured. Site quality information has been determined. Site Index is a way to determine productivity for a location. In southern forestry, site index is an average height of s stand at 25 years (Larsen, 1987). Basal area (BA) has also been calculated for each stand. Bettinger (2010) states "The basal area of a stand of trees is the sum of the cross-sectional surface areas of each tree, measured at DBH, and reported on a per-unit area basis. Basal area is a measure of tree density, and widely used in forestry, wildlife, and other natural resource management professions".

$$Basal\ Area\ (units^2) = \pi(\frac{DBH^2}{2})$$

This equation is for a single tree. To find BA for acre, we used this equation;

$$BA(per\ acre) = Avearge\ BA/tree * TPA$$

There are two different software packages calculating and simulating Loblolly stand volume using these parameters in the SFWS; PCWthin and PTAEDA. PCWthin uses BA, age, site index and TPA. PTAEDA uses DBH, site quality, age and TPA. For purposes of this study, site index is categorized in to three groups. Good, average and poor. We have used these groups in our study because exact site index was not determined.

Table 3.4: Site index groups

| | |
|---|---|
| Good | 75 |
| Average | 62 |
| Poor | 50 |

Our main goal in the study is to maximize the net land expectation value (LEV). Net revenue comes from final harvesting and thinning operations. We considered three products; Pulpwood, Chip-n-saw and Sawtimber. They were categorized based on the DBH.

Table 3.5: Product type according to DBH (inches)

| Product Type | DBH (inches) |
|---|---|
| Pulpwood | 6-9'' |
| Chip-n-saw | 10-13'' |
| Sawtimber | 14''+ |

PTAEDA uses DBH but it does not distribute average DBH in the future stand tables. PCWthin uses BA and it does distribute DBH. We wanted to see number of trees for each diameter class because NPV is based on product values and we needed quantity of each product to calculate these values. For this reason, we first used PCWthin not to find actual stand volume and simulate it but to learn about the DBH distribution of the volume of each stand.

In Figure 3.2, we indicate the information we had about stand 07. Stand 07 average DBH is 8.1 (From data). We wanted to know DBH distribution for 400 trees.

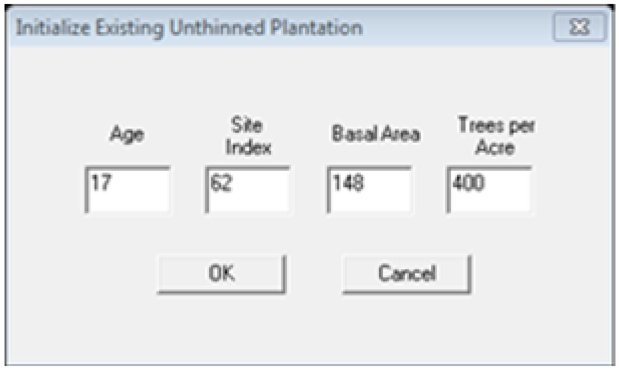


Figure 3.2: Input parameters for stand 07 to PCWTHIN

In Table 3.6, we see number of trees in each DBH class for stand 07 using PCWthin software packages. On the other hand, PCWthin does not provide information for stands which are older than 50 years. Optimal rotation age is generally considered to be 30 years in Southeast for Loblolly pine. Depending on the objectives of optimal rotation age, 50 years is considered too old for the species. However, in the study area there are 2 Loblolly pine stands older than 50 years. In addition, many stands will be older than 50 in 20 years (the planning horizon) if they are not completely harvested sooner. In doing so, we have to find the stands volume after 50 years. PTAEDA allows us to do this. After we determine the future DBH distribution using PCWthin, we are able to use this distribution in PTAEDA.

We found and simulated stand volume based on the thinned or unthinned options over a 20 years planning horizon. PTAEDA also calculated the NPV for 4 periods (Each period is 5 years). In this way, we observed NPV change.  In the study's traditional scheduling approach, we are going to use thinned stand simulations because it gives higher NPV. Also, Woodstock will select better options based on specified targets. In addition, we have to input existing stand volumes and whether it is thinned or not because Woodstock will use the differences in volume among them to calculate thinning harvest volumes. For this reason, we have simulated stands which are available for thin in any period without thin option.

Table 3.6: Distribution of DBH for stand 07 at its current age

| DBH Classes | Number of Trees | DBH Classes | Number of trees |
|---|---|---|---|
| 3 | 0.1 | 8 | 113.7 |
| 4 | 1.6 | 9 | 103.6 |
| 5 | 10.13 | 10 | 49.2 |
| 6 | 34.6 | 11 | 9.7 |
| 7 | 76.7 | 12 | 0.6 |

### 3.4 Traditional Harvest Planning Approach

Traditional harvest planning approaches target increasing Net Present Value. This approach also aims to supply sustainable forest products (Bettinger et al., 2010). Area control and volume control are the main traditional methods available to simulate and regulate the forest product flows.

Area control is a method to stipulate allowed cut area either periodically or annually (Boychuk and Martel, 1996). In the study area, our implementation of the traditional method uses the periodic management option. The rotation age is 30 years and the each period length is 5 years. In other words, the rotation length is 6 periods so according to area control, we only do final harvest 1/6 of the study area each period.

Volume control is another method to stipulate targeted volume each period. A manager can search for the largest sustainable volume under different silvicultural activities (Boychuk and Martel, 1996). In the study area, there is no available stand to thin in second period of our 20 year planning horizon. For this reason, we selected the area control method rather than the volume control method.

In the study area, there are many stands which are older than 30 years. When we look at their growth rate, we see that they rapidly decrease after 30 years step by step. Because of this, our strategy to schedule stands for final harvest uses the oldest first rule.

Based on our criteria related to thinning, we are going to be able to thin stands in period 1, period 3 and period 4. Harvest income (thin and clear-cut) will be discounted to today's value. Our costs such as fertilization and establishment will be discounted as well.  Present value of revenue and present value of costs will be calculated to find NPV.

### 3.5 Woodstock and Stanley Forest Planning Software

Remsoft inc. has been developed software packages for harvest scheduling and scheduling other forestry activities since 1992 (Walters, 1993).The software packages contain Woodstock, Stanley and Spatial Woodstock (Bettinger et al., 2010). Basically, Woodstock determines activities and reports a solution. Stanley uses the Woodstock solution to allocate stands if there is an action subject to spatial constraints (like certification adjacency guidelines). When we develop a Woodstock model, we need to understand six key concepts; landscape themes, development types, actions, transitions, yield components and outputs.

In the study area, we are going to describe the forested area under the landscape themes. Current stand type and desired stand type (after an action implemented) are going to be described. We also input each stand volume under the yield section. We will have two actions. First is clear cut stands and regenerate them. Second is thinning stands. When an action is carried out on a stand, stand type and its yield curve is changed. We are going to describe the changes in the transition section. In the output section, we determine many outputs (products) and their source and calculation equations. In the report section, we list outputs that we want to see after we run the model.

The most essential part in a Woodstock model is Queue section and Optimize section because targets are defined in these sections. These optional sections have to do with how the software approaches generating a solution. In the study, we are going to create one model and three types of scenarios. One will be simulation. Two of them will be optimization.

We will use the Queue section to simulate harvests on the forested area. The queue section allows a user to target exact an amount of a value (volume or revenue) rather than optimizing or minimizing a value. To compare to traditional approaches, we will first target thin area and clear cut area per period. Then, we are going to see how Woodstock selects the stands for clear cut and how NPV is changed.

Our second scenario is maximization of NPV. We turn off the targeting features of the software and turn on scheduling section. We also let Woodstock determine the optimal rotation age unlike traditional approach (where stands younger than 30 years are not subject to clear cut).

In addition to maximizing the NPV, we are going to generate a new scenario to maximize harvest volume. We simply modify change the objective function but the reports and schedule will be much different. This is one of the greatest benefits of using Woodstock.

# Chapter 4

# Result and Discussion

This chapter describes the four strategies we used to prepare the management plan for MOT. The four strategies are: 1 traditional harvest scheduling method, 2 simulation of harvest scheduling using Woodstock, 3 maximizing NPV and 4 maximizing total harvest volumes.

## 4.1 Traditional Harvest Scheduling Method

The traditional harvest scheduling approach involves scheduling of timber harvest based on a landowner's wishes. Our main goal was to maximize NPV in a sustainable value, while producing forest products. We used the area control method to schedule harvesting. For the next 20 years, we set the period length to be 5 years, so we will have 4 periods. Loblolly pine stand is approximately 240 acres in area, and the optimal rotation age for the loblolly pine is 30 years. In order to determine the amount of area that can be clear-cut on a regular basis, we divided the total area of stand (240) by 6, the number of harvest periods we selected for our rotation. Accordingly, we will clear-cut 40 acres each harvest period and plant loblolly pine to regenerate each 40 acre area.

Because our main goal is to maximize NPV during each period, we will use the oldest first method to select stands to clear cut, because many studies that have examined timber producing have indicated that old stands (i.e., older than optimal rotation age) grow a significantly slower rate than younger trees; thereby, reducing forest value.

When stands are the same age, we will look at the in respective growth rates for our second criteria. Stands with slower growth rates will be selected first for final harvest, in effect to increase the NPV. Table 4.1 provides a summary of stands, selected for final harvest during each period, as well as their total acreage.

Table 4.1: Schedule for clear-cut and regeneration of forest stands

| Period 1 | | Period 2 | | Period 3 | | Period 4 | |
|---|---|---|---|---|---|---|---|
| Stand Number | Acres | Stand Number | Acres | Stand Number | Acres | Stand Number | Acres |
| 1 | 10.10 | 28 | 8.35 | 23C | 23.97 | 13A | 6.06 |
| 2 | 4.96 | 23A | 3.31 | 11 | 14.05 | 13B | 9.40 |
| 22 | 8.65 | 25 | 1.81 | 14C | 2.25 | 13C | 3.53 |
| 17 | 15.46 | 27 | 4.50 | | | 14A | 6.62 |
| | | 27A | 0.25 | | | 14B | 2.74 |
| | | 24 | 2.64 | | | 9 | 8.75 |
| | | 23B | 18.30 | | | 7 | 3.66 |
| Total | 39.17 | | 39.16 | | 40.27 | | 40.76 |

Stands 3, 4, 15, 18, 33, and 34 will not be regenerated. Only a thin harvest will occur in these stands due to their age. Also, MOT rotation will take 20 years, which is equal to 4 periods with 40 acres harvested per period. Because the optimal rotation age is 30 years, which is equal to 6 periods, two 40 acre treatments will be leftover following the 20-year rotation. Using the area control method, all stands will be regenerated in the optimum rotation year.

Stands will be selected for thinning based on the methods previously mentioned (see Chapter 3). Because thinning increases stand growth, and NPV, we elected to thin every stands. If a stand was younger than 20 years, we thinned between 15 years and 20 years and applied fertilize to the soil. If a stand was older than 20 years, but younger than 25 years, we only thinned the stand. The area that will be thinned in period 1 will be 101 acres, there will be no thinning in period 2, and 37 acres will be thinned in period 3, and followed by 39 acres in period 4. We will fertilize areas are 56.13, 37.14, and 39.17 acres, respectively in periods 1, 3 and, 4. Table 4.2 provides the number and size of stands that will be thinned and fertilized in periods 1-4. Fertilization was written in bold.

Table 4.2: Thin and fertilization activities in periods (for all methods)

| Period 1 | | Period 2 | | Period 3 | | Period 4 | |
|---|---|---|---|---|---|---|---|
| Stand Number | Acres | Stand Number | Acres | Stand Number | Acres | Stand Number | Acres |
| **3** | **9.92** | | | **4** | **13.44** | **1** | **10.10** |
| **7** | **3.66** | | | **15** | **1.63** | **2** | **4.96** |
| **8** | **15.10** | | | **33** | **5.39** | **22** | **8.65** |
| **9** | **8.76** | | | **18** | **11.05** | **17** | **15.46** |
| 11 | 14.05 | | | **34** | **5.64** | | |
| **12** | **18.70** | | | | | | |
| 13A | 6.06 | | | | | | |
| 13B | 9.40 | | | | | | |
| 13C | 3.53 | | | | | | |
| 14A | 6.62 | | | | | | |
| 14B | 2.74 | | | | | | |
| 14C | 2.47 | | | | | | |
| Total | 101.00 | | 0 | | 37.14 | | 39.17 |

Our goal was to optimize NPV using traditional methods. Each period will result in a different NPV because the area available to thin will vary and yield tables will also vary considerably from stand to stand. Table 4.3 indicates that we will produce our highest NPV in Period 1, because the area available to thin in period 1 will be 101 acres (see figure 4.2), which greatly exceeds the area available to thin in latter periods, thus increases the NPV. Also, many of the stands that will be harvested during period 1 are very old, relative to stands that will be harvested later on. The growth rate of this stands is very slow compared to younger stands; however, they are still growing and their volumes per acre will be greater than other stands. For example, stand 2 which is 58 years old will produce 115.3 tons per acre. NPV will also decrease over time due to the discount rate. In this case, the interest rate is 5% and the period length is 5 years. When NPV is calculated, the discount rate will decrease from the beginning of the rotation to the end. This is based on the simple NPV calculation method where we assumed that the price of timber products price will not change in the future other than to account for inflation.

Table 4.3: Net present value for each period (traditional method)

| Period | NPV |
|---|---|
| 1 | $186,988.55 |
| 2 | $117,341.19 |
| 3 | $101,627.26 |
| 4 | *$70,891.25* |
| Total | $476,848.24 |

In order to evaluate the effectiveness of each harvest schedule, we looked at the volume of each product produced after harvest (table 4.4). NPV is commonly used in forestry, but it depends on future price and future interest rate, which are not easily determined. Harvest volume is the second method we used to compare approaches. Even though we used harvest volume quantities to calculate NPV, harvest volume is not affected by future prices or interest rates and may therefore be a better method for evaluating harvest approaches. In Table 4.4, we show that total harvest volume will decrease from period 1 to period 2. Afterward, total harvest volume will increase from period 2 to period 4. On the other hand, NPV will decrease continually (see Table 4.3).

Table 4.4: Harvest volume (tons; traditional method)

| Period | Pulpwood | Chip-n-Saw | Sawtimber | Total |
|---|---|---|---|---|
| 1 | 1868.82 | 3172.93 | 208.49 | 5250.24 |
| 2 | 7.515 | 1039.155 | 2553 | 3599.67 |
| 3 | 586.244 | 451.034 | 3167.02 | 4204.298 |
| 4 | 705.06 | 643.064 | 2938.205 | 4286.329 |
| Total | 3167.639 | 5306.183 | 8866.715 | 17340.537 |

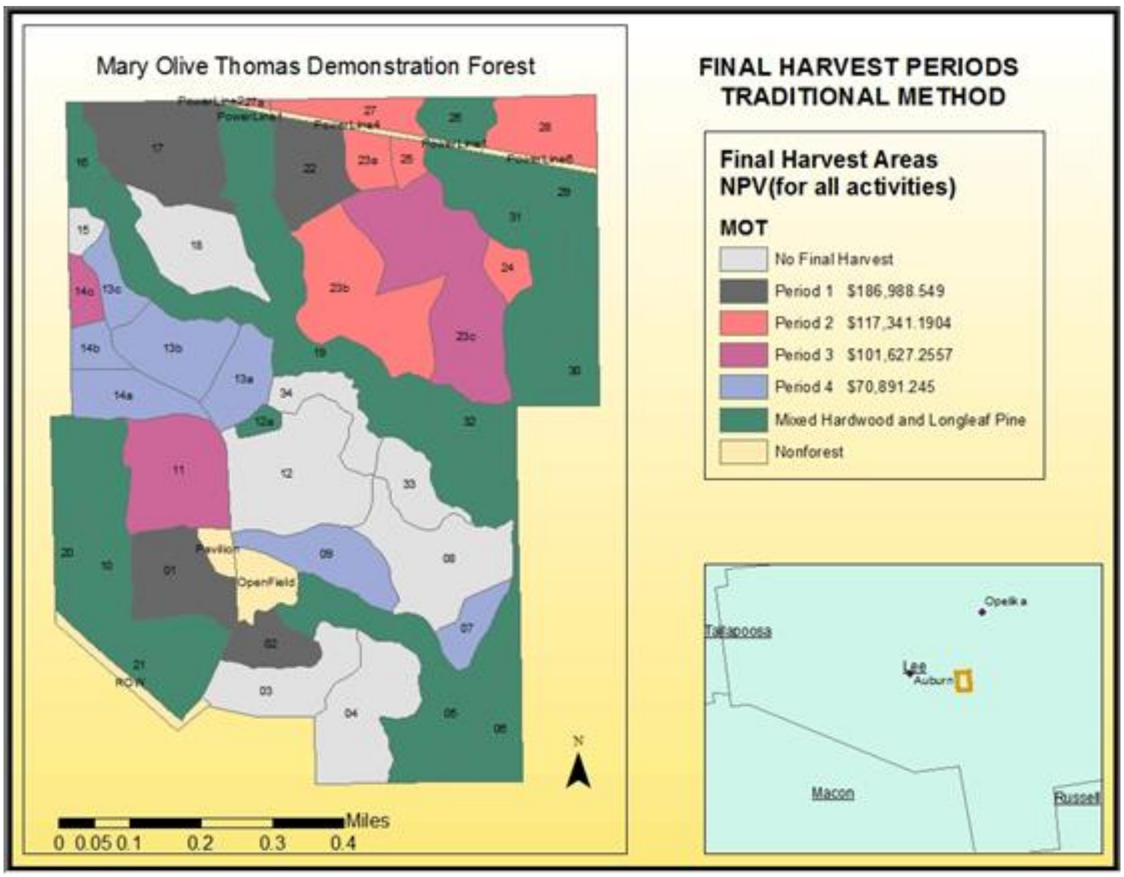


Figure 4.1: Final harvest map for the traditional method

Thinning a stand will increase the harvest volume as well as the NPV. Thinning also increases the total volume of a stand in the future. For this reason, we thinned all stands that were available. Our thinning strategy (Figure 4.2) was same for all approaches (i.e., traditional, simulation, maximization of NPV, and maximization of total harvest volume). In the simulation approach, we described the area available for thinning. In the maximization of NPV and maximization of total harvest volume approaches, we completely thinned stands that were available for thinning as well. We will explain and illustrate this process when we describe the results for the simulation approach.

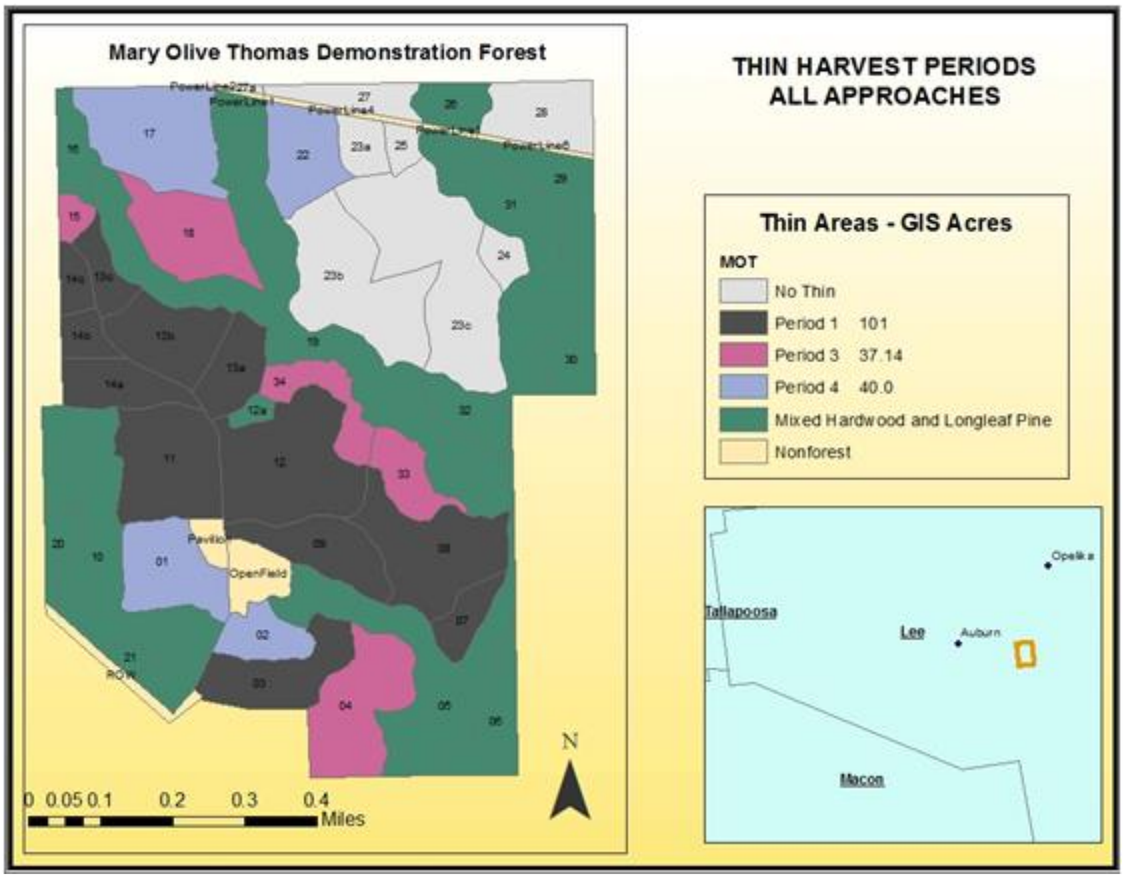


Figure 4.2: Stands thinned by period (all method)

## 4.2 Woodstock Models

### 4.2.1 Simulation Method

#### 4.2.1.1 Creation of the Method

We have called this approach the “simulation approach” because we have simulated the harvest as we did in traditional method. In other words, the area thinned and the area clear cut have been defined, and we have allowed the Woodstock to select stands, or part of stands, for the final harvest. Simulation is not like optimization. In the simulation approach, we defined the exact target that we desired. In contrast, optimization methods maximize or minimize a target in light of constraints. Sometimes, a landowner may want to know exact harvest volume, or exact NPV, because of some fluctuations in the market, for example. In this case, maximizing the harvest would not be desired, because the product harvested would likely exceed the needs of the market. Simulation is better than optimization in this situation. Woodstock allows the user to simulate, or optimize, their desired targets. We elected to set targets using simulation in Woodstock. Also, we sought to determine how the simulation approach in Woodstock performed relative to traditional method.

In the simulation model, we planned for a 20-year time horizon, split into four, 5 -year periods. The model was comprised of ten components: action, areas, control, landscape, lifespan, outputs, reports, transitions, yields, and queue. We will explain and illustrate to understand how Woodstock works and to understand the results.  Also, each user creates his or her own model, and the model should be explained to make it clear to other people. Woodstock does not have the same model type; therefore it is partially depending on users.

In the landscape section, we have used landscape themes to describe our landscape scheme. Up to 25 themes can be created. Themes can be forest type, soil type, site quality or individual stand number. Our theme is depending on stand number for actual description of landscape. After an action such as thin or clear cut, the stand condition may be changed. In this case, we have coded possible stand condition. Each stand number or possible stand code is referred to its attribute code. In ArcGIS, the attribute table should have same theme whenever we want to open the map in Woodstock. For example, the table would read the following:

07 stand 07 unthinned

07t stand 07 thinned

lbyave stand loblolly pine average site quality unthinned

In this part of the landscape, we have selected three attributes codes from landscape themes to illustrate how we described the landscape. "07" is the stand number. It is also an attribute code. Stand 07 unthinned is described by the "07". Stand 07 is unthinned and it is the current condition of the stand. We can question of what happens if we thin or clear cut the stand 07? In this case, condition of stand 07 will be changed and it will have a new yield table. "07t" is an attribute code if stand 07 is thinned. "lbyave" is a thematic attribute code if stand 07 is harvested completely and regenerated. After final harvest, a landowner may want to generate other species. Species and stand condition can be changed for wildlife, soil conservation and other ecologic and economic desires using Woodstock.

In this specific study, we have not changed species. We have described the new generation based on species and site quality. We have used 36 thematic attribute codes to describe both the current condition of the forest, as well as any possible future conditions.

A Woodstock model needs to specify how old a stand can survive. In the lifespan section, we specify the maximum age for a development type:

*; Lifespan*

? 25; maximum lifespan for all types = 125yrs

Note that “?” indicates that all stands will be assigned the same maximum life span of 25 periods, which is equal to 125 years.

The area section is where we initialize the forest area based on development type, signified by a specific stand number. Area section should be based on development type. A development type is simply a portion of the landscape theme. For instance, consider that a user defined two themes in the landscape section, such as forest type and site quality. Forest type has two thematic codes which are loblolly pine and longleaf pine. In addition, site quality has three thematic attribute codes which are 1- good, 2-avearge, and 3-poor. In this case, loblolly pine in good site quality is a development type. In our study, we have just one theme which the stand number. Hereby, each stand number is a development type.

*; Areas*

*A 01 12 10.0988

Note that “*A” indicates that following part is about area. “01” is stand number. “12” refers to stand age. “10.0988” is the stand 01 area (acres). We have written areas for just the current stand conditions which are existing development types. New development types created during periods are assigned to the area by Woodstock.

Yield section is also another part of a Woodstock model in which examples like stand volumes and basal area estimates are associated with the development types in the model. We have defined the yield section according to timber volume based on product type, stumpage price for products, costs and the discount factor. The yield table is based on age in periods.

```
; Yields
;volume in tons
*Y 01 { stand 1 }
_AGE    Pulp   Chip-Saw   Saw
12        -        -      115.3
13        -        -      118.3
14        -        -      120.6
15        -        -      121.1
```

Note that yield set begins with the "*Y" keyword. Following the "*Y" keyword is the thematic attribute for the associated development type.

```
*YT ?
est$ 1 232.31
frtz$ 1 86.33
*YT ?
disc5% _DISCOUNTFACTOR (5%,5,half)
*YT ?
; stumpage in $/tons
Pulp$ 1 9.32
```

Chip-Saw$ 1 37.31

Saw$ 1 50

*YC ? ? ? ?

totv _SUM (Pulp, Chip-saw, Saw)

Note that “*YT” refers to the time dependent yield table keyword and “*YC” is the complex keyword. “Est$” the is establishment cost. “Frtz$” the is fertilization cost. “Disc5%” refers to discount factor which is 5%. (5%, 5, half) indicates that discount factor is 5%, period length is 5 years, and actions occur in the half of each period. Total volume is found by “totv” code which sums up the product type volume.

The action section is where we have declared the thin and clear cut activities that change the dynamics of forest development. Woodstock declares death and inventory but other activities must be declared by the user.

*; Actions*

*ACTION ccplt Y clearcut planting

*OPERABLE ccplt

? _AGE >= 5 *{ age is in periods }*

Note that “ccplt” code signifies to clear cut the stand and plant the area. “Y” indicates that this action has changed the age of the stand. “?” refers to any thematic attribute code for theme 1. If there were two themes, we would write “??”. If we want to apply this action to certain thematic attribute tables, we would simply write their codes instead of the question mark. This action can be applied to stands which are older than 25 years old.

*ACTION thin N commercial thin

*OPERABLE thin

03 _AGE = 4

Note that “thin” code signifies thinning the stand activity. “N” indicates that this action does not change the age of a stand when it is applied. We did not use the question mark. We described all stands which are available for thinning and we associated the thinning time. In the yield table, we declared the yield for a stand for both thinned and no thinned options. “03t” thematic attribute code is used if the stand 03 is thinned.

*PARTIAL thin

pulp chip-saw saw

“*Partial” keyword for the thin action is specified here because only a certain part of the total volume of the stand has been harvested. For instance, when stand 03 was thinned, Woodstock calculated the yield as the difference between the standing volume before the thinning and the standing volume afterward. We have written pulp, chip-saw, and saw timber codes because the volume difference between pulpwood, chip-n-sawtimber, and sawtimber volume has been calculated.

We have declared two actions which are clear cut and thin. We must specify the transition matrix for them. The transition section is where we declare the new condition of a development type after an action is applied.

*; Transitions*

*CASE ccplt

*SOURCE 01

*TARGET lbyave 100

The transition section must be declared for each action. The "*CASE" keyword indicates each specified action you specify. We first described clear cut and plantation action. Even though we have one forest type which is loblolly pine and we have three site qualities, each stand has a specific yield table. After clear cut, we want to have three different yield tables for loblolly pine based on site quality. As such, we are going to have three different stand types. Here, stand 01 will be regenerated after clear cut. Its new yield table will be loblolly pine in average site quality. "100" indicates the transition percentage.

*CASE thin

*SOURCE 03

*TARGET 03t 100

The second case is thin action. Thin action only changes the yield table of the stand. 03t is declared in the yield and landscape sections in terms of its explanation and its yield table. After stand 03 is thinned, stand 03 will be stand 03t which is stand 03 thinned.

Control section is where we tell the Woodstock interpreter how long the planning horizon is. Also, we can control our approaches based on simulation or optimization, which is a linear programming model.

*; Control*

*LENGTH   4

*GRAPHICS OFF

*REPORTS ON

*IMAGE    OFF

*BUILD    OFF

*OPTIMIZE OFF

*SCHEDULE OFF

*QUEUE    ON

Our plan horizon is 4 periods which is equal to 20 years. Because this is a simulation model, we turned off schedule and turned on queue.

Our action changes the stand volume and stand area. We calculated the output based on volume and area. Each output is triggered by an action. For instance, thin volume and thin area are outputs which are triggered by thin action. The output section is where we declared the values in order to get reports and to evaluate management success. In this study, our main reports are harvest volume and NPV. We tried to write codes to calculate these. In addition, thin area, clear cut area, harvest volumes and other values have been calculated and reported.

*OUTPUT npv net present value

*SOURCE distrev – discost

In this part of the output section, the output that we declared is “npv” which is net present value. The calculation source is discounted total revenue minus discounted costs.

In the report section, we have selected the outputs that we want to report. The report section is where we declare the outputs in report files.

npv 1.._LENGTH

In this part of the report section, we have selected the “npv” to report this value for all period lengths. The values could not be reported for management horizon.

In a simulation model, we turned on queue section in the control section. We wanted to control timing and magnitude of actions during the simulation model run. In a simulation model, targets should be exact. In contrast, simulation does not minimize or maximize a value like optimization.

```
; Queue
*SELECT thin
_MAX _AGE
*SELECT ccplt
_MAX _AGE
*TARGET ccpltth = 40 1.._LENGTH
*SOURCE ccplt 100
*TARGET thinth = 100.9981 1
*SOURCE thin 100
*TARGET thinth = 37 3
*SOURCE thin 100
*TARGET thinth = 40 4
*SOURCE thin 100
```

In summary, we selected rules for actions as oldest first. We have targeted 40 acres clear cut area for each period. We have written the available thin area for periods. This is what we did in the traditional method. We wanted to see how Woodstock selects stands or parts of stands for final harvest. Also, changes to total harvest volume and NPV are our main values to compare the simulation method to other methods.

#### 4.2.1.2 Model Reports

After we ran the simulation method model, we obtained report results. In the output section, we report the clear cut area for each stand. In the report section, we have selected these outputs. Using the traditional method, we did not divide any stands into separate sections that would be harvested in different periods because we did not need. Using the simulation method, we split stands into separate sections.

In Table 4.5, we see that the Woodstock method has succeeded to scheduling 40 acre harvest areas for each period. Stand 23c was divided to be partially harvested in period 1, with the remainder harvested in period 2.

Table 4.5: Schedule for the clear-cut and regeneration of stands (simulation method)

| Period 1 | | Period 2 | | Period 3 | | Period 4 | |
|---|---|---|---|---|---|---|---|
| Stand Number | Acres | Stand Number | Acres | Stand Number | Acres | Stand Number | Acres |
| 1 | 10.10 | 22 | 1.81 | 11 | 14.05 | 3 | 9.92 |
| 2 | 4.96 | 23a | 3.31 | 13a | 3.64 | 7 | 2.90 |
| 23c | 7.39 | 23b | 18.30 | 22 | 6.85 | 13a | 2.42 |
| 24 | 2.64 | 23c | 16.58 | 17 | 15.47 | 13b | 9.40 |
| 25 | 1.81 | | | | | 13c | 3.53 |
| 27 | 4.50 | | | | | 14a | 6.62 |
| 27a | 0.25 | | | | | 14b | 2.74 |
| 28 | 8.35 | | | | | 14c | 2.47 |
| Total | 40 | | 40 | | 40 | | 40 |

We did not run the Stanley model because we did not have the spatial constraints such as maximum opening size. In ArcGIS, we divided the stands according to the model reports. We planned which stands to cut during each harvest period based on their proximity to each other in effort to facilitate timber transportation and harvesting.

In Figure 4.3, we have used same color scheme for clear cut areas and regeneration areas as we did for the traditional method. The map of areas to be thinned is the same because all of the stands that were scheduled to be thinned have been thinned at this point.

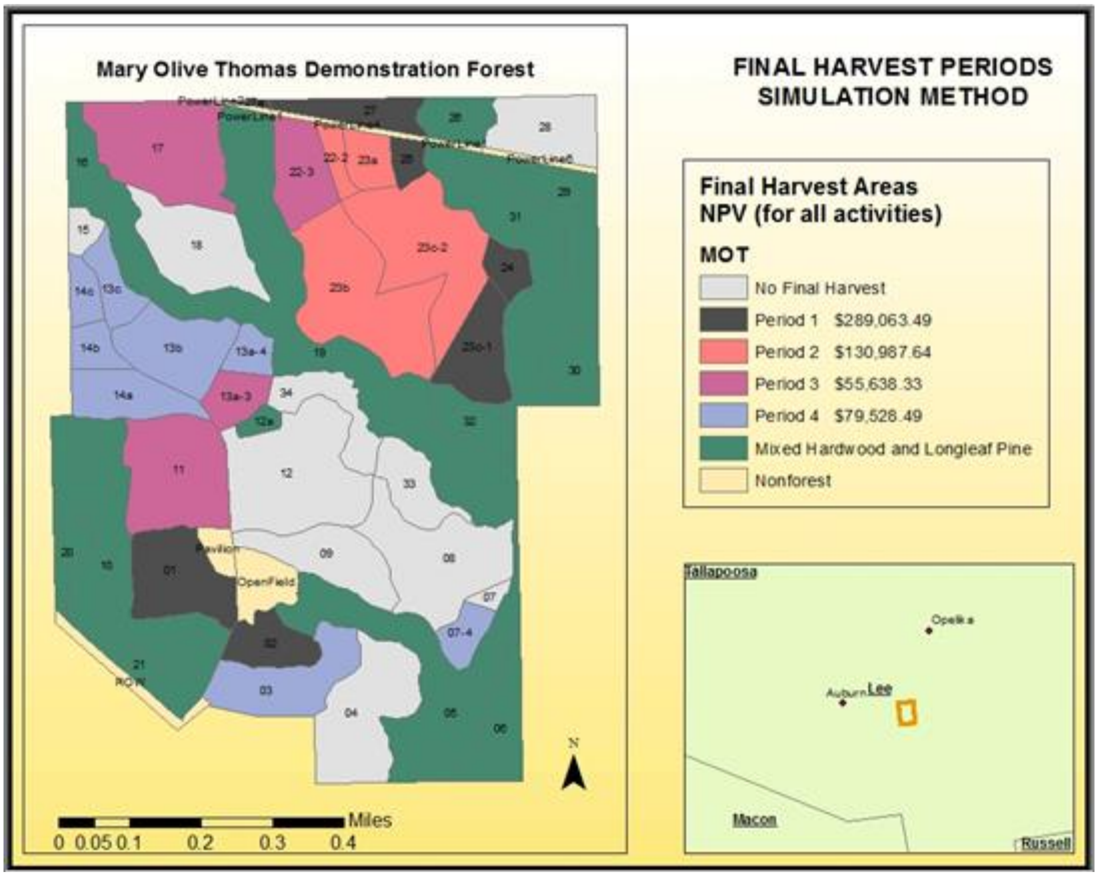

Figure 4.3: Final harvest map for the traditional method

Using the simulation method, we did create any targets related to NPV directly. On the other hand, selection rules for clear cuts and areas designed for both thinning and clear cutting are derived from the traditional method. These selection rules increase NPV and lead the production of sustainable forest products. We used these selection rules in the traditional method to maximize NPV. We have simulated the forest plan according to the traditional method in Woodstock. We let Woodstock select stands for final harvest. This process is one of the strengths of the traditional method.

In Table 4.6, we see the NPV for each period in the simulation. The simulation method produces a higher NPV compared to the traditional method. We will explain this result in discussion section.

Table 4.6: Net present value for each period (simulation method)

| Period | NPV |
|---|---|
| 1 | $289,063.49 |
| 2 | $130,987.64 |
| 3 | $55,638.33 |
| 4 | $67,086.34 |
| Total | $542,775.80 |

The harvest volume of thinned areas was the same. Final harvest volume changed due to selecting different stand which result in a different yield table. In Table 4.7, total harvest volume for the management horizon was 21,342.08 ton.

Table 4.7: Harvest volume (tons; simulation method)

| Period | Pulpwood | Chip-n-Saw | Sawtimber | Total |
|---|---|---|---|---|
| 1 | 1,008.05 | 3,543.11 | 4,242.19 | 8,793.35 |
| 2 | 4 | 990.84 | 3,266.79 | 4,261.64 |
| 3 | 699.43 | 934.55 | 2,036.40 | 3,670.39 |
| 4 | 669.9 | 319.61 | 3,627.20 | 4,616.70 |
| Total | 2,381.38 | 5,788.11 | 13,172.58 | 21,342.08 |

### 4.2.2 Maximization of Harvest Volume Method

#### 4.2.2.1 Creation of the Model

An optimization model was constructed for maximization of harvest volume. The main goal of this model was to maximize total harvest volume obtained from thinning and clear cutting during each period. This model uses a similar set of parameters where the schedule section is turned on and the queue section is turned off. In the Woodstock model, we turned on the schedule section to build the matrix for the model. On the other hand, we has described our objective function and constraints in the “optimize” section, which is required for any LP formulation.

In the “optimize” section, we formulated our forest model to be a linear programming by describing an objective function and by placing constraints on outputs.

```
*OPTIMIZE
*OBJECTIVE
_MAX harvest 1.._LENGTH
*CONSTRAINTS
ccpltth = 40 1.._LENGTH
*FORMAT MOSEK
```

Note that the optimize section is headed by the OPTIMIZE keyword. Because we sought to maximize total harvest volume during each period, our objective function was declared with the “_MAX” keyword. “Harvest” was declared in the output section, corresponding to total harvest volume, and “ccpltth” refers to the clear-cut area. We only had one constraint

#### 4.2.2.2 Model Reports

During each period, 40 acres were harvested and planted using the Woodstock model. This was our constraint due to the fact that we have managed the forest according to the area control method. Another constraint stated that final harvest could only occur if a stand was older than 25 years. This constraint was declared in the action section. In Table 4.8, we see stands, or part of stands, scheduled for clear-cut and regeneration by period. In general, model selected the stands that had more timber volume.

Table 4.8: Schedule for clear-cut and regeneration of forest stands

| Period 1 | | Period 2 | | Period 3 | | Perid 4 | |
|---|---|---|---|---|---|---|---|
| Stand Number | Acres | Stand Number | Acres | Stand Number | Acres | Stand Number | Acres |
| 1 | 10.10 | 11 | 14.05 | 9 | 3.89 | 7 | 3.66 |
| 2 | 4.96 | 23a | 3.31 | 23b | 13.00 | 8 | 15.10 |
| 22 | 8.65 | 23c | 0.87 | 23c | 23.11 | 9 | 2.54 |
| 23b | 5.30 | 25 | 1.81 | | | 12 | 18.70 |
| 24 | 2.64 | 27 | 4.50 | | | | |
| 28 | 8.35 | 17 | 15.47 | | | | |
| Total | 40.00 | | 40.01 | | 40 | | 40 |

We have created a map showing the finally harvested stands in MOT.

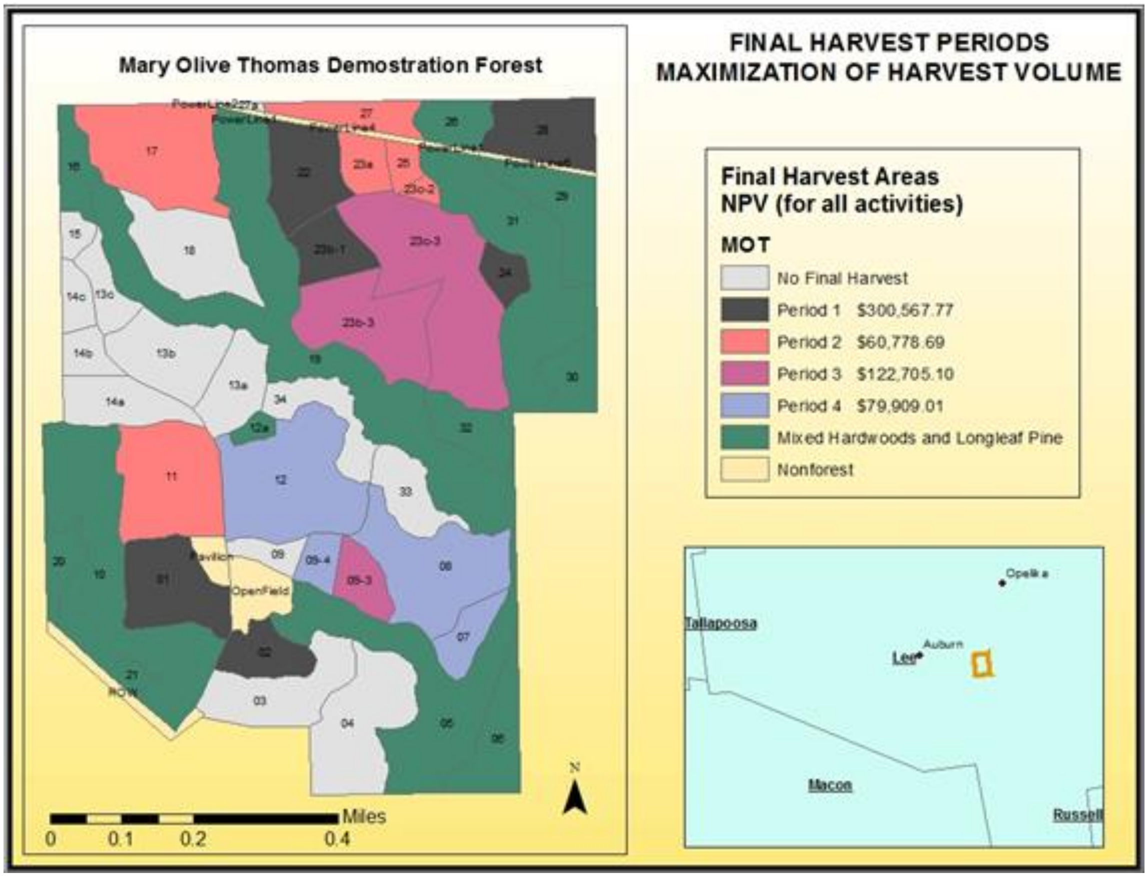


Figure 4.4: Final harvest map for the maximization of harvest volume method

NPV is examined in Table 4.9. Total NPV was $563,960.57. This was a large dollar amount than previous approaches. NPV was less in period 2 because thinning did not occur in period 2.

Table 4.9: Net present value for periods (maximization of harvest volume method)

| Period | NPV |
|---|---|
| 1 | $300,567.77 |
| 2 | $60,778.69 |
| 3 | $122,705.10 |
| 4 | $79,909.01 |
| Total | $563,960.57 |

The area thinned did not change in this approach because we sought to maximize the total harvest volume. Thinning increased total harvest volume so, all areas available for thinning were thinned. In Table 4.10, total harvest volume is 21,871.64.

Table 4.10: Harvest volume (tons; maximization of harvest volume method)

| Period | Pulpwood | Chip-n-Saw | Sawtimber | Total |
|---|---|---|---|---|
| 1 | 1,008.05 | 3,543.11 | 4,242.19 | 8,793.35 |
| 2 | 895.95 | 1,213.37 | 866.10 | 2,975.42 |
| 3 | 703.02 | 530.70 | 4,238.97 | 5,472.68 |
| 4 | 669.90 | 302.31 | 3,657.98 | 4,630.19 |
| Total | 3,276.92 | 5,589.49 | 13,005.24 | 21,871.64 |

### 4.2.3 Maximization of NPV Method

#### 4.2.3.1 Creation of the Model

A related set of models were developed where the objective was to maximize NPV. We only changed the objective function.

_MAX harvest 1.._LENGTH

Note that "npv" is net present value (NPV). NPX has been maximized for all periods according to the objective function.

NPV was obtained by subtracting the discounted revenue from the discounted cost. Discounted revenue was calculated by multiplying the discount factor by the harvest revenue. These calculations were developed in the output section.

#### 4.2.3.2 Model Reports

In Table 4.11, we have summarized the model report based on stands harvested in periods 1-4. Stand selection for the final harvest in period 1 was the same as stand selection in the maximization of total harvest volume method. In the twenty year plan horizon, almost 40 acres loblolly pine area will be harvested since it was the constraint in the optimize section.

Table 4.11: Schedule for clear-cut and regeneration for forest stands

| Period 1 | | Period 2 | | Period 3 | | Period 4 | |
|---|---|---|---|---|---|---|---|
| Stand Number | Acres | Stand Number | Acres | Stand Number | Acres | Stand Number | Acres |
| 1 | 10.10 | 23a | 3.31 | 3 | 7.38 | 3 | 2.54 |
| 2 | 4.96 | 23b | 18.30 | 9 | 8.76 | 7 | 3.66 |
| 22 | 8.65 | 23c | 18.39 | 11 | 14.05 | 8 | 15.10 |
| 23c | 5.58 | | | 13b | 0.76 | 12 | 18.70 |
| 24 | 2.35 | | | 14c | 2.47 | | |
| 28 | 8.35 | | | 24 | 0.29 | | |
| | | | | 25 | 1.81 | | |
| | | | | 27 | 4.50 | | |
| Total | 39.99 | | 40 | | 40.02 | | 40 |

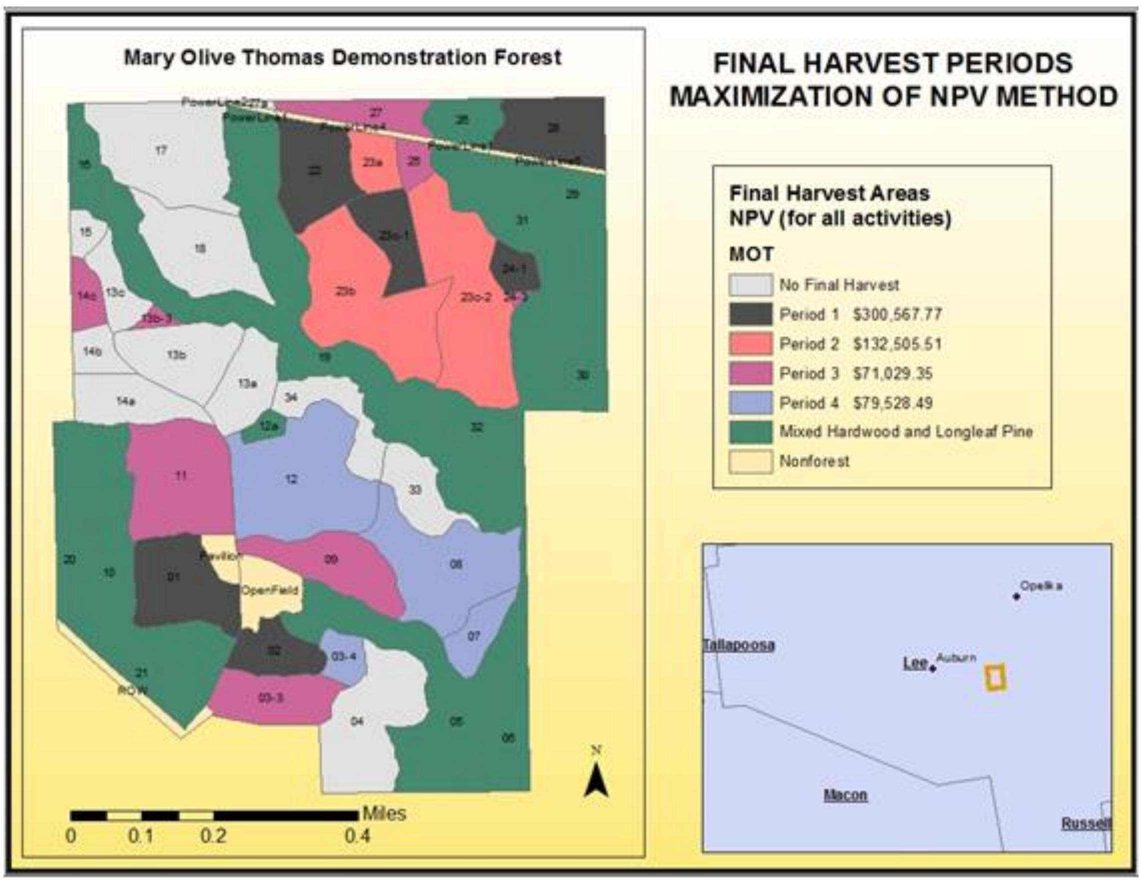


Figure 4.5: Final harvest map for the maximization of NPV method

We have selected those stands from attribute table in ArcGIS to show them visually. Many stands were divided to be harvested in periods. For example, stand 03 will be harvested in period 3 (7.38 acres) and period 4 (2.54 acres). We have divided them based on the Woodstock report. Also, we took care of spatial relationship.

In this method, we aimed to maximize NPV for each period. Total NPV was $583,631.12. In Table 4.12, we see that NPV has been decreased between periods 1-3. Discount rate was the main reason for this decrease.

Table 4.12: Net present value for periods (maximization of NPV method)

| Period | NPV |
|---|---|
| 1 | $300,567.77 |
| 2 | $132,505.51 |
| 3 | $71,029.35 |
| 4 | $79,528.49 |
| Total | $583,631.12 |

Maximization of NPV was our main target because the School of Forestry and Wildlife Science manages the Mary Olive Thomas Demonstration Forest for both research and income.

Table 4.13: Harvest volume (tons; maximization of NPV method)

| Period | Pulpwood | Chip-n-Saw | Sawtimber | Total |
|---|---|---|---|---|
| 1 | 1,008.05 | 3,543.11 | 4,242.19 | 8,793.35 |
| 2 | 4.00 | 990.84 | 3,266.79 | 4,261.64 |
| 3 | 699.43 | 934.55 | 2,036.40 | 3,670.39 |
| 4 | 669.90 | 319.61 | 3,627.20 | 4,616.70 |
| Total | 2,381.38 | 5,788.11 | 13,172.58 | 21,342.08 |

Because we have maximized NPV, all stands, available for thinning, have been thinned. We have understood that this method has selected stands which have higher volume. Unlike maximization of total harvest volume, this method has considered the product type because prices depend on product type. For these reasons, maximization of total harvest volume report and maximization of NPV were similar but not same. In Table 8, we see that total harvest volume was 21,342.08 tons.

## 4.3 Comparison of Methods

### 4.3.1 NPV Comparison

Net present value was the main criteria used to compare the traditional method to the Woodstock models (simulation, maximization of NPV, and maximization of total harvest volume). As we expected, all Woodstock models provided higher NPV than the traditional method. Maximization of the NPV model provided the highest NPV ($583,631.12; Figure 4.6). It is approximately 18.30% more than traditional method, 7.00% more than the simulation model, and 3.37% more than the maximization of total harvest volume.

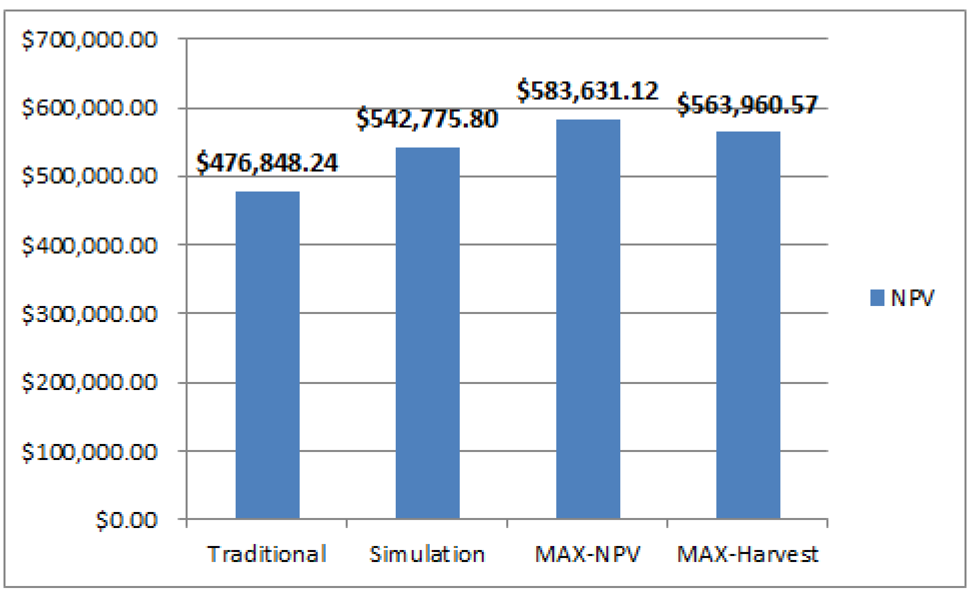


Figure 4.6: Net present value for methods

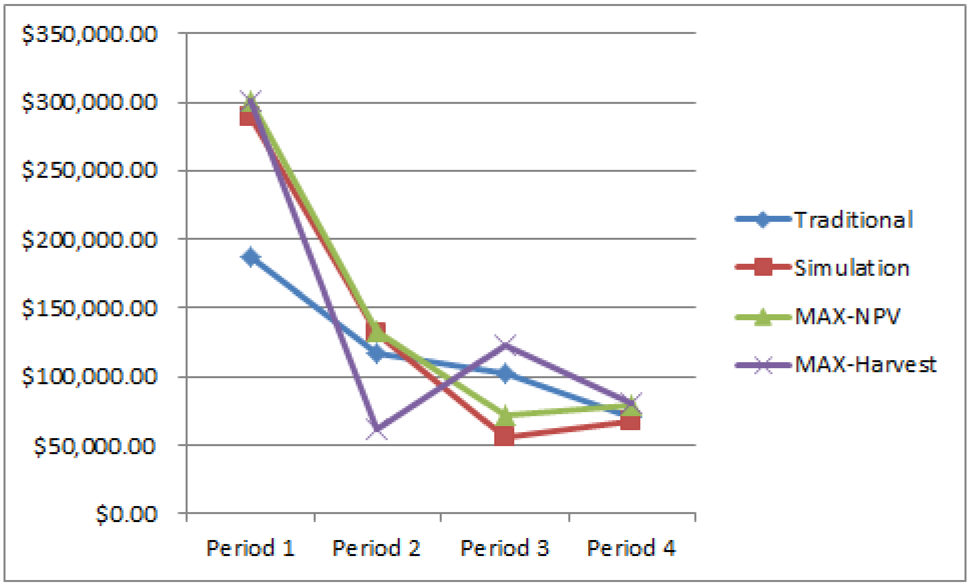


Figure 4.7: Change in NPV during each period for each method

Figure 4.7 indicates NPV change for each method. From the figure it is clear that maximization of NPV model is the best model for NPV.

From period 1 to period 2, NPV fell gradually for all methods. From period 2 to period 3, there was a significant increase in NPV for maximization of total harvest volume. In this time period, NPV in other models dropped slightly. From period 3 to period 4, there was a significant increase for the simulation method and the maximization of NPV method. The maximization of total harvest volume and the traditional method showed a decrease in NPV during this time period.

In summary, the maximization of NPV method provided the best NPV by a considerable margin.

### 4.3.2 Total Harvest Volume Comparison

The second criteria to compare the methods, was the comparison of total harvest volume. When a landowner manages the forest, the most important aspect behind profits is keeping the forest sustainable. There are many ways to do that such as limiting inventory, using the area control method, or the volume control method, which constraints for harvesting. In light of these kinds of constraints, a land owner should strive to achieve maximum harvest volume.

Our constraint was the area control for sustainable forest products. We have created a model called maximization of total harvest volume to yield the highest possible harvest volume.

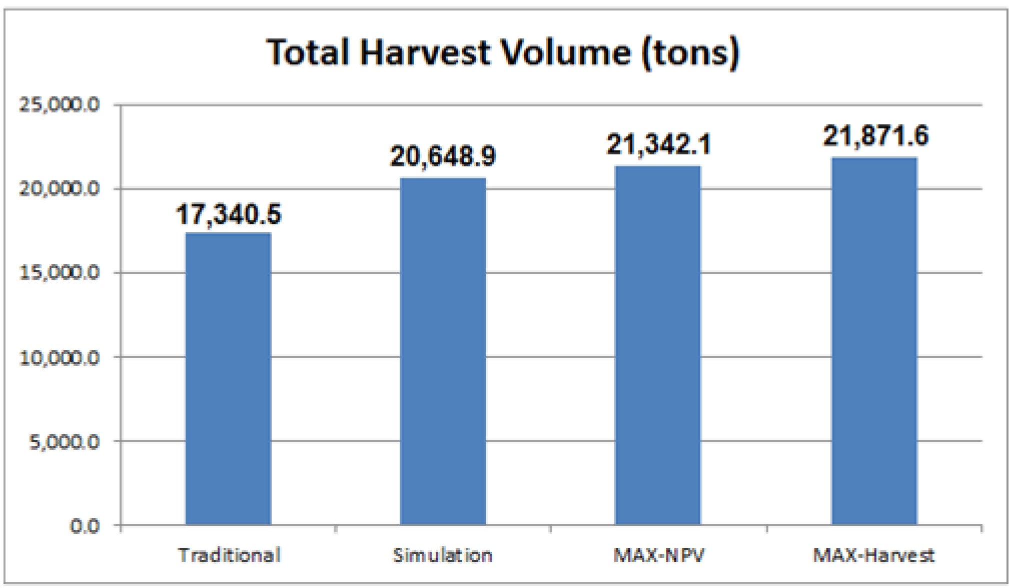


Figure 4.8: Total harvest volume for each method

The maximization of total harvest volume yielded the maximum harvest as we expected. Total harvest volume was 21,871.64 tons, 20.72% more than the traditional method, 5.59% more than the simulation method, and 2.42% more than the maximization of NPV method (Figure 4.8).

Total harvested pulpwood volume was highest for the maximization of total harvest volume (Figure 4.9). Total harvested chip-n-saw timber volume was highest for the simulation model (Figure 4.10). Total harvested sawtimber volume was highest for the maximization of NPV method (Figure 4.11).

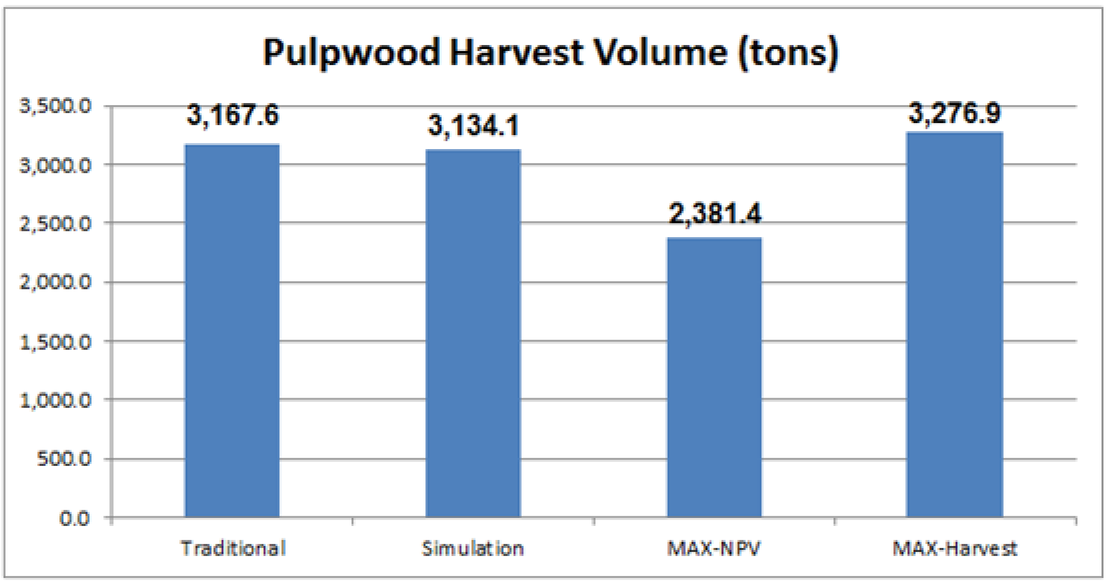


Figure 4.9: Total harvested pulpwood volume for each method

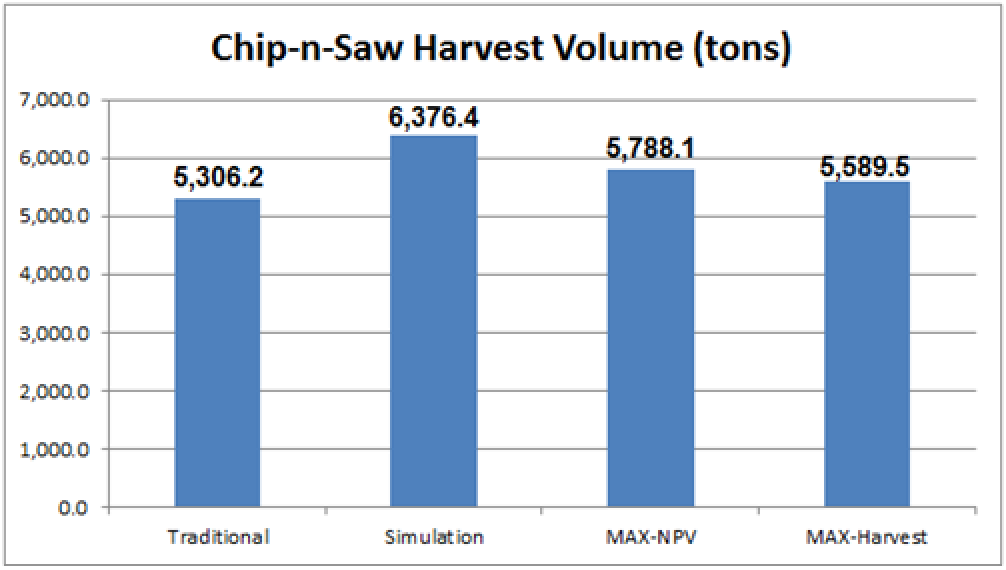

Figure 4.10: Total harvested chip-n-saw volume for each method

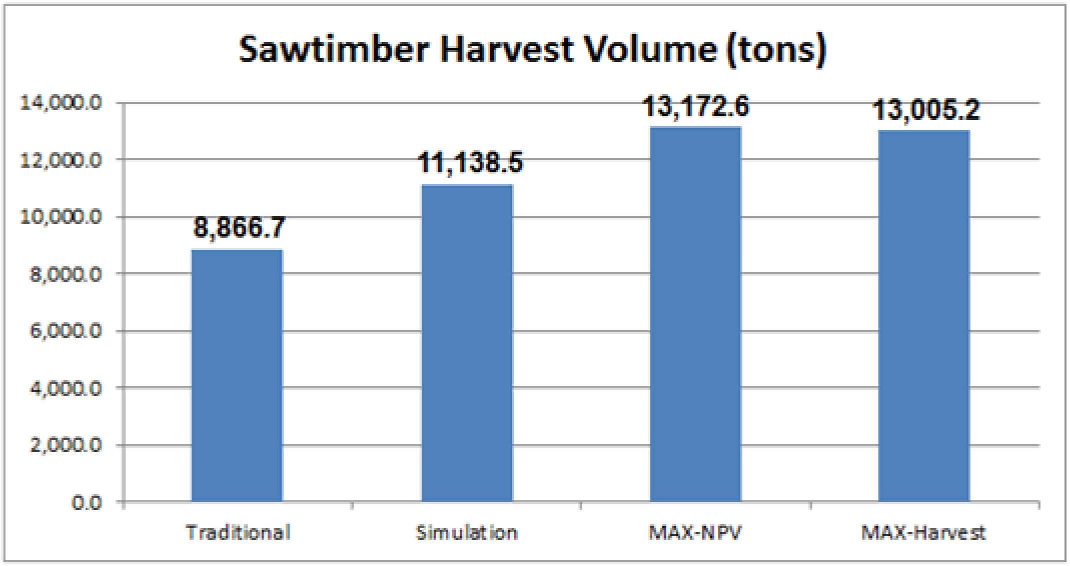

Figure 4.11: Total harvested sawtimber volume for each method

# Chapter 5

# Conclusion and Recommendation

## 5.1 Conclusion and Recommendation

In this study, we aimed a compare the Woodstock model approach to the traditional harvest scheduling approaches. We first found the volume of each stand of loblolly pine. Then we simulated volume across a 20-years period, which was our planning horizon. Other species could not be simulated due to software and research limitation. This was the main limitation for the study. Secondly, we found that the optimal rotation age was 30 years, with only one thinning occurring after 15-20 years (see Chapter 3). Using the traditional method, we used area control methods to clear-cut only about 40 acres each period. We used “oldest first” selection rules which indicated that older stands must harvested and regenerated first. As a result, we scheduled our harvest and found NPV to be $476,848.24, for the planning horizon. This is the amount that the school would profit if technology was not used.

We created three Woodstock models: (1) Simulation model, (2) maximization on harvest volume model, and (3) maximization of NPV model. Our Simulation model was formulated to simulate a forest according to the area control method and the oldest first final harvest selection method. This was what we did using the traditional method. The maximization of harvest model was formulated to maximize total harvest volume of yielded clear-cut and thinning in 20 years. The maximization of NPV model was formulated to maximize net present value.

We ran all of the Woodstock models step by step, and we conduced that all of them included a much higher NPV compared to the traditional method. The maximization of NPV model was the best for net present value. The maximization of harvest volume was the best for yielded total harvest volume. The simulation model was best in cases where maximization on NPV and harvest volume was not the objective, but reaching specific targets for these metrics was desired.

Stanley would be used for spatial constraints but we did not have any spatial constraints due to the fact that we selected a small area. On the other hand, the only drawback to the software that we observed was that Stanly was not able to divide or allocate divided stands as we desired. Some stands were specifically harvested in periods. In this case, we wanted to divide them as nearly as possible according to the Woodstock model reports. We were not able to do that using Stanly.

In conclusion, the Woodstock models were much better than the traditional method in case of maximization of NPV and harvest volume. Also, harvest scheduling was easier using the Woodstock model approach. In addition, using Stanley spatial constraints would benefit the forest ecologically.

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# Appendices

## Appendix A. Simulation Method Woodstock Model formulation

```
; Actions
*ACTION ccplt Y clearcut planting
 *OPERABLE ccplt
  ? _AGE >= 5 { age is in periods }
*ACTION thin N commercial thin
 *OPERABLE thin
  03 _AGE = 4
  04 _AGE = 4
  07 _AGE = 4
  08 _AGE = 4
  09 _AGE = 4
  12 _AGE = 4
  15 _AGE = 4
  18 _AGE = 4
  18 _AGE = 4
  33 _AGE = 4
  34 _AGE = 4
  11 _AGE = 5
  13a _AGE = 5
  13b _AGE = 5
  13c _AGE = 5
  14a _AGE = 5
  14b _AGE = 5
  14c _AGE = 5
  lbyave _AGE = 3
  lbyg _AGE = 3
  lbyp _AGE = 3
*PARTIAL thin
pulp chip-saw saw

; Areas
*A 01 12 10.0988
*A 02 12 4.9599
*A 03 4 9.9207
*A 04 2 13.4352
*A 07 4 3.6618
*A 08 4 15.0981
*A 09 4 8.7566
*A 11 5 14.0463
*A 12 4 18.6961
*A 13a 5 6.0648
*A 13b 5 9.4002
*A 13c 5 3.5325
*A 14a 5 6.6164
*A 14b 5 2.7379
*A 14c 5 2.4667
*A 15 2 1.6269
*A 17 8 15.4669
*A 18 2 11.0504
*A 22 8 8.6535
*A 23a 8 3.31
*A 23b 8 18.3
*A 23c 8 23.9747
*A 24 8 2.6391
*A 25 8 1.8149
```

```
*A 27 8 4.4965
*A 27a 8 0.2491
*A 28 8 8.3497
*A 33 2 5.3872
*A 34 2 5.6354

; Control
*LENGTH   4
*GRAPHICS OFF
*REPORTS  ON
*IMAGE    OFF
*BUILD    OFF
*OPTIMIZE OFF
*SCHEDULE OFF
*QUEUE    ON

; Landscape
*THEME  stand number
01  stand 01
02  stand 02
03  stand 03 unthinned
03t stand 03 thinned
04  stand 04 unthinned
04t stand 04 thinned
07  stand 07 unthinned
07t  stand 07 thinned
08 stand 08 unthinned
08t stand 08 thinned
09 stand 09 unthinned
09t stand 09 thinned
11 stand 11 unthinned
11t stand 11 thinned
12  stand 12 unthinned
12t  stand 12 thinned
13a  stand 13a unthinned
13at stand 13a thinned
13b  stand 13b unthinned
13bt stand 13b thinned
13c  stand 13c unthinned
13ct stand 13c thinned
14a  stand 14a unthinned
14at stand 14a thinned
14b stand 14b unthinned
14bt stand 14b thinned
14c stand 14c unthinned
14ct stand 14c thinned
15  stand 15 unthinned
15t stand 15 thinned
17  Stand 17
18  stand 18 unthinned
18t stand 018 thinned
22  Stand 22
23a  Stand 23a
23b Stand 23b
23c  Stand 23c
24  Stand 24
25  Stand 25
```

```
27  Stand 27
27a Stand 27a
28 stand 28
33 stand 33 unthinned
33t stand 33 thinned
34 stand 34 unthinned
34t stand 34 thinned
lbyave  stand lobloly pine average site quality unthinned
lbyavet stand lblyave thinned
lbyp  stand lbyp unthinned
lbypt stand lbyp thinned
lbyg  stand lbyg unthinned
lbygt stand lbyg thinned
; Lifespan
? 25; maximum lifespan for all types = 125yrs
; Outputs
*OUTPUT ccpltth  clear cut area
*SOURCE ? ccplt _AREA
*OUTPUT thinth  thinnid area
*SOURCE ? thin _AREA

;volume
;thin harvestvolume
*OUTPUT thinpulp thin pulpwood harvest
*SOURCE ? thin pulp
*OUTPUT thinchipsaw thin chip-saw harvest
*SOURCE ? thin chip-saw
*OUTPUT thinsaw thin sawtimber harvest
*SOURCE ? thin saw
*OUTPUT thinharvest thin harvest volume
*SOURCE  thinpulp + thinchipsaw + thinsaw
;clear cut harvest volume
*OUTPUT ccpltpulp clear cut pulpwood harvest volume
*SOURCE ? ccplt pulp
*OUTPUT ccpltchipsaw clear cut Chip&Sawtimber  harvest volume
*SOURCE ? ccplt chip-saw
*OUTPUT ccpltsaw clear cut sawtimber harvest volume
*SOURCE ? ccplt saw
*OUTPUT ccpltharvest Clear cut volume
*SOURCE ccpltpulp + ccpltchipsaw + ccpltsaw
*OUTPUT totharvest Total harvest volume
*SOURCE thinharvest + ccpltharvest
; volume depend on product
*OUTPUT Pulpvol Pulpwood volume
*SOURCE ? ccplt Pulp + ? thin Pulp
*OUTPUT Chip-sawvol Chip and Sawtimber volume
*SOURCE ? ccplt Chip-saw + ? thin Chip-saw
*OUTPUT Sawvol Sawtimber volume
*SOURCE ? ccplt Saw + ? thin Saw

;Revenue
*OUTPUT Pulprev Pulpwood revenue
*SOURCE Pulpvol * Pulp$
*OUTPUT Chip-sawrev Chip and Sawtimber revenue
*SOURCE Chip-sawvol * Chip-saw$
*OUTPUT Sawrev Sawtimber revenue
*SOURCE Sawvol * Saw$
```

```
*OUTPUT trev total revenue
*SOURCE Pulprev + Chip-sawrev + Sawrev


;Costs
;After thin fertilization cost
*OUTPUT bdt03 stand 03 thin cost
*SOURCE 03 thin  frtz$
*OUTPUT bdt04 stand 04 thin cost
*SOURCE 04 thin  frtz$
*OUTPUT bdt07 stand 07 thin cost
*SOURCE 07 thin  frtz$
*OUTPUT bdt08 stand 08 thin cost
*SOURCE 08 thin  frtz$
*OUTPUT bdt09 stand 09 thin cost
*SOURCE 09 thin  frtz$
*OUTPUT bdt12 stand 12 thin cost
*SOURCE 12 thin  frtz$
*OUTPUT bdt15 stand 15 thin cost
*SOURCE 15 thin  frtz$
*OUTPUT bdt33 stand 33 thin cost
*SOURCE 33 thin  frtz$
*OUTPUT bdt18 stand 18 thin cost
*SOURCE 18 thin  frtz$
*OUTPUT bdt34 stand 34 thin cost
*SOURCE 34 thin  frtz$
*OUTPUT bdtlbyave stand lbyave thin cost
*SOURCE lbyave thin  frtz$
*OUTPUT bdtlbyp stand lbyp thin cost
*SOURCE lbyp thin  frtz$
*OUTPUT bdtlbyg stand lbyg thin cost
*SOURCE lbyg thin  frtz$
*OUTPUT thincost thin fertilization cost
*SOURCE  bdt03 +  bdt04 + bdt07 + bdt08 +  bdt09 + bdt12 + bdt15 +
bdt33 + bdt18 + bdt34 + bdtlbyave + bdtlbyp + bdtlbyg
;establishment cost
*OUTPUT bdtest establishment cost
*SOURCE ? ccplt est$
;total cost
*OUTPUT budget silvicultural cost
*SOURCE thincost + bdtest

;Discount of revenues and costs
*OUTPUT distrev Discounted revenue
*SOURCE trev * disc5%
*OUTPUT discost Discounted expenditures
*SOURCE budget * disc5%

;net value and net present value
*OUTPUT nv net value
*SOURCE trev - budget
*OUTPUT npv net present value
*SOURCE distrev - discost

;Clear cut areas for each stand
*OUTPUT 01clr Stand 01 clear-cut area
*SOURCE 01 ccplt _AREA
```

```
*OUTPUT 02clr Stand 02 clear-cut area
*SOURCE 02 ccplt _AREA
*OUTPUT 03clr Stand 03 clear-cut area
*SOURCE 03 ccplt _AREA + 03t ccplt _AREA
*OUTPUT 04clr Stand 04 clear-cut area
*SOURCE 04 ccplt _AREA + 04t ccplt _AREA
*OUTPUT 07clr Stand 07 clear-cut area
*SOURCE 07 ccplt _AREA + 07t ccplt _AREA
*OUTPUT 08clr Stand 08 clear-cut area
*SOURCE 08 ccplt _AREA + 08t ccplt _AREA
*OUTPUT 09clr Stand 09 clear-cut area
*SOURCE 09 ccplt _AREA + 09t ccplt _AREA
*OUTPUT 11clr Stand 11 clear-cut area
*SOURCE 11 ccplt _AREA + 11t ccplt _AREA
*OUTPUT 12clr Stand 12 clear-cut area
*SOURCE 12 ccplt _AREA + 12t ccplt _AREA
*OUTPUT 13aclr Stand 13a clear-cut area
*SOURCE 13a ccplt _AREA + 13at ccplt _AREA
*OUTPUT 13bclr Stand 13b clear-cut area
*SOURCE 13b ccplt _AREA + 13bt ccplt _AREA
*OUTPUT 13cclr Stand 13c clear-cut area
*SOURCE 13c ccplt _AREA + 13ct ccplt _AREA
*OUTPUT 14aclr Stand 14a clear-cut area
*SOURCE 14a ccplt _AREA + 14at ccplt _AREA
*OUTPUT 14bclr Stand 14b clear-cut area
*SOURCE 14b ccplt _AREA + 14bt ccplt _AREA
*OUTPUT 14cclr Stand 14c clear-cut area
*SOURCE 14c ccplt _AREA + 14ct ccplt _AREA
*OUTPUT 15clr Stand 15 clear-cut area
*SOURCE 15 ccplt _AREA + 15t ccplt _AREA
*OUTPUT 33clr Stand 33 clear-cut area
*SOURCE 33 ccplt _AREA + 33t ccplt _AREA
*OUTPUT 18clr Stand 18 clear-cut area
*SOURCE 18 ccplt _AREA + 18t ccplt _AREA
*OUTPUT 34clr Stand 34 clear-cut area
*SOURCE 34 ccplt _AREA + 34t ccplt _AREA
*OUTPUT 22clr Stand 22 clear-cut area
*SOURCE 22 ccplt _AREA
*OUTPUT 23aclr Stand 23a clear-cut area
*SOURCE 23a ccplt _AREA
*OUTPUT 23bclr Stand 23b clear-cut area
*SOURCE 23b ccplt _AREA
*OUTPUT 23cclr Stand 23c clear-cut area
*SOURCE 23c ccplt _AREA
*OUTPUT 24clr Stand 24 clear-cut area
*SOURCE 24 ccplt _AREA
*OUTPUT 25clr Stand 25 clear-cut area
*SOURCE 25 ccplt _AREA
*OUTPUT 27clr Stand 27 clear-cut area
*SOURCE 27 ccplt _AREA
*OUTPUT 27aclr Stand 27a clear-cut area
*SOURCE 27a ccplt _AREA
*OUTPUT 28clr Stand 28 clear-cut area
*SOURCE 28 ccplt _AREA
*OUTPUT 17clr Stand 17 clear-cut area
*SOURCE 17 ccplt _AREA
```

```
;total harvest volume based on totv
*OUTPUT harvest total totv harvest volume
*SOURCE ? ccplt totv + ? thin totv

; Reports
*TARGET  THomas.txt
ccpltth 1.._LENGTH
thinth 1.._LENGTH
nv  1.._LENGTH
npv 1.._LENGTH

totharvest 1.._LENGTH
ccpltharvest 1.._LENGTH
thinharvest 1.._LENGTH
Pulpvol 1.._LENGTH
Chip-sawvol 1.._LENGTH
Sawvol 1.._LENGTH

01clr 1.._LENGTH
02clr 1.._LENGTH
03clr 1.._LENGTH
04clr 1.._LENGTH
07clr 1.._LENGTH
08clr 1.._LENGTH
09clr 1.._LENGTH
11clr 1.._LENGTH
12clr 1.._LENGTH
13aclr 1.._LENGTH
13bclr 1.._LENGTH
13cclr 1.._LENGTH
14aclr 1.._LENGTH
14bclr 1.._LENGTH
14cclr 1.._LENGTH
15clr 1.._LENGTH
33clr 1.._LENGTH
18clr 1.._LENGTH
34clr 1.._LENGTH
22clr 1.._LENGTH
23aclr 1.._LENGTH
23bclr 1.._LENGTH
23cclr 1.._LENGTH
24clr 1.._LENGTH
25clr 1.._LENGTH
27clr 1.._LENGTH
27aclr 1.._LENGTH
28clr 1.._LENGTH
17clr 1.._LENGTH
; Transitions
*CASE ccplt
*SOURCE 01
 *TARGET lbyave 100
*SOURCE 02
 *TARGET lbyave 100
*SOURCE 03
 *TARGET lbyave 100
*SOURCE 08
 *TARGET lbyave 100
```

```
*SOURCE 09
 *TARGET lbyave 100
*SOURCE 11
 *TARGET lbyave 100
*SOURCE 12
 *TARGET lbyave 100
*SOURCE 13a
 *TARGET lbyave 100
*SOURCE 13b
 *TARGET lbyave 100
*SOURCE 13c
 *TARGET lbyave 100
*SOURCE 14a
 *TARGET lbyave 100
*SOURCE 14b
 *TARGET lbyave 100
*SOURCE 14c
 *TARGET lbyave 100
*SOURCE 15
 *TARGET lbyave 100
*SOURCE 17
 *TARGET lbyave 100
*SOURCE 18
 *TARGET lbyave 100
*SOURCE 22
 *TARGET lbyave 100
*SOURCE 23a
 *TARGET lbyave 100
*SOURCE 23b
 *TARGET lbyave 100
*SOURCE 23c
 *TARGET lbyave 100
*SOURCE 24
 *TARGET lbyave 100
*SOURCE 33
 *TARGET lbyave 100
*SOURCE 34
 *TARGET lbyave 100
*SOURCE 04
 *TARGET lbyp 100

*SOURCE 25
 *TARGET lbyp 100
*SOURCE 27
 *TARGET lbyp 100
*SOURCE 27a
 *TARGET lbyp 100
*SOURCE 28
 *TARGET lbyp 100
*SOURCE 07
 *TARGET lbyg 100
*SOURCE 03t
 *TARGET lbyave 100
*SOURCE 08t
 *TARGET lbyave 100
*SOURCE 09t
 *TARGET lbyave 100
```

```
*SOURCE 11t
 *TARGET lbyave 100
*SOURCE 12t
 *TARGET lbyave 100
*SOURCE 13at
 *TARGET lbyave 100
*SOURCE 13bt
 *TARGET lbyave 100
*SOURCE 13ct
 *TARGET lbyave 100
*SOURCE 14bt
 *TARGET lbyave 100
*SOURCE 14at
 *TARGET lbyave 100
*SOURCE 14ct
 *TARGET lbyave 100
*SOURCE 15t
 *TARGET lbyave 100
*SOURCE 18t
 *TARGET lbyave 100
*SOURCE 33t
 *TARGET lbyave 100
*SOURCE 34t
 *TARGET lbyave 100
*SOURCE 04t
 *TARGET lbyp 100
*SOURCE 07t
 *TARGET lbyg 100

*CASE thin
*SOURCE 03
 *TARGET 03t 100
*SOURCE 04
 *TARGET 04t 100
*SOURCE 07
 *TARGET 07t 100
*SOURCE 08
 *TARGET 08t 100
*SOURCE 09
 *TARGET 09t 100
*SOURCE 11
 *TARGET 11t 100
*SOURCE 12
 *TARGET 12t 100
*SOURCE 13a
 *TARGET 13at 100
*SOURCE 13b
 *TARGET 13bt 100
*SOURCE 13c
 *TARGET 13ct 100
*SOURCE 14a
 *TARGET 14at 100
*SOURCE 14b
 *TARGET 14bt 100
*SOURCE 14c
 *TARGET 14ct 100
*SOURCE 15
```

```
 *TARGET 15t 100
*SOURCE 18
 *TARGET 18t 100
*SOURCE 33
 *TARGET 33t 100
*SOURCE 34
 *TARGET 34t 100
*SOURCE lbyave
 *TARGET lbyavet 100
*SOURCE lbyp
 *TARGET lbypt 100
*SOURCE lbyg
 *TARGET lbygt 100
; Yields
;volume in tons
 *Y 01 { stand 1 }
_AGE      Pulp   Chip-Saw   Saw
12         -         -       115.3
13         -         -      118.3
14         -         -       120.6
15         -         -       121.1
 *Y 02 {stand 2 }
_AGE     Pulp   Chip-Saw   Saw
12       -      21.6      95.7
13       -      2.7       116
14       -        -        118
15       -        -        114.4
*Y 03 {stand 3 unthinned}
_AGE     Pulp   Chip-Saw   Saw
4        23.6   70.6       -
5        16.2   99.3       4.9
6        10.2   109.3      15.1
7        6.2    105.7      38.5
*Y 03t {stand 3 thinned}
_AGE     Pulp   Chip-Saw   Saw
4         -     35.4       -
5         -     42.3      13.5
6         -     24.5      46.5
7         -     7         80.1
*Y 04 {stand 4 unthinned}
_AGE   Pulp   Chip-Saw   Saw
2       -        -       -
3       11.3     -       -
4       33.2   1.7       -
5       42.6    11.5     -
*Y 04t {stand 4 thinned}
_AGE    Pulp   Chip-Saw   Saw
2        -        -        -
3       11.3     -         -
4       23     1           -
5       27.6   13.6        -
*Y 07 {stand 7 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
```

```
*Y 08 {stand 8 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
*Y 07t {stand 7 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 08t {stand 8 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 09 {stand 09 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     56        2.7
5       0.8     57.4      27.5
6       0.4     45.6      61.9
7       0.1     33.1      92.6
*Y 09t {stand 09 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -     33.4       2.2
5        -     22.2       30.9
6        -     2.5        68.6
7        -     0.2        92.2
*Y 11 {stand 11 unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       14.9   60.2       1.8
6       8.9    75.7       8.2
7       5.6    76.8       21.3
8       3.3    67.6       35.7
*Y 11t {stand 11 thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -     40         1.8
6        -     44.8       12.2
7        -     37.5       32.3
8        -     20.4       61.2
*Y 12 {stand 12 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     55.6       2.7
5       0.6     58.5       26.7
6       0.5     45.3       61.3
7       0.1     35.4       90.1
*Y 12t {stand 12 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -      33.3      2.2
5        -      21        31.8
6        -      3.5       67.7
7        -      -         92.3
*Y 13a {stand 13a unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
```

```
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13b {stand 13b unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13c {stand 13c unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14a {stand 14a unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14b {stand 14b unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14c {stand 14c unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13at {stand 13a thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 13bt {stand 13b thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 13ct {stand 13c thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 14at {stand 14a thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
```

```
*Y 14bt {stand 14b thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 14ct {stand 14c thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -     39.5      1.6
6         -     42.1      13.3
7         -     34.9      34
8         -     18.2      63.5
*Y 15 {stand 15 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       29      0.6       -
4       45.2    12.8      -
5       43.6    36.1      -
*Y 33 {stand 33 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -      -           -
3       29      0.6        -
4       45.2    12.8       -
5       43.6    36.1       -
*Y 33t {stand 33 thinned}
_AGE    Pulp   Chip-Saw   Saw
2        -     -           -
3       29     0.6         -
4       19.5   10.4        -
5       2.7    43.7        -
*Y 15t {stand 15 thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       29     0.6        -
4       19.5   10.4       -
5       2.7    43.7       -
*Y 22 {stand 22 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1     27         78.3
9        -      17.2       65.2
10       -      12.4       77
11       -      7.6        85.9
*Y 23a {stand 23a unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1     26.3      45.3
9       0.1     17.8      63.6
10      -       10.3      75.5
11      -       5.4       84.8
*Y 23b {stand 23b unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1      75.1
9       -       25.4       83.3
10      -       13.1       110
11      -       7.8        123.1
*Y 23c {stand 23c unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1      75.1
```

```
9       -       25.4      83.3
10      -       13.1      110
11      -       7.8       123.1
*Y 24 {stand 24 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1      75.1
9       -       25.4      83.3
10      -       13.1      110
11      -       7.8       123.1
*Y 18 {stand 18 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -         -       -
3       23        -       -
4       45.3    8.1       -
5       46.3    30.8      -
*Y 34 {stand 34 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -       -         -
3       23      -         -
4       45.3    8.1       -
5       46.3    30.8      -
*Y 34t {stand 34 thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -         -       -
3       23        -       -
4       22.4    6.8       -
5       5.2     40.7      -
*Y 18t {stand  thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       23       0        -
4       22.4    6.8       -
5       5.2     40.7      -
*Y 25 {stand 25 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       -       19.2      46.3
9       -       11.6      65.3
10      -       6.5       78.9
11      -       4.8       90.1
*Y 27 {stand 27 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8        -      19.2      46.3
9        -      11.6      65.3
10       -      6.5       78.9
11       -      4.8       90.1
*Y 28 {stand 28 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       1.6      53.6     156
9       0.9      48       31.1
10      0.6      38.8     47.2
11      0.2      28.4     63.6
*Y 27a {stand 27a unthinned}
_AGE    Pulp   Chip-Saw   Saw
8        -       30.4      11
9        -       10        35.5
10       -       3         48.9
11       -       1.8       56.7
```

```
*Y 17 {stand 17 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       56.9    20.8       -
9       57.9    27.8       -
10      51.3    28.4       -
11      31.3    41.2       -
*Y lbyave {stand lblyave unthinned}
_AGE    Pulp   Chip-Saw   Saw
1        -       -        -
2       18.9    0.3       -
3       34.5    15.7      -
*Y lbyavet {stand lblyave thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -      -         -
2       18.9    0.3       -
3       16.5    12.5      -
4       12.4    41        -
*Y lbyp {stand lblyp unthinned}
_AGE    Pulp   Chip-Saw   Saw
1        -       -        -
2       9.6     0         -
3       28.3    5.2       -
*Y lbypt {stand lblyp thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -        -       -
2       9.6      -        -
3       16.3   4.3        -
4       12.6   24.6       -
*Y lbyg {stand lblyg unthinned}
_AGE    Pulp   Chip-Saw   Saw
1       -       -          -
2       26.8   2.5         -
3       36.3   32.5        -
*Y lbygt {stand lblyg thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -     -          -
2       26.8   2.5        -
3       14.8   25.4       -
4       17.8   51.7       -
*YT ?
est$ 1 232.31
frtz$ 1 86.33
*YT ?
disc5% _DISCOUNTFACTOR (5%,5,half)

*YT ?
; stumpage in $/tons
Pulp$ 1 9.32
Chip-Saw$ 1 37.31
Saw$ 1 50
*YC ? ? ? ?
totv _SUM (Pulp, Chip-saw, Saw)
; Queue
*SELECT thin
_MAX _AGE
*SELECT ccplt
_MAX _AGE
```

```
*TARGET ccpltth = 40 1.._LENGTH
*SOURCE ccplt 100
*TARGET thinth = 100.9981 1
*SOURCE thin 100
*TARGET thinth = 37 3
*SOURCE thin 100
*TARGET thinth = 40 4
*SOURCE thin 100
```

## Appendix B. Maximization of Harvest Volume Woodstock Model formulation

```
; Actions
*ACTION ccplt Y clearcut planting
 *OPERABLE ccplt
  ? _AGE >= 5 { age is in periods }
*ACTION thin N commercial thin
 *OPERABLE thin
  03 _AGE = 4
  04 _AGE = 4
  07 _AGE = 4
  08 _AGE = 4
  09 _AGE = 4
  12 _AGE = 4
  15 _AGE = 4
  18 _AGE = 4
  18 _AGE = 4
  33 _AGE = 4
  34 _AGE = 4
  11 _AGE = 5
  13a _AGE = 5
  13b _AGE = 5
  13c _AGE = 5
  14a _AGE = 5
  14b _AGE = 5
  14c _AGE = 5
  lbyave _AGE = 3
  lbyg _AGE = 3
  lbyp _AGE = 3
*PARTIAL thin
pulp chip-saw saw
; Areas
*A 01 12 10.0988
*A 02 12 4.9599
*A 03 4 9.9207
*A 04 2 13.4352
*A 07 4 3.6618
*A 08 4 15.0981
*A 09 4 8.7566
*A 11 5 14.0463
*A 12 4 18.6961
*A 13a 5 6.0648
*A 13b 5 9.4002
*A 13c 5 3.5325
*A 14a 5 6.6164
*A 14b 5 2.7379
*A 14c 5 2.4667
*A 15 2 1.6269
*A 17 8 15.4669
*A 18 2 11.0504
*A 22 8 8.6535
*A 23a 8 3.31
*A 23b 8 18.3
*A 23c 8 23.9747
*A 24 8 2.6391
*A 25 8 1.8149
```

```
*A 27 8 4.4965
*A 27a 8 0.2491
*A 28 8 8.3497
*A 33 2 5.3872
*A 34 2 5.6354
; Control
*LENGTH   4
*GRAPHICS OFF
*REPORTS  ON
*IMAGE    OFF
*BUILD    OFF
*OPTIMIZE OFF
*SCHEDULE ON
*QUEUE    OFF
; Landscape
*THEME  stand number
01  stand 01
02  stand 02
03  stand 03 unthinned
03t stand 03 thinned
04  stand 04 unthinned
04t stand 04 thinned
07  stand 07 unthinned
07t  stand 07 thinned
08 stand 08 unthinned
08t stand 08 thinned
09 stand 09 unthinned
09t stand 09 thinned
11 stand 11 unthinned
11t stand 11 thinned
12  stand 12 unthinned
12t  stand 12 thinned
13a  stand 13a unthinned
13at stand 13a thinned
13b  stand 13b unthinned
13bt stand 13b thinned
13c  stand 13c unthinned
13ct stand 13c thinned
14a  stand 14a unthinned
14at stand 14a thinned
14b stand 14b unthinned
14bt stand 14b thinned
14c stand 14c unthinned
14ct stand 14c thinned
15  stand 15 unthinned
15t stand 15 thinned
17  Stand 17
18  stand 18 unthinned
18t stand 018 thinned
22  Stand 22
23a  Stand 23a
23b Stand 23b
23c  Stand 23c
24  Stand 24
25  Stand 25
27  Stand 27
27a Stand 27a
```

```
28 stand 28
33 stand 33 unthinned
33t stand 33 thinned
34 stand 34 unthinned
34t stand 34 thinned
lbyave  stand lobloly pine average site quality unthinned
lbyavet stand lblyave thinned
lbyp  stand lbyp unthinned
lbypt stand lbyp thinned
lbyg  stand lbyg unthinned
lbygt stand lbyg thinned
; Lifespan
? 25; maximum lifespan for all types = 125yrs
*OBJECTIVE

 _MAX harvest 1.._LENGTH
*CONSTRAINTS
   ccpltth = 40 1.._LENGTH
*FORMAT MOSEK
; Outputs
*OUTPUT ccpltth  clear cut area
*SOURCE ? ccplt _AREA
*OUTPUT thinth  thinnid area
*SOURCE ? thin _AREA

;volume
;thin harvestvolume
*OUTPUT thinpulp thin pulpwood harvest
*SOURCE ? thin pulp
*OUTPUT thinchipsaw thin chip-saw harvest
*SOURCE ? thin chip-saw
*OUTPUT thinsaw thin sawtimber harvest
*SOURCE ? thin saw
*OUTPUT thinharvest thin harvest volume
*SOURCE  thinpulp + thinchipsaw + thinsaw
;clear cut harvest volume
*OUTPUT ccpltpulp clear cut pulpwood harvest volume
*SOURCE ? ccplt pulp
*OUTPUT ccpltchipsaw clear cut Chip&Sawtimber  harvest volume
*SOURCE ? ccplt chip-saw
*OUTPUT ccpltsaw clear cut sawtimber harvest volume
*SOURCE ? ccplt saw
*OUTPUT ccpltharvest Clear cut volume
*SOURCE ccpltpulp + ccpltchipsaw + ccpltsaw
*OUTPUT totharvest Total harvest volume
*SOURCE thinharvest + ccpltharvest
; volume depend on product
*OUTPUT Pulpvol Pulpwood volume
*SOURCE ? ccplt Pulp + ? thin Pulp
*OUTPUT Chip-sawvol Chip and Sawtimber volume
*SOURCE ? ccplt Chip-saw + ? thin Chip-saw
*OUTPUT Sawvol Sawtimber volume
*SOURCE ? ccplt Saw + ? thin Saw

;Revenue
*OUTPUT Pulprev Pulpwood revenue
*SOURCE Pulpvol * Pulp$
```

```
*OUTPUT Chip-sawrev Chip and Sawtimber revenue
*SOURCE Chip-sawvol * Chip-saw$
*OUTPUT Sawrev Sawtimber revenue
*SOURCE Sawvol * Saw$
*OUTPUT trev total revenue
*SOURCE Pulprev + Chip-sawrev + Sawrev


;Costs
;After thin fertilization cost
*OUTPUT bdt03 stand 03 thin cost
*SOURCE 03 thin  frtz$
*OUTPUT bdt04 stand 04 thin cost
*SOURCE 04 thin  frtz$
*OUTPUT bdt07 stand 07 thin cost
*SOURCE 07 thin  frtz$
*OUTPUT bdt08 stand 08 thin cost
*SOURCE 08 thin  frtz$
*OUTPUT bdt09 stand 09 thin cost
*SOURCE 09 thin  frtz$
*OUTPUT bdt12 stand 12 thin cost
*SOURCE 12 thin  frtz$
*OUTPUT bdt15 stand 15 thin cost
*SOURCE 15 thin  frtz$
*OUTPUT bdt33 stand 33 thin cost
*SOURCE 33 thin  frtz$
*OUTPUT bdt18 stand 18 thin cost
*SOURCE 18 thin  frtz$
*OUTPUT bdt34 stand 34 thin cost
*SOURCE 34 thin  frtz$
*OUTPUT bdtlbyave stand lbyave thin cost
*SOURCE lbyave thin  frtz$
*OUTPUT bdtlbyp stand lbyp thin cost
*SOURCE lbyp thin  frtz$
*OUTPUT bdtlbyg stand lbyg thin cost
*SOURCE lbyg thin  frtz$
*OUTPUT thincost thin fertilization cost
*SOURCE  bdt03 +  bdt04 + bdt07 + bdt08 +  bdt09 + bdt12 + bdt15 +
bdt33 + bdt18 + bdt34 + bdtlbyave + bdtlbyp + bdtlbyg
;establishment cost
*OUTPUT bdtest establishment cost
*SOURCE ? ccplt est$
;total cost
*OUTPUT budget silvicultural cost
*SOURCE thincost + bdtest

;Discount of revenues and costs
*OUTPUT distrev Discounted revenue
*SOURCE trev * disc5%
*OUTPUT discost Discounted expenditures
*SOURCE budget * disc5%

;net value and net present value
*OUTPUT nv net value
*SOURCE trev - budget
*OUTPUT npv net present value
*SOURCE distrev - discost
```

```
;Clear cut areas for each stand
*OUTPUT 01clr Stand 01 clear-cut area
*SOURCE 01 ccplt _AREA
*OUTPUT 02clr Stand 02 clear-cut area
*SOURCE 02 ccplt _AREA
*OUTPUT 03clr Stand 03 clear-cut area
*SOURCE 03 ccplt _AREA + 03t ccplt _AREA
*OUTPUT 04clr Stand 04 clear-cut area
*SOURCE 04 ccplt _AREA + 04t ccplt _AREA
*OUTPUT 07clr Stand 07 clear-cut area
*SOURCE 07 ccplt _AREA + 07t ccplt _AREA
*OUTPUT 08clr Stand 08 clear-cut area
*SOURCE 08 ccplt _AREA + 08t ccplt _AREA
*OUTPUT 09clr Stand 09 clear-cut area
*SOURCE 09 ccplt _AREA + 09t ccplt _AREA
*OUTPUT 11clr Stand 11 clear-cut area
*SOURCE 11 ccplt _AREA + 11t ccplt _AREA
*OUTPUT 12clr Stand 12 clear-cut area
*SOURCE 12 ccplt _AREA + 12t ccplt _AREA
*OUTPUT 13aclr Stand 13a clear-cut area
*SOURCE 13a ccplt _AREA + 13at ccplt _AREA
*OUTPUT 13bclr Stand 13b clear-cut area
*SOURCE 13b ccplt _AREA + 13bt ccplt _AREA
*OUTPUT 13cclr Stand 13c clear-cut area
*SOURCE 13c ccplt _AREA + 13ct ccplt _AREA
*OUTPUT 14aclr Stand 14a clear-cut area
*SOURCE 14a ccplt _AREA + 14at ccplt _AREA
*OUTPUT 14bclr Stand 14b clear-cut area
*SOURCE 14b ccplt _AREA + 14bt ccplt _AREA
*OUTPUT 14cclr Stand 14c clear-cut area
*SOURCE 14c ccplt _AREA + 14ct ccplt _AREA
*OUTPUT 15clr Stand 15 clear-cut area
*SOURCE 15 ccplt _AREA + 15t ccplt _AREA
*OUTPUT 33clr Stand 33 clear-cut area
*SOURCE 33 ccplt _AREA + 33t ccplt _AREA
*OUTPUT 18clr Stand 18 clear-cut area
*SOURCE 18 ccplt _AREA + 18t ccplt _AREA
*OUTPUT 34clr Stand 34 clear-cut area
*SOURCE 34 ccplt _AREA + 34t ccplt _AREA
*OUTPUT 22clr Stand 22 clear-cut area
*SOURCE 22 ccplt _AREA
*OUTPUT 23aclr Stand 23a clear-cut area
*SOURCE 23a ccplt _AREA
*OUTPUT 23bclr Stand 23b clear-cut area
*SOURCE 23b ccplt _AREA
*OUTPUT 23cclr Stand 23c clear-cut area
*SOURCE 23c ccplt _AREA
*OUTPUT 24clr Stand 24 clear-cut area
*SOURCE 24 ccplt _AREA
*OUTPUT 25clr Stand 25 clear-cut area
*SOURCE 25 ccplt _AREA
*OUTPUT 27clr Stand 27 clear-cut area
*SOURCE 27 ccplt _AREA
*OUTPUT 27aclr Stand 27a clear-cut area
*SOURCE 27a ccplt _AREA
*OUTPUT 28clr Stand 28 clear-cut area
```

```
*SOURCE 28 ccplt _AREA
*OUTPUT 17clr Stand 17 clear-cut area
*SOURCE 17 ccplt _AREA

;total harvest volume based on totv
*OUTPUT harvest total totv harvest volume
*SOURCE ? ccplt totv + ? thin totv

; Reports
*TARGET  THomas.txt
ccpltth 1.._LENGTH
thinth 1.._LENGTH
nv  1.._LENGTH
npv 1.._LENGTH

totharvest 1.._LENGTH
ccpltharvest 1.._LENGTH
thinharvest 1.._LENGTH
Pulpvol 1.._LENGTH
Chip-sawvol 1.._LENGTH
Sawvol 1.._LENGTH

01clr 1.._LENGTH
02clr 1.._LENGTH
03clr 1.._LENGTH
04clr 1.._LENGTH
07clr 1.._LENGTH
08clr 1.._LENGTH
09clr 1.._LENGTH
11clr 1.._LENGTH
12clr 1.._LENGTH
13aclr 1.._LENGTH
13bclr 1.._LENGTH
13cclr 1.._LENGTH
14aclr 1.._LENGTH
14bclr 1.._LENGTH
14cclr 1.._LENGTH
15clr 1.._LENGTH
33clr 1.._LENGTH
18clr 1.._LENGTH
34clr 1.._LENGTH
22clr 1.._LENGTH
23aclr 1.._LENGTH
23bclr 1.._LENGTH
23cclr 1.._LENGTH
24clr 1.._LENGTH
25clr 1.._LENGTH
27clr 1.._LENGTH
27aclr 1.._LENGTH
28clr 1.._LENGTH
17clr 1.._LENGTH
; Transitions
*CASE ccplt
*SOURCE 01
 *TARGET lbyave 100
*SOURCE 02
 *TARGET lbyave 100
```

```
*SOURCE 03
 *TARGET lbyave 100
*SOURCE 08
 *TARGET lbyave 100
*SOURCE 09
 *TARGET lbyave 100
*SOURCE 11
 *TARGET lbyave 100
*SOURCE 12
 *TARGET lbyave 100
*SOURCE 13a
 *TARGET lbyave 100
*SOURCE 13b
 *TARGET lbyave 100
*SOURCE 13c
 *TARGET lbyave 100
*SOURCE 14a
 *TARGET lbyave 100
*SOURCE 14b
 *TARGET lbyave 100
*SOURCE 14c
 *TARGET lbyave 100
*SOURCE 15
 *TARGET lbyave 100
*SOURCE 17
 *TARGET lbyave 100
*SOURCE 18
 *TARGET lbyave 100
*SOURCE 22
 *TARGET lbyave 100
*SOURCE 23a
 *TARGET lbyave 100
*SOURCE 23b
 *TARGET lbyave 100
*SOURCE 23c
 *TARGET lbyave 100
*SOURCE 24
 *TARGET lbyave 100
*SOURCE 33
 *TARGET lbyave 100
*SOURCE 34
 *TARGET lbyave 100
*SOURCE 04
 *TARGET lbyp 100

*SOURCE 25
 *TARGET lbyp 100
*SOURCE 27
 *TARGET lbyp 100
*SOURCE 27a
 *TARGET lbyp 100
*SOURCE 28
 *TARGET lbyp 100
*SOURCE 07
 *TARGET lbyg 100
*SOURCE 03t
 *TARGET lbyave 100
```

```
*SOURCE 08t
 *TARGET lbyave 100
*SOURCE 09t
 *TARGET lbyave 100
*SOURCE 11t
 *TARGET lbyave 100
*SOURCE 12t
 *TARGET lbyave 100
*SOURCE 13at
 *TARGET lbyave 100
*SOURCE 13bt
 *TARGET lbyave 100
*SOURCE 13ct
 *TARGET lbyave 100
*SOURCE 14bt
 *TARGET lbyave 100
*SOURCE 14at
 *TARGET lbyave 100
*SOURCE 14ct
 *TARGET lbyave 100
*SOURCE 15t
 *TARGET lbyave 100
*SOURCE 18t
 *TARGET lbyave 100
*SOURCE 33t
 *TARGET lbyave 100
*SOURCE 34t
 *TARGET lbyave 100
*SOURCE 04t
 *TARGET lbyp 100
*SOURCE 07t
 *TARGET lbyg 100

*CASE thin
*SOURCE 03
 *TARGET 03t 100
*SOURCE 04
 *TARGET 04t 100
*SOURCE 07
 *TARGET 07t 100
*SOURCE 08
 *TARGET 08t 100
*SOURCE 09
 *TARGET 09t 100
*SOURCE 11
 *TARGET 11t 100
*SOURCE 12
 *TARGET 12t 100
*SOURCE 13a
 *TARGET 13at 100
*SOURCE 13b
 *TARGET 13bt 100
*SOURCE 13c
 *TARGET 13ct 100
*SOURCE 14a
 *TARGET 14at 100
*SOURCE 14b
```

```
 *TARGET 14bt 100
*SOURCE 14c
 *TARGET 14ct 100
*SOURCE 15
 *TARGET 15t 100
*SOURCE 18
 *TARGET 18t 100
*SOURCE 33
 *TARGET 33t 100
*SOURCE 34
 *TARGET 34t 100
*SOURCE lbyave
 *TARGET lbyavet 100
*SOURCE lbyp
 *TARGET lbypt 100
*SOURCE lbyg
 *TARGET lbygt 100
; Yields
;volume in tons
 *Y 01 { stand 1 }
_AGE      Pulp   Chip-Saw   Saw
12         -          -       115.3
13         -          -      118.3
14         -          -       120.6
15         -          -       121.1
 *Y 02 {stand 2 }
_AGE     Pulp   Chip-Saw   Saw
12       -      21.6      95.7
13       -      2.7       116
14       -        -        118
15       -        -        114.4
*Y 03 {stand 3 unthinned}
_AGE     Pulp   Chip-Saw   Saw
4        23.6   70.6       -
5        16.2   99.3       4.9
6        10.2   109.3      15.1
7        6.2    105.7      38.5
*Y 03t {stand 3 thinned}
_AGE     Pulp   Chip-Saw   Saw
4         -     35.4      -
5         -     42.3      13.5
6         -     24.5      46.5
7         -     7         80.1
*Y 04 {stand 4 unthinned}
_AGE   Pulp   Chip-Saw   Saw
2       -       -        -
3       11.3    -        -
4       33.2   1.7       -
5       42.6    11.5     -
*Y 04t {stand 4 thinned}
_AGE    Pulp   Chip-Saw   Saw
2        -       -         -
3       11.3     -         -
4       23     1           -
5       27.6   13.6        -
*Y 07 {stand 7 unthinned}
_AGE    Pulp   Chip-Saw   Saw
```

```
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
*Y 08 {stand 8 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
*Y 07t {stand 7 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 08t {stand 8 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 09 {stand 09 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     56        2.7
5       0.8     57.4      27.5
6       0.4     45.6      61.9
7       0.1     33.1      92.6
*Y 09t {stand 09 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -     33.4       2.2
5        -     22.2       30.9
6        -     2.5        68.6
7        -     0.2        92.2
*Y 11 {stand 11 unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       14.9   60.2       1.8
6       8.9    75.7       8.2
7       5.6    76.8       21.3
8       3.3    67.6       35.7
*Y 11t {stand 11 thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -     40         1.8
6        -     44.8       12.2
7        -     37.5       32.3
8        -     20.4       61.2
*Y 12 {stand 12 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     55.6       2.7
5       0.6     58.5       26.7
6       0.5     45.3       61.3
7       0.1     35.4       90.1
*Y 12t {stand 12 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -      33.3      2.2
5        -      21        31.8
6        -      3.5       67.7
```

```
7        -      -         92.3
*Y 13a {stand 13a unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 13b {stand 13b unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 13c {stand 13c unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 14a {stand 14a unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 14b {stand 14b unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 14c {stand 14c unthinned}
_AGE     Pulp   Chip-Saw   Saw
5        9.3     55.9      1.6
6        4.9     65.8      10.8
7        3.1     67.1      23.4
8        1.7     63.3      38.5
*Y 13at {stand 13a thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -      39.5      1.6
6         -      42.1      13.3
7         -      34.9      34
8         -      18.2      63.5
*Y 13bt {stand 13b thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -      39.5      1.6
6         -      42.1      13.3
7         -      34.9      34
8         -      18.2      63.5
*Y 13ct {stand 13c thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -      39.5      1.6
6         -      42.1      13.3
7         -      34.9      34
8         -      18.2      63.5
*Y 14at {stand 14a thinned}
_AGE     Pulp   Chip-Saw   Saw
```

```
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 14bt {stand 14b thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 14ct {stand 14c thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -     39.5      1.6
6         -     42.1      13.3
7         -     34.9      34
8         -     18.2      63.5
*Y 15 {stand 15 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       29      0.6       -
4       45.2    12.8      -
5       43.6    36.1      -
*Y 33 {stand 33 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -      -           -
3       29      0.6        -
4       45.2    12.8       -
5       43.6    36.1       -
*Y 33t {stand 33 thinned}
_AGE    Pulp   Chip-Saw   Saw
2        -     -           -
3       29     0.6         -
4       19.5   10.4        -
5       2.7    43.7        -
*Y 15t {stand 15 thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       29     0.6        -
4       19.5   10.4       -
5       2.7    43.7       -
*Y 22 {stand 22 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1     27         78.3
9        -      17.2       65.2
10       -      12.4       77
11       -      7.6        85.9
*Y 23a {stand 23a unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1     26.3      45.3
9       0.1     17.8      63.6
10      -       10.3      75.5
11      -       5.4       84.8
*Y 23b {stand 23b unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1      75.1
9       -       25.4       83.3
10      -       13.1       110
```

```
11      -       7.8         123.1
*Y 23c {stand 23c unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1       75.1
9       -       25.4       83.3
10      -       13.1       110
11      -       7.8        123.1
*Y 24 {stand 24 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       0.1      28.1       75.1
9       -       25.4       83.3
10      -       13.1       110
11      -       7.8        123.1
*Y 18 {stand 18 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -         -       -
3       23        -       -
4       45.3    8.1       -
5       46.3    30.8      -
*Y 34 {stand 34 unthinned}
_AGE    Pulp   Chip-Saw   Saw
2       -       -         -
3       23      -         -
4       45.3    8.1       -
5       46.3    30.8      -
*Y 34t {stand 34 thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -         -       -
3       23        -       -
4       22.4    6.8       -
5       5.2     40.7      -
*Y 18t {stand  thinned}
_AGE    Pulp   Chip-Saw   Saw
2       -        -        -
3       23        0       -
4       22.4    6.8       -
5       5.2     40.7      -
*Y 25 {stand 25 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       -       19.2      46.3
9       -       11.6      65.3
10      -       6.5       78.9
11      -       4.8       90.1
*Y 27 {stand 27 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8        -      19.2      46.3
9        -      11.6      65.3
10       -      6.5       78.9
11       -      4.8       90.1
*Y 28 {stand 28 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       1.6      53.6     156
9       0.9      48       31.1
10      0.6      38.8     47.2
11      0.2      28.4     63.6
*Y 27a {stand 27a unthinned}
_AGE    Pulp   Chip-Saw   Saw
```

```
8        -       30.4      11
9        -       10        35.5
10       -       3         48.9
11       -       1.8       56.7
*Y 17 {stand 17 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        56.9    20.8       -
9        57.9    27.8       -
10       51.3    28.4       -
11       31.3    41.2       -
*Y lbyave {stand lblyave unthinned}
_AGE     Pulp   Chip-Saw   Saw
1         -       -        -
2        18.9    0.3       -
3        34.5    15.7      -
*Y lbyavet {stand lblyave thinned}
_AGE     Pulp   Chip-Saw   Saw
1         -      -         -
2        18.9    0.3       -
3        16.5    12.5      -
4        12.4    41        -
*Y lbyp {stand lblyp unthinned}
_AGE     Pulp   Chip-Saw   Saw
1         -       -        -
2        9.6     0         -
3        28.3    5.2       -
*Y lbypt {stand lblyp thinned}
_AGE     Pulp   Chip-Saw   Saw
1         -        -       -
2        9.6      -        -
3        16.3   4.3        -
4        12.6   24.6       -
*Y lbyg {stand lblyg unthinned}
_AGE     Pulp   Chip-Saw   Saw
1        -       -          -
2        26.8   2.5         -
3        36.3   32.5        -
*Y lbygt {stand lblyg thinned}
_AGE     Pulp   Chip-Saw   Saw
1         -     -          -
2        26.8   2.5        -
3        14.8   25.4       -
4        17.8   51.7       -
*YT ?
est$ 1 232.31
frtz$ 1 86.33
*YT ?
disc5% _DISCOUNTFACTOR (5%,5,half)

*YT ?
; stumpage in $/tons
Pulp$ 1 9.32
Chip-Saw$ 1 37.31
Saw$ 1 50
*YC ? ? ? ?
totv _SUM (Pulp, Chip-saw, Saw)
```

## Appendix C. Maximization of NPV Method Woodstock Model formulation

```
; Actions
*ACTION ccplt Y clearcut planting
 *OPERABLE ccplt
  ? _AGE >= 5 { age is in periods }
*ACTION thin N commercial thin
 *OPERABLE thin
  03 _AGE = 4
  04 _AGE = 4
  07 _AGE = 4
  08 _AGE = 4
  09 _AGE = 4
  12 _AGE = 4
  15 _AGE = 4
  18 _AGE = 4
  18 _AGE = 4
  33 _AGE = 4
  34 _AGE = 4
  11 _AGE = 5
  13a _AGE = 5
  13b _AGE = 5
  13c _AGE = 5
  14a _AGE = 5
  14b _AGE = 5
  14c _AGE = 5
  lbyave _AGE = 3
  lbyg _AGE = 3
  lbyp _AGE = 3
*PARTIAL thin
pulp chip-saw saw
; Areas
*A 01 12 10.0988
*A 02 12 4.9599
*A 03 4 9.9207
*A 04 2 13.4352
*A 07 4 3.6618
*A 08 4 15.0981
*A 09 4 8.7566
*A 11 5 14.0463
*A 12 4 18.6961
*A 13a 5 6.0648
*A 13b 5 9.4002
*A 13c 5 3.5325
*A 14a 5 6.6164
*A 14b 5 2.7379
*A 14c 5 2.4667
*A 15 2 1.6269
*A 17 8 15.4669
*A 18 2 11.0504
*A 22 8 8.6535
*A 23a 8 3.31
*A 23b 8 18.3
*A 23c 8 23.9747
*A 24 8 2.6391
```

```
*A 25 8 1.8149
*A 27 8 4.4965
*A 27a 8 0.2491
*A 28 8 8.3497
*A 33 2 5.3872
*A 34 2 5.6354

; Control
*LENGTH   4
*GRAPHICS OFF
*REPORTS  ON
*IMAGE    OFF
*BUILD    OFF
*OPTIMIZE OFF
*SCHEDULE ON
*QUEUE    OFF

; Landscape
*THEME  stand number
01  stand 01
02  stand 02
03  stand 03 unthinned
03t stand 03 thinned
04  stand 04 unthinned
04t stand 04 thinned
07  stand 07 unthinned
07t  stand 07 thinned
08 stand 08 unthinned
08t stand 08 thinned
09 stand 09 unthinned
09t stand 09 thinned
11 stand 11 unthinned
11t stand 11 thinned
12  stand 12 unthinned
12t  stand 12 thinned
13a  stand 13a unthinned
13at stand 13a thinned
13b  stand 13b unthinned
13bt stand 13b thinned
13c  stand 13c unthinned
13ct stand 13c thinned
14a  stand 14a unthinned
14at stand 14a thinned
14b stand 14b unthinned
14bt stand 14b thinned
14c stand 14c unthinned
14ct stand 14c thinned
15  stand 15 unthinned
15t stand 15 thinned
17  Stand 17
18  stand 18 unthinned
18t stand 018 thinned
22  Stand 22
23a  Stand 23a
23b Stand 23b
23c  Stand 23c
24  Stand 24
```

```
25  Stand 25
27  Stand 27
27a Stand 27a
28 stand 28
33 stand 33 unthinned
33t stand 33 thinned
34 stand 34 unthinned
34t stand 34 thinned
lbyave  stand lobloly pine average site quality unthinned
lbyavet stand lblyave thinned
lbyp  stand lbyp unthinned
lbypt stand lbyp thinned
lbyg  stand lbyg unthinned
lbygt stand lbyg thinned
; Lifespan
? 25; maximum lifespan for all types = 125yrs
*OBJECTIVE
 _MAX npv 1.._LENGTH
*CONSTRAINTS
   ccpltth = 40 1.._LENGTH
*FORMAT MOSEK
; Outputs
*OUTPUT ccpltth  clear cut area
*SOURCE ? ccplt _AREA
*OUTPUT thinth  thinnid area
*SOURCE ? thin _AREA

;volume
;thin harvestvolume
*OUTPUT thinpulp thin pulpwood harvest
*SOURCE ? thin pulp
*OUTPUT thinchipsaw thin chip-saw harvest
*SOURCE ? thin chip-saw
*OUTPUT thinsaw thin sawtimber harvest
*SOURCE ? thin saw
*OUTPUT thinharvest thin harvest volume
*SOURCE  thinpulp + thinchipsaw + thinsaw
;clear cut harvest volume
*OUTPUT ccpltpulp clear cut pulpwood harvest volume
*SOURCE ? ccplt pulp
*OUTPUT ccpltchipsaw clear cut Chip&Sawtimber  harvest volume
*SOURCE ? ccplt chip-saw
*OUTPUT ccpltsaw clear cut sawtimber harvest volume
*SOURCE ? ccplt saw
*OUTPUT ccpltharvest Clear cut volume
*SOURCE ccpltpulp + ccpltchipsaw + ccpltsaw
*OUTPUT totharvest Total harvest volume
*SOURCE thinharvest + ccpltharvest
; volume depend on product
*OUTPUT Pulpvol Pulpwood volume
*SOURCE ? ccplt Pulp + ? thin Pulp
*OUTPUT Chip-sawvol Chip and Sawtimber volume
*SOURCE ? ccplt Chip-saw + ? thin Chip-saw
*OUTPUT Sawvol Sawtimber volume
*SOURCE ? ccplt Saw + ? thin Saw

;Revenue
```

```
*OUTPUT Pulprev Pulpwood revenue
*SOURCE Pulpvol * Pulp$
*OUTPUT Chip-sawrev Chip and Sawtimber revenue
*SOURCE Chip-sawvol * Chip-saw$
*OUTPUT Sawrev Sawtimber revenue
*SOURCE Sawvol * Saw$
*OUTPUT trev total revenue
*SOURCE Pulprev + Chip-sawrev + Sawrev


;Costs
;After thin fertilization cost
*OUTPUT bdt03 stand 03 thin cost
*SOURCE 03 thin  frtz$
*OUTPUT bdt04 stand 04 thin cost
*SOURCE 04 thin  frtz$
*OUTPUT bdt07 stand 07 thin cost
*SOURCE 07 thin  frtz$
*OUTPUT bdt08 stand 08 thin cost
*SOURCE 08 thin  frtz$
*OUTPUT bdt09 stand 09 thin cost
*SOURCE 09 thin  frtz$
*OUTPUT bdt12 stand 12 thin cost
*SOURCE 12 thin  frtz$
*OUTPUT bdt15 stand 15 thin cost
*SOURCE 15 thin  frtz$
*OUTPUT bdt33 stand 33 thin cost
*SOURCE 33 thin  frtz$
*OUTPUT bdt18 stand 18 thin cost
*SOURCE 18 thin  frtz$
*OUTPUT bdt34 stand 34 thin cost
*SOURCE 34 thin  frtz$
*OUTPUT bdtlbyave stand lbyave thin cost
*SOURCE lbyave thin  frtz$
*OUTPUT bdtlbyp stand lbyp thin cost
*SOURCE lbyp thin  frtz$
*OUTPUT bdtlbyg stand lbyg thin cost
*SOURCE lbyg thin  frtz$
*OUTPUT thincost thin fertilization cost
*SOURCE  bdt03 +  bdt04 + bdt07 + bdt08 +  bdt09 + bdt12 + bdt15 +
bdt33 + bdt18 + bdt34 + bdtlbyave + bdtlbyp + bdtlbyg
;establishment cost
*OUTPUT bdtest establishment cost
*SOURCE ? ccplt est$
;total cost
*OUTPUT budget silvicultural cost
*SOURCE thincost + bdtest

;Discount of revenues and costs
*OUTPUT distrev Discounted revenue
*SOURCE trev * disc5%
*OUTPUT discost Discounted expenditures
*SOURCE budget * disc5%

;net value and net present value
*OUTPUT nv net value
*SOURCE trev - budget
```

```
*OUTPUT npv net present value
*SOURCE distrev - discost

;Clear cut areas for each stand
*OUTPUT 01clr Stand 01 clear-cut area
*SOURCE 01 ccplt _AREA
*OUTPUT 02clr Stand 02 clear-cut area
*SOURCE 02 ccplt _AREA
*OUTPUT 03clr Stand 03 clear-cut area
*SOURCE 03 ccplt _AREA + 03t ccplt _AREA
*OUTPUT 04clr Stand 04 clear-cut area
*SOURCE 04 ccplt _AREA + 04t ccplt _AREA
*OUTPUT 07clr Stand 07 clear-cut area
*SOURCE 07 ccplt _AREA + 07t ccplt _AREA
*OUTPUT 08clr Stand 08 clear-cut area
*SOURCE 08 ccplt _AREA + 08t ccplt _AREA
*OUTPUT 09clr Stand 09 clear-cut area
*SOURCE 09 ccplt _AREA + 09t ccplt _AREA
*OUTPUT 11clr Stand 11 clear-cut area
*SOURCE 11 ccplt _AREA + 11t ccplt _AREA
*OUTPUT 12clr Stand 12 clear-cut area
*SOURCE 12 ccplt _AREA + 12t ccplt _AREA
*OUTPUT 13aclr Stand 13a clear-cut area
*SOURCE 13a ccplt _AREA + 13at ccplt _AREA
*OUTPUT 13bclr Stand 13b clear-cut area
*SOURCE 13b ccplt _AREA + 13bt ccplt _AREA
*OUTPUT 13cclr Stand 13c clear-cut area
*SOURCE 13c ccplt _AREA + 13ct ccplt _AREA
*OUTPUT 14aclr Stand 14a clear-cut area
*SOURCE 14a ccplt _AREA + 14at ccplt _AREA
*OUTPUT 14bclr Stand 14b clear-cut area
*SOURCE 14b ccplt _AREA + 14bt ccplt _AREA
*OUTPUT 14cclr Stand 14c clear-cut area
*SOURCE 14c ccplt _AREA + 14ct ccplt _AREA
*OUTPUT 15clr Stand 15 clear-cut area
*SOURCE 15 ccplt _AREA + 15t ccplt _AREA
*OUTPUT 33clr Stand 33 clear-cut area
*SOURCE 33 ccplt _AREA + 33t ccplt _AREA
*OUTPUT 18clr Stand 18 clear-cut area
*SOURCE 18 ccplt _AREA + 18t ccplt _AREA
*OUTPUT 34clr Stand 34 clear-cut area
*SOURCE 34 ccplt _AREA + 34t ccplt _AREA
*OUTPUT 22clr Stand 22 clear-cut area
*SOURCE 22 ccplt _AREA
*OUTPUT 23aclr Stand 23a clear-cut area
*SOURCE 23a ccplt _AREA
*OUTPUT 23bclr Stand 23b clear-cut area
*SOURCE 23b ccplt _AREA
*OUTPUT 23cclr Stand 23c clear-cut area
*SOURCE 23c ccplt _AREA
*OUTPUT 24clr Stand 24 clear-cut area
*SOURCE 24 ccplt _AREA
*OUTPUT 25clr Stand 25 clear-cut area
*SOURCE 25 ccplt _AREA
*OUTPUT 27clr Stand 27 clear-cut area
*SOURCE 27 ccplt _AREA
*OUTPUT 27aclr Stand 27a clear-cut area
```

```
*SOURCE 27a ccplt _AREA
*OUTPUT 28clr Stand 28 clear-cut area
*SOURCE 28 ccplt _AREA
*OUTPUT 17clr Stand 17 clear-cut area
*SOURCE 17 ccplt _AREA

;total harvest volume based on totv
*OUTPUT harvest total totv harvest volume
*SOURCE ? ccplt totv + ? thin totv
; Reports
*TARGET  THomas.txt
ccpltth 1.._LENGTH
thinth 1.._LENGTH
nv  1.._LENGTH
npv 1.._LENGTH

totharvest 1.._LENGTH
ccpltharvest 1.._LENGTH
thinharvest 1.._LENGTH
Pulpvol 1.._LENGTH
Chip-sawvol 1.._LENGTH
Sawvol 1.._LENGTH

01clr 1.._LENGTH
02clr 1.._LENGTH
03clr 1.._LENGTH
04clr 1.._LENGTH
07clr 1.._LENGTH
08clr 1.._LENGTH
09clr 1.._LENGTH
11clr 1.._LENGTH
12clr 1.._LENGTH
13aclr 1.._LENGTH
13bclr 1.._LENGTH
13cclr 1.._LENGTH
14aclr 1.._LENGTH
14bclr 1.._LENGTH
14cclr 1.._LENGTH
15clr 1.._LENGTH
33clr 1.._LENGTH
18clr 1.._LENGTH
34clr 1.._LENGTH
22clr 1.._LENGTH
23aclr 1.._LENGTH
23bclr 1.._LENGTH
23cclr 1.._LENGTH
24clr 1.._LENGTH
25clr 1.._LENGTH
27clr 1.._LENGTH
27aclr 1.._LENGTH
28clr 1.._LENGTH
17clr 1.._LENGTH
; Transitions
*CASE ccplt
*SOURCE 01
 *TARGET lbyave 100
*SOURCE 02
```

```
 *TARGET lbyave 100
*SOURCE 03
 *TARGET lbyave 100
*SOURCE 08
 *TARGET lbyave 100
*SOURCE 09
 *TARGET lbyave 100
*SOURCE 11
 *TARGET lbyave 100
*SOURCE 12
 *TARGET lbyave 100
*SOURCE 13a
 *TARGET lbyave 100
*SOURCE 13b
 *TARGET lbyave 100
*SOURCE 13c
 *TARGET lbyave 100
*SOURCE 14a
 *TARGET lbyave 100
*SOURCE 14b
 *TARGET lbyave 100
*SOURCE 14c
 *TARGET lbyave 100
*SOURCE 15
 *TARGET lbyave 100
*SOURCE 17
 *TARGET lbyave 100
*SOURCE 18
 *TARGET lbyave 100
*SOURCE 22
 *TARGET lbyave 100
*SOURCE 23a
 *TARGET lbyave 100
*SOURCE 23b
 *TARGET lbyave 100
*SOURCE 23c
 *TARGET lbyave 100
*SOURCE 24
 *TARGET lbyave 100
*SOURCE 33
 *TARGET lbyave 100
*SOURCE 34
 *TARGET lbyave 100
*SOURCE 04
 *TARGET lbyp 100

*SOURCE 25
 *TARGET lbyp 100
*SOURCE 27
 *TARGET lbyp 100
*SOURCE 27a
 *TARGET lbyp 100
*SOURCE 28
 *TARGET lbyp 100
*SOURCE 07
 *TARGET lbyg 100
*SOURCE 03t
```

```
 *TARGET lbyave 100
*SOURCE 08t
 *TARGET lbyave 100
*SOURCE 09t
 *TARGET lbyave 100
*SOURCE 11t
 *TARGET lbyave 100
*SOURCE 12t
 *TARGET lbyave 100
*SOURCE 13at
 *TARGET lbyave 100
*SOURCE 13bt
 *TARGET lbyave 100
*SOURCE 13ct
 *TARGET lbyave 100
*SOURCE 14bt
 *TARGET lbyave 100
*SOURCE 14at
 *TARGET lbyave 100
*SOURCE 14ct
 *TARGET lbyave 100
*SOURCE 15t
 *TARGET lbyave 100
*SOURCE 18t
 *TARGET lbyave 100
*SOURCE 33t
 *TARGET lbyave 100
*SOURCE 34t
 *TARGET lbyave 100
*SOURCE 04t
 *TARGET lbyp 100
*SOURCE 07t
 *TARGET lbyg 100

*CASE thin
*SOURCE 03
 *TARGET 03t 100
*SOURCE 04
 *TARGET 04t 100
*SOURCE 07
 *TARGET 07t 100
*SOURCE 08
 *TARGET 08t 100
*SOURCE 09
 *TARGET 09t 100
*SOURCE 11
 *TARGET 11t 100
*SOURCE 12
 *TARGET 12t 100
*SOURCE 13a
 *TARGET 13at 100
*SOURCE 13b
 *TARGET 13bt 100
*SOURCE 13c
 *TARGET 13ct 100
*SOURCE 14a
 *TARGET 14at 100
```

```
*SOURCE 14b
 *TARGET 14bt 100
*SOURCE 14c
 *TARGET 14ct 100
*SOURCE 15
 *TARGET 15t 100
*SOURCE 18
 *TARGET 18t 100
*SOURCE 33
 *TARGET 33t 100
*SOURCE 34
 *TARGET 34t 100
*SOURCE lbyave
 *TARGET lbyavet 100
*SOURCE lbyp
 *TARGET lbypt 100
*SOURCE lbyg
 *TARGET lbygt 100
; Yields
;volume in tons
 *Y 01 { stand 1 }
_AGE      Pulp   Chip-Saw   Saw
12        -          -        115.3
13        -          -       118.3
14        -          -        120.6
15        -          -        121.1
 *Y 02 {stand 2 }
_AGE     Pulp   Chip-Saw   Saw
12       -      21.6      95.7
13       -      2.7       116
14       -        -        118
15       -        -        114.4
*Y 03 {stand 3 unthinned}
_AGE     Pulp   Chip-Saw   Saw
4        23.6   70.6       -
5        16.2   99.3       4.9
6        10.2   109.3      15.1
7        6.2    105.7      38.5
*Y 03t {stand 3 thinned}
_AGE     Pulp   Chip-Saw   Saw
4         -     35.4       -
5         -     42.3      13.5
6         -     24.5      46.5
7         -     7         80.1
*Y 04 {stand 4 unthinned}
_AGE   Pulp   Chip-Saw   Saw
2       -        -        -
3       11.3     -        -
4       33.2   1.7        -
5       42.6    11.5      -
*Y 04t {stand 4 thinned}
_AGE    Pulp   Chip-Saw   Saw
2        -       -         -
3       11.3     -         -
4       23     1           -
5       27.6   13.6        -
*Y 07 {stand 7 unthinned}
```

```
_AGE    Pulp   Chip-Saw   Saw
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
*Y 08 {stand 8 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       10.8   76.5       2.2
5       6.8    93.7       18.4
6       4      99.1       36
7       2.9    83.6       64.7
*Y 07t {stand 7 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 08t {stand 8 thinned}
_AGE    Pulp   Chip-Saw   Saw
4       -       35        1.5
5       -       26.8      27.5
6       -       6.8       64.3
7       -       -         90.5
*Y 09 {stand 09 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     56        2.7
5       0.8     57.4      27.5
6       0.4     45.6      61.9
7       0.1     33.1      92.6
*Y 09t {stand 09 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -     33.4       2.2
5        -     22.2       30.9
6        -     2.5        68.6
7        -     0.2        92.2
*Y 11 {stand 11 unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       14.9   60.2       1.8
6       8.9    75.7       8.2
7       5.6    76.8       21.3
8       3.3    67.6       35.7
*Y 11t {stand 11 thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -     40         1.8
6        -     44.8       12.2
7        -     37.5       32.3
8        -     20.4       61.2
*Y 12 {stand 12 unthinned}
_AGE    Pulp   Chip-Saw   Saw
4       2.2     55.6       2.7
5       0.6     58.5       26.7
6       0.5     45.3       61.3
7       0.1     35.4       90.1
*Y 12t {stand 12 thinned}
_AGE    Pulp   Chip-Saw   Saw
4        -      33.3      2.2
5        -      21        31.8
```

```
6        -      3.5       67.7
7        -      -         92.3
*Y 13a {stand 13a unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13b {stand 13b unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13c {stand 13c unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14a {stand 14a unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14b {stand 14b unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 14c {stand 14c unthinned}
_AGE    Pulp   Chip-Saw   Saw
5       9.3     55.9      1.6
6       4.9     65.8      10.8
7       3.1     67.1      23.4
8       1.7     63.3      38.5
*Y 13at {stand 13a thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 13bt {stand 13b thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 13ct {stand 13c thinned}
_AGE    Pulp   Chip-Saw   Saw
5        -      39.5      1.6
6        -      42.1      13.3
7        -      34.9      34
8        -      18.2      63.5
*Y 14at {stand 14a thinned}
```

```
_AGE     Pulp   Chip-Saw   Saw
5         -      39.5      1.6
6         -      42.1      13.3
7         -      34.9      34
8         -      18.2      63.5
*Y 14bt {stand 14b thinned}
_AGE     Pulp   Chip-Saw   Saw
5         -      39.5      1.6
6         -      42.1      13.3
7         -      34.9      34
8         -      18.2      63.5
*Y 14ct {stand 14c thinned}
_AGE      Pulp   Chip-Saw   Saw
5          -     39.5      1.6
6          -     42.1      13.3
7          -     34.9      34
8          -     18.2      63.5
*Y 15 {stand 15 unthinned}
_AGE     Pulp   Chip-Saw   Saw
2        -        -        -
3        29      0.6       -
4        45.2    12.8      -
5        43.6    36.1      -
*Y 33 {stand 33 unthinned}
_AGE     Pulp   Chip-Saw   Saw
2        -       -          -
3        29      0.6        -
4        45.2    12.8       -
5        43.6    36.1       -
*Y 33t {stand 33 thinned}
_AGE     Pulp   Chip-Saw   Saw
2         -     -           -
3        29     0.6         -
4        19.5   10.4        -
5        2.7    43.7        -
*Y 15t {stand 15 thinned}
_AGE     Pulp   Chip-Saw   Saw
2        -        -        -
3        29     0.6        -
4        19.5   10.4       -
5        2.7    43.7       -
*Y 22 {stand 22 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        0.1     27         78.3
9         -      17.2       65.2
10        -      12.4       77
11        -      7.6        85.9
*Y 23a {stand 23a unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        0.1     26.3      45.3
9        0.1     17.8      63.6
10       -       10.3      75.5
11       -       5.4       84.8
*Y 23b {stand 23b unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        0.1      28.1      75.1
9        -       25.4       83.3
```

```
10       -        13.1       110
11       -        7.8        123.1
*Y 23c {stand 23c unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        0.1      28.1       75.1
9        -        25.4       83.3
10       -        13.1       110
11       -        7.8        123.1
*Y 24 {stand 24 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        0.1      28.1       75.1
9        -        25.4       83.3
10       -        13.1       110
11       -        7.8        123.1
*Y 18 {stand 18 unthinned}
_AGE     Pulp   Chip-Saw   Saw
2        -          -        -
3        23         -        -
4        45.3    8.1         -
5        46.3    30.8        -
*Y 34 {stand 34 unthinned}
_AGE     Pulp   Chip-Saw   Saw
2        -       -           -
3        23      -           -
4        45.3    8.1         -
5        46.3    30.8        -
*Y 34t {stand 34 thinned}
_AGE     Pulp   Chip-Saw   Saw
2        -          -        -
3        23         -        -
4        22.4    6.8         -
5        5.2     40.7        -
*Y 18t {stand  thinned}
_AGE     Pulp   Chip-Saw   Saw
2        -         -         -
3        23        0         -
4        22.4    6.8         -
5        5.2     40.7        -
*Y 25 {stand 25 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        -       19.2      46.3
9        -       11.6      65.3
10       -       6.5       78.9
11       -       4.8       90.1
*Y 27 {stand 27 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8         -      19.2      46.3
9         -      11.6      65.3
10        -      6.5       78.9
11        -      4.8       90.1
*Y 28 {stand 28 unthinned}
_AGE     Pulp   Chip-Saw   Saw
8        1.6      53.6     156
9        0.9      48       31.1
10       0.6      38.8     47.2
11       0.2      28.4     63.6
*Y 27a {stand 27a unthinned}
```

```
_AGE    Pulp   Chip-Saw   Saw
8        -       30.4      11
9        -       10        35.5
10       -       3         48.9
11       -       1.8       56.7
*Y 17 {stand 17 unthinned}
_AGE    Pulp   Chip-Saw   Saw
8       56.9    20.8       -
9       57.9    27.8       -
10      51.3    28.4       -
11      31.3    41.2       -
*Y lbyave {stand lblyave unthinned}
_AGE    Pulp   Chip-Saw   Saw
1        -       -        -
2       18.9    0.3       -
3       34.5    15.7      -
*Y lbyavet {stand lblyave thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -      -         -
2       18.9    0.3       -
3       16.5    12.5      -
4       12.4    41        -
*Y lbyp {stand lblyp unthinned}
_AGE    Pulp   Chip-Saw   Saw
1        -       -        -
2       9.6     0         -
3       28.3    5.2       -
*Y lbypt {stand lblyp thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -        -       -
2       9.6      -        -
3       16.3   4.3        -
4       12.6   24.6       -
*Y lbyg {stand lblyg unthinned}
_AGE    Pulp   Chip-Saw   Saw
1       -       -          -
2       26.8   2.5         -
3       36.3   32.5        -
*Y lbygt {stand lblyg thinned}
_AGE    Pulp   Chip-Saw   Saw
1        -     -          -
2       26.8   2.5        -
3       14.8   25.4       -
4       17.8   51.7       -
*YT ?
est$ 1 232.31
frtz$ 1 86.33
*YT ?
disc5% _DISCOUNTFACTOR (5%,5,half)

*YT ?
; stumpage in $/tons
Pulp$ 1 9.32
Chip-Saw$ 1 37.31
Saw$ 1 50
*YC ? ? ? ?
totv _SUM (Pulp, Chip-saw, Saw)
```

## Appendix D. Simulation Method Woodstock Model Results

Run = 1    Period = 1

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 101.00 |
| net value | 326,562.63 |
| net present value | 289,063.49 |
| Total harvest volume | 8,521.18 |
| Clear cut volume | 4,969.57 |
| thin harvest volume | 3,551.62 |
| Pulpwood volume | 1,007.40 |
| Chip and Sawtimber volume | 3,497.03 |
| Sawtimber volume | 4,016.76 |
| Stand 01 clear-cut area | 10.10 |
| Stand 02 clear-cut area | 4.96 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 7.39 |
| Stand 24 clear-cut area | 2.64 |
| Stand 25 clear-cut area | 1.81 |
| Stand 27 clear-cut area | 4.50 |
| Stand 27a clear-cut area | 0.25 |
| Stand 28 clear-cut area | 8.35 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 2

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 0.00 |
| net value | 188,864.38 |
| net present value | 130,987.64 |
| Total harvest volume | 4,214.11 |
| Clear cut volume | 4,214.11 |
| thin harvest volume | 0.00 |
| Pulpwood volume | 4.00 |
| Chip and Sawtimber volume | 976.02 |
| Sawtimber volume | 3,234.08 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 1.81 |
| Stand 23a clear-cut area | 3.31 |
| Stand 23b clear-cut area | 18.30 |
| Stand 23c clear-cut area | 16.58 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 3

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 37.00 |
| net value | 102,385.94 |
| net present value | 55,638.33 |
| Total harvest volume | 3,822.58 |
| Clear cut volume | 3,076.72 |
| thin harvest volume | 745.86 |
| Pulpwood volume | 1,492.16 |
| Chip and Sawtimber volume | 1,225.78 |
| Sawtimber volume | 1,104.63 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 14.05 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 3.64 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 6.85 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 15.47 |

Run = 1    Period = 4

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 40.00 |
| net value | 157,560.32 |
| net present value | 67,086.34 |
| Total harvest volume | 4,091.08 |
| Clear cut volume | 3,366.83 |
| thin harvest volume | 724.25 |
| Pulpwood volume | 630.54 |
| Chip and Sawtimber volume | 677.52 |
| Sawtimber volume | 2,783.02 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 9.92 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 2.90 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 2.42 |
| Stand 13b clear-cut area | 9.40 |
| Stand 13c clear-cut area | 3.53 |
| Stand 14a clear-cut area | 6.62 |
| Stand 14b clear-cut area | 2.74 |
| Stand 14c clear-cut area | 2.47 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

## Appendix E. Maximization of Harvest Volume Method Woodstock Model Results

Run = 1    Period = 1

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 101.00 |
| net value | 339,559.32 |
| net present value | 300,567.77 |
| Total harvest volume | 8,793.35 |
| Clear cut volume | 5,241.73 |
| thin harvest volume | 3,551.62 |
| Pulpwood volume | 1,008.05 |
| Chip and Sawtimber volume | 3,543.11 |
| Sawtimber volume | 4,242.19 |
| Stand 01 clear-cut area | 10.10 |
| Stand 02 clear-cut area | 4.96 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 8.65 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 5.30 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 2.64 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 8.35 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 2

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 0.00 |
| net value | 87,633.68 |
| net present value | 60,778.69 |
| Total harvest volume | 2,975.42 |
| Clear cut volume | 2,975.42 |
| thin harvest volume | 0.00 |
| Pulpwood volume | 895.95 |
| Chip and Sawtimber volume | 1,213.37 |
| Sawtimber volume | 866.10 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 14.05 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 3.31 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.87 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 1.81 |
| Stand 27 clear-cut area | 4.50 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 15.47 |

Run = 1    Period = 3

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 37.14 |
| net value | 225,802.56 |
| net present value | 122,705.10 |
| Total harvest volume | 5,472.68 |
| Clear cut volume | 4,725.35 |
| thin harvest volume | 747.34 |
| Pulpwood volume | 703.02 |
| Chip and Sawtimber volume | 530.70 |
| Sawtimber volume | 4,238.97 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 3.89 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 13.00 |
| Stand 23c clear-cut area | 23.11 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 4

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 40.00 |
| net value | 187,675.89 |
| net present value | 79,909.01 |
| Total harvest volume | 4,630.19 |
| Clear cut volume | 3,851.49 |
| thin harvest volume | 778.70 |
| Pulpwood volume | 669.90 |
| Chip and Sawtimber volume | 302.31 |
| Sawtimber volume | 3,657.98 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 3.66 |
| Stand 08 clear-cut area | 15.10 |
| Stand 09 clear-cut area | 2.54 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 18.70 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

## Appendix F. Maximization of NPV Method Woodstock Model Results

Run = 1    Period = 1

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 101.00 |
| net value | 339,559.32 |
| net present value | 300,567.77 |
| Total harvest volume | 8,793.35 |
| Clear cut volume | 5,241.73 |
| thin harvest volume | 3,551.62 |
| Pulpwood volume | 1,008.05 |
| Chip and Sawtimber volume | 3,543.11 |
| Sawtimber volume | 4,242.19 |
| Stand 01 clear-cut area | 10.10 |
| Stand 02 clear-cut area | 4.96 |
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 8.65 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 5.58 |
| Stand 24 clear-cut area | 2.35 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 8.35 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 2

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 0.00 |
| net value | 191,052.92 |
| net present value | 132,505.51 |
| Total harvest volume | 4,261.64 |
| Clear cut volume | 4,261.64 |
| thin harvest volume | 0.00 |
| Pulpwood volume | 4.00 |
| Chip and Sawtimber volume | 990.84 |
| Sawtimber volume | 3,266.79 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 03 clear-cut area | 0.00 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 3.31 |
| Stand 23b clear-cut area | 18.30 |
| Stand 23c clear-cut area | 18.39 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 3

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 37.14 |
| net value | 130,708.58 |
| net present value | 71,029.35 |
| Total harvest volume | 3,670.39 |
| Clear cut volume | 2,923.05 |
| thin harvest volume | 747.34 |
| Pulpwood volume | 699.43 |
| Chip and Sawtimber volume | 934.55 |
| Sawtimber volume | 2,036.40 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 7.38 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 0.00 |
| Stand 08 clear-cut area | 0.00 |
| Stand 09 clear-cut area | 8.76 |
| Stand 11 clear-cut area | 14.05 |
| Stand 12 clear-cut area | 0.00 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.76 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 2.47 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |

| | |
|---|---|
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 0.29 |
| Stand 25 clear-cut area | 1.81 |
| Stand 27 clear-cut area | 4.50 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |

Run = 1    Period = 4

| | |
|---|---|
| clear cut area | 40.00 |
| thinnid area | 40.00 |
| net value | 186,782.20 |
| net present value | 79,528.49 |
| Total harvest volume | 4,616.70 |
| Clear cut volume | 3,838.01 |
| thin harvest volume | 778.70 |
| Pulpwood volume | 669.90 |
| Chip and Sawtimber volume | 319.61 |
| Sawtimber volume | 3,627.20 |
| Stand 01 clear-cut area | 0.00 |
| Stand 02 clear-cut area | 0.00 |
| Stand 03 clear-cut area | 2.54 |
| Stand 04 clear-cut area | 0.00 |
| Stand 07 clear-cut area | 3.66 |
| Stand 08 clear-cut area | 15.10 |
| Stand 09 clear-cut area | 0.00 |
| Stand 11 clear-cut area | 0.00 |
| Stand 12 clear-cut area | 18.70 |
| Stand 13a clear-cut area | 0.00 |
| Stand 13b clear-cut area | 0.00 |
| Stand 13c clear-cut area | 0.00 |
| Stand 14a clear-cut area | 0.00 |
| Stand 14b clear-cut area | 0.00 |
| Stand 14c clear-cut area | 0.00 |
| Stand 15 clear-cut area | 0.00 |
| Stand 33 clear-cut area | 0.00 |
| Stand 18 clear-cut area | 0.00 |
| Stand 34 clear-cut area | 0.00 |
| Stand 22 clear-cut area | 0.00 |
| Stand 23a clear-cut area | 0.00 |
| Stand 23b clear-cut area | 0.00 |
| Stand 23c clear-cut area | 0.00 |
| Stand 24 clear-cut area | 0.00 |
| Stand 25 clear-cut area | 0.00 |
| Stand 27 clear-cut area | 0.00 |
| Stand 27a clear-cut area | 0.00 |
| Stand 28 clear-cut area | 0.00 |
| Stand 17 clear-cut area | 0.00 |