NETL AAD DOCUMENT CONTROL BLDG. 921
U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
P. O. BOX 10940
PITTSBURGH, PA 15236-0940

Technical Progress Report

“Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services”

Quarterly Report

Report Period: October - December, 2003

Principal Author: James A. Burger

Principal Investigators: J. Burger, J. Galbraith, T. Fox, G. Amacher, J. Sullivan, and C. Zipper

December 18, 2003

Instrument No: DE-FG26-02NT41619

Department of Forestry (0324)
228 Cheatham Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

DISCLAIMER

ABSTRACT

The overall purpose of this project is to evaluate the biological and economic feasibility of restoring high-quality forests on mined land, and to measure carbon sequestration and wood production benefits that would be achieved from forest restoration procedures. In this quarterly report, we present a preliminary comparison of the carbon sequestration benefits for two forest types used to convert abandoned grasslands for carbon sequestration. Annual mixed hardwood benefits, based on total stand carbon volume present at the end of a given year, range from a minimum of $0/ton of carbon to a maximum of $5.26/ton of carbon (low prices). White pine benefits based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $18.61/ton of carbon (high prices). The higher maximum white pine carbon payment can primarily be attributed to the fact that the shorter rotation means that payments for white pine carbon are being made on far less cumulative carbon tonnage than for that of the long-rotation hardwoods. Therefore, the payment per ton of white pine carbon needs to be higher than that of the hardwoods in order to render the conversion to white pine profitable by the end of a rotation. These carbon payments may seem appealingly low to the incentive provider. However, payments (not discounted) made over a full rotation may add up to approximately $17,493/ha for white pine (30-year rotation), and $18,820/ha for mixed hardwoods (60-year rotation). The literature suggests a range of carbon sequestration costs, from $0/ton of carbon to $120/ton of carbon, although the majority of studies suggest a cost below $50/ ton of carbon, with van Kooten et al. (2000) suggesting a cutoff cost of $20/ton of carbon sequestered. Thus, the ranges of carbon payments estimated for this study fall well within the ranges of carbon sequestration costs estimated in previous studies.

TABLE OF CONTENTS

LIST OF GRAPHICAL MATERIALS

INTRODUCTION

Public Law 95-87 mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before (Torbert et al. 1995). Research has shown that restored forests on mined lands can be equally as or more productive than the native forests removed by mining (Burger and Zipper 2002). Given that most land surface-mined for coal in the Appalachians was originally forested, it would appear that forestry is a logical land use for most of the reclaimed mined land in the region (Torbert and Burger 1990). However, since implementation of the SMCRA, it appears that fewer forests are being restored (Burger et al. 1998). At the same time, planting of tree seedlings is in fact one of the most commonly used methods of revegetating spoil bank areas in some states (Brown 1962), such as Virginia, where 86% of Virginia's mined land has been reclaimed to forested post-mining land uses since 1991. Unfortunately, the majority of mined land reclaimed as forest land is not reclaimed in a way that favors tree establishment, timber production, carbon sequestration, and, more importantly, long-term forest productivity (Torbert and Burger 1990).

It is believed that these reclaimed mined lands are producing timber and sequestering carbon at rates far below their potential for reasons that include poor mine soil quality, inadequate stocking of trees, lack of reforestation incentives, and regulatory disincentives for planting trees on previously forested land (Boyce 1999, Burger and Maxey 1998). A number of these problems can be ameliorated simply through intensive silvicultural management. Through established site preparation techniques such as ripping, weed control, fertilizing and liming, the quality of a given site can be improved considerably. Other management and silvicultural techniques such as site-species matching, correct planting techniques, employing optimal planting densities, post-planting weed control, and thinning can also go a long way to ensuring improved development of forest stands, and subsequently improved timber production and carbon sequestration.

Similar to the much-debated topic of converting agricultural land to forests, the conversion of reclaimed mined lands to forests carries with it many economic implications. The primary difference between converting agricultural lands to forests and converting reclaimed mined lands to forests is the absence of any obvious extrinsic opportunity cost in the latter scenario; this, of course, only under the assumption that the reclaimed mined land has been abandoned and is not being utilized for any economically beneficial purpose.

A fair amount of research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The effect that a carbon market may have on decisions pertaining to the reclamation of mined lands has also been researched. According to previous research, it appears that mined lands are capable of sequestering carbon and producing harvest volumes of equal or greater magnitude to similar non-mined lands. This fact alone, however, does not render afforestation of mined lands economically profitable or feasible in all cases. There appears at this stage to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests and the economic implications of such a land use conversion. Furthermore, the potential for an incentive scheme aimed at promoting the conversion of reclaimed mined lands to forests has yet to be explored in depth.

This study ultimately addresses the potential for increasing carbon sequestration on surface-mined land. The overall research objective of this study is to determine the economic feasibility of carbon sequestration through converting reclaimed mined lands to forests using high-value tree species, and to demonstrate the economic and decision-making implications of an incentive scheme on such a land use conversion.

TASK 1: Estimate forest productivity and carbon sequestration potential on mined lands supporting abandoned grasslands. (Burger et al.)

Executive Summary

In the previous quarterly report, we reported an extensive analysis of carbon sequestration potential on 14 mined-site forests located in a 7-state region. During this quarter we refined these estimates based on new algorithms for estimating carbon as a function of species-specific biomass. Based on the carbon sequestration models generated in this study, the natural forest stands that were growing well on medium- to highly-productive forest sites (SI greater than 50 ft) produced more tree biomass and sequestered more carbon than mined sites across the same spectrum of stand age (15 to 60 years). These revisions will be reported next quarter.

Experimental

In order to achieve our second objective of comparing carbon sequestration in forests on mined and non-mined land, we projected, by location, natural site carbon pools to the age of their corresponding mined sites. Age projection techniques were applied both to 'grow' (IL-C and IN-C) and to 'reduce' (KY-C, OH-C, WV-C1, WV-C2, PA-C, and VA-C) the present biomass of the natural forest stands to the biomass levels associated with earlier or later ages. Tree measurements, including stem cores for the last 10 years of stand development and bark thickness, were used to generate regression equations for predicting DBH by tree species at any age (Rodrigue, 2001).

Species with similar growth characteristics were grouped together in order to increase the amount of tree measurement data that was used in each per tree species group regression analysis (Rodrigue, 2001). The following lognormal linear regression model was used:

$$\ln(Core_{10}) = b_0 + b_1\left(\frac{1}{DBH_{10}}\right) \qquad \textbf{[1]}$$

where:

$\ln(Core_{10})$ = the natural log of the 10-year DBH increment
b_0 = intercept coefficient
b_1 = slope coefficient
DBH_{10} = tree diameter outside bark at 10 years prior to current age.

For example, using the regression equation for the pitch pine species group, $\ln(\text{Core}_{10}) = -0.2856 + 0.9579\ (1/\text{DBH}_{10})$, we estimated that the 1-year DBH increment increases for a 4-inch (DBH_{10}) and a 25 inch (DBH_{10}) tree were 0.096 inches and 0.078 inches, respectively.
Due to a paucity of information in the literature relative to changes in soil carbon pools with time under tree vegetation cover, we assumed that soil carbon in our natural sites was in equilibrium with the rest of the forest ecosystem components. Therefore, we assumed negligible changes in natural site soil carbon during a period of 50 years or less of forest stand development.

We assumed that litter layer and soil carbon pools follow the same trend of carbon stock change as that of the tree carbon pool. The latter assumption was justified by the fact that the major source for terrestrial carbon input is the atmospheric CO_2 that is captured by the tree canopy. Hence, the greater the cumulative leaf area of a forest ecosystem, the greater the inputs into the other ecosystem components, resulting in an increase in total sequestered carbon per unit area of forested land.

Average ecosystem carbon estimates were computed for all sites by summing the simple averages for tree, litter layer, and soil carbon data from the four replicate plots that were measured at each location. Similarly, average site index and average stand age were calculated. We used standard regression procedures (proc REG) in SAS statistical software (SAS Institute Inc., Cary, NC) to generate multivariate regression models using site index (SI, feet for white oak at base age 50 years) and stand age (years) as the independent variables and total ecosystem carbon (Mg ha^{-1}) as the dependent variable.

We based our multivariate regression equations on well-established and widely-used tree growth and yield models (Brender, 1960; Nelson et al., 1961; Clutter, 1963; Brender and Clutter, 1970). The final regression model that was chosen had the following general format:

$$\ln(C_{ecosystem}) = b_0 + b_1(SI) + b_2(Age) + b_3(SI^2) + b_4\left(\frac{1}{Age}\right) + b_5\left(\frac{1}{Age^2}\right) + b_6\left(\frac{SI}{Age}\right) \qquad \textbf{[2]}$$

where:

$\ln(C_{ecosystem})$ = natural log of the total ecosystem carbon (Mg ha^{-1})
b_i = regression coefficient, i=0,1,2,…,6
SI = average site index (feet for white oak at base age 50 years)
Age = average stand age

Ecosystem carbon for the natural sites was modeled using this general model. The regression model as well as each model component (i.e. *SI* versus SI^2 versus 1/Age) were statistically significant at the 0.1 confidence level. We then applied this same model to the mined site total carbon data. Finally, both regression models were plotted on a 3D diagram showing total carbon estimates for natural and mined sites across the spectrum of SI and stand age. The latter 3D representation of carbon estimates as a function of time and SI allowed for important inferences to be made about the effect of surface coal mining on forest productivity and the potential of mined sites to sequester carbon relative to that of non-mined natural stands.

Conclusions

Our results indicate that pre-SMCRA surface coal mining procedures used in the Midwestern and the Appalachian coalfields of the USA degraded forest site quality and the potential to sequester carbon at pre-mining levels. Based on the carbon sequestration models generated in this study, the natural forest stands that were growing well on medium- to highly-productive forest sites (SI greater than 50 ft) produced more tree biomass and sequestered more carbon than mined sites across the same spectrum of stand age (15 to 60 years). A complete report on this Task 1 research component will be submitted in the second quarter of 2004.

TASK 2: Develop classification and inventory criteria and procedures for mined land. (Galbraith et al.)

Executive Summary

Three 45-ha reclaimed mined sites on which three replications of a 3 x 3 factorial experiment were established (see Task 3 report below for details) are being used to develop and test a forest site classification and mapping system. The three sites are made up of mine soils derived from a variety of parent materials. Mine soil properties found to determine tree survival, productivity, and rate of carbon sequestration in forests, measured as part of Task 1, were analyzed at five locations in each of nine plots in each of nine replications of the experiment for use as criteria for establishing site quality classes. These criteria have been assembled in a land classification matrix that will be used to map mined land on the basis of potential carbon sequestration.

Experimental

The research sites have been located and installed in Lawrence County, Ohio, Nicolas County, West Virginia, and Wise County, Virginia, at the Powell River site. Three replications at each site have been established with an attempt to represent three different site quality classes. The initial criteria used for establishing the reps were pH (taken with field meter), and rock type. Areas with a slope of greater than 15% were avoided if at all possible. The West Virginia site was fairly uniform over all three reps. The other sites showed more variety.

The experiment is represented by a RCB (Randomized Complete Block) design. The reps are 2.25 ha in size and are made up of a 3 x 3 plot block which gives nine plots per rep. These plots were all given an herbicide treatment to reduce herbaceous competition. Three of the nine plots will be randomly chosen to receive a ripping treatment to reduce soil compaction and enhance root growth. Three other plots will randomly be chosen to receive a ripping treatment along with a fertilization treatment. The other three plots will receive no further treatments other than the herbicide. Each set of three plots will be associated with three different forest types, being white pine, hybrid poplar, and native hardwoods.

Each of the plots were sampled in an "X" pattern, taking one sample in each corner and one in the middle, giving five samples per plot. At each of these holes, a sample from 0-10 cm was taken, and one either from 10-30 cm or at a depth of where a different spoil material was obvious was taken as well.

Three of the five holes per plot were randomly chosen for description. Deep pits were dug at each site also. Full descriptions and samples for lab analysis were taken from these pits, as well as bulk density samples by horizon using the core/fill (BB's) method. Further assessments of bulk densities will be made by using the same method for two randomly selected areas in each plot and at two different depths.

Lab Analysis

Composite samples of the plots were made to reduce the time and money needed to analyze every sample. All samples have been sieved and analyzed for pH and EC using a 1:2 soil water ratio with an AGRI-METER. Particle-size distributions are being determined by the hydrometer method (Gee and Bauder, 1986). Coarse fragment percentage will be determined by weight difference. Exchangeable cations (K, Ca, Mg, Na, Mn,) were extracted with a 1M NH_4OAc solution buffered at pH 7 and quantified with the ICP instrument located in the Soil Testing

Laboratory (SCS 1972). Phosphorus will be extracted with sodium bicarbonate (Olsen and Sommers 1982) and analyzed with the ICP instrument. Total C (g kg^{-1}) and N (g kg^{-1}) will be measured by combustion with an Elementar CNS analyzer (Nelson and Sommers, 1996). Exchangeable aluminum (Al^{3+}) was extracted with a 1 *N* KCl solution and quantified by titration (McLean, 1965). Base Saturation and ECEC will be calculated from results of previous analyses.

Results

A summary of the mine soil characterization data will be included in the next report.

Conclusions

None to report at this time.

References

Gee, G.W. and Bauder, J.W.1986. Particle Size Analysis. pp. 383-410. *In* Klute, Arnold. (ed.) Methods of Soil Analysis. Part 1. 2nd ed. SSSA. Inc. Madison, WI.

McLean, E.O. 1965. Aluminum. p. 978-998. *In* C.A. Black et al. (ed.) Methods of soil analysis, Part 2. Agron. Monogr. 9. ASA, Madison, WI

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. *In* J.M. Bigham (ed.) Methods of soil analysis. Part 2. 2nd ed. SSSA. Madison, WI.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-431. In A.L. Page et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. ASA and SSSA. Madison, WI.

SCS. 1972. Soil survey laboratory methods and procedures for collecting soil samples. USDA. SSIR 1. U.S. Government Printing Office, Washington, D.C.

TASK 3: Develop reforestation methods and procedures for mined land. (Fox et al.)

Executive Summary

Installation of the field sites designed to evaluate reforestation methods and procedures is under way. Sites in Ohio, West Virginia, and Virginia have been located. Plots were installed. Soil samples were collected in all plots to characterize the sites. Initial weed control was completed at all sites. Tillage treatments were completed at the Ohio site and are planned for the West Virginia and Virginia sites. Seedlings required to plant the three locations have been ordered. Arrangements have been made to plant the seedlings early in 2004.

Experimental

Installation of the field sites designed to evaluate reforestation methods and procedures continued. Three field sites have been located. The first site is located in Lawrence County, Ohio, on land owned by MeadWestvaco Corporation. This land was recently sold to the Nature Conservancy and we are negotiating with that organization to have them join the restoration project as a research partner. The second site is located in Nicholas, County, West Virginia, on land owned by Plum Creek Timber Company. The third site is located in Wise County, Virginia, on land owned by PennVirginia Company.

The experimental design was revised based on site conditions. Site variation prohibited installation of plots in a manner consistent with a split plot. Rather than a split plot, the study was installed as a 3 x 3 factorial in a random complete block design with three replications at each location. The treatments include three forest types (white pine, hybrid poplar, mixed hardwood) and three silvicultural regimes (competition control, competition control plus tillage, competition control plus tillage plus fertilization). Each individual treatment plot is 0.5 acres. Each block of nine plots requires 4.5 acres, and the complete installation at each site requires 13.5 acres. The plots at all three locations have been installed and monumented with PVC stakes. GPS coordinates of each plot have been collected. The forest type and silvicultural treatments were randomly assigned to each plot according to the revised experimental design discussed above.

Soil samples were collected from each plot to characterize the sites prior to treatment. Samples of the surface 15 cm and the subsurface to a depth of 50 cm were collected in each plot. The soil samples are being analyzed. A detailed description of the soil at each location was made using a single soil pit dug with a backhoe.

The initial weed control treatments were applied in each stand. A broadcast application of 4 qts/acre of Glyphosate was made in the fall before the first frost at each location to kill the fescue present at each site. The tillage treatments at the site in Ohio were completed using a bulldozer equipped with a single tooth ripping shank. Tillage treatments at the sites in West Virginia and Virginia will be done during the first quarter of 2004. The costs associated with installing the three field installations are being paid by MeadWestvaco Corporation, Plum Creek Timber Company, and PennVirginia Company, which is a significant contribution to this project that leverages the DOE contributions.

The species composition of the mixed hardwood planting will vary at each location. The species composition of an adjacent, undisturbed forest was inventoried to determine the appropriate mix of species to include at each site.

The West Virginia Division of Forestry has joined the project as a partner and has agreed to provide the white pine and hardwood seedlings required for the project. MeadWestvaco has agreed to provide the hybrid poplar seedlings. The following table summarizes the seedlings required to plant the three installations.

Species	**Number of Seedlings Required**
Hybrid Poplar	10,000
White Pine	10,000
White Oak	700
Chestnut Oak	500
Pignut Hickory	700
Sugar Maple	1500
Black Oak	500
Tulip Poplar	1500
Northern Red Oak	1500
Scarlet Oak	500
Red Maple	500
White Ash	1000
Basswood	500
Redbud	1000
Dogwood	1000
Hawthorn	1000
Total	**32,400**

Arrangements have been made for planting the sites during the spring of 2004. Williams Forestry has joined as a partner in the project and will plant the seedlings at the three locations. Planting is scheduled to take place early in the second quarter of 2004. This is another significant in-kind contribution to the project that leverages the DOE contribution.

Results and Discussion

None to date. The installation phase of the progress is still under way.

Conclusions

None to date.

TASK 4: Conduct economic analyses of reforestation and forest management activites for carbon sequestration and a variety of forest products and services. (Amacher and Sullivan)

Executive Summary

In Task 4, the economic feasibility of a range of land-use conversion scenarios was analyzed for both mixed hardwoods and white pine, under a set of low product prices and under a set of high product prices. In addition, three types of incentive schemes were investigated for encouraging reforestation of these sites: (1) lump sum payment at planting (and equivalent series of annual payments); (2) revenue incentive at harvest; and (3) annual incentive payments based on carbon volume. Mixed hardwood land expectation values (LEV) ranged from -$2416.71/ha (low prices) to $3955.72/ha (high prices), and white pine LEVs ranged from -$2330.43/ha (low prices) to $3746.65/ha (high prices); hence, a greater proportion of white pine scenarios yielded economically feasible land-use conversions than did the mixed hardwood scenarios. Mixed hardwoods lump sum incentive payments, made at the time of planting, ranged from $0/ha to $2416.71/ha (low prices), and white pine lump sum payments ranged from $0/ha to $2330.53/ha (low prices). Mixed hardwoods benefits based on an increase in revenue at harvest ranged from $0/ha to $784449.52/ha (low prices), while white pine benefits based on an increase in revenue at harvest ranged from $0/ha to $7011.48/ha (high prices). Annual mixed hardwood incentives, based on total stand carbon volume present at the end of a given year, ranged from $0/ton of carbon to $5.26/ton carbon (low prices), and white pine benefits ranged from $0/ton of carbon to $18.61/ton of carbon (high prices). When the coal operator pays the costs of converting mined sites to forest, mixed hardwood LEVs range from $15 to $2058/ha, and white pine LEVs range from $220 to $4732/ha, demonstrating the substantial difference in profitability for landowners when forest conversion is accomplished according to the spirit of the law rather than the minimum effort that has been applied across many hectares of mined land.

Experimental

In order to calculate the financial feasibility of a given silvicultural regime for a particular site, it is necessary to know: (1) the volume of timber available at a given rotation age; (2) the mix of merchantable sawtimber and pulpwood at harvest; (3) the value of the timber and pulpwood; (4) the value of any other associated amenity values and opportunity costs; (5) the costs associated with implementing the given regime; and (6) the timing of costs incurred and revenues received.

Considering the economic profitability of converting reclaimed mined lands to forests entails comparing the expected net financial returns from forest production to any opportunity costs associated with the land use conversion. To compare the potential profitability of alternative reforestation strategies, net present values (NPV, for single rotation) and land expectation values (LEV, for multiple rotations) are simulated for the various silvicultural regimes. These measures of economic feasibility are simulated for a range of scenarios by varying site preparation intensity, timber and pulpwood prices, rotation lengths, site class, and alternative rate of return. Further, various incentive schemes are explored in an effort to determine what financial remuneration would be necessary in order to render a given scenario economically feasible.

Data

The bulk of this financial feasibility study begins with forest inventory data collected on reclaimed mined sites taken from a study by Rodrigue (2001). These data were gathered from 14 planted forest sites across seven states, located on reclaimed mined lands in the midwestern and Appalachian coalfields (Figure 1).

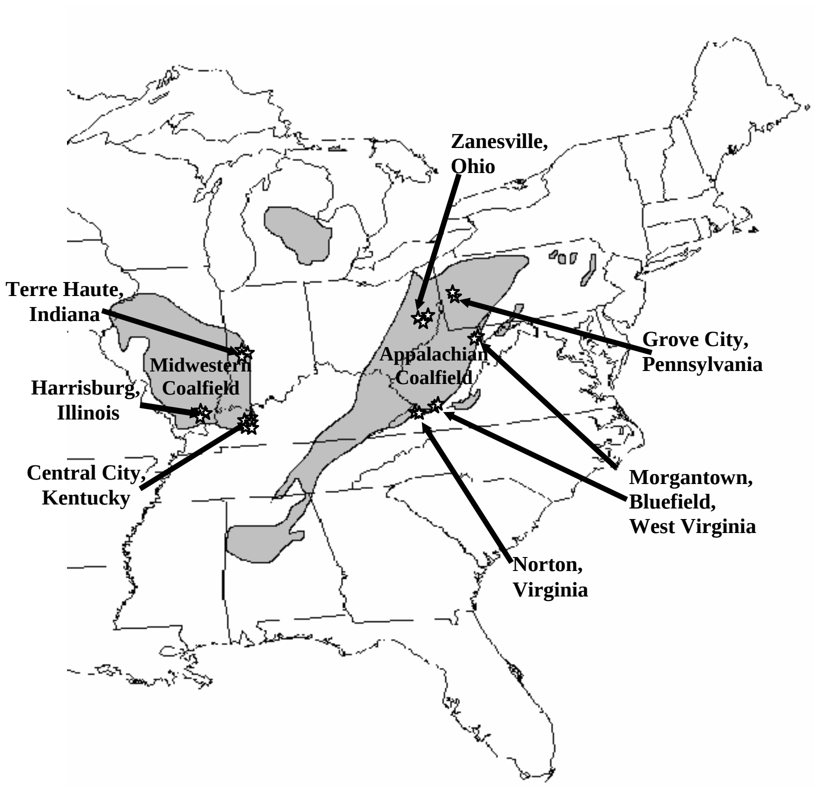

Figure 1. General location of study sites in the Midwestern and Appalachian coalfields.

Within each similar geographic region (e.g., southern Illinois), reference native forest sites representing minimally manipulated regional forests were also located and measured. In total, eight reference sites were located within the seven-state study area. Henceforth, these reference sites will be referred to as non-mined or "natural" sites.

Growth and Yield Model Formulation

Two forest stand types are considered for reforestation purposes: (1) mixed Appalachian hardwoods, and (2) white pine. Therefore, the Rodrigue data were first divided into hardwood stand data and pine stand data. A growth and yield model of the following form was then developed for each of these sets of data:

$$\ln(V) = b_0 + b_1S + b_2N + b_3/A + e$$

where: V = total stand volume (m^3/ha)
S = site index
N = stand density at harvest (stems/ha)
A = stand age (years)

e = random error

This variable-density growth and yield equation is similar to the prediction model developed by MacKinney and Chaiken (1939) for natural stands of loblolly pine. The primary difference between our model and that of MacKinney and Chaiken is that our stand density (N) is measured in stems/ha, whereas their stand density (log SDI) is presented as the logarithm of a stand density index.

Site indices identified by Rodrigue (2001) for the mixed hardwood stands were converted to site indices for white oak (base age 50 years), and site indices for the pine stands were converted to site indices for white pine (base age 50 years), using a site index comparison graph for species on the same land in the southern Appalachians (Doolittle, 1958).

Survival of Planted Trees

The stand density variable used in the yield equations estimated for this study is stand density at harvest. Thus, given the fact that planting density will be a controlled factor in the conversion of these reclaimed mined lands, survival equations (Table 1) were developed for both mixed hardwoods and white pine, based on stand age, in order to calculate stand density at harvest from the predetermined planting density. Hence, stand density at harvest is a function of planting density and harvest age. The mixed hardwood survival equation developed for this study is based on survival data from the following studies: Mickalitz and Kutz (1949), Deitschman (1950), DenUyl (1955), Czapowskyj (1970), Plass (1975), Larson and Vimmerstedt (1976), Plass (1977), Larson and Vimmerstedt (1983), Schuster and Hutnik (1983), Ashby (1999) and Demchik and Sharpe (1999). The white pine survival equation developed for this study is based on survival data from the following studies: Brown (1962), Sluder (1963), Branan and Porterfield (1971), Larson and Vimmerstedt (1976), Plass (1977) and Dierauf and Scrivani (1995).

The survival equations in Table 1 were estimated using ordinary least squares regressions on the published survival data. The corresponding regression statistics for these survival equations are summarized in Table 2. The data used in developing these survival equations are illustrated in Figures 2 and 3.

Table 1. Survival equations. y = survival (%); A = stand age (yrs); e = random error.

Species	Survival Equation
Mixed hardwoods	y = -8.6881n(A) + 84.472 + e
White pine	y = -15.0441n(A) + 101.90 + e

Table 2. Regression statistics for survival equations.

	Data Set	
ln(A)	**Mixed Hardwoods**	**White Pine**
Coefficient	-8.68844	-15.04359
t-stat	-3.40477	-6.05245
P-value	0.00392	0.00000
Observations	17	104

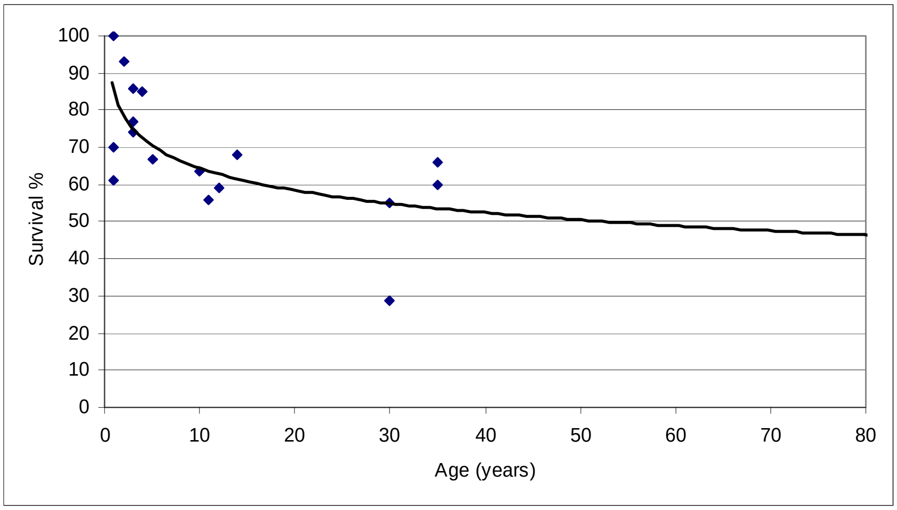

Figure 2. Survival curve for mixed hardwoods.

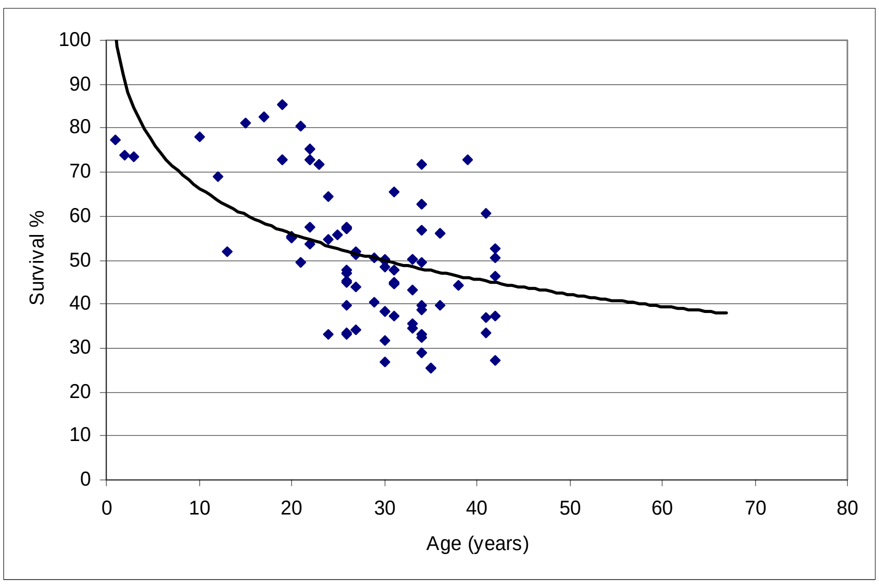

Figure 3. Survival curve for white pine.

The literature suggests that survival of planted trees may range from 0% to almost 100%, depending on the specific planting scenario, as there are many factors which determine the survival of a tree. Hence, it is understood that no one survival equation will yield an accurate estimate for all given scenarios. The survival equations developed for the sake of this study simply provide an approximation of survival percentage for the sake of data manipulation for this study.

Stand Volume

Multiple linear regression was used to estimate per-hectare stand volume, with ln(V) as the dependent variable, and S, N and A^{-1} as the independent variables. The growth and yield models estimated for mixed hardwoods and white pine are presented in Table 3. The corresponding regression statistics for these equations are presented in Table 4.

Table 3. Estimated yield equations for mixed hardwood and white pine plantations on mined land, based on data from study by Rodrigue (2001). V = total stand volume (m^3/ha); S = site index; N = stand density at harvest (stems/ha); A = stand age (yrs); e = random error.

Species	Yield equation
Mixed hardwoods (pooled data)	ln(V) = 4.862 + 0.015S – 0.0002N – 11.229/A + e
Mixed hardwoods (mined data only)	ln(V) = 6.156 + 0.006S – 0.0003N – 34.400/A + e
White pine	ln(V) = 5.328 + 0.016S – 0.0004N – 34.131/A + e

Table 4. Regression statistics for yield equations.

	Data set		
	Mixed Hardwoods (pooled)	**Mixed Hardwoods (mined only)**	**White pine**
Site index (S)			
Coefficient	**0.0145****	**0.00570**	**0.01604****
t-stat	2.90857	0.54625	3.13600
P-value	0.00529	0.59065	0.00448
Stand density (N)			
Coefficient	**-0.00023**	**-0.00025**	**-0.00038**
t-stat	-0.86142	-0.60100	-1.50392
P-value	0.39289	0.55427	0.14565
Age (1/A)			
Coefficient	**-11.22905**	**-34.39954***	**-34.13108****
t-stat	-1.03875	-1.97406	-3.81126
P-value	0.30364	0.06167	0.00085
Observations	57	25	28

*indicates coefficient is significant at $\alpha = 0.10$ level
** indicates coefficient is significant at $\alpha = 0.01$ level

Rodrigue (2001) reported that comparisons of forest productivity between mined and non-mined mixed hardwood stands suggest that mined sites, if managed correctly, are capable of being just as productive as their non-mined counterparts, if not more so. Hence, a regression was run initially on the pooled mined and non-mined mixed hardwood data, with a dummy variable distinguishing between mined and non-mined data. The results suggested that the yields from the mined and non-mined sites were not significantly different. Thus, the mined and non-mined mixed hardwood data were pooled to allow for a larger data set. A growth and yield model was also developed for mixed hardwoods, based on the mined data only. This model, however, yielded higher volumes than the model developed for the pooled mined and non-mined data. The model for the pooled data was implemented in the rest of this study. Rodrigue did not present any data for non-mined white pine stands. Hence, we have not distinguished between mined and non-mined white pine data.

Silvicultural Treatments

Restoration of productive forest land requires the construction of a deep, non-compacted, non-toxic minesoil, and the absence of a competitive ground cover (Torbert et al. 1996). The three proposed silvicultural treatments for this study are aimed at sequentially addressing the three major factors limiting reforestation success on reclaimed mined land:

- incompatible ground cover
- soil compaction
- incompatible soil chemical properties and low fertility

Silviculture treatment 1 (low intensity): This treatment addresses only the existing incompatible ground cover. Herbicides will be used to kill the existing groundcover. Trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

Silviculture treatment 2 (medium intensity: This treatment will address the existing incompatible groundcover and soil compaction problems. Herbicides will be used to kill the existing groundcover. The site will be tilled to a depth of 0.7 m in one direction to ameliorate soil compaction problems. Trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

Silviculture treatment 3 (high intensity): This treatment will address the existing incompatible groundcover, soil compaction, and soil chemical and fertility problems. Herbicides will be used to kill the existing groundcover. The site will be tilled to a depth of 0.7 m in one direction to ameliorate soil compaction problems. Soil chemical and fertility problems will be corrected/improved through liming and fertilization. Trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

Estimation of Reforestation Costs

In order to estimate the costs of converting reclaimed mined lands from grasslands to forests under the various silvicultural regimes, cost estimates were made for each of the three site preparation intensities. The activities and costs associated with each of the three site preparation intensities are reported in Table 5. A number of these costs are average costs from the literature, while some of them were collected via personal communication. The total costs incurred per site preparation intensity for the mixed hardwood and white pine scenarios are summarized in Table 6.

These site preparation costs are similar to those estimated by Kronrad (2002) for his study on reclaiming mined lands to forests in a number of states.

Table 5. Estimated costs of various site preparation activities in a given year.

Year	Activity	Cost ($/ha)	Site Preparation Intensity
0	Weed control (herbicide + application)	262.54[1]	High, medium, low
	Ripping (D8 bulldozer)	296.52[2]	High, medium
	Fertilize (6oz/tree: materials + application)	197.16[3]	High
	Lime (2.47 tons/ha: materials + application)	97.23[4]	High
	Seedlings ($0.25/tree: mixed hardwoods)	369.66*[5]	High, medium, low
	Hand planting	672.11[6]	High, medium, low
1	Weed control 1 (herbicide + application)	90.19[7]	High, medium, low
	Weed control 2 (herbicide + application)	90.19	High, medium, low
2	Weed control 1 (herbicide + application)	90.19	High, medium, low
	Weed control 2 (herbicide + application)	90.19	High, medium, low
	Fertilize (12 oz/tree)	237.49	High

* $0.20/tree for white pine = $268.84/ha
[1] 1.25 gal/ac @ $45/gal + application @ $50/ac (tractor sprayer)
[2] D8 bulldozer @ $120/ac
[3] Walmart (2003): $4/50lbs bag of 10:10:10 + application @ $7/hr (labor wage)
[4] Sisson & Ryan Quarry (2003): $4.35/ton of lime + application @ $35/ac (farm tractor)
[5] Forest Landowner 2001-2001 Seedling Nursery Directory
[6] 1344 trees/ha @ $0.5/tree
[7] 0.5gal/ac @ $45/gal + application @ $14/ac (hand spray)

Table 6. Total costs incurred per site preparation intensity.

Site Preparation Intensity	Total Cost ($/ha – not discounted)	
	Hardwoods	White pine
Low	1665.08	1591.15
Medium	1961.60	1887.67
High	2493.48	2419.55

Net Present Value and Land Expectation Value Calculations

For the sake of this study, net present values (NPV) and land expectation values (LEV) will be calculated as measures of economic feasibility of various land-use conversion scenarios. All results will be presented and discussed in terms of LEV. NPV recognizes money's time value by using the minimum acceptable alternative rate of return to discount all revenues and costs back to the time of project initiation. The discounted costs are then subtracted from the discounted revenues as shown below:

NPV = present value (revenues) – present value (costs)

The general formula used in calculating NPV values is:

$$\text{NPV} = \sum_{t=0}^{T} R_t /(1+i)^t - \sum_{t=0}^{T} C_t / (1+i)^t$$

where: R_t = revenue received at time t ($/ha)
C_t = cost incurred at time t ($/ha)
i = alternative rate of return
t = time since project initiation (years)
T = harvest age (years)

LEV is the NPV for an infinite time horizon. Whereas NPV takes into account the opportunity cost of money that is tied up in the investment in forestry over a single rotation, LEV also takes into account the opportunity cost of land by considering subsequent rotations. Put simply, calculating LEV is similar to assuming that a project will be replicated an infinite number of times into the future. This is the underlying assumption in reforesting these abandoned mine lands; hence the calculation of LEV. The general formula used in calculating LEV values is:

$$\text{LEV} = [\sum_{t=0}^{T} R_t /(1+i)^t - \sum_{t=0}^{T} C_t / (1+i)^t]/(1-(1 + i)^T)$$

More often than not, there is an opportunity cost of land in another use involved in the conversion of land from one use to another. The mined lands of relevance in this study are those that have already been reclaimed to grasslands. With very little opportunity for alternative uses, one may expect these lands to be used for grazing. However, in most cases, often due to the steep terrain, these lands are not put to use at all and are simply abandoned. Hence, in converting such lands to another land use, there is no opportunity cost of land in another use involved. This will remain the assumption throughout this study.

A wide variety of decision parameters must be considered when examining the financial feasibility of reforesting mined lands, including rate of return, timber and pulpwood prices, rotation age, and site class. All NPV and LEV calculations were conducted under the assumption of an initial planting density of 1344 stems/ha. This is a standard 10 x 8 ft stocking for plantations. A sensitivity analysis was conducted by varying the following factors:

- *Alternative rate of return (ARR):* Scenarios were developed using 3.5%, 5%, 7.5%, and 10% as alternative rates of return. This range of ARRs covers a broad spectrum of interest rates and is consistent with other studies.

- *Timber and pulpwood prices:* Two sets of prices were used. For the sake of convenience, we will label these two sets of prices (1) low prices and (2) high prices. The first set of prices used (low prices) were first-quarter 2003 Timber Mart-South standing timber average prices for mixed hardwoods and pine in Virginia. The second set of prices used (high prices) in our analysis comprises a set of ideal, high-end prices, where only high-value timber species and top quality timber products are considered. Standing timber prices from the 2003 Pennsylvania Woodlands timber market report were averaged for the following hardwood species: red oak, white oak, black cherry, white ash, yellow poplar, and sugar maple (hard maple). An average of $379.63/MBF was calculated and converted to a $/ton value. The white pine timber price used in the second set of prices is that quoted by Turman Lumber Company (July 2003). This price was used in an effort to represent the potential value of white pine sawtimber, were it to be sold in a "niche market," and had a range of $100 to $200/MBF. The high end of this range was chosen for our "high-end ideal scenario" and was converted to a $/ton value. Turman Lumber Company did not place a value on white pine pulpwood. Both the hardwood and white pine pulpwood prices are those taken from the Pennsylvania Woodlands timber market report. Both sets of prices are presented in Table 7.

Table 7. Low and high prices for sawtimber and pulpwood.

	Low Prices[1]		**High Prices[2]**	
	Hardwoods	**Pine**	**Hardwoods**	**Pine**
	------------------------- $/ton -------------------------			
Sawtimber	20.07	29.68	61.04	34.64
Pulpwood	4.65	8.51	9.05	11.89

[1]First-quarter 2003 Timber-Mart South.
[2]Pennsylvania Woodlands timber market report and Turman Lumber Co.

- *Rotation age:* Hardwood rotation ages were varied, in increments of 10 years, from 40 to 80 years. Pine rotation ages were varied, in increments of 5 years, from 20 to 40 years. These ranges cover a spectrum of feasible rotation ages for hardwoods and softwoods.
- *Site class:* Economic feasibility calculations were made for each of the three site preparation intensities on each of the designated site classes I-V.

The purpose of this sensitivity analysis was to analyze how varying any of these factors affected the decision-making process in the quest for the optimal management regime.

Site Classes

NPV and LEV values in this study are reported for each site preparation intensity on each site class. Table 8 shows the site class delineations used in this study.

Table 8. Site index classes for mixed hardwoods and white pine (ft at base age 50).

Site Class	V	IV	III	II	I
Mixed Hardwoods:					
Range	<51	52-61	62-71	72-80	80 +
Average	46	56	66	75	85
White Pine:					
Range	<64	65-77	78-88	89-99	100+
Average	58	71	83	94	106

When forest sites are harvested, landowners tend to merchandise their products by selling larger logs as sawtimber and smaller pieces of wood as pulpwood. The proportions of these products often depend on species and site quality. On higher quality sites, the proportion of sawtimber tends to be higher, and the reverse tends to be true on poorer sites (Amacher et al. 1997). For the sake of this study, site classes I and II were classified as high-quality sites. Site classes III, IV and V were classified as poor-quality sites. Based on these assumptions, the proportions of sawtimber and pulpwood shown in Table 9 were used in this study.

Table 9. Proportions of sawtimber and pulpwood for various site classes by species (Amacher et al. 1997).

Site Class	Sawtimber	Pulpwood
I & II (hardwoods & pine)	75%	25%
III, IV & V (hardwoods)	66.7%	33.4%
III, IV & V (pine)	50%	50%

Competition control, fertilization, and ripping can have significant effects on the growth of a forest stand. In a study by Will et al. (2002), a difference of approximately 18 ft was reported in 13-year-old height data between a control stand of *Pinus taeda* in Georgia and a similar stand that was treated with a combination of competition control and fertilization. Kozlowski (1999) reported on a study that suggested a 40% increase in growth of *P. rigida, P. nigra and Picea abies* seedlings in cutover sites from similar seedlings growing on adjacent compacted skid trails. Kozlowski also reported that a study in Sweden suggested a 25% increase in height growth of *P. abies* seedlings from similar seedlings growing on compacted soils. Burger et al. (1998) suggested a white pine site index (base age 25) of 45 ft for an average-quality post-SMCRA reclaimed mine soil and a site index of 70 ft for a properly reclaimed mine soil in Virginia.

Productivity increases associated with the site preparation and silvicultural treatments we considered on our particular site conditions are not well documented. Thus, a set of assumptions was made for this study, based somewhat on the aforementioned site productivity information, and keeping in mind the law of diminishing returns; i.e., a given site preparation intensity will tend to have decreasing positive growth effects when moving from poor quality sites to better quality sites.

<u>Hardwoods</u>

- Medium-intensity site preparation increases average site index values of site classes II, III, IV and V by 10 ft, and increases average site index value of site class I by 5 ft.
- High-intensity site preparation increases average site index values of site classes III, IV and V by 20 ft, increases average site index value of site class II by 15 ft and increases average site index value of site class I by 5 ft. (90 ft at base age 50 years was set as a maximum site index for hardwoods. Hence, an increase in average site index value of site class I of only 5 ft.)

<u>White Pine</u>

- Medium-intensity site preparation increases average site index values of site classes I, II, III, IV and V by 12 ft (no decreasing returns, as a site class I site starts out with a site index of 106 ft, and can still be significantly improved upon).
- High-intensity site preparation increases average site index values of site classes II, III, IV and V by 24 ft, and increases average site index value of site class I by 18 ft (124 ft at base age 50 years was set as a maximum site index for white pine).

These improvements, due to differing site preparation intensities, are primarily based on average site index increments from one site class to the next of 9.75 ft and 12 ft for mixed hardwoods and white pine, respectively. The improvements are ultimately reflected in the timber volumes produced at rotation.

Incentive Schemes and Policy Design

In order to justify the conversion of land from one land use to another from a purely economic standpoint, the LEV of the proposed land use must be at least equal to the LEV of the current land use. For the sake of this study, the LEV for all reclaimed land in its current state is assumed to be zero. This land has been abandoned; hence, for the sake of this study, it is assumed that this land does not yield any monetary benefits. So too, any potential costs such as management costs and property taxes associated with the abandoned land are not taken into account in this study, since we anticipate that these costs will remain equal across all the proposed land use regimes. Therefore, in order to justify the conversion of these reclaimed mined lands from their current state to forests, the LEV of a given management regime should at least be equal to zero, thus suggesting no financial loss. However, some of the proposed management regimes may yield negative LEV values, which would suggest that such regimes are not economically feasible.

Such economically infeasible management regimes are not necessarily a lost cause. In order to render such a regime economically feasible, an incentive can be offered to the landowner in order to sway the associated LEV from a negative value to zero or even to a positive value. Therefore, the next step in this economic analysis was to determine the minimum payment for each proposed management regime that will yield non-negative LEVs for conversion of land use on a representative hectare. Incentive values were calculated for all negative LEVs in the subset of scenarios that assume a rotation age of 60 years for mixed hardwoods and 30 years for white pine, and that are in the 3.5% to 7.5% range of alternative rate of return. In order to predict a potential range of incentives, incentive values were also calculated for each of the high base case and low LEV scenarios for both mixed hardwood and white pine. An incentive payment could take on many forms, three of which are explored in this study, namely:

1. *Lump sum benefit, paid at the time of planting*. This benefit will equate to a one-time payment made at the time of planting, in order to render the given scenario economically feasible. This incentive is simply calculated as being the value that would balance the loss represented by any negative LEV:

   $$\text{Incentive} = -(\text{LEV}) \qquad \text{for all LEV} < 0$$

   This lump sum payment will also be translated into a set of equal annual payments. In order to translate this lump sum payment into a set of equal annual payments, the following calculation was used:

   $$\text{Annual payment} = -(\text{LEV}) \times i \qquad \text{for all LEV} < 0$$

2. *Benefit based on revenue received.* This benefit will equate to the increase in revenue required to render the given regime economically feasible. The lump sum subsidy to be paid at harvest is calculated by first solving the following equation for K, and then multiplying K by the revenue at harvest:

   $$\left[\sum_{t=0}^{T} R_t(1+K)/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t\right]/(1-(1+i)^{-T}) = 0$$

   where: K = proportional increase in revenue received at harvest

3. *Benefit based on carbon volume present each year.* This benefit will equate to an annual payment per unit carbon volume present, required to render the given scenario economically feasible. In other words, we will calculate the necessary value of carbon to render a given scenario economically feasible. The payment per unit carbon volume is calculated by solving the following equation for Z:

   $$\left[\sum_{t=0}^{T} R_t/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t + Z\sum_{t=1}^{T} X_t/(1+i)^t\right]/(1-(1+i)^{-T}) = 0$$

   where: Z = annual per unit carbon volume payment ($/ton)
   X_t = carbon volume present at end of year t (tons/ha)

Conversions from timber volume to total carbon content (X_t) were based on the conversion factors used by van Kooten et al. (2000):

- multiply the merchantable stand volume by an expansion factor (=1.57) to obtain total above-ground biomass (G):

  hardwoods and softwoods: G = 1.57V

  where: V = total stand volume (m^3/ha)

- root biomass (R) is related to above-ground biomass as follows, with both measured in tons per ha:

$$\textit{hardwoods:}\ R = 1.4319G^{0.639}$$
$$\textit{softwoods:}\ R = 0.2317G$$

- total biomass (m^3/ha) = G + R
- average carbon content in timber is given by:

hardwoods: 0.187 tons carbon per m^3
softwoods: 0.207 tons carbon per m^3

- total carbon content (tons/ha) is given by:

hardwoods: 0.187(G+R)
softwoods: 0.207(G+R)

The economic implications of these various incentive schemes and the implications that each one has on the landowner's decision-making process are subsequently analyzed. This part of the economic analysis is ultimately aimed at helping develop a framework for evaluating the best types of policies that the government or other agencies might use to encourage the establishment of forests on reclaimed mined lands.

Results and Discussion

Introduction

In evaluating the economic feasibility of converting reclaimed mined lands to forests, a broad spectrum of scenarios has been investigated based on site class, site preparation intensity, alternative rate of return, rotation length, and product prices. A few general trends run throughout a large portion of the results, even though a number of the proposed scenarios differ subtly from one another. A subset of scenarios are discussed to highlight the general trends. As a reference point, the base case scenario will be the land use conversion scenario based on average site conditions and input factors. Hence, the base case scenario is based on rotations of 60 years and 30 years for mixed hardwoods and white pine, respectively, an alternative rate of return of 5%, a site class III site, and medium site preparation intensity. Discussion of results will also be limited to the 3.5% to 7.5% range of alternative rate of return. This range of alternative rates of return covers the general trends in the results. Land expectation value and incentive results will be discussed in detail for the set of low product prices, and will be more briefly summarized for the set of high product prices.

Growth and Yield

The volume of sawtimber and pulpwood present in a forest stand at harvest age ultimately determines the amount of revenue that can be earned from sawtimber and pulpwood sales. The value of sales, in turn, partly determines the land expectation value (LEV) of a given reforestation regime. Hence, knowledge of the volumes of sawtimber and pulpwood produced by a given forest stand over a range of rotation ages is the first step in calculating LEVs and incentive values for this study. Also, knowledge of the volume of carbon present in a forest stand at a given age is necessary in calculating incentive values based on forest stand carbon content.

Hardwoods

The mixed hardwood growth and yield function estimated for this study is presented graphically in Figure 4 for units of m^3/ha and tons/ha for a site class III site under low-intensity site preparation. Results suggest that the maximum periodic annual increment (PAI) for this forest stand is occurring between 10 and 20 years of age. Thereafter, the marginal rate of timber production decreases. Stand volumes estimated with this yield equation are comparable to the 46-year-old stand volumes measured by Zeleznik and Skousen (1996) on reclaimed mines in Ohio.

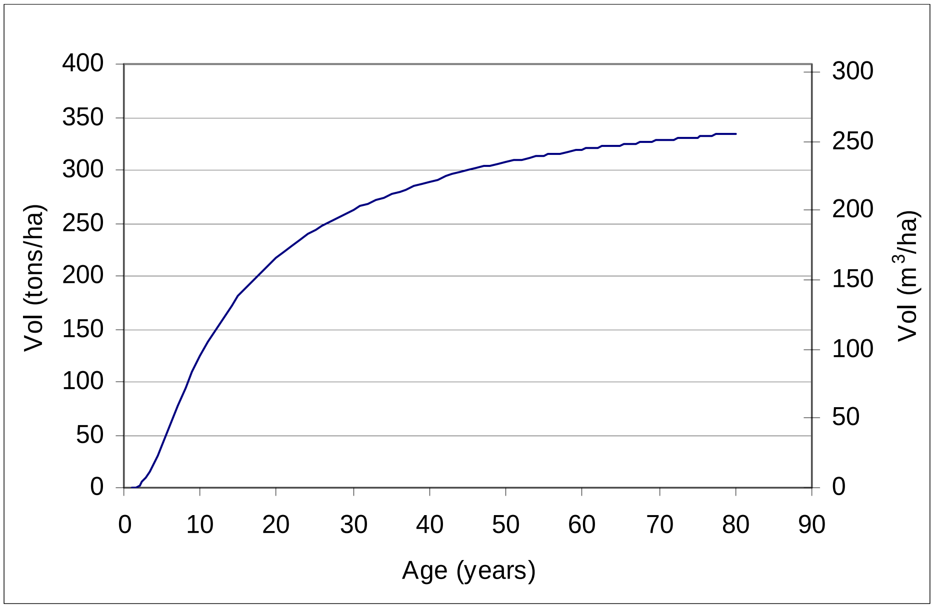

Figure 4. Growth and yield of mixed hardwoods (site class III, low-intensity site preparation).

Figure 5 shows carbon volume content of a mixed hardwood forest stand at a given age for a class III site under low-intensity site preparation. These carbon volumes are based on the mixed hardwood growth and yield equation estimated for this study and a series of conversion factors taken from the study by van Kooten et al. (2000). These carbon volumes are consistent with the volumes estimated by Ravindrath and Somashekhar (1995) for the revegetation of degraded lands to hardwood plantations, and are within the range of carbon volumes estimated by Xu (1995) over a range of afforestation management scenarios.

Figure 5. Mixed hardwood forest stand carbon volume by age (site class III, low-intensity site preparation), based on van Kooten et al. (2000) carbon conversion factors.

White Pine

The white pine growth and yield function estimated for this study is presented graphically in Figure 6 for units of m^3/ha and tons/ha for a class III site under low-intensity site preparation. Results suggest that the maximum periodic annual increment (PAI) for this forest stand is occurring between 25 and 35 years of age. Stand volumes estimated with this yield equation are similar to the white pine stand volumes reported by Davidson (1981) for plantings on mined lands in Pennyslvania.

Figure 6. Growth and yield of white pine (site class III, low-intensity site preparation).

Figure 7 shows carbon volume content of a white pine forest stand at a given age for a class III site under low-intensity site preparation. These carbon volumes are based on the white pine growth and yield equation estimated for this study and a series of conversion factors taken from the study by van Kooten et al. (2000). These carbon volumes are consistent with the volumes estimated by Ravindrath and Somashekhar (1995) for the revegetation of degraded lands to softwood plantations, and are within the range of carbon volumes estimated by Xu (1995) over a range of afforestation management scenarios.

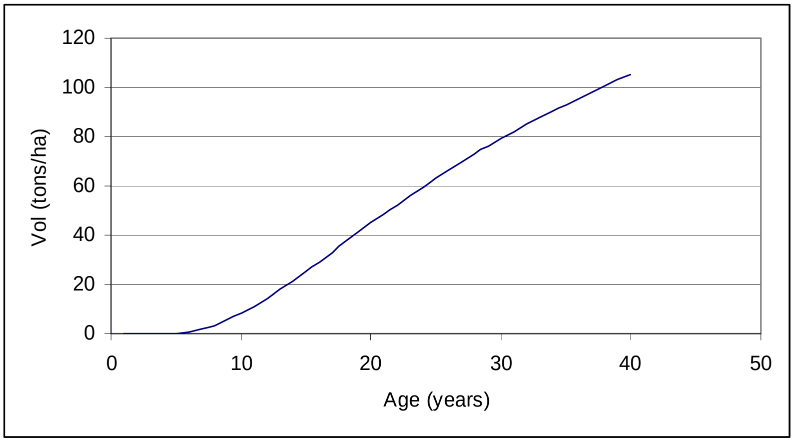

Figure 7. White pine forest stand carbon volume by age (site class III, low-intensity site preparation), based on van Kooten et al. (2000) carbon conversion factors.

Low Price Scenarios

All results presented and discussed in the following sections are based on the low set of product prices. In the following sections, the economic feasibility of converting reclaimed mined lands to mixed hardwood and white pine forests will be discussed in terms of LEVs. More specifically, the effects of the following factors on LEV will be analyzed: rotation age, site class, site preparation intensity, and alternative rate of return.

Effect of Rotation Age on LEV

An investment made in a land-use conversion to forestry is a long-term investment. A rotation length of 20 years versus one of 80 years has significant implications in terms of factors such as the time value of money and alternative investments, stand growth and volume, levels of risk, and markets. Hence, deciding how long to grow a stand of trees is one of the first management decisions a landowner has to make in an effort to optimize his or her investment.

Hardwoods

Figures 8, 9, and 10 show mixed hardwood LEV trends for each site class over a range of rotation ages. These trends remain relatively constant throughout all three site preparation intensities. Note that for the high-intensity site preparation scenario (Figure 10), site classes I and II yield equivalent LEV values. This is due to both of these site classes having the same site index value under high-intensity site preparation, as was discussed earlier.

The initial results did not yield any obvious maximum LEV or optimal rotation age for mixed hardwoods within the rotation age range of 40-80 years. Subsequently, additional data points were plotted for the medium-intensity site preparation scenario (Figure 9), as LEVs were projected back to a rotation age of 8 years for site classes I and V. For both site classes I and V, the maximum LEV occurred at a rotation age of approximately 20 years, thus suggesting that a rotation age of 20 years would be optimal if maximizing LEV were the primary objective, based solely on total standing timber volume and value, and not product volumes and values.

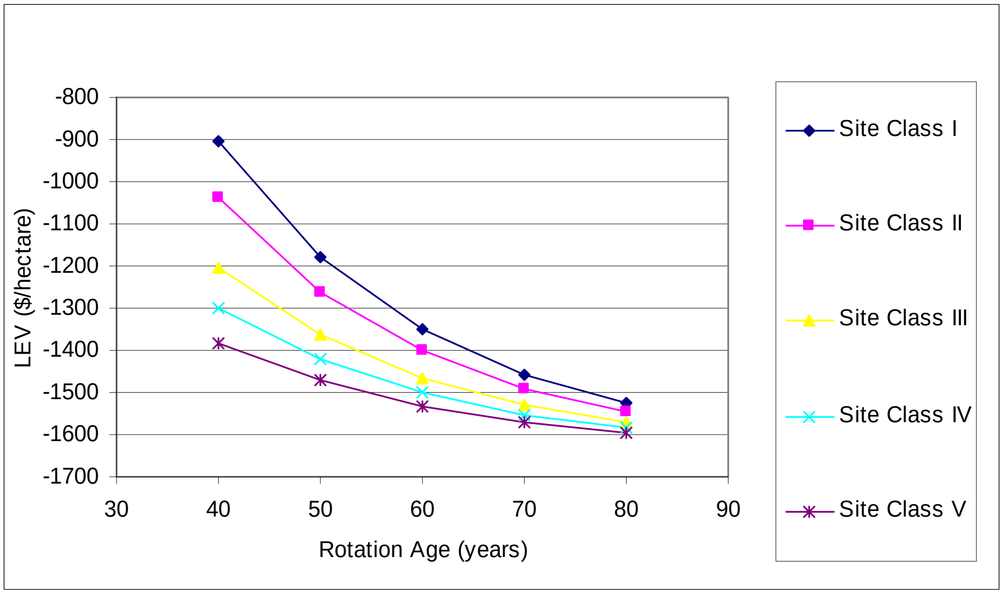

Figure 8. Mixed hardwood LEV by rotation for various site classes (low-intensity site preparation, low prices, 5% ARR).

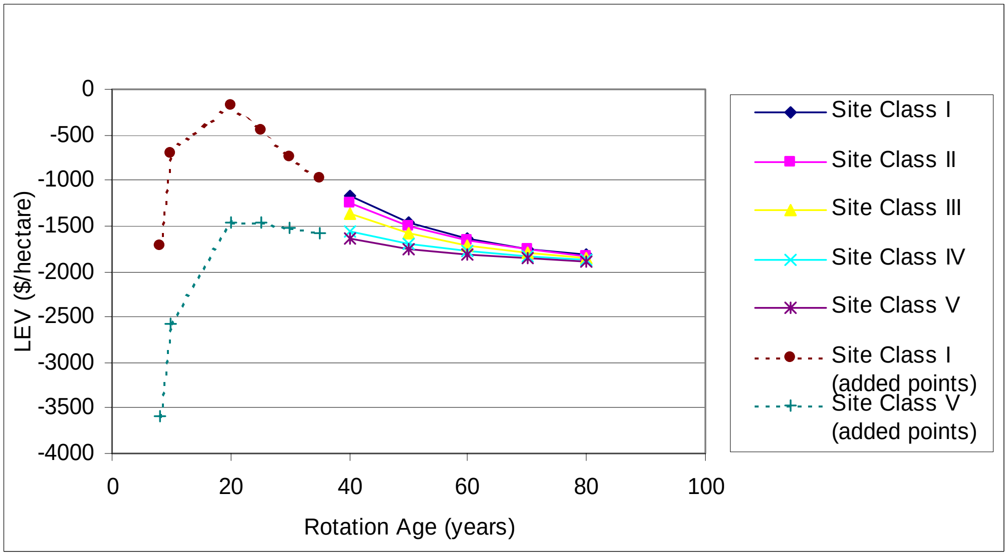

Figure 9. Mixed hardwood LEV by rotation for various site classes – projected back to 8 years (medium-intensity site preparation, low prices, 5% ARR).

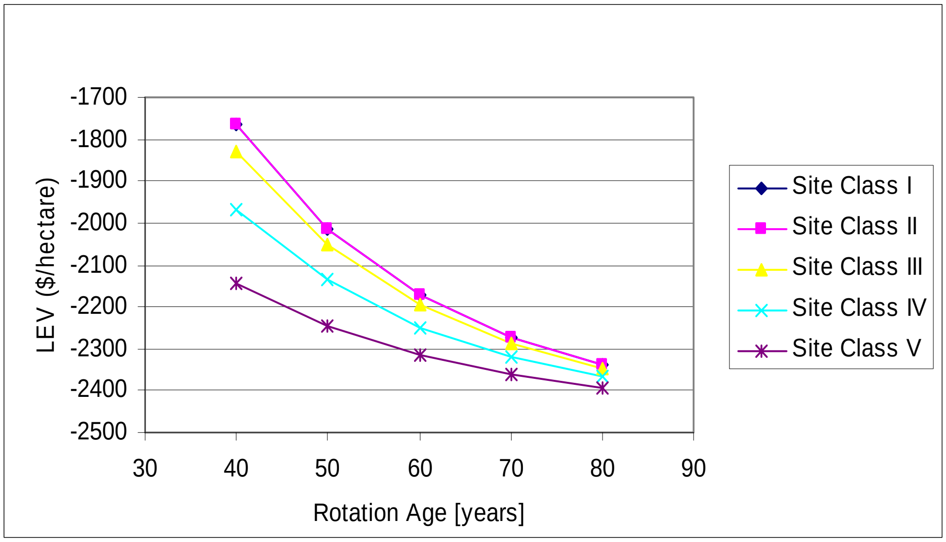

Figure 10. Mixed hardwood LEV by rotation for various site classes (high intensity site preparation, low prices, 5% ARR).

A rotation age of 20 years for mixed hardwoods, however, is somewhat unrealistic when growing sawtimber is one of the primary objectives. Hardwood sawtimber would not yet be mature by this age. It is suspected that the reason for this short "optimal" rotation was a failure to take into account the fact that product ratios vary with rotation age; i.e., a young forest stand will tend to comprise a high percentage of pulpwood and a low percentage of sawtimber, whereas a mature forest stand will tend to comprise a low percentage of pulpwood and a high percentage of sawtimber. Due to the higher value of sawtimber over pulpwood, one would expect the maximum LEV to occur at a higher rotation age when taking into account varying product ratios and values with age, as opposed to the scenario where LEV is maximized, based solely on total standing timber volume. This suspected limitation was somewhat verified by simulating additional data points, by estimating varying product ratios with rotation age (Figure 11). A site of average quality (site class III) was used, and a case was simulated for both a low price and a high price scenario. The low price scenario yielded a maximum LEV at rotation age 50 years, and the high price scenario yielded a maximum LEV at rotation age 40 years. These rotation ages are more acceptable for hardwood stands grown primarily for sawtimber. Hence, the failure to account for varying product ratios with rotation age is recognized as a limitation to this study, and is something that can be improved upon in future research.

Henceforth, mixed hardwood results and general trend discussions will be primarily based on scenarios utilizing an average rotation age of 60 years.

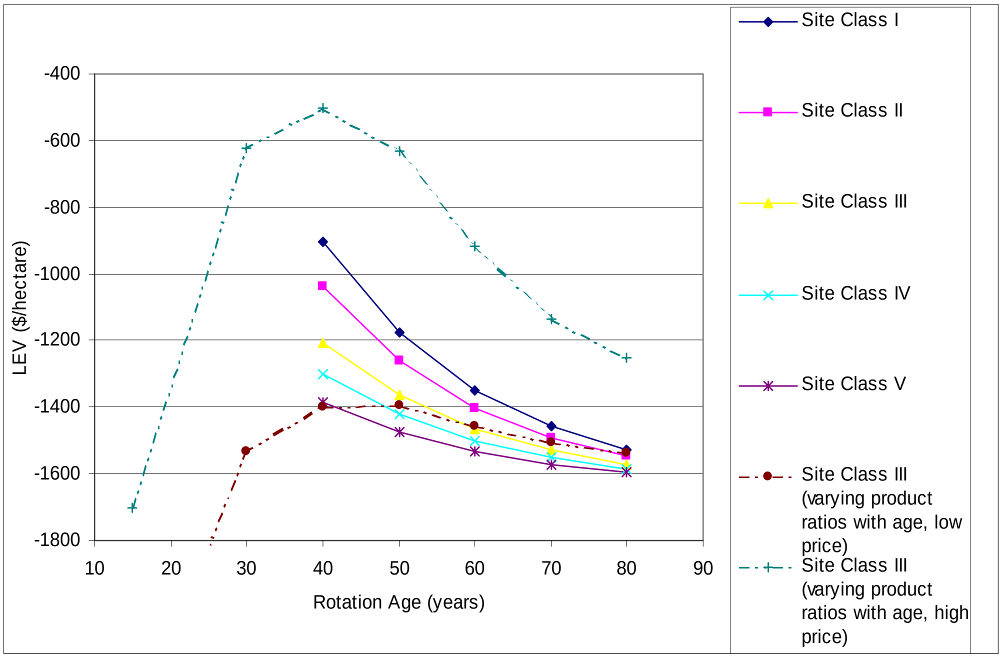

Figure 11. Mixed hardwood LEV by rotation for various site classes. Product ratios varied with rotation age (low-intensity site preparation, low prices, 5% ARR).

White Pine

Figures 12-14 show white pine LEV trends for each site class over a range of rotation ages. These trends remain relatively constant throughout all three site preparation intensities. The results suggest that, depending on the quality of the site, the optimal white pine rotation falls somewhere in the range of 25 to 35 years. A rotation age of 25 years would maximize LEV on site classes I and II. Similarly, a rotation age of 30 years would maximize LEV on site class III, and a rotation age of 35 years would maximize LEV on site classes IV and V.

The failure to vary product ratios with rotation age was not evident in the white pine results. This is primarily due to the rapid rate of growth that white pine trees exhibit, which results in shorter rotations used in growing white pine as opposed to longer rotations used in growing mixed hardwoods. These shorter rotations result in a greater percentage of product class overlap with changing rotation age; hence, the failure to distinguish between product classes with changing rotation ages should not change the results significantly. However, this is something that should be taken into consideration in future research, as it will aid in refining the results.

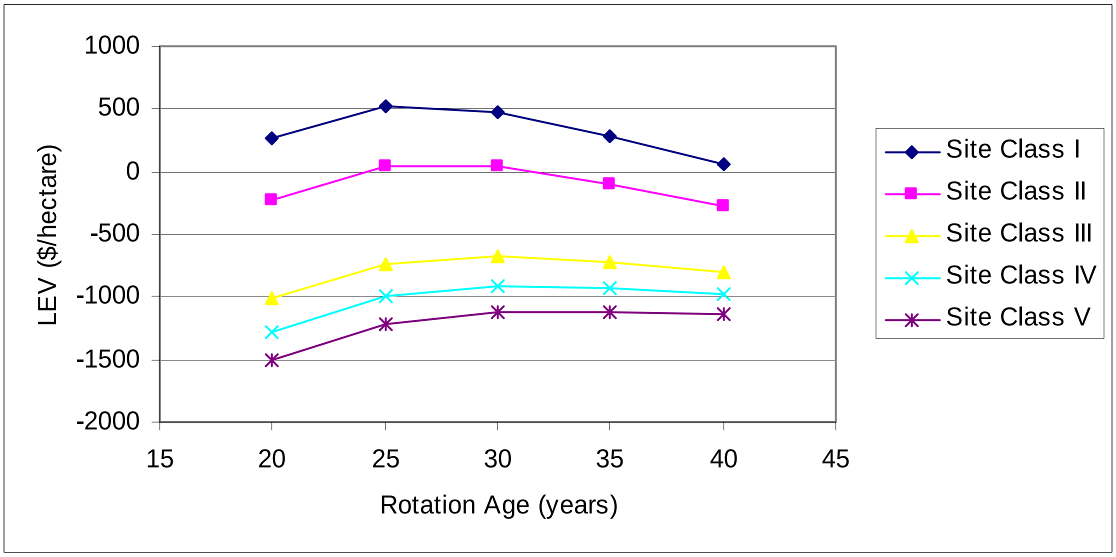

Figure 12. White pine LEV by rotation for various site classes (low-intensity site preparation, low prices, 5% ARR).

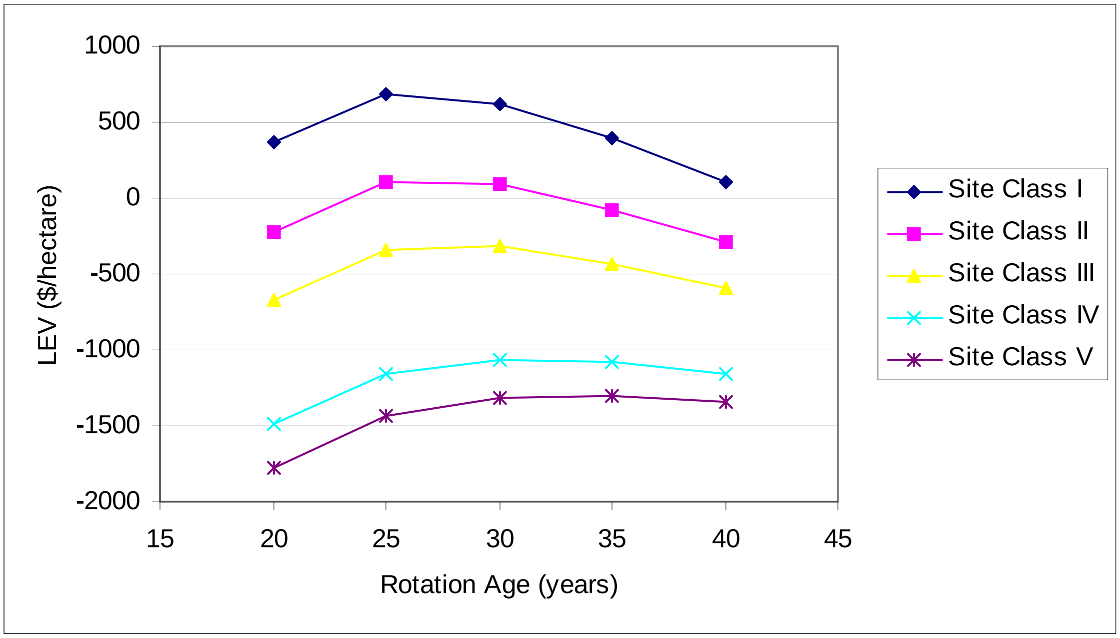

Figure 13. White pine LEV by rotation for various site classes (medium-intensity site preparation, low prices, 5% ARR)

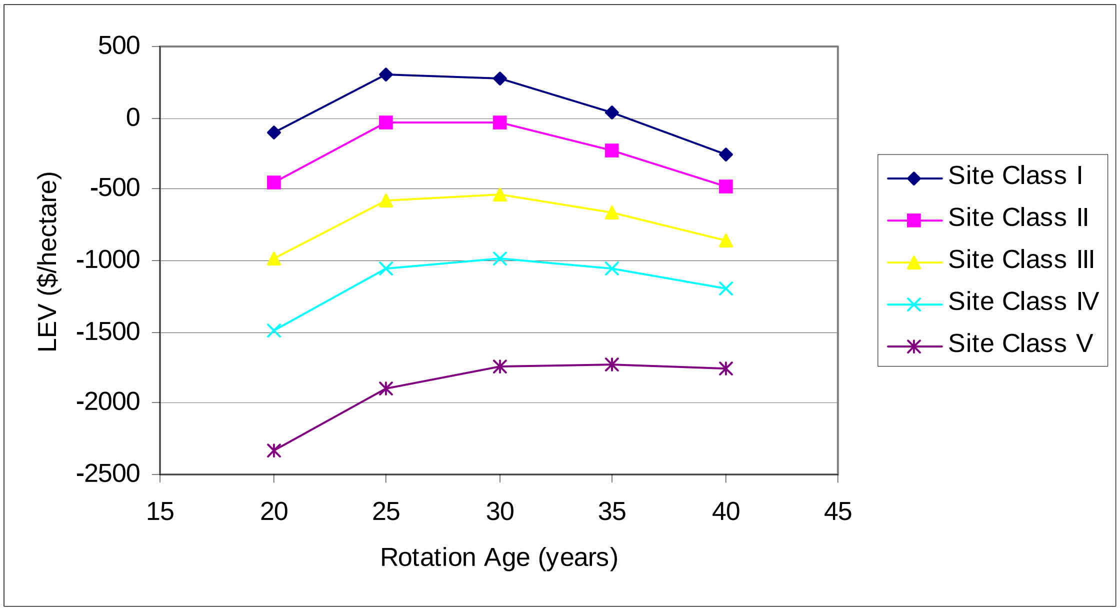

Figure 14. White pine LEV by rotation for various site classes (high intensity site preparation, low prices, 5% ARR)

It is clear that the optimal rotation age for a given site preparation intensity does depend on site class. It would seem that, based on maximizing LEV, the optimal white pine rotation is shorter on better sites and longer on poorer sites. Henceforth, white pine results and general trend discussions will be primarily based on scenarios utilizing an average rotation age of 30 years.

Effect of Site Class on LEV

The innate ability of a given site to support the growth and development of a forest stand is a valuable attribute that is exploited in forestry. In general, the higher the productive potential of a site, the better the quality of the site. For this study, site quality is ranked on a scale of I to V, with site class I being the best quality and site class V being the poorest quality. The productive potential of a site is directly related to the volume of sawtimber and pulpwood present at harvest, which is directly related to the LEV of a given forestry investment. Therefore, we analyze the effect of site class on LEV.

Hardwoods

Of course, LEVs increase when moving from poor-quality sites (class V) to good-quality sites (class I) (Table 10). This trend is also illustrated in Figures 15-17.

According to results, for a mixed hardwood plantation with low-intensity site preparation, a 60-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $31.24/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $36.10/ha when moving from site class IV to site class III, at a rate of $63.31/ha when moving from site class III to site class II, and at a rate of $51.62/ha when moving from site class II to site class I. Under low-intensity site preparation (Figure 15), LEV tends to increase sharply from site class III to site class II. This increase in LEV is a result of the sawtimber-to-pulpwood ratio increasing from 66.7%**:**33.4% to 75%**:**25%. The higher proportion of the more valued sawtimber results in the sharp increase in LEV.

Table 10. Mixed hardwood LEVs ($/ha) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-1532.35	-1814.41	-2316.93
4	-1501.11	-1778.30	-2248.79
3	-1465.01	-1710.16	-2196.42
2	-1350.08	-1634.61	-2173.24
1	-1350.08	-1634.61	-2173.24

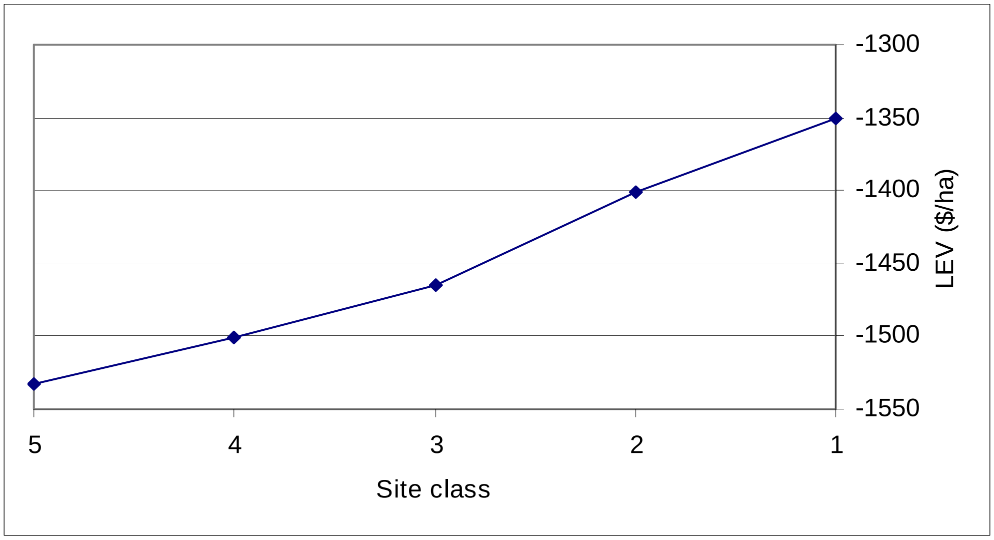

Figure 15. General trend for mixed hardwood LEV over range of site classes (low-intensity site preparation, 60-year rotation, low prices, 5% ARR).

Based on the assumption made in the Methods section of increasing site index with increasing intensity of site preparation, under medium-intensity site preparation a site that was a class III site before site preparation becomes a class II site as a result of site preparation, and a site that was a class IV site becomes a class III site as a result of site preparation. Thus, due to the changing product ratios when moving from site class III to site class II under low-intensity site preparation, under medium-intensity site preparation LEV tends to increase sharply from site class IV to site class III (Figure 16). According to results for a mixed hardwood plantation with medium-intensity site preparation, a 60-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $36.11/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $68.14/ha when moving from site class IV to site class III, at a rate of $46.79/ha when moving from site class III to site class II, and at a rate of $28.76/ha when moving from site class II to site class I.

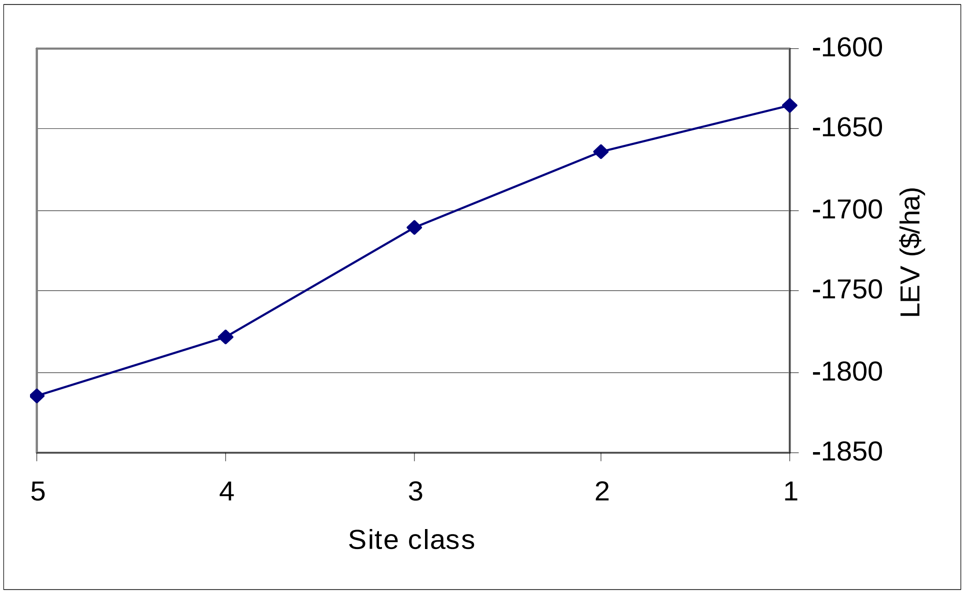

Figure 16. General trend for mixed hardwood LEV over range of site classes (medium-intensity site preparation, 60-year rotation, low prices, 5% ARR).

Similarly, under high-intensity site preparation, a site that was class IV before site preparation becomes a class II site as a result of site preparation, and a site that was class V becomes a class III site as a result of site preparation. Therefore, under high-intensity site preparation, LEV tends to increase sharply from site class V to site class IV (Figure 17). According to results, for a mixed hardwood plantation with high-intensity site preparation, a 60-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $68.14/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $52.37/ha when moving from site class IV to site class III, increases at a rate of $23.18ha when moving from site class III to site class II, and does not increase when moving from site class II to site class I.

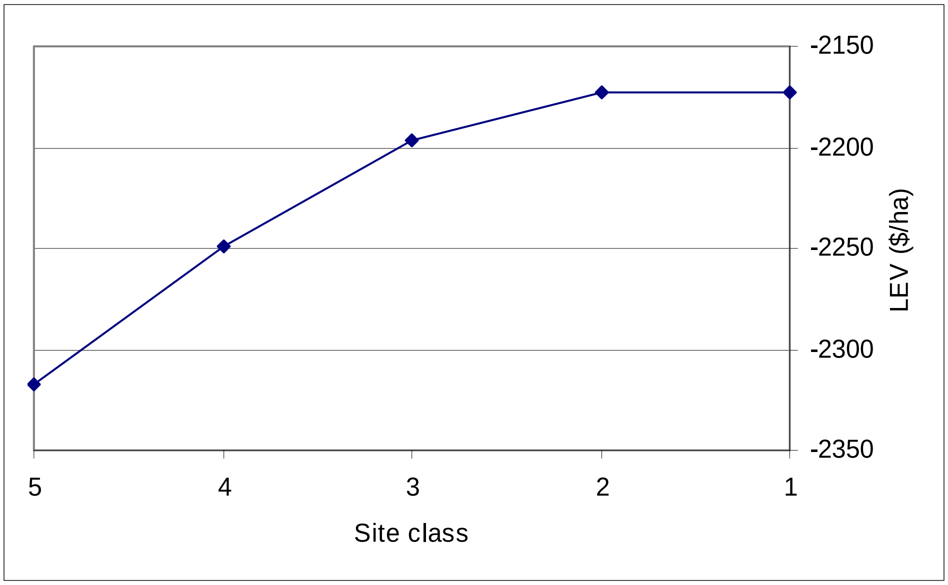

Figure 17. General trend for mixed hardwood LEV over range of site classes (high-intensity site preparation, 60-year rotation, low prices, 5% ARR).

White Pine

Similar to the mixed hardwoods, under low-intensity site preparation, LEV tends to increase sharply from site class III to site class II (Table 11, Figure 18). This increase is a result of the sawtimber-to-pulpwood ratio increasing from 50%**:**50% to 75%**:**25%. The higher proportion of the more valued sawtimber results in the sharp increase in LEV.

According to results, for a white pine plantation with low-intensity site preparation, a 30-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $211.30/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $238.29/ha when moving from site class IV to site class III, at a rate of $712.57/ha when moving from site class III to site class II, and at a rate of $440.16/ha when moving from site class II to site class I.

Table 11. White pine LEVs ($/ha) (30-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-1125.97	-1318.31	-1747.07
4	-914.67	-1062.16	-979.31
3	-676.38	-316.06	-532.05
2	36.19	90.56	-39.10
1	476.35	624.15	268.78

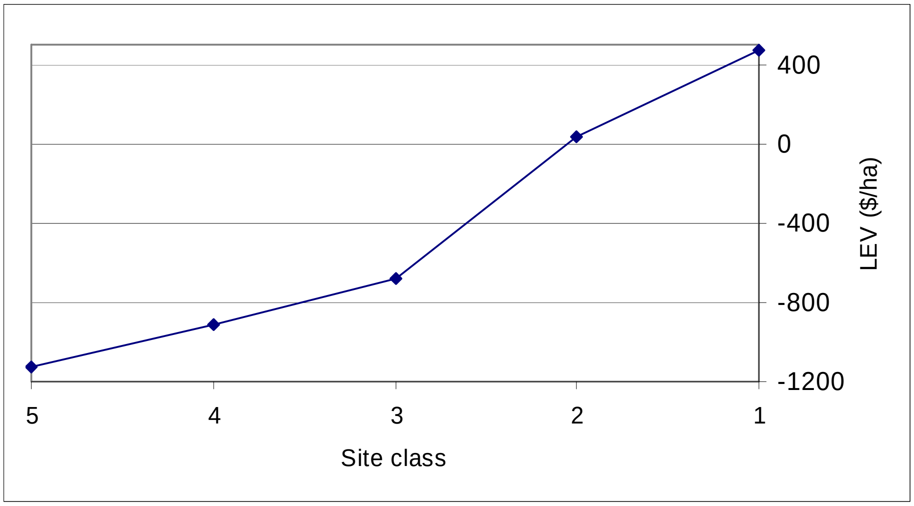

Figure 18. General trend for white pine LEV over range of site classes (low-intensity site preparation, 30-year rotation, low prices, 5% ARR).

As with the mixed hardwoods, based on the assumption made in chapter III of increasing site index with increasing intensity of site preparation under medium-intensity site preparation, a site that was class III before site preparation becomes a class II site as a result of site preparation, and a site that was class IV becomes a class III site as a result of site preparation. Thus, due to the changing product ratios when moving from site class III to site class II, under medium-intensity site preparation LEV tends to increase sharply from site class IV to site class III (Figure 19). According to results, for a white pine plantation with medium-intensity site preparation, a 30-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $256.15/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $746.10/ha when moving from site class IV to site class III, at a rate of $406.62/ha when moving from site class III to site class II, and at a rate of $533.59/ha when moving from site class II to site class I.

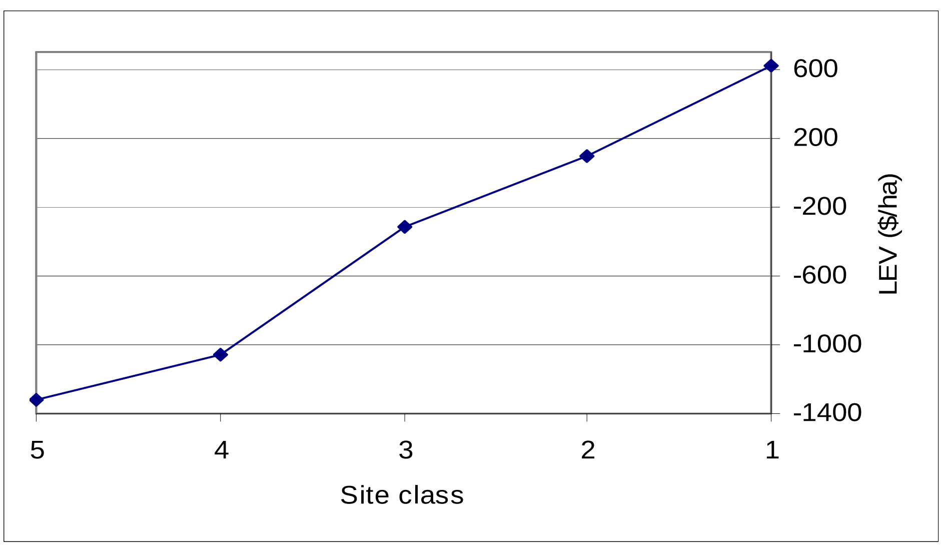

Figure 19. General trend for white pine LEV over range of site classes (medium-intensity site preparation, 30-year rotation, low prices, 5% ARR).

Similarly, under high-intensity site preparation, a site that was class IV before site preparation becomes a class II site as a result of site preparation, and a site that was class V becomes a class III site as a result of site preparation. Therefore, under high-intensity site preparation, LEV tends to increase sharply from site class V to site class IV (Figure 20). According to results, for a white pine plantation with high-intensity site preparation, a 30-year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $767.76/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $447.26/ha when moving from site class IV to site class III, at a rate of $492.95/ha when moving from site class III to site class II, and at a rate of $307.88/ha when moving from site class II to site class I.

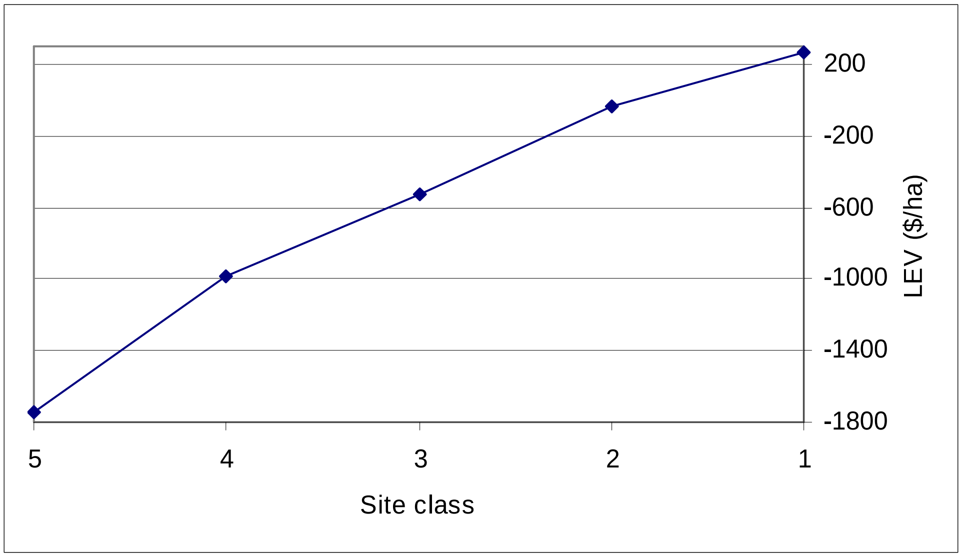

Figure 20. General trend for white pine LEV over range of site classes (high-intensity site preparation, 30-year rotation, low prices, 5% ARR).

Effect of Site Preparation Intensity on LEV

Having discussed the effect of site class on LEV, it is important to note that the productive capacity of a forest site is also something that can be enhanced through various site preparation techniques. However, site preparation does come at a cost. This cost increases with increasing intensity of site preparation. Hence, it is necessary to determine whether the artificially enhanced productive capacity of a site is worth the cost of preparing the site.

Hardwoods

According to results, the intensity with which a site is prepared does influence the LEV of mixed hardwood plantations. For all site classes, mixed hardwood LEV tends to decrease with increasing site preparation intensity (Figure 21). This trend is consistent throughout all the proposed mixed hardwood scenarios, which are based on the low price set. This trend would suggest that increasing site preparation beyond the low-intensity level is not an economically beneficial option.

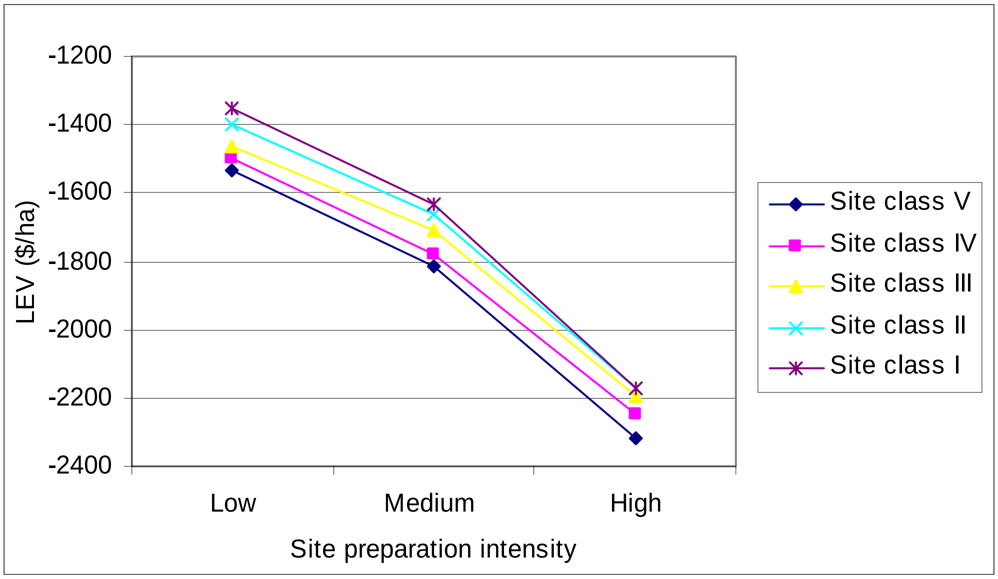

Figure 21. Effect of site preparation on mixed hardwood LEV, over range of site classes (60-year rotation, low prices, 5% ARR).

In other words, the increased costs of site preparation associated with increasing site preparation intensity outweigh the growth and yield benefits associated with the improved site quality. This trend is further verified in Figure 22, which clearly shows that for any given rotation age, regimes based on a low site preparation intensity yield the highest LEVs. Hence, the results from our study suggest that minimal site preparation would be advisable for mixed hardwoods on reclaimed mined lands.

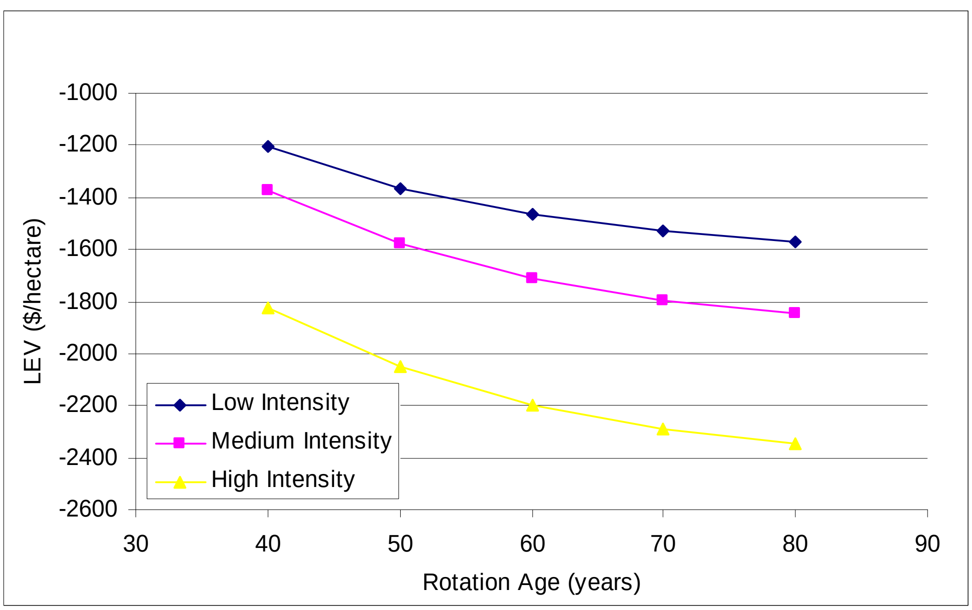

Figure 22. Effect of site preparation on mixed hardwood LEV, over range of rotation ages (site class III, low prices, 5% ARR).

White Pine

The results also show that the intensity with which a site is prepared influences the LEV of white pine plantations. The white pine results, however, do not exhibit as clear and consistent a trend as do the mixed hardwood results. Figure 23 shows trends based on a rotation age of 30 years, an alternative rate of return of 5%, and low product prices. Results for this subset of scenarios suggest that LEV is maximized on site classes I, II, and III under medium-intensity site preparation. On these good-quality sites, it would seem economically beneficial to implement a medium-intensity site preparation regime. In other words, the financial benefits received due to the improved site quality as a result of ripping outweigh the costs of increasing the site preparation intensity from low to medium. This distinct increase in LEV for site classes I, II, and III when moving from low to medium site preparation intensity can be attributed in part to the substantial increase in the sawtimber-to-pulpwood ratio when moving from a class IV site to a class III site under medium-intensity site preparation.

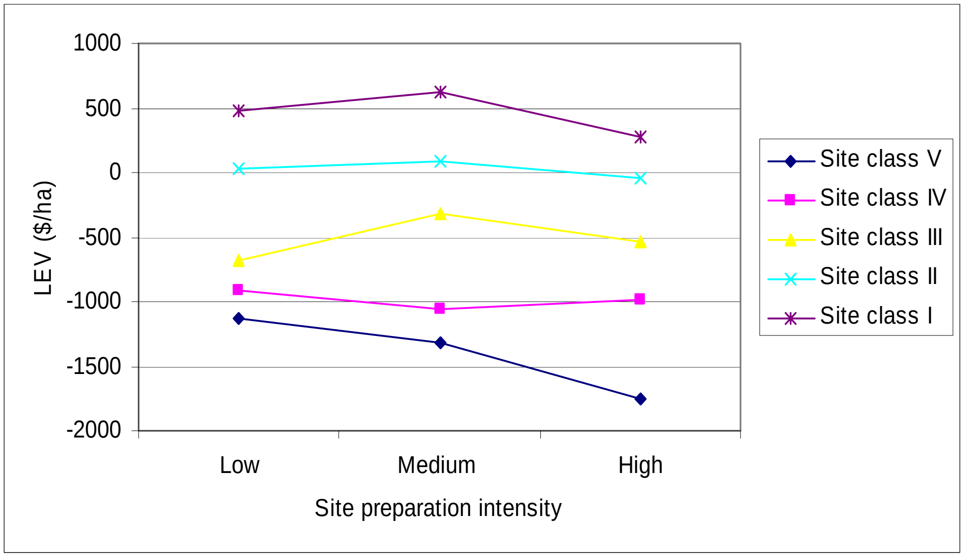

Figure 23. Effect of site preparation on white pine LEV over range of site classes (30-year rotation, low prices, 5% ARR).

Site classes IV and V show a distinctly different trend. According to results, LEV is maximized under low-intensity site preparation on these poorer-quality sites. This decrease in LEV when moving from a low-intensity to a medium-intensity site preparation regime suggests that the increased costs associated with this increased site preparation intensity outweigh the benefits of the associated improvement in site quality on these poorer-quality sites. The apparent increase in LEV when moving from medium to high site preparation intensity on site class IV can be attributed in part to the substantial increase in sawtimber-to-pulpwood ratio when moving from a class V site to a class IV site under high-intensity site preparation. This increase in LEV as a result of changing product ratios, however, still does not outweigh the increase in costs associated with increasing the site preparation intensity from low to high. The product ratios produced on site class V remain constant under all site preparation intensities, which is in part the reason for the trend of decreasing LEV with increasing site preparation intensity on class V.

Figure 24 illustrates the effect that site preparation intensity has on white pine LEV over a range of rotation ages on a site class III site and for a 5% alternative rate of return. It is clear that for this subset of scenarios, white pine LEV is maximized for all proposed rotation ages under medium-intensity site preparation. Low-intensity site preparation appears to yield the lowest LEVs for rotation ages between 20 years and approximately 38 years, which in itself suggests that some form of site preparation beyond the initial low-intensity weed control is economically profitable within this rotation age range. Figure 25 shows that, in comparison to the 5% ARR scenario, a lower alternative rate of return tends to warrant a higher intensity of site preparation. At the 3.5% ARR level, there is not much difference between the white pine LEVs yielded under medium- and high-intensity site preparation, particularly in the 25- to 40-year range of rotation ages.

In addition, Figure 26 illustrates that, in comparison to the 5% ARR scenario, a higher alternative rate of return tends to warrant a lower intensity of site preparation. At the 7.5% ARR level, white pine LEV is maximized under medium-intensity site preparation for rotation ages 20 years to approximately 28 years. For any rotation longer than 28 years, however, white pine LEV appears to be maximized under low-intensity site preparation.

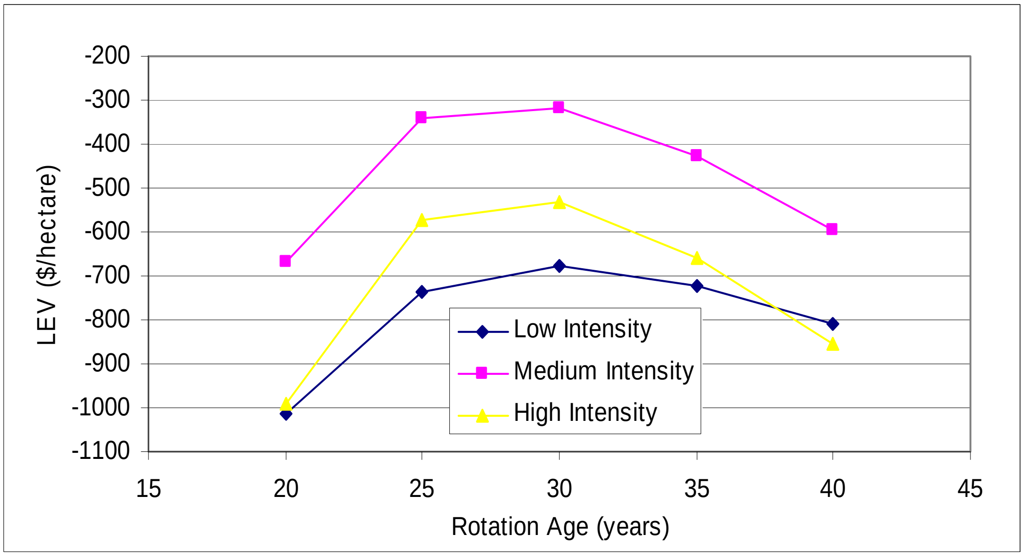

Figure 24. Effect of site preparation on white pine LEV over range of rotation ages (site class III, low prices, 5% ARR).

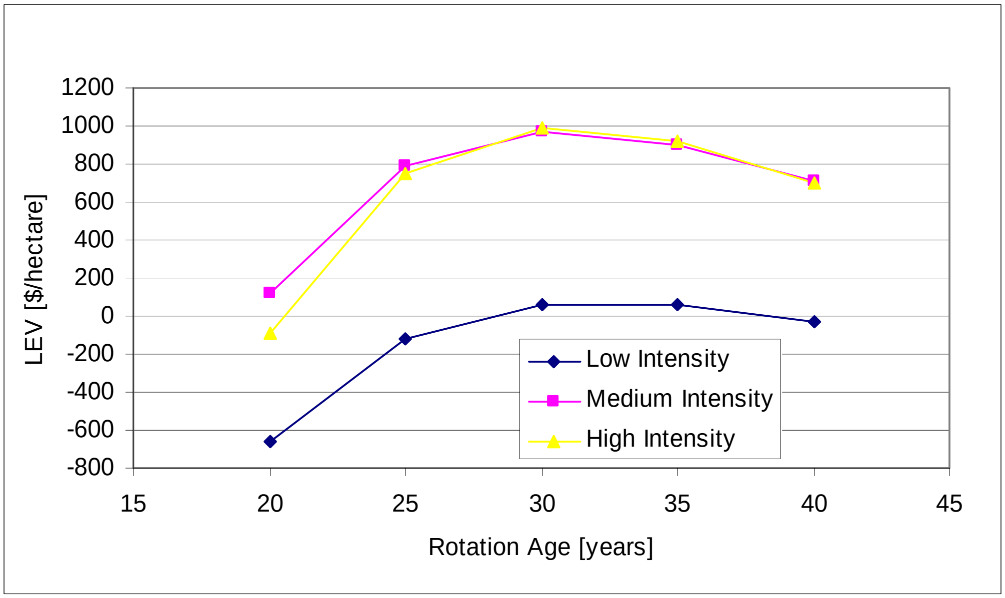

Figure 25. Effect of site preparation on white pine LEV over range of rotation ages (site class III, low prices, 3.5% ARR).

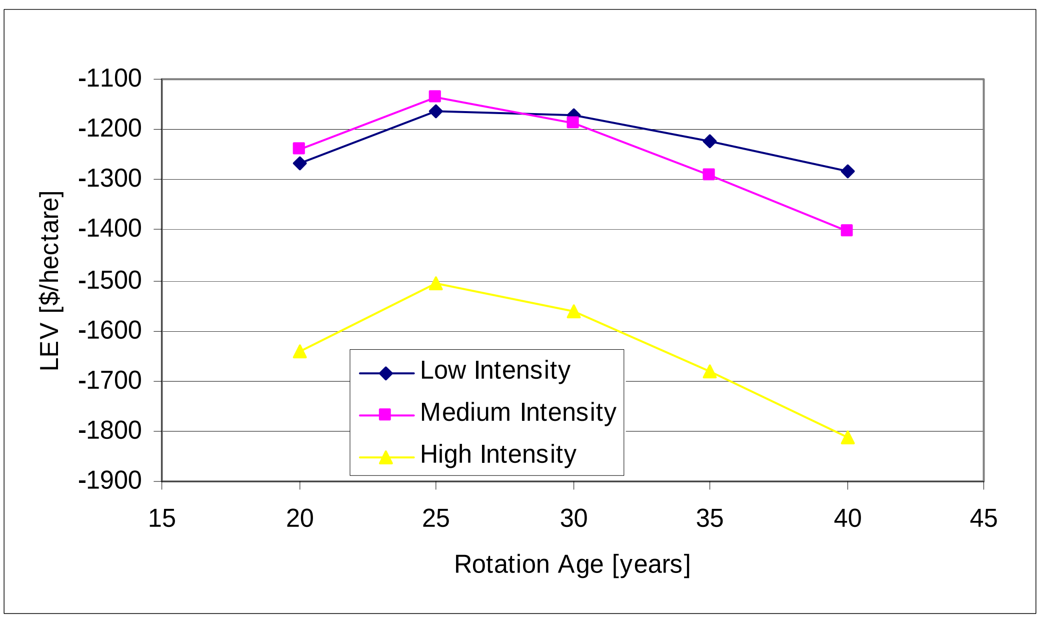

Figure 26. Effect of site preparation on white pine LEV over range of rotation ages (site class III, low prices, 7.5% ARR).

Effect of Alternative Rate of Return on LEV

When making the decision to remove money from one investment in order to invest in another, or when analyzing one's investment options in general, the rate at which one could be earning on an alternative investment is of importance. It would seem probable that, given the decision to invest in forestry, one would use money from the current investment that is earning the lowest alternative rate of return in order to establish the forest.

Hardwoods

Figure 27 shows that, for a given site preparation intensity, mixed hardwood LEVs tend to decrease with increasing alternative rate of return. Also, the trend of decreasing LEV with increasing intensity of site preparation remains consistent over the entire range of alternative rates of return.

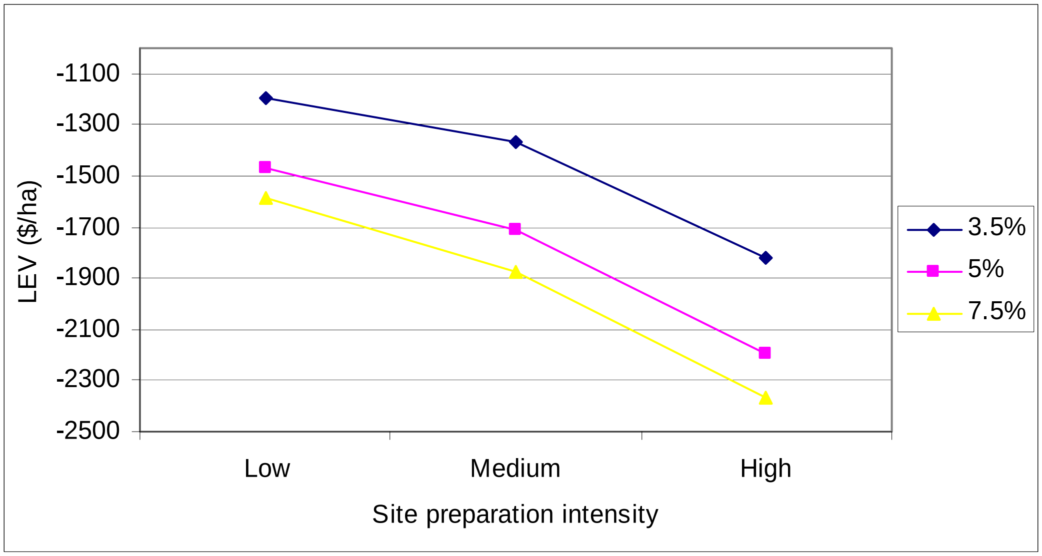

Figure 27. Effect of alternative rate of return on mixed hardwood LEV (site class III, 60-year rotation, low prices).

Figure 28 shows further that for a given site class, mixed hardwood LEV tends to decrease with increasing alternative rate of return. It is also evident that increases in mixed hardwood LEV when moving from poorer site classes to better site classes become less pronounced with increasing alternative rates of return. Based on the aforementioned observation, it seems that the quality of a site becomes less significant as part of the decision-making process as the alternative rate of return increases.

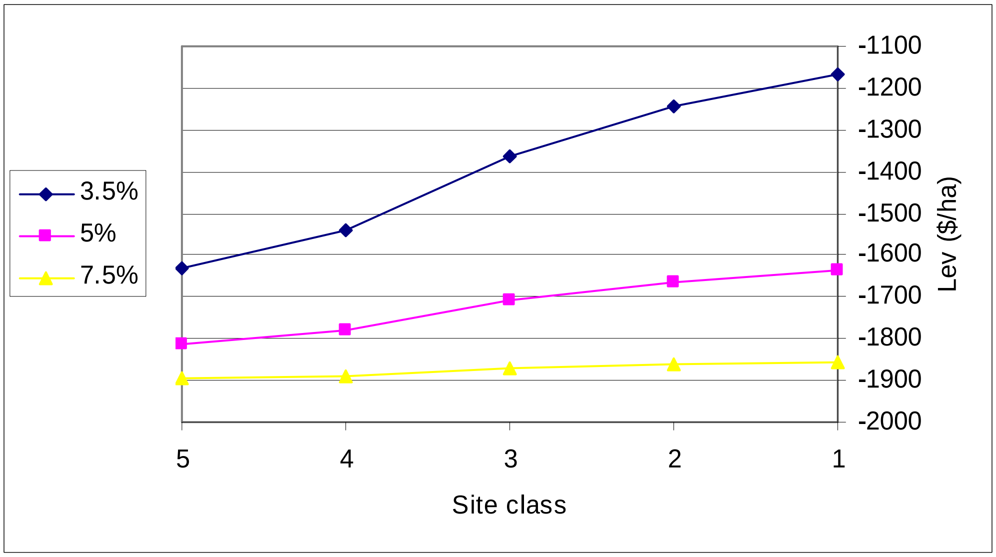

Figure 28. Effect of alternative rate of return on mixed hardwood LEV (medium-intensity site preparation, 60-year rotation, low prices).

Furthermore, Figure 29 shows that the trend of decreasing mixed hardwood LEV with increasing rotation age within the proposed rotation age range is consistent over the 3.5% to 7.5% range of alternative rate of return. Also, for a given rotation age, mixed hardwood LEV appears to decrease with increasing alternative rate of return.

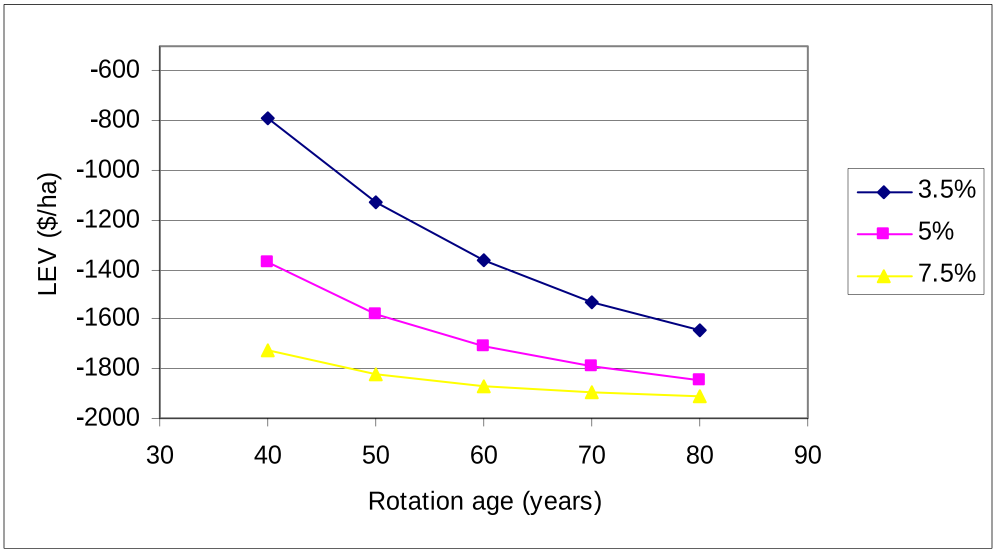

Figure 29. Effect of alternative rate of return on mixed hardwood LEV over a range of rotation ages (site class III, medium-intensity site preparation, low prices).

White Pine

Figure 30 shows that for a given site preparation intensity, white pine LEVs tend to decrease with increasing alternative rate of return. The trends displayed, however, are not consistent over the full range of alternative rates of return. Results suggest that with an ARR of 3.5%, white pine LEV is maximized under high-intensity site preparation. With an ARR of 5%, white pine LEV is maximized under medium-intensity site preparation. With an ARR of 7.5%, it appears that white pine LEV is maximized under low-intensity site preparation. Thus, this trend would suggest that, with the objective of maximizing LEV, the optimal intensity of site preparation decreases as the alternative rate of return increases. This would seem logical, since the higher the opportunity cost of money, the less money one would want to invest in site preparation.

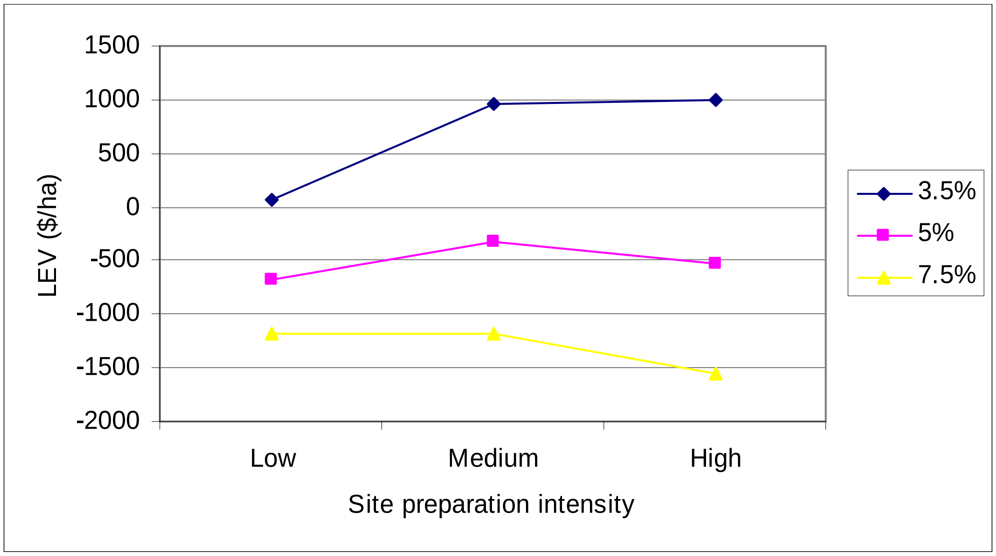

Figure 30. Effect of alternative rate of return on white pine LEV (site class III, 30-year rotation, low prices).

As for the mixed hardwoods, Figure 31 shows that for a given site class, white pine LEV tends to decrease with increasing alternative rate of return. It is also evident that increases in white pine LEV when moving from poorer site classes to better site classes become less pronounced with increasing alternative rates of return. Based on the aforementioned observation, it would seem that the quality of a site becomes less significant as part of the decision-making process as the alternative rate of return increases.

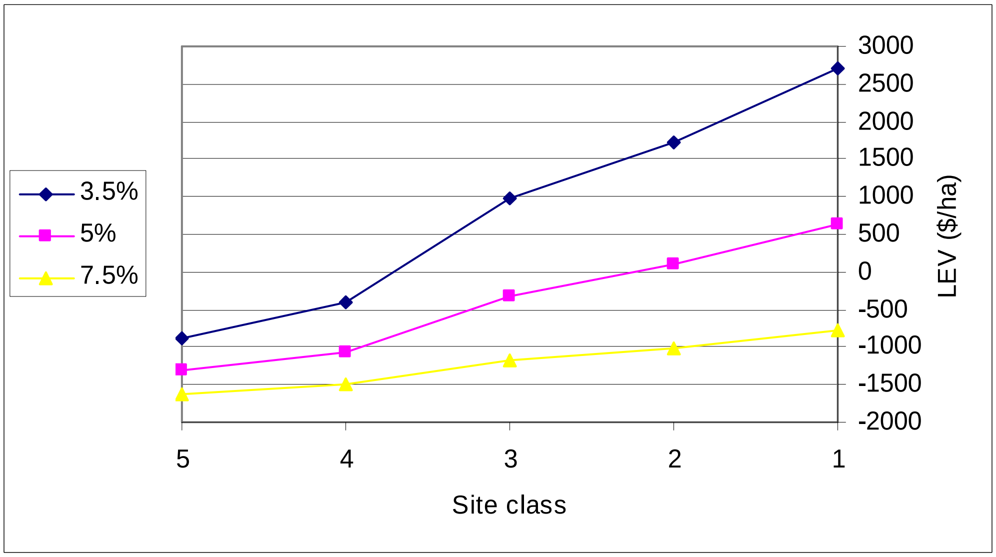

Figure 31. Effect of alternative rate of return on white pine LEV (medium-intensity site preparation, 30-year rotation, low prices).

Figure 32 shows further that in maximizing white pine LEV, the optimal rotation age remains within the range of 25 to 35 years over the 3.5% to 7.5% range of alternative rate of return. It appears that, with the objective of maximizing LEV, the optimal rotation age decreases with increasing alternative rate of return. This would seem logical, as the higher the opportunity cost of money, the shorter period of time one would want to keep money tied up in the forestry investment. It is also clear that, for a given rotation age, white pine LEV tends to decrease with increasing alternative rate of return.

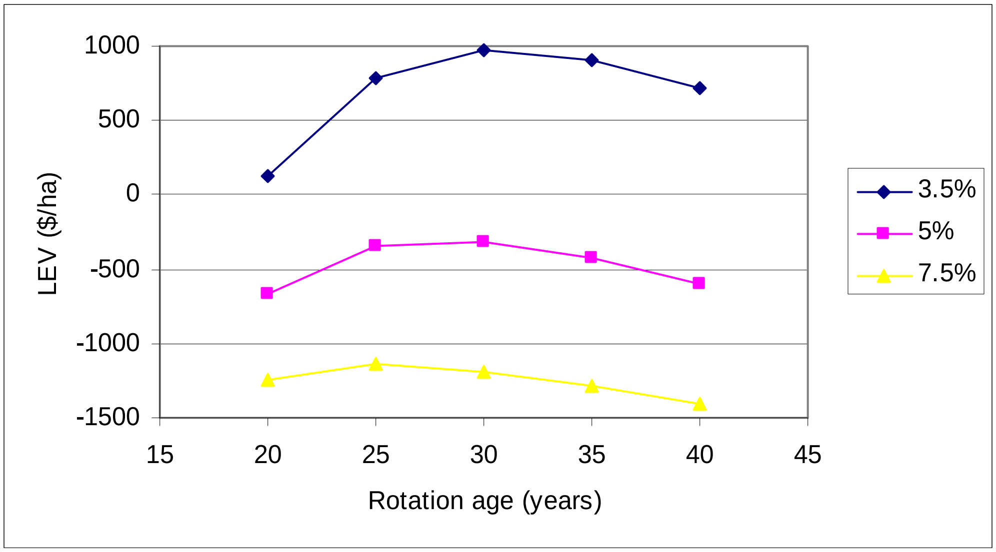

Figure 32. Effect of alternative rate of return on white pine LEV over a range of rotation ages (site class III, medium-intensity site preparation, low prices).

Ranges of LEVs

As previously discussed, given the information at hand, it would be impossible to calculate exact LEVs for all proposed scenarios in this study. At best, we are able to estimate broad ranges of potential LEVs.

Hardwoods

Under the low price set, the highest mixed hardwood LEV yielded within the 3.5% to 7.5% ARR range was -$145.58/ha. This maximum LEV represents a mixed hardwood plantation on a class I site with low-intensity site preparation, on a 40-year rotation, with an alternative rate of return of 3.5% (Table 12).

Table 12. Mixed hardwood LEVs ($/ha) (40-year rotation, 3.5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-1126.51	-1355.14	-1851.30
4	-958.42	-1160.82	-1484.60
3	-764.10	-794.12	-1202.72
2	-423.41	-542.30	-1078.01
1	-145.58	-387.53	-1078.01

The base case scenario for mixed hardwoods, represented by a 60-year rotation, a site class III site with medium-intensity site preparation, and an alternative rate of return of 5% (Table 10), yields a LEV of -$1710.16/ha under the low price set. Under the low price set, the lowest mixed hardwood LEV yielded within the 3.5% to 7.5% ARR range was -$2416.71/ha. This minimum LEV represents a mixed hardwood plantation on a class V site with high-intensity site preparation, on an 80-year rotation, with an alternative rate of return of 7.5% (Table 13).

Table 13. Mixed hardwood LEVs ($/ha) (80-year rotation, 7.5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-1621.71	-1917.35	-2416.71
4	-1619.92	-1915.27	-2412.79
3	-1617.84	-1911.35	-2409.77
2	-1614.20	-1908.66	-2408.44
1	-1611.23	-1907.01	-2408.44

White Pine

Under the low price set, the highest white pine LEV yielded within the 3.5% to 7.5% ARR range was $2,697.98/ha. This maximum LEV represents a white pine plantation on a class I site with medium-intensity site preparation on a 30-year rotation, with an alternative rate of return of 3.5% (Table 14).

Table 14. White pine LEVs ($/ha) (30-year rotation, 3.5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	-768.42	-873.41	-1,243.99
4	-379.93	-402.45	167.60
3	58.18	969.32	989.94
2	1,368.31	1,716.93	1,896.26
1	2,177.56	2,697.98	2,462.32

The base case scenario for white pine, represented by a 30-year rotation, a class III site with medium-intensity site preparation, and an alternative rate of return of 5% (Table 11), yields a LEV of -$316.06/ha under the low price set. Under the low price set, the lowest white pine LEV yielded within the 3.5% to 7.5% ARR range was -$2,330.53/ha. This minimum LEV represents a white pine plantation on a class V site with high-intensity site preparation, on a 20-year rotation, with an alternative rate of return of 5% (Table 15). It is interesting to note that this minimum white pine LEV did not occur under the highest alternative rate of return, but rather, due to the interaction of all variables involved, it occurred under a 5% ARR.

Table 15. White pine LEVs ($/ha) (20-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	-1,508.30	-1,770.91	-2,330.53
4	-1,275.35	-1,488.51	-1,484.08
3	-1,012.64	-665.94	-990.97
2	-227.03	-217.64	-447.51
1	258.23	370.64	-108.07

Comparison of Mixed Hardwood and White Pine LEVs

Table 16 shows that, over a range of scenarios, white pine LEVs tend to be higher than mixed hardwood LEVs. It is also evident that not one of the investigated mixed hardwood scenarios yielded a positive LEV, whereas a number of the white pine scenarios did yield positive LEVs within the 3.5% to 5% range of alternative rate of return. However, all investigated white pine scenarios with an alternative rate of return greater than 5% yielded negative LEVs. According to results, under the low price assumption, in terms of LEV, an investment in a 30-year rotation white pine regime under medium-intensity site preparation on a class III site is worth $1,394.10/ha more than a similar investment in a 60-year rotation mixed hardwood regime.

Table 16. Comparison of mixed hardwood and white pine LEVs (low prices).

	LEV	Mixed hardwoods	White pine
Low	*LEV ($/ha)*	**-2,416.71**	**-2,330.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*LEV ($/ha)*	**-1,710.16**	**-316.06**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**-145.58**	**2,697.98**
	Rotation	40 years	30 years
	Site class	I	I
	Site preparation	Low	Medium
	ARR	3.5%	3.5%

Summary

Based on the low price LEV trends that have been discussed, a few primary points of significance can be highlighted. Mixed hardwood LEVs are negative for all of the proposed scenarios. Hence, it appears that converting reclaimed mined lands to mixed hardwood plantations is not financially feasible for any of the proposed scenarios. This lack of financially feasible mixed hardwood scenarios highlights the importance of landowners capturing the changing product ratios with rotation age, which would potentially render some mixed hardwood scenarios financially feasible. Results do suggest a trend of decreasing mixed hardwood LEV with increasing intensity of site preparation; hence, minimal site preparation seems advisable for most mixed hardwood regimes.

The white pine scenarios did yield a number of positive LEVs. These financially feasible white pine scenarios occur primarily on class I and II sites, within the 3.5% to 5% range of alternative rate of return, for all site preparation intensities. The most profitable of these scenarios occurs on a class I site, under medium-intensity site preparation, with a 3.5% alternative rate of return, and on a 30-year rotation. According to white pine results, LEV is maximized on site classes I, II, and III under medium-intensity site preparation, and LEV is maximized on site classes IV and V under low-intensity site preparation. This trend does depend, however, on the alternative rate of return. Results suggest that for a given site class, the optimal intensity of site preparation increases with decreasing alternative rate of return for white pine scenarios. For both mixed hardwood and white pine scenarios, the quality of a site appears to become less significant as part of the decision-making process as the alternative rate of return increases.

Incentives

As it pertains to this study, an incentive is a payment offered to a landowner in an effort to render a land use conversion profitable and more appealing. Three types of incentives are considered for this study: (1) lump sum benefit, paid at the time of planting; (2) revenue incentive, paid at harvest (and corresponding series of annual payments); and (3) benefit based on carbon volume. The provider of this incentive will no doubt have financial limitations as to how much money can be spent on these incentive payments. Hence, a range of potential incentive payment values over a spectrum of possible land use conversion scenarios is useful to the incentive provider. For the sake of this study, incentive values have been calculated for the low price subset of scenarios that assume a rotation age of 60 years and 30 years for mixed hardwoods and white pine, respectively, and that are in the 3.5% to 7.5% range of alternative rate of return. Results will only be presented and discussed for scenarios with an alternative rate of return of 5%, as trends are fairly consistent throughout the 3.5% to 7.5% range. As opposed to the mixed hardwoods, many of the white pine scenarios yielded positive LEVs. However, incentives may only be necessary for scenarios that yield negative LEV values; hence the limited number of white pine scenarios for which incentives have been calculated within the selected subset of scenarios. For the sake of comparison between mixed hardwoods and white pine, incentive values have also been calculated and will be presented for scenarios corresponding to the high, low, and base case LEV scenarios.

Lump Sum Payment Paid at the Time of Planting and Related Set of Annual Payments

The lump sum payment equates to a one-time payment made at the time of planting, which would render a given scenario economically feasible for a landowner. This lump sum payment is equal to the dollar value that would sum to zero with the corresponding negative LEV value. This incentive would reduce the burden for a landowner in that he or she would be able to undertake this land use conversion with some up-front financial backing. This up-front payment could also go toward covering the site preparation and forest establishment costs. The money could be invested elsewhere as well. However, a landowner may prefer to spread payments throughout the duration of a full rotation; hence, the calculation of the annual payments. In reality, the LEV of a given scenario cannot be accurately calculated at the beginning of a rotation, as harvest volumes, revenues, and costs can only be accurately calculated at harvest. Hence, the results presented are merely a prediction of incentive ranges one may expect.

Hardwoods

Lump sum payments and corresponding annual payments for mixed hardwoods under the low price set are presented in Tables 17 and 18, respectively, for all scenarios that assume a rotation age of 60 years and an alternative rate of return of 5%.

Table 17. Mixed hardwood lump sum payment, paid at time of planting, required to yield a non-negative LEV ($/ha) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	1532.35	1814.41	2316.93
4	1501.11	1778.30	2248.79
3	1465.01	1710.16	2196.42
2	1401.70	1663.37	2173.24
1	1350.08	1634.61	2173.24

Table 18. Mixed hardwood equal annual payment required to yield a non-negative LEV ($/ha/yr) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	76.62	90.72	115.85
4	75.06	88.91	112.44
3	73.25	85.51	109.82
2	70.09	83.17	108.66
1	67.50	81.73	108.66

These incentive values display trends exactly opposite to those trends displayed by the LEVs of the corresponding mixed hardwood scenarios. In short, as mixed hardwood LEVs increase, incentive values decrease. Mixed hardwood incentive values tend to decrease when moving from poor-quality sites (class V) to good-quality sites (class I), and tend to increase with increasing site preparation intensity and increasing alternative rate of return. Thus, results suggest that the poorer the site quality, the higher the site preparation intensity, and the higher the alternative rate of return, the higher the incentive necessary to render a land use conversion to mixed hardwoods profitable for a landowner.

White Pine

Lump sum payments and corresponding annual payments for white pine under the low price set are presented in Tables 19 and 20, respectively, for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%.

Table 19. White pine lump sum payment, paid at time of planting, required to yield a non-negative LEV ($/ha) (30-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	1125.97	1318.31	1747.07
4	914.67	1062.16	979.31
3	676.38	316.06	532.05
2	*	*	39.10
1	*	*	*

* Indicates LEV is positive without additional payments.

Table 20. White pine equal annual payment required to yield a non-negative LEV ($/ha/yr) (30-year rotation, 5% ARR, low prices)

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	56.30	65.92	87.35
4	45.73	53.11	48.97
3	33.82	15.80	26.60
2	*	*	1.96
1	*	*	*

* Indicates LEV is positive without additional payments.

These incentive values display trends exactly opposite to those trends displayed by the LEVs of the corresponding white pine scenarios. As is the case with the mixed hardwoods, as white pine LEVs increase, corresponding incentive values decrease. White pine incentives tend to decrease when moving from poor-quality sites (class V) to good-quality sites (class I), and tend to increase with increasing alternative rate of return. Other than these two common trends, as for the LEVs, these white pine incentives exhibit some different trends than those of the mixed hardwoods. Results suggest that when moving from poorer-quality sites (class V) to better-quality sites (class III), maximum incentive payments tend to occur with decreasing site preparation intensity.

Payment Based on Revenue Received at Harvest

The payment based on revenue received at harvest is a one-time payment made at the time of harvest. This payment equates to the per-hectare dollar amount by which the revenue received from sawtimber and pulpwood sales at harvest would have to increase in order to render a given scenario economically feasible for the landowner. One advantage of such an incentive is the fact that it can be accurately determined at the end of a rotation, as it is not based on predicted costs and revenues, but rather on actual costs incurred and actual revenues received during the rotation and at harvest. A disadvantage of such an incentive would be the risk that the landowner undertakes, in that he or she will only be "rewarded" for what remains standing at the end of a rotation. There would be no guarantee against natural disasters, which could damage or destroy the landowner's crop and render the harvest at rotation age fruitless.

Hardwoods

Payments based on increase in revenue at harvest for mixed hardwoods under the low price set are presented in Table 21 for all scenarios that assume a rotation age of 60 years and an alternative rate of return of 5%. These mixed hardwood incentive values are rather large, especially given the fact that they are per-hectare payments. These large values are a result of the time value of money being taken into account over a long period of time; i.e., a 60-year rotation. The trends displayed by these mixed hardwood incentives based on revenue received at harvest are consistent with those displayed by the other incentives considered in this study.

Table 21. Mixed hardwoods revenue incentive required at harvest to yield non-negative LEVs ($/ha) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	27,090.65	32,077.21	40,961.42
4	26,538.47	31,438.86	39,756.83
3	25,900.11	30,234.27	38,830.85
2	24,780.95	29,407.04	38,421.18
1	23,868.29	28,898.61	38,421.18

White Pine

Benefits based on increase in revenue at harvest for white pine under the low price set are presented in Table 22 for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%. The trends displayed by these white pine incentives based on revenue received at harvest are consistent with those displayed by the other incentives considered in this study.

Table 22. White pine revenue incentive required at harvest to yield non-negative LEVs ($/ha) (30-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	3,740.39	4,379.36	5,803.68
4	3,038.47	3,528.43	3,253.23
3	2,246.89	1,049.92	1,767.43
2	*	*	129.90
1	*	*	*

* Indicates LEV is positive without additional payments.

Payment Based on Carbon Volume

Payment based on carbon volume is an annual payment made to the landowner throughout a rotation. This incentive equals the dollar amount per ton of carbon present in a given forest stand that would have to be offered to a landowner on an annual basis in order to render the given land use conversion economically feasible for the landowner. The purpose of this incentive is to encourage the landowner to delay harvesting as long as possible. This objective is achieved by “rewarding” the landowner not only for the carbon volume growth increment from year to year, but also for the cumulative carbon volume present at the end of each year. In other words, to delay harvest by one more year would mean being “rewarded” for the carbon volume that was present at the end of the previous year plus the carbon volume growth increment during the last year of growth. Due to this incentive being paid on an annual basis, the level of risk assumed by the landowner is reduced in that he or she does not have to wait until the end of a rotation for an incentive payment, but can make decisions on a year-to-year basis. This incentive is also a source of steady income for the landowner throughout a rotation.

Hardwoods

Benefits based on carbon volume for mixed hardwoods under the low price set are presented in Table 23 for all scenarios assuming a rotation age of 60 years and an alternative rate of return of 5%. The trends displayed by these mixed hardwood incentives based on carbon volume are again consistent with those displayed by the other incentives considered in this study.

Table 23. Mixed hardwood carbon subsidy required to yield non-negative LEVs ($/ton of carbon, paid annually) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	2.45	2.54	2.82
4	2.10	2.17	2.39
3	1.79	1.82	2.03
2	1.51	1.56	1.90
1	1.27	1.43	1.90

This benefit based on carbon volume could be paid in terms of an annual per-hectare payment. This per-hectare payment would be dynamic in that it would increase from year to year at the rate at which carbon is sequestered. For example, 10th-year, 30th-year and 60th-year per-hectare payments (not discounted) made on a mixed hardwood plantation (60-year rotation) on a class III site with low-intensity site preparation, under low prices and a 5% ARR, would be $60.52, $122.63. and $146.52, respectively. Total per-hectare payments made over the full 60-year rotation would add up to approximately $6,404.65 (not discounted).

White Pine

Benefits based on carbon volume for white pine under the low price set are presented in Table 24 for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%.

Table 24. White pine carbon subsidy required to yield non-negative LEVs ($/ton of carbon, paid annually) (30-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	**Medium**	**High**
5	4.13	3.99	4.36
4	2.72	2.61	1.98
3	1.66	0.64	0.89
2	*	*	0.05
1	*	*	*

* Indicates LEV is positive without additional payments.

The trends displayed by these white pine incentives based on carbon volume differ slightly from the trends displayed by the other white pine incentives considered in this study, particularly on the poorer-quality sites (classes IV and V). This could be due to the fact that the carbon payment is the only incentive in this study based on cumulative volumes; i.e., payments are made on an annual basis, rewarding the landowner not only for the carbon volume increment for a given year, but also for the volume of carbon present at the end of the previous year. For corresponding scenarios, the other incentives display a clear trend of increasing white pine subsidy with increasing site preparation intensity on a class V site. Results for this incentive based on carbon volume, however, suggest that the minimum subsidy on a class V site would coincide with medium site preparation intensity. So too, for corresponding scenarios, trends displayed by the other incentives suggest that the maximum subsidy payment on a class IV site coincides with medium site preparation intensity, followed by high-intensity site preparation, with the lowest subsidies coinciding with a low-intensity site preparation. Results for this incentive based on carbon volume, however, suggest a clear trend of decreasing subsidy payment with increasing intensity of site preparation on a class IV site.

As for the mixed hardwoods, this benefit based on carbon volume could be paid in terms of an annual per-hectare payment. For example, 5th-year, 15th-year and 30th-year per-hectare payments (not discounted) made on a white pine plantation (30-year rotation), on a class III site, with low-intensity site preparation, under low prices and a 5% ARR, would be $0.45, $42.15, and $131.48, respectively. Total per-hectare payments made over the full 30-year rotation would add up to approximately $1560.97 (not discounted).

Comparison of Mixed Hardwood and White Pine Incentive Values

It is evident from the results that the mixed hardwood incentive ranges are higher than those of the white pine incentives for all three incentive types investigated in this study. This is to be expected, as the range of mixed hardwood LEVs was lower than that of the white pine. These ranges of incentives for both mixed hardwoods and white pine are compared in Tables 25-28. The "high" incentive values correspond with the "low" LEVs, the "base case" incentive values correspond with the "base case" LEVs, and the "low" incentive values correspond with the "high" LEVs previously presented in Table 18. In the case of white pine, a number of scenarios yielded positive LEVs. For such scenarios, incentives to convert land would not be necessary, in that the given scenario is already an economically feasible option. Hence, the lowest incentive value, represented by all scenarios that yielded positive LEVs, is $0. Therefore, the value of $0 has been assigned to all the "low" white pine incentive values in the following tables of comparison.

Table 25. Comparison of mixed hardwood and white pine lump sum payments (low prices).

	Lump Sum	Mixed hardwoods	White pine
High	*Lump sum ($/ha)*	**2416.71**	**2330.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Lump sum ($/ha)*	**1710.16**	**316.06**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Lump sum ($/ha)*	**145.58**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwood lump sum payments made at the time of planting range from a minimum of $145.58/ha to a maximum of $2416.71/ha (Table 25). The corresponding range for mixed hardwood annual payments is $5.10/ha to $181.25/ha (Table 26). White pine lump sum payments made at the time of planting range from a minimum of $0/ha to a maximum of $2330.53/ha (Table 25). The corresponding range for white pine annual payments is $0/ha to $116.53/ha (Table 26). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a lump sum payment at planting that is $145.58/ha greater, or an annual payment that is $5.10/ha greater, than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a lump sum payment at planting that is $86.18/ha greater, or an annual payment that is $64.72/ha greater, than would be the case for a conversion to white pine.

Table 26. Comparison of mixed hardwood and white pine annual payments (low prices).

	Annual Payment	**Mixed hardwoods**	**White pine**
High	*Annual payments ($/ha/year)*	**181.25**	**116.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Annual payments ($/ha/year)*	**85.51**	**15.80**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Annual payments ($/ha/year)*	**5.10**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwood payments based on an increase in revenue at harvest range from a minimum of $430.82/ha to a maximum of $784449.52/ha (Table 27). White pine payments based on an increase in revenue at harvest range from a minimum of $0/ha to a maximum of $3853.06/ha (Table 27). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a payment at harvest that is $430.82/ha greater than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a payment at harvest that is $780,596.46/ha greater than would be the case for a conversion to white pine.

Table 27. Comparison of mixed hardwood and white pine increase in revenue at harvest (low prices).

	Revenue incentive	Mixed Hardwoods	White Pine
High	*Increase in revenue ($/ha)*	**784,449.52**	**3,853.06**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Increase in revenue ($/ha)*	**30,234.27**	**1,049.92**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Increase in revenue ($/ha)*	**430.82**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwood benefits based on carbon volume range from a minimum of $0.10/ton of carbon to a maximum of $5.26/ton of carbon (Table 28). White pine benefits based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $11.39/ton of carbon (Table 28). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a carbon subsidy that is $0.10/ton of carbon greater than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a carbon subsidy that is $6.13/ton of carbon less than would be the case for a conversion to white pine.

Table 28. Comparison of mixed hardwood and white pine carbon payments (low prices).

	Carbon Payment	Mixed Hardwoods	White Pine
High	*Carbon payment ($/ton of carbon)*	**5.26**	**11.39**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Carbon payment ($/ton of carbon)*	**1.82**	**0.64**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Carbon payment ($/ton of carbon)*	**0.10**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

The literature review revealed no other studies that directly calculated carbon subsidies against which our results could be compared. However, a number of studies did present average per-ton costs of sequestering carbon. These per-ton costs ranged throughout the literature from $0/ton of carbon to $120/ton of carbon. These costs could be seen as costs incurred by the incentive provider in an effort to sequester carbon, and in so doing, can be compared to our incentive values. Our results yield incentive values that are well within the cost of $20/ton of carbon sequestered suggested by van Kooten et al. (2000) to be a reasonable cutoff for socially desirable investment in forestry.

Summary

The incentive values calculated for both mixed hardwood and white pine scenarios display trends that are exactly opposite to those displayed by the LEVs of the corresponding scenarios. For both mixed hardwood and white pine scenarios, incentive values increase as site quality decreases. Thus, it would seem more appealing to the incentive provider to offer incentives to landowners who are willing to undertake a land use conversion on their best quality sites. Due to the higher average LEVs of white pine scenarios as opposed to mixed hardwood scenarios, average white pine incentive values are lower than average mixed hardwood incentive values. This is especially so for the incentive based on an increase in revenue at harvest, where the difference between the white pine and mixed hardwood incentive values is a matter of hundreds of thousands of dollars per hectare for some scenarios. The only case where the white pine incentive value is greater than that of the mixed hardwoods is for the maximum carbon payment scenario. This variation can be attributed to the significantly shorter white pine rotation compared to that of mixed hardwoods, during which carbon payments can be made to render the land use conversion economically feasible. The white pine carbon payment may be less than that of the mixed hardwoods in terms of a per-ton payment. However, the sum of all annual per-hectare carbon payments (not discounted) made by the end of a 60-year mixed hardwood rotation is approximately four times greater than the sum of all annual per-hectare carbon payments (not discounted) made by the end of a 30-year white pine rotation. Hence, the lower per-ton mixed hardwood carbon payment is not necessarily the more appealing option.

It appears that, for white pine scenarios, there is not much difference between incentive values for lump sum payments at planting, revenue incentives at harvest, and total carbon payments over a rotation. For mixed hardwoods, however, it appears that the carbon payment incentive is the cheapest option of encouraging landowners to convert land.

High Prices

The second set of prices used in our analysis (high prices) comprises a set of ideal, high-end prices, for which only high-value timber species and top-quality timber products are considered. Average prices were estimated based on the following species: red oak, white oak, black cherry, white ash, yellow poplar, and sugar maple (hard maple). All results presented and discussed in the following sections are based on this high set of product prices.

Land Expectation Values and Incentive Values

As for the low price set, in the following sections, the economic feasibility of converting reclaimed mined lands to mixed hardwood and white pine forests will be discussed in terms of LEVs. More specifically, the effects of the following factors on LEV will be analyzed: rotation age, site class, site preparation intensity, and alternative rate of return. As for the low price set, three different types of incentives will be discussed in terms of the high price set.

Effect of Rotation Age and Site Class on LEV

Similar to the low price scenarios, the effects of rotation age and site class on the decision to convert reclaimed mined lands to forests are analyzed in the following section for scenarios based on the set of high prices.

<u>Hardwoods</u>

Similar to results for the low price scenarios, Figure 33 shows a trend of decreasing mixed hardwood LEVs with increasing rotation age for all site classes using high prices. It is also clear that LEV increases when moving from poorer-quality sites (class V) to good-quality sites (class I). The absence of an obvious maximum LEV or optimal rotation age is again evident. This limitation is once again attributed to the failure to take into account varying product ratios with rotation. In fact, higher prices would result in shorter optimal rotations without taking into account product differentiation.

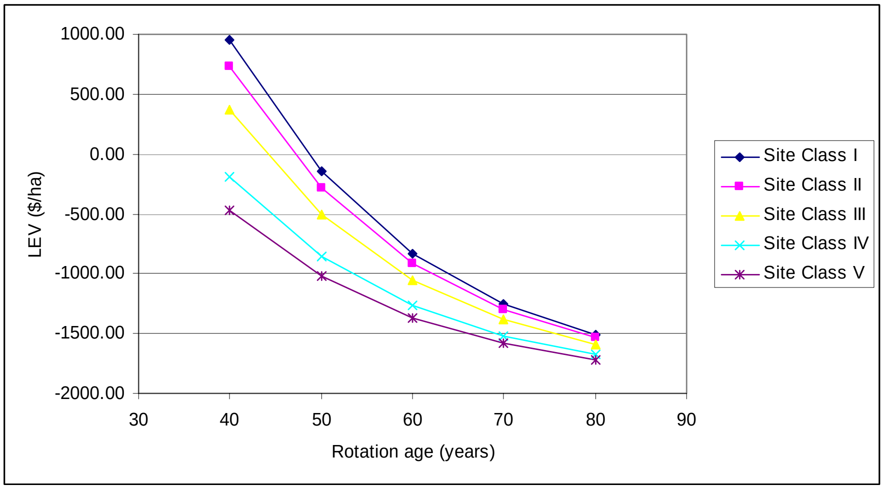

Figure 33. Mixed hardwood LEV by rotation and site class (medium-intensity site preparation, high prices, 5% ARR).

<u>White Pine</u>

Figure 34 shows white pine LEV trends over a range of rotation ages for all site classes. Trends displayed by site classes I-IV are similar to those of the low price scenarios. However, as expected, the high price scenario tends to yield a slightly shorter optimal rotation than the low price scenario on site class V. These high price scenarios suggest an optimal rotation age range of 25 to 30 years, depending on site quality, whereas the low price scenarios yielded an optimal rotation age range of 25 to 35 years. High price LEVs for all white pine scenarios increase significantly from those for the low price scenarios. For example, on a class I site under medium-intensity site preparation with an alternative rate of return of 5% and a 30-year rotation, white pine LEV increases by approximately 91.4%.

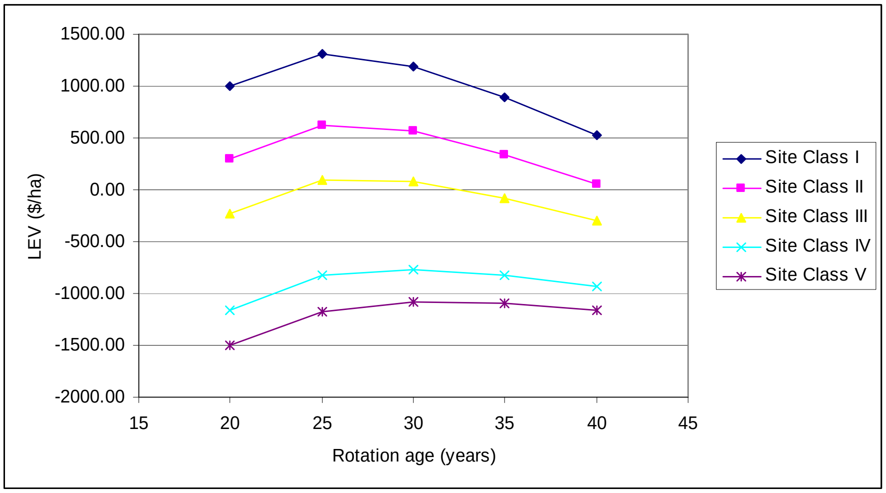

Figure 34. White pine LEV by rotation and site class (medium-intensity site preparation, high prices, 5% ARR).

Effect of Site Preparation Intensity and Alternative Rate of Return on LEV

Similar to the low price scenarios, the effects of site preparation intensity and alternative rate of return on the decision to convert reclaimed mined lands to forests are analyzed in the following section for scenarios based on the set of high prices.

Hardwoods

Consistent with the low price scenarios, Figure 35 shows a trend of decreasing mixed hardwood LEV with increasing site preparation intensity on all site classes. Figure 36 shows further that, for this subset of scenarios, the trend of decreasing mixed hardwood LEV with increasing site preparation intensity is constant for the rotation age range of 50 to 80 years. However, for a rotation age shorter than 50 years (and in the range of 40 to 80 years), it appears that mixed hardwood LEV is maximized under medium-intensity site preparation.

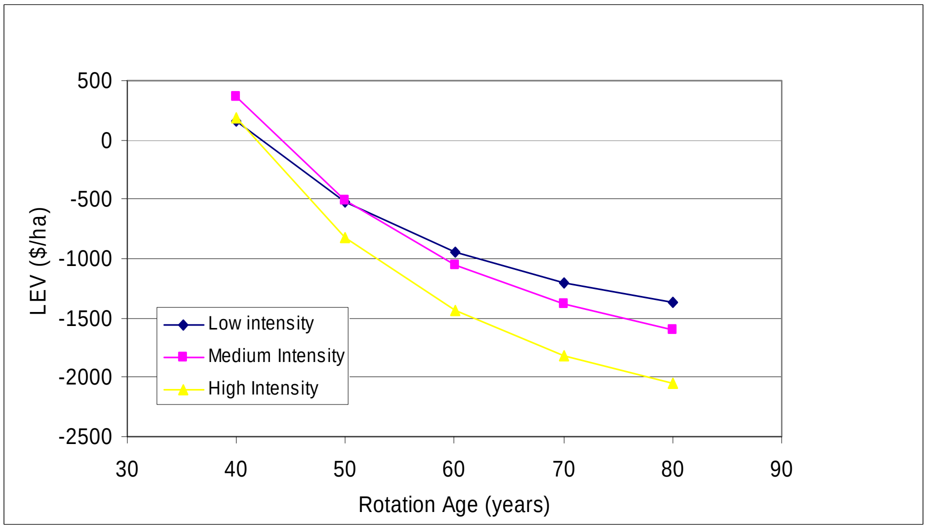

Figure 35. Effect of site preparation intensity on mixed hardwood LEV by site class (60-year rotation, 5% ARR, high prices).

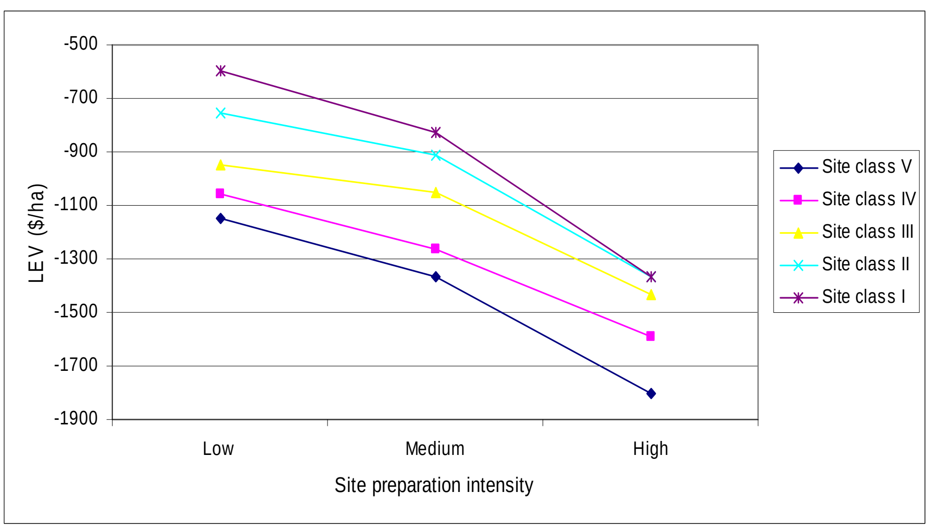

Figure 36. Effect of site preparation intensity on mixed hardwood LEV over a range of rotation ages (site class III, 5% ARR, high prices).

Also consistent with the low price scenarios, Figure 37 shows that for a given site class, mixed hardwood LEV tends to decrease with increasing rate of return. It is once again evident that increases in mixed hardwood LEV when moving from poorer-quality sites to better-quality sites become less pronounced with increasing alternative rates of return. Figure 38 shows further that the trend of decreasing mixed hardwood LEV with increasing rotation age within the proposed rotation age range is consistent over the 3.5% to 7.5% range of alternative rate of return. Also consistent with the low price scenarios, mixed hardwood LEV appears to decrease with increasing alternative rate of return for a given rotation age.

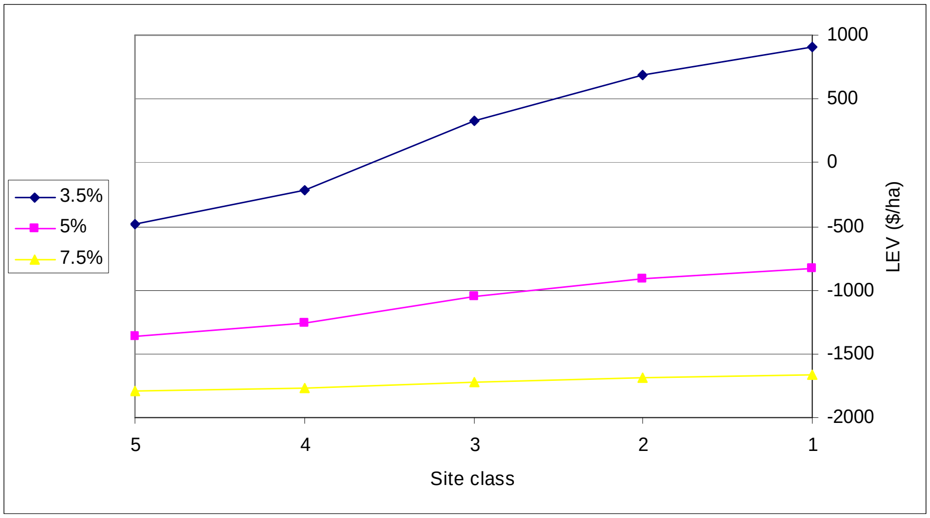

Figure 37. Effect of alternative rate of return on mixed hardwood LEV by site class (medium-intensity site preparation, 60-year rotation, high prices).

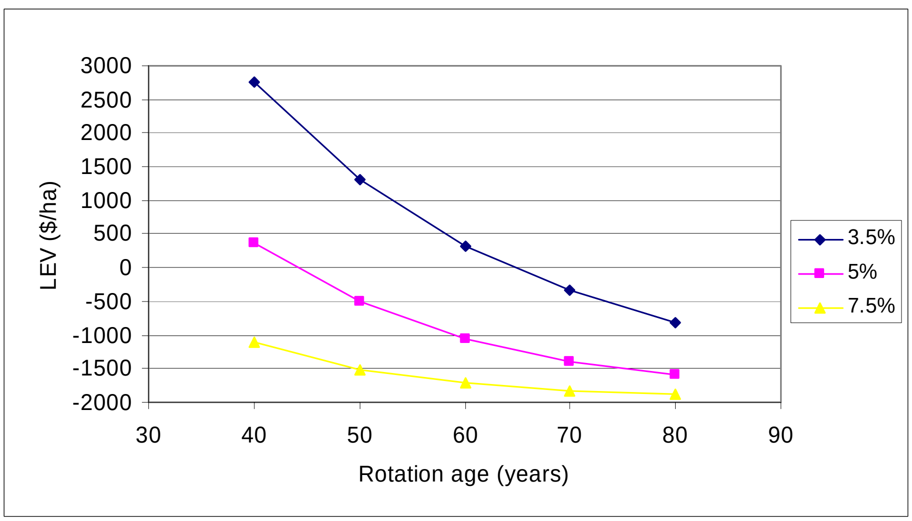

Figure 38. Effect of alternative rate of return on mixed hardwood LEV over a range of rotation ages (site class III, medium-intensity site preparation, high prices).

White Pine

Similar to the trends displayed by the low price scenarios, Figure 39 shows that for the high price scenarios, white pine LEV is maximized on site classes I, II, and III under medium-intensity site preparation, and is maximized on site class V under low-intensity site preparation. The only obvious difference from the low price scenarios is that LEV appears to be maximized on site class IV under high-intensity site preparation (high prices), as opposed to the low price scenario, in which LEV is maximized on site class IV under low-intensity site preparation. This apparent increase in LEV when moving from medium- to high-intensity site preparation can be attributed in part to the substantial increase in sawtimber-to-pulpwood ratio when moving from a class V site to a class IV site.

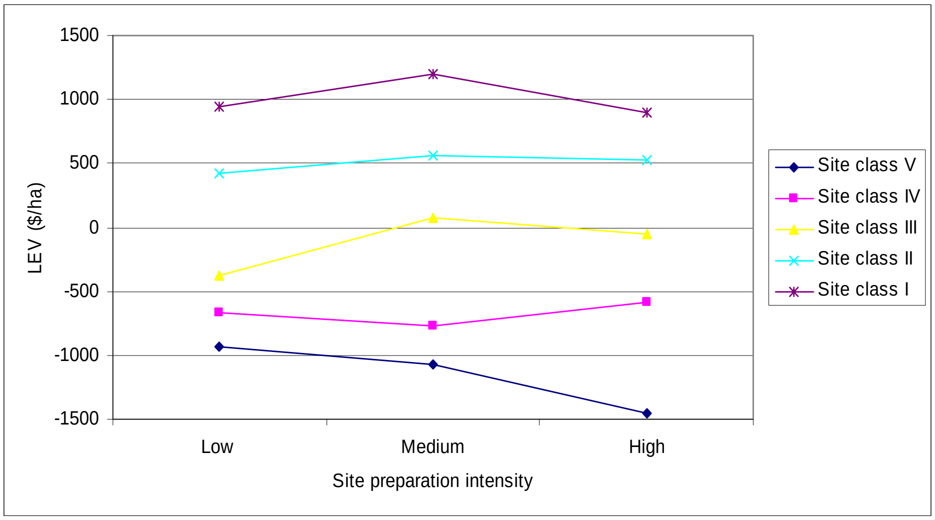

Figure 39. Effect of site preparation intensity on white pine LEV by site class (30-year rotation, 5% ARR, high prices).

Thus, results suggest that for the presented subset of scenarios, the increased cost of increasing site preparation intensity from medium to high is outweighed on a class IV site by the increase in revenue brought about by an increase in sawtimber-to-pulpwood ratio and the increase in timber and pulpwood volume produced at harvest. Results presented in Figure 40 suggest that for the given subset of scenarios, on a site class III site and for a 5% alternative rate of return, white pine LEV is maximized for all proposed rotation ages under a medium-intensity site preparation regime.

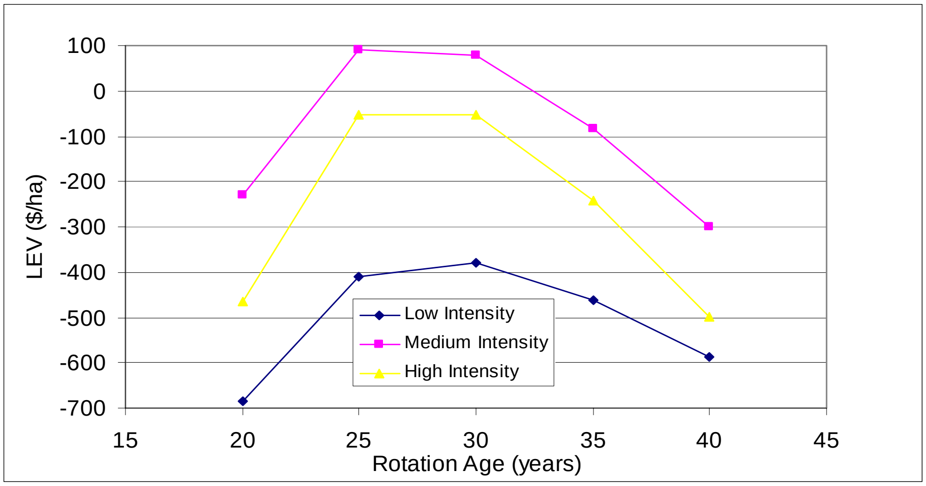

Figure 40. Effect of site preparation intensity on white pine LEV over a range of rotation ages (site class III, 5% ARR, high prices).

Consistent with the low price scenarios, Figure 41 shows that for a given site class, white pine LEV decreases with increasing alternative rate of return. It is once again evident that increases in white pine LEV, when moving from poorer-quality sites to better-quality sites, become less pronounced with increasing alternative rates of return. Figure 42 shows that in maximizing white pine LEV, the optimal rotation age remains within the range of 25 to 30 years over the 3.5% to 7.5% range of alternative rate of return. As for the low price scenarios, it also appears that the optimal rotation age decreases with increasing alternative rate of return. It is also clear that for a given rotation age, white pine LEV decreases with increasing alternative rate of return.

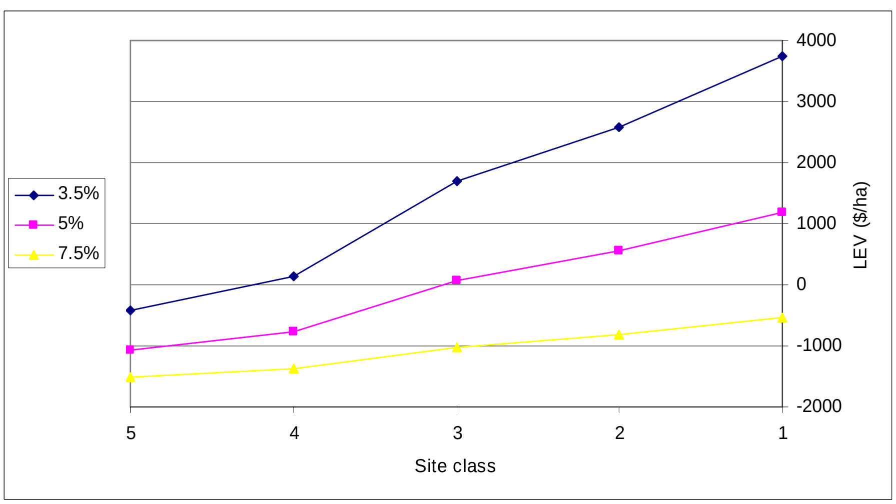

Figure 41. Effect of alternative rate of return on white pine LEV by site class (medium-intensity site preparation, 30-year rotation, high prices).

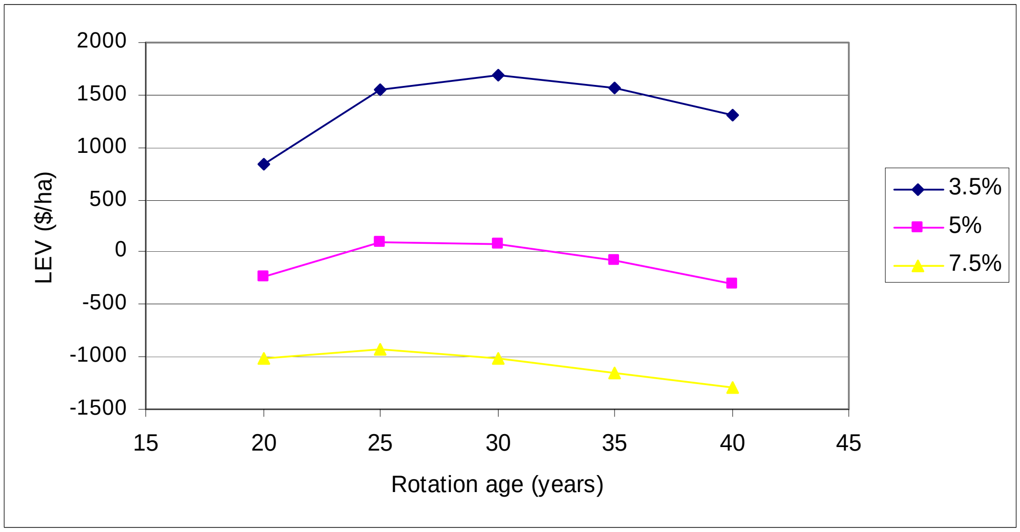

Figure 42. Effect of alternative rate of return on white pine LEV over a range of rotation ages (site class III, medium-intensity site preparation, high prices).

Comparison of Mixed Hardwood and White Pine LEV Ranges

Results for the high price scenarios suggest that within the 3.5% to 7.5% range of alternative rate of return, results for the mixed hardwood scenarios exhibit a wider range of LEVs than those for white pine. Under the high price set, the highest mixed hardwood LEV yielded within the 3.5% to 7.5% ARR range was $3,955.72/ha. This maximum LEV represents a mixed hardwood plantation on a class I site with low-intensity site preparation on a 40-year rotation with an alternative rate of return of 3.5% (Table 29).

The base case scenario for mixed hardwoods, represented by a 60-year rotation, a class III site with medium-intensity site preparation, and an alternative rate of return of 5% (Table 29), yields a LEV of -$1,051.43/ha under the high price set. Under the high price set, the lowest mixed hardwood LEV yielded within the 3.5% to 7.5% ARR range was -$2,387.05/ha. This minimum LEV represents a mixed hardwood plantation on a class V site with high-intensity site preparation on an 80-year rotation with an alternative rate of return of 7.5% (Table 29).

Table 29. Comparison of mixed hardwood and white pine LEV ranges (high prices).

LEV		Mixed Hardwoods	White Pine
Low	*LEV ($/ha)*	**-2,387.05**	**-2,158.81**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**-1,051.43**	**78.32**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3,955.72**	**3,746.65**
	Rotation	40 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

Under the high price set, the highest white pine LEV yielded within the 3.5% to 7.5% ARR range was $3,746.65/ha. This maximum LEV represents a white pine plantation on a class I site with medium-intensity site preparation on a 30-year rotation with an alternative rate of return of 3.5% (Table 29). The base case scenario for white pine, represented by a 30-year rotation, a site class III site with medium-intensity site preparation, and an alternative rate of return of 5% (Table 29), yields a LEV of -$78.32/ha under the high price set. Under the high price set, the lowest white pine LEV yielded within the 3.5% to 7.5% ARR range was -$2,158.81/ha. This minimum LEV represents a white pine plantation on a class V site with high-intensity site preparation on a 20-year rotation with an alternative rate of return of 7.5% (Table 29).

As an example, under the high price assumption, in terms of LEV, an investment in a 30-year rotation white pine regime under medium-intensity site preparation on a class III site is worth $1,129.75/ha more than a similar investment in a 60-year rotation mixed hardwood regime. Overall, under the high price assumption, the white pine scenarios yielded more positive LEVs than did the mixed hardwood scenarios. However, the highest and the lowest LEVs were yielded by mixed hardwood scenarios.

Comparison of Mixed Hardwood and White Pine Incentive Values

Incentives for the high price scenarios have been calculated for those scenarios corresponding to the high, base case, and low LEVs in order to estimate incentive ranges for both mixed hardwoods and white pine. These incentive ranges are compared in Tables 30-33. The "high" incentive values correspond with the "low" LEVs, the "base case" incentive values correspond with the "base case" LEVs, and the "low" incentive values correspond with the "high" LEVs previously presented in Table 29.

Table 30. Comparison of mixed hardwood and white pine lump sum payments (high prices).

Lump Sum		**Mixed Hardwoods**	**White Pine**
High	*Lump sum ($/ha)*	**2,387.05**	**2,158.81**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Lump sum ($/ha)*	**1,051.43**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Lump sum ($/ha)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

As for the low price scenarios, any high price scenario that yields a positive LEV does not require an incentive in order to render the given scenario economically feasible. Hence, the incentive value given to all scenarios that yield positive LEVs is $0. Therefore, the value of $0 has been assigned to all the “low” mixed hardwood and white pine incentive values, and to all the “base case” white pine incentive values in the following tables of comparison.

High price scenario mixed hardwood lump sum payments made at the time of planting range from a minimum of $0/ha to a maximum of $2,387.05/ha (Table 30). The corresponding range for mixed hardwood annual payments is $0/ha to $179.05/ha (Table 31). White pine lump sum payments made at the time of planting range from a minimum of $0/ha to a maximum of $2,158.81/ha (Table 30). The corresponding range for white pine annual payments is $0/ha to $161.91/ha (Table 31). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a lump sum payment at planting that is $228.24/ha greater (or an annual payment that is $17.14/ha greater) than would be the case for a conversion to white pine.

Table 31. Comparison of mixed hardwood and white pine annual payments (high prices).

Annual Payment		Mixed Hardwoods	White Pine
High	*Annual payments ($/ha/yr)*	**179.05**	**161.91**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Annual payments ($/ha/yr)*	**52.57**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Annual payments ($/ha/yr)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

High price scenario mixed hardwood payments based on an increase in revenue at harvest range from a minimum of $0/ha to a maximum of $774,824.73/ha (Table 32). White pine benefits based on an increase in revenue at harvest range from a minimum of $0/ha to a maximum of $7,011.48/ha (Table 32). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a payment at harvest that is $767,813.25/ha greater than would be the case for a conversion to white pine.

Table 32. Comparison of mixed hardwood and white pine increase in revenue at harvest (high prices).

Revenue Incentive		Mixed Hardwoods	White Pine
High	*Increase in revenue ($/ha)*	**774,824.73**	**7,011.48**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Increase in revenue ($/ha)*	**18,588.37**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Increase in revenue ($/ha)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

High price scenario mixed hardwood payments based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $5.19/ton of carbon (Table 33). White pine benefits based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $18.61/ton of carbon (Table 33). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, in order to render a conversion to mixed hardwoods economically feasible, the incentive provider would have to offer the landowner a carbon subsidy that is $13.42/ton of carbon less than would be the case for a conversion to white pine.

Table 33. Comparison of mixed hardwood and white pine carbon payments (high prices).

Carbon Payment		Mixed Hardwoods	White Pine
High	*Carbon payment ($/ton of carbon)*	**5.19**	**18.61**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Carbon payment ($/ton of carbon)*	**1.12**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Carbon payment ($/ton of carbon)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

Summary

A few important points can be highlighted from the high price scenario results. Naturally, all mixed hardwood and white pine LEVs increased from the low price scenarios, while incentive values decreased from the low price scenarios. A number of mixed hardwood scenarios became financially feasible, given the increase in product prices. These financially feasible mixed hardwood scenarios all fell within the 3.5% to 5% range of alternative rate of return. For the 3.5% alternative rate of return, all mixed hardwood scenarios with a rotation age of 50 years or shorter became financially feasible. Furthermore, other scenarios that became financially feasible are primarily those on good-quality sites (classes I, II, and III) under medium- and low-intensity site preparation. The number of financially feasible white pine scenarios increased from the low price scenarios. However, all financially feasible white pine scenarios still fell within the 3.5% to 5% range of alternative rate of return. The "base case LEV" for white pine increased by approximately 125% with the product price increase. The "high LEV" for white pine increased by approximately 39% with the product price increase. These significant increases in white pine LEV associated with the product prices increase highlight the financial benefits of selling timber in a niche market.

Costs Assumed by Landowner Versus Costs Assumed by Coal Company

This entire study is based on the assumption that the landowner assumes the costs of converting land from its current use to forests. For the purposes of this study, this assumption is typically true, given that the land that is to undergo a land use conversion is reclaimed mined land for which the current landowner, and not the mine operator, is now responsible. However, it is also feasible that the coal company, at the time of mining, may specify forestry as a post-mining land use. Such a scenario would require that the mine operator be responsible for establishment of the forest and that costs involved with establishment of the forest be born by the coal company until bond release is achieved. At that time, the landowner would be handed an established forest for which he or she has not had to incur any establishment costs, which would mean that he or she simply benefits from the revenue received from sawtimber and pulpwood sales at harvest. The assumption that the coal company bears the costs of forest establishment has significant implications for the landowner in terms of the economic profitability of forestry as a post-mining land use. These economic implications will be briefly discussed for both mixed hardwood and white pine scenarios.

Hardwoods

LEVs for mixed hardwood scenarios, under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 60-year rotation, an alternative rate of return of 5%, and low prices, are presented in Table 34.

Table 34. Mixed hardwood LEVs (coal company assumes costs) ($/ha) (60-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	200.13	231.36	267.47
4	231.36	267.47	335.60
3	267.47	335.60	387.98
2	330.77	382.39	411.15
1	382.39	411.15	411.15

Trends displayed by low price mixed hardwood LEVs of scenarios in which the landowner assumes the costs of forest establishment (Table 10) have been discussed previously. Some of the trends displayed by LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 24) differ from those in which the landowner assumes the costs of forest establishment. LEV still increases steadily when moving from poorer-quality sites (class V) to better-quality sites (class I). However, LEV now also increases steadily with increasing intensity of site preparation. This increase in LEV with increasing intensity of site preparation can be attributed to the fact that for the landowner, there is no associated increase in costs of forest establishment with increasing intensity of site preparation, but rather an improvement in site quality, and hence, increased volumes and revenues at harvest.

Table 35 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the low price scenarios. For example, for the "base case" scenario, mixed hardwood LEV increases by $2,045.76/ha in favor of the landowner when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

Table 35. Comparison of mixed hardwood LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (low prices).

LEV		**Landowner Assumes Costs**	**Coal Company Assumes Costs**
	LEV ($/ha)	**-2,416.71**	**15.38**
	Rotation	80 years	80 years
Low	*Site class*	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
	LEV ($/ha)	**-1,710.16**	**335.60**
	Rotation	60 years	60 years
Base case	*Site class*	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
	LEV ($/ha)	**-145.58**	**2,057.96**
	Rotation	40 years	40 years
High	*Site class*	I	I
	Site preparation	Low	Low
	ARR	3.5%	3.5%

LEVs for mixed hardwood scenarios, under the assumption that the landowner bears the costs of reforestation and under the assumptions of a 60-year rotation, an alternative rate of return of 5%, and high prices, are presented in Table 36. LEVs for mixed hardwood scenarios, under the assumption that the coal company bears the costs of reforestation and under the assumptions of a 60-year rotation, an alternative rate of return of 5%, and high prices, are presented in Table 37. Trends displayed by high price LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 37) are similar to those displayed by the corresponding low price scenarios.

Table 36. Mixed hardwood LEVs (landowner assumes costs) ($/ha) (60-year rotation, 5% ARR, high prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-1,146.60	-1,368.46	-1,801.39
4	-1,055.17	-1,262.75	-1,590.06
3	-949.46	-1,051.43	-1,434.87
2	-752.45	-912.79	-1,366.22
1	-599.50	-827.59	-1,366.22

Table 37. Mixed hardwood LEVs (coal company assumes costs) ($/ha) (60-year rotation, 5% ARR, high prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	585.87	677.30	783.01
4	677.30	783.01	994.34
3	783.01	994.34	1,149.52
2	980.02	1,132.97	1,218.18
1	1,132.97	1,218.18	1,218.18

Table 38 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the high price scenarios. For example, for the “low LEV” scenario, mixed hardwood LEV increases by $2,432.09/ha in favor of the landowner when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

Table 38. Comparison of mixed hardwood LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (high prices).

LEV		Landowner Assumes Costs	Coal Company Assumes Costs
Low	*LEV ($/ha)*	**-2,387.05**	**45.04**
	Rotation	80 years	80 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**-1,051.43**	**994.34**
	Rotation	60 years	60 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3,955.72**	**6,555.98**
	Rotation	40 years	40 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

White Pine

LEVs for white pine scenarios under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 30-year rotation, an alternative rate of return of 5%, and low prices, are presented in Table 39.

Table 39. White pine LEVs (coal company assumes costs) ($/ha) (30-year rotation, 5% ARR, low prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	911.17	1,104.61	1,339.11
4	1,122.47	1,360.76	2,106.86
3	1,360.76	2,106.86	2,554.13
2	2,073.33	2,513.48	3,047.07
1	2,513.48	3,047.07	3,354.95

Trends displayed by low price white pine LEVs of scenarios in which the landowner assumes the costs of forest establishment (Table 25) have been discussed previously. Some of the trends displayed by LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 39) differ from those in which the landowner assumes the costs of forest establishment. LEV still increases steadily when moving from poorer-quality sites (class V) to better-quality sites (class I). However, LEV now also increases steadily with increasing intensity of site preparation. As for the mixed hardwoods, this increase in LEV with increasing intensity of site preparation can be attributed to the fact that for the landowner, there is no associated increase in costs of forest establishment with increasing intensity of site preparation, but rather an improvement in site quality, and hence, increased volumes and revenues at harvest.

Table 40 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the low price scenarios. For example, for the “base case” scenario, white pine LEV increases by $2,422.92/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

Table 40. Comparison of white pine LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (low prices).

LEV		**Landowner Assumes Costs**	**Coal Company Assumes Costs**
Low	*LEV ($/ha)*	**-2,330.53**	**1,476.35**
	Rotation	20 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	5%	5%
Base case	*LEV ($/ha)*	**-316.06**	**2,106.86**
	Rotation	30 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**2,697.98**	**5,602.30**
	Rotation	30 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

LEVs for white pine scenarios under the assumption that the landowner bears the costs of reforestation, and under the assumptions of a 30-year rotation, an alternative rate of return of 5%, and high prices, are presented in Table 41. LEVs for white pine scenarios, under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 30-year rotation, an alternative rate of return of 5% and high prices, are presented in Table 42. Trends displayed by high price LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 42) are similar to those displayed by the corresponding low price scenarios.

Table 41. White pine LEVs (landowner assumes costs) ($/ha) (30-year rotation, 5% ARR, high prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	-926.98	-1,077.09	-1,454.64
4	-669.54	-764.99	-584.94
3	-379.21	78.32	-53.95
2	424.29	561.05	531.27
1	946.83	1,194.52	896.78

Table 42. White pine LEVs (coal company assumes costs) ($/ha) (30-year rotation, 5% ARR, high prices).

Site Class	Site Preparation Intensity		
	Low	Medium	High
5	1,110.16	1,345.83	1,631.54
4	1,367.60	1,657.93	2,501.24
3	1,657.93	2,501.24	3,032.23
2	2,461.43	2,983.97	3,617.44
1	2,983.97	3,617.44	3,982.95

Table 43 shows the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the high price scenarios. For example, for the “high LEV” scenario, white pine LEV increases by $2,904.33/ha in favor of the landowner when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

Table 43. Comparison of white pine LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (high prices).

LEV		Landowner Assumes Costs	Coal Company Assumes Costs
Low	*LEV ($/ha)*	**-2,158.81**	**915.65**
	Rotation	20 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**78.32**	**2,501.24**
	Rotation	30 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3,746.65**	**6,650.98**
	Rotation	30 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

It is evident that for both the low and the high price scenarios, under the assumption that the coal company assumes the costs of reforestation, all of the proposed mixed hardwood and white pine scenarios yielded positive LEVs, which would suggest that all of these scenarios are economically feasible. Therefore, there is no need for incentives.

Summary

From the standpoint of a landowner, it would obviously be preferable, from a financial point of view, to leave site preparation and reforestation up to the coal company, and in so doing, spare the landowner the costs of reclaiming the mined land. The risk in leaving this reforestation responsibility up to the coal company is the possibility of a half-hearted attempt at reforesting the land, due to the coal company having no long-term interest in the future use of the mined land. Were the coal company to assume the costs of reclaiming the mined lands, from a landowner's perspective, it would now be most profitable to invest in high-intensity site preparation on the best-quality sites. However, in reality, the coal company would seek to reclaim the mined land in such a way that bond release is achieved at the least cost possible. This least-cost option would most likely entail low-intensity site preparation, regardless of site quality or other market factors. As an example of how this least-cost reforestation scenario (coal company assumes costs) would impact the landowner economically, mixed hardwood LEV on a class I site, under low-intensity site preparation, rotation age 60 years, 5% ARR, and low prices, would increase by approximately 164% from the corresponding scenario in which the landowner assumed the costs of reforestation. Thus, under this least-cost reforestation scenario, the landowner, who assumes no costs, would still come out the winner.

Conclusion

It must once again be emphasized that the purpose of this study was not to determine the perfect land use conversion scenario, or to calculate land expectation values and incentive values upon which landowners should base financial decisions. The primary purpose of this study was to develop a framework for calculating and understanding the economic implications of converting reclaimed mined lands to forests, and the incentives that would be required to render these land use conversion regimes profitable for the landowners. This framework is ultimately aimed at assisting landowners in the land use conversion decision-making process. Furthermore, it was the purpose of this study to identify trends in the calculated LEVs and incentive values based on species type, rotation age, alternative rate of return, site quality, site preparation intensity, and product prices. At the same time, broad ranges of LEVs and incentive values were estimated for the conversion of reclaimed mined lands to forests.

Framework

The framework developed for this study, for the assessment of the economic feasibility of converting reclaimed mined lands from their current use to forests, comprised a few key steps. Firstly, data from reclaimed mined lands were used to estimate forest stand growth and yield equations for both mixed hardwoods and white pine. Secondly, costs were estimated for the three proposed levels of site preparation intensity. Thirdly, LEVs were calculated for both mixed hardwoods and white pine over a broad spectrum of land-use conversion scenarios. These scenarios differed according to rotation age, alternative rate of return, initial site quality, site preparation intensity, and product prices. Based on these calculated LEVs, trends were evaluated in an effort to identify which scenarios tended to be most profitable and least profitable to the landowner. Further, three types of incentives were investigated, each with the common objective of rendering a land use conversion profitable for a landowner. The three incentive schemes were: (1) lump sum payment at planting and equivalent series of annual payments; (2) revenue incentive at harvest; and (3) benefit based on carbon volume. Incentive values were then calculated for a subset of scenarios, including those corresponding to the most profitable and least profitable land use conversion scenarios for both mixed hardwoods and white pine. The primary purpose of calculating a benefit based on carbon volume was to determine a range of potential carbon values; i.e., to give an idea of how much carbon is worth under various land use conversion conditions.

Summary of Findings

Given the number of variables involved in the economic feasibility assessment, it is nearly impossible to identify one correct or best solution. Based on some of the trends that have been identified, however, it is possible to identify a few land use conversion regimes that would potentially be the most profitable or least profitable for the landowner. The mixed hardwood and white pine results share a few general trends, but also differ significantly in some areas.

Mixed Hardwoods LEVs

An optimal rotation length for mixed hardwoods has not been identified in this study. The results suggested a particularly short optimal rotation length of 20 years – outside of the proposed rotation range – for mixed hardwoods. It is suspected that this short rotation length is primarily due to the fact that varying product ratios with rotation length were not taken into account. This is noted as a limitation to this study. As would be expected, for a given site preparation intensity, results suggested that mixed hardwood LEVs tended to increase when moving from poorer-quality sites to better-quality sites. Results suggested a trend of decreasing mixed hardwood LEV with increasing intensity of site preparation; hence, minimal site preparation seems advisable for most mixed hardwood regimes. Consistent over all site classes, all site preparation intensities, and all rotation ages, was the trend of decreasing LEV with increasing alternative rate of return. Therefore, in short, were a landowner to be set on planting mixed hardwoods, in general it would be most profitable for him or her to invest in such a land use conversion on the best-quality sites (class I), with low-intensity site preparation, and with the lowest alternative rate of return possible. This finding is in keeping with the conclusions made by Kronrad et al. (2002). Results for the high price set did suggest, however, that on shorter rotations (less than 50 years), mixed hardwood LEV was maximized under medium-intensity site preparation. Results also suggested that, were a landowner to be set on planting mixed hardwoods, in general it would be least profitable for him or her to invest in such a land use conversion on poor-quality sites (class V), especially under high-intensity site preparation, a high alternative rate of return, and on a long rotation (80 years).

White Pine LEVs

Results suggested an optimal white pine rotation age range of 25 to 35 years for the low price set. This range decreased to approximately 25 to 30 years for the high price set. As for the mixed hardwood LEVs, white pine LEVs tended to increase when moving from poorer-quality sites to better-quality sites. White pine results suggested that LEV was maximized on site classes I, II, and III under medium-intensity site preparation, and that LEV was maximized on site classes IV and V under low-intensity site preparation. This trend did depend, however, on the alternative rate of return, as optimal intensity of site preparation tended to increase with decreasing alternative rate of return for white pine scenarios. As with the mixed hardwoods, the trend of decreasing white pine LEV with increasing alternative rate of return was consistent over all site classes, all site preparation intensities, and all rotation ages. White pine results also suggested that the optimal intensity of site preparation and the optimal rotation age both decreased as the alternative rate of return increased. Therefore, in short, were a landowner to be set on planting white pine, in general it would be most profitable for him or her to invest in such a land use conversion on the best-quality sites (class I), with medium-intensity site preparation, on a rotation of approximately 30 years, and with the lowest alternative rate of return possible. Results also suggest that, were a landowner to be set on planting white pine, in general it would be least profitable for him or her to invest in such a land use conversion on poor-quality sites (class V), especially under high-intensity site preparation, a high alternative rate of return, and on a short rotation (20 years).

Comparison of Mixed Hardwood and White Pine LEVs

Under the low price set, the mixed hardwood results yielded a LEV range of -$2,416.71/ha to -$145.58/ha. Under the low price set, the white pine results yielded a LEV range of -$2,330.43/ha to $2,697.98/ha. Thus, it would appear that under the low price set, planting white pine on reclaimed mine lands could be profitable for the landowner under a number of different reforestation regimes, whereas converting the land to mixed hardwood plantations does not offer the landowner any profitable options. These LEV ranges changed significantly under the set of high prices. Under the high price set, the mixed hardwood results yielded a LEV range of -$2387.05/ha to $3955.72/ha. Under the high price set, the white pine results yielded a LEV range of -$2158.81/ha to $3746.65/ha. These LEV ranges for the high price set are much more similar for mixed hardwoods and white pine than those for the low price set. Under the high price set, the number of white pine reforestation regimes that appeared to be economically feasible (positive LEVs) still outnumbered the economically feasible mixed hardwood regimes. However, given these high prices, converting land to mixed hardwood plantations now offers a number of economically profitable options, the most profitable of which is slightly more profitable than the most profitable white pine scenario. Thus, given the product price increase, it appears that the decision to convert land to mixed hardwood plantations versus converting the land to white pine plantations became less significant for scenarios yielding the highest and the lowest LEVs for both mixed hardwood and white pine scenarios. In general, the higher prices make a land use conversion on lower site classes feasible for both mixed hardwoods and white pine. Given that Sullivan et al. (2003) showed the average sale price per hectare of forested land in Southwest Virginia to be approximately $1259.67, a number of the more profitable land use conversion scenarios for both mixed hardwoods and white pine in this study (particularly for the high price set) yielded LEVs that suggest a comparable sales price for bare land.

Incentives

As expected, the incentive values calculated for both mixed hardwood and white pine scenarios displayed trends that are exactly the opposite of those displayed by the LEVs of the corresponding scenarios. Useful for the policy maker are the incentive value ranges calculated for this study.

Comparison of Mixed Hardwood and White Pine Lump Sum Payments at Planting (and Corresponding Series of Annual Payments)

Mixed hardwood lump sum payments, made at the time of planting, ranged from a minimum of $0/ha to a maximum of $2416.71/ha (low prices). The corresponding range for mixed hardwood annual payments was $0/ha to $181.25/ha. White pine lump sum payments, made at the time of planting, ranged from a minimum of $0/ha to a maximum of $2,330.53/ha (low prices). The corresponding range for white pine annual payments was $0/ha to $161.91/ha (high prices). Based on these incentive ranges, it would appear that, although the white pine option renders somewhat lower incentive ranges, incentive providers could expect to offer similar lump sum payments (or annual payments) to landowners converting to mixed hardwoods or white pine options, especially for the least profitable scenarios.

Comparison of Mixed Hardwood and White Pine Revenue Incentives at Harvest

Mixed hardwood benefits, based on an increase in revenue at harvest, ranged from a minimum of $0/ha to a maximum of $784,449.52/ha (low prices). It must be noted that this maximum mixed hardwood revenue incentive at harvest occurred under the extreme and somewhat unlikely conditions of an 80-year rotation and an alternative rate of return of 7.5%. White pine benefits based on an increase in revenue at harvest ranged from a minimum of $0/ha to a maximum of $7011.48/ha (high prices). There was a huge difference between these mixed hardwood and white pine maximum incentive values based on an increase in revenue at harvest. However, it must be pointed out that it would seem likely that an incentive provider would not be inclined to offer a landowner a payment at harvest of anything near the magnitude of the maximum payment calculated for the mixed hardwood scenarios. Were this to be the type of incentive offered to landowners, it would seem probable that incentive providers would be more inclined to offer financial assistance to landowners converting to white pine plantations.

Comparison of Mixed Hardwood and White Pine Payments Based on Carbon Volume

Annual mixed hardwood benefits, based on total stand carbon volume present at the end of a given year, ranged from a minimum of $0/ton of carbon to a maximum of $5.26/ton carbon (low prices). White pine benefits based on carbon volume ranged from a minimum of $0/ton of carbon to a maximum of $18.61/ton of carbon (high prices). The higher maximum white pine carbon payment can primarily be attributed to the fact that the shorter rotation means that payments for white pine carbon are being made on far less cumulative carbon tonnage than for that of the long-rotation hardwoods. Therefore, the payment per ton of white pine carbon needs to be higher than that of the hardwoods in order to render the conversion to white pine profitable by the end of a rotation. These carbon payments may seem appealingly low to the incentive provider. However, payments (not discounted) made over a full rotation may add up to approximately $17,493/ha for white pine (30-year rotation) and $18,820/ha for mixed hardwoods (60-year rotation). The literature suggests a range of carbon sequestration costs from $0/ton of carbon to $120/ton of carbon, although the majority of studies suggest a cost below $50/ton of carbon, with van Kooten et al. (2000) suggesting a cut-off cost of $20/ton of carbon sequestered. Thus, the ranges of carbon payments estimated for this study fall well within the ranges of carbon sequestration costs estimated in previous studies.

Value of This Study

More than anything, this study provides a basic framework for assessing the economic implications of converting reclaimed mined lands to forests and the incentives that may be necessary in encouraging landowners to undertake such land use conversions. This framework offers landowners and policy makers a foundation upon which the decision-making process to convert land can be built. The LEV and incentive value trends and ranges estimated in this study should go towards assisting both the landowner and the policy maker in their decisions to undertake a land use conversion and to provide incentives, respectively. This study will add to the limited literature available, pertaining to the economic implications of converting reclaimed mined lands to forests, for the primary purpose of sequestering carbon, and pertaining to the use of incentive schemes to encourage this land use conversion.

Limitations and Future Research

The primary limitation to this study was the limited range of case study data on which our economic analysis was based. This may affect the results, especially when input data is outside the range of data upon which the model was built. Being one of the first studies of its kind, a secondary limitation has been the lack of real data to which the accuracy of the model can be directly compared. The framework developed in this study for examining the economic feasibility of converting reclaimed mined lands to forests and the potential for incentive schemes provides the groundwork for future policy-related research addressing such land use conversions. Future research related to this study could be aimed at refining the model upon which this study was based. This could be done by improving on the assumptions made for this study and by examining in more detail the interrelations among all the variables involved in this economic analysis.

Part of this refining and improvement process should include the incorporation of varying product ratios with rotation age, and perhaps the incorporation of amenity values associated with forests. These varying product ratios with rotation age are difficult to estimate accurately for a number of reasons. In considering hardwood products, it is necessary to take into account not only the size of trees, but also their species and bole form. With limited growth and yield models available for mixed Appalachian hardwood stands, accurate prediction of some of these factors becomes very difficult. For policy makers, a broader spectrum of potential incentive schemes may be an important area for future research. Furthermore, it will be important in the future to compare the results of this research to case study data. Based on these comparisons and the ever-increasing pool of input and output data that becomes available, it will be possible to improve upon the framework developed in this study for analyzing the economic feasibility of converting reclaimed mined lands to forests.

References

Amacher, G., J. Sullivan, L. Shabman and L. Zepp. 1997. Restoration of the lower Mississippi Delta bottomland hardwood forest: Economic and policy considerations. Res. Bull. 185. Virginia Water Resources Res. Ctr, Virginia Polytechnic Inst. and State Univ.

Ashby, W. C. 1999. Growth of white and red oak seedlings and seed on mined ungraded cast overburden. In: Stringer, J. W., and Loftis, D. L. (eds.). Proc., 12th Central Hardwood Forest Conf., Lexington, KY.

Boyce, S. 1999. Office of Surface Mining (OSM) revegetation team survey results. p. 31-35. In: Vories, K., and D. Throgmorton (eds.). Proc., Enhancement of Reforestation at Surface Coal Mines: Tech. Interactive Forum. OSM, Alton, IL, and Coal Res. Ctr, S. Ill. Univ., Carbondale, and Texas Utilities.

Branan, J. R., and Porterfield, E. J. 1971. A comparison of six species of southern pines planted in the piedmont of South Carolina. USDA For. Serv., Southeastern For. Exp. Sta., Res. Note SE-171. 3p.

Brown, J. H. 1962. Success of tree planting on strip-mined areas in West Virginia. West Virginia Univ., Agricultural Experiment Station.

Burger, J. A., Kelting, D. K. and Zipper, C. 1998. Maximizing the value of forests on reclaimed mined land. Virginia Coop. Exten. Pub. No. 460-138. Blacksburg, VA.

Burger, J. A. and W. R. Maxey. 1998. Maximizing the value of forests on reclaimed land. *Green Lands* 28:37-46.

Burger, J. A., and Zipper, C. E. 2002. How to restore forests on surface-mined land. Virginia Coop. Exten. Pub. No. 460-123. Blacksburg,VA. 21p.

Czapowskyj, M. M. 1970. Experimental planting of 14 tree species on Pennsylvania’s anthracite strip-mine spoils. USDA For. Serv. Northeast For. Exp. Sta. Res Pap. NE-155. 18p.

Davidson, W. H. 1981. Timber volumes of old Pennsylvania surface mine reclamation plantations. USDA For. Serv., Northeastern For. Exp. Sta., Res. Note NE-303. 5p.

Deitschman, G. H. 1950. Seedling survival and height growth on graded and ungraded strip-mined land in southern Illinois. USDA For. Serv. Central States For. Exp. Sta. Notes No. 62. Columbus, OH. 2p.

Demchik, M. C. and Sharpe, W. E. 1999. Survivorship and growth of natural northern red oak (*Quercus rubra* L.) seedlings in response to selected treatments on an extremely acidic forest floor. In: Stringer, J. W., and Loftis, D. L. (eds.). Proc., 12th Central Hardwood Forest Conference, Lexington, KY.

DenUyl, D. 1955. Hardwood tree planting experiments on strip mine spoil banks of Indiana. Purdue Univ. Agric. Exp. Sta. Bull. 619. West Lafayette, IN. 16p.

Dierauf, T. A., and Scrivani, J. A. 1995. White pine old-field plantation yield study. Virginia Dept. of Forestry, Occasional Rep. No. 123.

Doolittle, W. T. 1958. Site index comparisons for several forest species in the southern Appalachians. Soil Sci. Soc. Amer. Proc. 22:455-458.

Kozlowski, T. T. 1999. Soil compaction and growth of woody plants. *Scandinavian J. For. Resour.* 14:596-619.

Kronrad, G. D. 2002. Enhancement of terrestrial carbon sinks through reclamation of abandoned mine land in the Appalachian region (unpublished).

Larson, M. M., and Vimmerstedt, J. P. 1983. Evaluation of 30-year-old plantations on strip-mined land in east central Ohio. Ohio State Univ, Agric. Res. and Devel. Ctr. Res. Bull. 1149. 20p.

Mickalitz, A. B., and Kutz, D. B. 1949. Experiments and observations on planting areas "stripped" for coal in Pennsylvania. *Penn. Forests and Waters* 1(3):62-66, 70.

Plass, W. T. 1975. An evaluation of trees and shrubs for planting surface-mine spoils. USDA For. Serv. Res. Pap. NE-317. 8p.

Plass, W. T. 1977. Growth and survival of hardwoods and pine interplanted with European alder. USDA For. Serv. Res. Pap. NE-376. 10p.

Ravindranath, N. H., and Somashekar, B. S. 1995. Potential and economics of forestry options for carbon sequestration in India. *Biomass and Bioenergy* 8(5):323-336.

Rodrigue, J. A. 2001. Woody species diversity, forest and site productivity, stumpage value, and carbon sequestration of forests on mined lands reclaimed prior to the passage of the Surface Mining Control and Reclamation Act of 1977. M.S. Thesis, Virginia Polytechnic Institute and State University.

Schuster, W. S., and Hutnick, R. J. 1983. Strip-mine test plantings in Pennsylvania after 35 years. p. 119-128. In: Better Reclamation with Trees Conf., Amax Coal Co. and Purdue Univ., Dept. of Forestry. Terre Haute, IN, 2-3 June 1983.

Sluder, E. R. 1963. A white pine provenance study in the southern Appalachians. USDA For. Serv. Southeastern For. Exp. Sta. Res. Pap. SE-2. 16p.

Torbert, J. L., and Burger, J. A. 1990. Guidelines for establishing productive forest land on reclaimed surface mines in the central Appalachians. Mining and Reclamation Conf. and Exhibition, Charleston, WV.

Torbert, J. L., Burger, J. A. and Probert, T. 1995. Evaluation of techniques to improve white pine establishment on an Appalachian minesoil. *J. Envir. Qual.* 24:869-873.

Torbert, J. L., Burger, J. A. and Johnson, J. E. 1996. Commercial forestry as a post-mining land use. Virginia Coop. Exten. Pub. No. 460-136. Blacksburg, VA.

Van Kooten, G. C., Stennes, B., Krcmar-Nozic, E., and Van Gorkom, R. 2000. Economics of afforestation for carbon sequestration in western Canada. *The For. Chron.* 76(1):165-172.

Will, R. E., Munger, G. T., Zhang, Y. and Borders, B. E. 2002. Effects of annual fertilization and complete competition control on current annual increment, foliar development, and growth efficiency of different aged *Pinus taeda* stands. *Can. J. For. Res.* 32:1728-1739.

Xu, D. 1995. The potential for reducing atmospheric carbon by large-scale afforestation in China and related cost/benefit analysis. *Biomass and Bioenergy* 8(5):337.

Zeleznik, J. D., and Skousen, J. G. 1996. Survival of three tree species on old reclaimed surface mines in Ohio. *J. Environ. Qual.* 25(6):1429-1435.

TASK 5: Determine the potential of large-scale SMCRA grassland restoration to sequester carbon and create other societal benefits. (Zipper et al.)

Executive Summary

Because of our inability to identify a graduate student who would conduct the work required by Task 5, a search for a post-doctoral research associate to conduct this work was initiated. A candidate has been identified, and an offer has been extended. If the candidate accepts, this work will begin in April of 2004.

Report

Activity during the reporting period consisted of searching for a post-doctoral research associate who will conduct research activities related to reclaimed coal mine soils capability to support forests and sequester atmospheric carbon with support provided jointly by NASA (Wynne et al. 2003) and US Department of Energy (Burger et al 2002). The DOE-supported activities would locate and characterize mine sites available for reforestation, while the NASA-supported project component would support additional site characterization work necessary to assess spectral characteristics, and acquisition and analysis of remote sensing data.

The position announcements were circulated through professional journals and societies during Fall of 2003. 22 applications were received. In December of 2003, two applicants were selected to interview for the position. Both interviewed in early 2004, and one applicant has been selected. An offer to this applicant is pending. Assuming the applicant follows through on his verbal acceptance of the offer, we expect him to begin working in April of 2004, and to make rapid progress during subsequent months.

References

Burger, J.A., T. R. Fox, G. S. Amacher, B. J. Sullivan, C. Zipper, J. Galbraith. 2002. Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services. Research proposal to US Department of Energy. 10/02 - 10/05. (funded).

Randolph H. Wynne, James B. Campbell, Carl E. Zipper, and Layne T. Watson. 2003. Remote Sensing for Forest Productivity, Carbon Management and Monitoring. National Aeronautics and Space Administration / George Mason University. 10/03 – 9/04 (renewal through 10/05 anticipated)

PROJECT TIMETABLE

Planned   Completed

Year:	2002	2003				2004				2005		
Quarter:	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**
Task 1												
Subtask 1.1	Baseline CarbonSequestration Potential											
Subtask 1.2	Mine Soil Productivity											
Subtask 1.3					Carbon Sequestration by Forest Practice							
Subtask 1.4						Accounting Procedures						
Task 2												
Subtask 2.1	Classification Criteria											
Subtask 2.2				GIS Mapping								
Subtask 2.3				Test Remote Sensing								
Subtask 2.4						Experimental Plots						
Subtask 2.5							Soil Analyses					
Subtask 2.6											Validate classification criteria	
Task 3												
Subtask 3.1	Locate sites											
Subtask 3.2			Establish experiment									
Subtask 3.3				Silvicultural recommendations								
Subtask 3.4					Reforestation costs							
Subtask 3.5						Evaluate survival & growth						
Subtask 3.6						Estimate growth potential						
Subtask 3.7							Estimate timber & carbon value					
Task 4	Economic feasibility											
Subtask 4.1				Future evaluation								
Subtask 4.2								Government policies				
Subtask 4.3												
Task 5												
Subtask 5.1			Identify SMCRA	grass- land								
Subtask 5.2				Use characteristics of permits								
Subtask 5.3							Soil properties by permit					
Subtask 5.4								Est. quantity grassland				
Subtask 5.5								Est. C. sequ. by site quality class				
Subtask 5.6											Est. C. sequ. by policy scenario	