CORRIM: Phase I Final Report

Module A

FOREST RESOURCES
PACIFIC NORTHWEST AND SOUTHEAST

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EXECUTIVE SUMMARY

Removal of wood biomass from the forest and the activities associated with growth, removal, and reestablishment of trees requires careful analysis to determine the total life cycle inventories (LCIs) and their impacts. Life cycle impacts are not stationary and will change over the years based on both past and prospective technologies, evolving forest management procedures and population demands. Time becomes a critical element of this analysis since the period from initial planting or forest establishment to removal can range from five years for short rotation intensive culture to 100 years or more for selectively managed forests. Inputs and outputs of the life cycle process include quantitative measures that can be used to interpret costs, production and environmental results and qualitative measures that describe other aspects of the forest environment.

This report illustrates quantitative measures for a set of structured scenarios in two regions providing the inputs needed to develop LCIs for wood products. The more qualitative measures require a blending of the management activities in a single unit with activities on adjacent acreages. In particular, landscape scenarios and documentation of environmental co-products of forest management are developed in modules N and O of this report, as they are not inputs to processing LCIs.

This specific analysis involves scenarios for the Southeastern US and Pacific Northwest regions. These were structured from three general combinations of management intensity (forest treatment regime) and site productivity for each region. The management intensities ranged from little intervention on low site productivity lands to higher management intensities involving combinations of fertilization and thinning on high productivity lands. Associated with each combination of management intensity and site productivity was an estimated yield of biomass. Management options were focused on private forest lands that generally involved planting, intermediate forest management activities such as fertilization and thinning, and a final harvest at the rotation age of the forest. Vegetation growth for the scenarios was simulated through established growth and yield vegetation simulators developed for each respective region. The simulation models produced estimates of standing and harvested biomass. Volumes of harvested biomass in the form of logs were passed on as resources to the manufacturing segments for lumber, plywood, or oriented strand board (OSB). Volumes of logs destined for pulp and paper manufacture were treated as co-products of the forest resource module.

Within each region, the three combinations of management intensity and site productivity were merged into a single estimate of yield and the corresponding harvesting impacts. The single estimate was developed as a weighted average of the yield and environmental factors associated with each of the three combinations of site productivity and management intensity. The weighting factors for each region were developed through expert opinion and subsequent analysis of inventory data developed by the US Forest Service. The Forest Service information categorizes the number of private forest acres in each region by site classification and management intensity

The allocation of acreage to management intensity / site productivity class represented a base case for each region. In the Southeast, 37% of industrial and non-industrial private forestlands were classified in the lowest productivity class, 58% in the middle productivity class, and 5% in the highest class. In the Pacific Northwest, 42% of the lands were classified in the lowest productivity/management class, 46% in the middle class, and 12% in the highest productivity class.

The impacts of introducing higher levels of management intensity to private forest lands was also considered by shifting acreage to a higher level of management intensity. In the Southeast, an assumption was made to shift all lands in one class of management intensity to the next higher level. This alternate case included a distribution in the Southeast of 0% in the lowest productivity class, 37% in the middle class, and 63% in the highest classification. In the Pacific Northwest, the shift of lands to a higher classification was based on analysis that indicated the potential to shift some, but not all acres to a higher management intensity. This resulted in 24% of the lands in the lowest productivity class, 40% in the middle class and 36% in the highest class. These shifts resulted in higher volume production of biomass volume from the forested sites as a result of increased inputs (fertilization and thinning) throughout the life of the forest stand.

The shift to the higher intensity scenario in the Southeast increased the average production of merchantable volume from 222 cubic meters / hectare (3174 cubic feet / acre) to 291 cubic meters / hectare (4163 cubic feet / acre). The percent of the volume categorized as logs capable of producing lumber increased from 34.9% to 44.1%. In addition, more of the volume produced in the higher intensity scenario was categorized as saw timber rather than chip-n-saw. Although this difference will not be evident in the volumes passed to the next stages of processing, saw timber is a higher value product than the chip-n-saw resource.

In the Pacific Northwest, all the harvested volume is first delivered to sawmill or plywood plants. Residual chips are generated from the lumber and plywood manufacturing process. Direct delivery of pulpwood from the woods was not assumed to represent a significant part of the harvested volume. This affects the commercial volume removed from the woods and the volume left on site after harvest. Average yield for the base case was 501 cubic meters / hectare (7159 cubic feet / acre). This volume increased to 581 cubic meters per hectare (8307 cubic feet / acre) under the higher intensity alternative.

Timber harvesting generally consists of five components: felling (severing the standing tree from the stump), processing (cutting trees into log lengths and removing non-merchantable limbs and tops), secondary transportation (moving logs or trees from the woods to a landing area – sometimes called skidding or yarding), loading (placement of logs on trucks for transportation), and primary transportation (hauling of logs to the subsequent processing point). Harvesting production, cost and fuel consumption rates were assimilated from existing studies of harvesting equipment typical of the systems used to harvest sites both in the southeastern United States and the Pacific Northwest. The costs, production and consumption rates were developed for equipment options within each component of the system. Harvesting systems involved an assimilation of harvesting components. For the southeast, this consisted of mechanized, ground-based systems. Since whole trees are moved to the landing with both systems, the removed carbon from the site includes both the stem and the crown. Harvesting systems selected for the Pacific Northwest included systems that utilize manual felling and the movement of the material to the landing with cable based systems. In cable systems, trees are typically felled and bucked into logs at the point of felling so limbs, tops and other unmerchantable materials are left in the woods. Cost and fuel consumption information for primary transportation (hauling) are included in the tabular output of this module, but the airborne emissions and SimaPro analysis were considered as part of the analysis of the manufacturing systems for the manufactured products of lumber, plywood or oriented strand board.

Tabular results in the body of the report present harvesting costs for all scenarios, the resulting consumption of fuel, the amount of fertilizer applied in each of the scenarios, and average, standing and removed carbon. Standing carbon estimates and annual carbon production are also shown graphically as a function of time since planting. Emission factors related to the consumed fuel and fertilizer were developed from the SimaPro model.

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1.0 BACKGROUND

The CORRIM research project is designed to (1) collect environmental and economic data on all life-cycle stages from planting and growing the renewable raw material through the manufacturing of product, transport, design and construction of buildings as well as activities associated with occupation, use and final demolition (life-cycle inventories (LCI)); (2) ensure that the data follows consistent definitions and collection procedures; and (3) develop analytical procedures that facilitate integration of results across the full life-cycle for all stages of processing to address environmental performance questions (life-cycle analysis (LCA)) (CORRIM 1998). This module develops a life cycle inventory (LCI) analysis for the Forest Resources stage of processing, i.e. from regeneration to harvest and delivery of logs to the mill. It follows CORRIM's research guidelines that are consistent with ISO standards but does not duplicate information provided in the guidelines except as necessary to provide the details appropriate for the Forest Resources stage of processing.

The data generated for Forest Resources shows raw resource, energy and water inputs required for the production of a unit of an industry's product and the associated releases to air, land and water. These quantities are often referred to as "unit factors".

Removal of wood biomass from the forest and the activities associated with growth, removal, and reestablishment of trees requires careful analysis to determine the total life cycle impacts and sustainability of the use of biomass-based products. Life cycle inventories (LCIs) and their impacts are not stationary and will change based on both past and prospective technologies, evolving forest management procedures and population demands. Time becomes a critical element of this analysis since the period from initial planting or forest establishment to removal can range from five years for short rotation intensive culture to 100 years or more for selectively managed forests. Inputs and outputs of the life cycle process include quantitative measures that can be used to interpret costs, production and environmental results and qualitative measures that describe other aspects of the forest environment. Understanding the time dependent linkages between technology changes and management practices and their effects on these factors is essential to improve forest management alternatives that enhance the critical environmental features, but are also cost effective.

In a fully developed scenario, two classes of output can be developed. One represents costs, quantities of product, measures of consumed resources, and the emission factors associated with those resources. This information is developed for the acres being managed for timber production and passed on to the next stage of processing. The second class of output involves measures unique to the forest resources stage that provide an indication of the impact of the management activity on the forest. This chapter provides estimates of the production rates, costs, and emissions associated with management of representative timber producing acres for the Southeast United States and the Pacific Northwest (west of the Cascades in Washington and Oregon), but does not develop indicators of other impacts and co-products associated with the management activity. The impacts from acres of different site class and management intensity are weighted to be representative of the impact for the timber producing acres in these regions but not necessarily for all forest acres within the regions.

Development of estimators for other co-products associated with forest management activities requires a landscape approach to forest management and these are developed for the Pacific Northwest in module O. This more detailed case study utilizes the same base assumptions as developed for the alternatives presented here, but considers a variety of rotation ages for the forest stand and an alternative with no management activity.

Management levels of varying intensities are differentially applied to forest sites which are often adjacent to lands that do not have active forest management. The blend of management intensity levels within a watershed or landscape are important to development of other environmental indicators. Outputs and co-products include measures of vegetation diversity and related information important to water quantity and quality, and habitat as well as product type (sawlog, pulpwood, etc).

The forest resource module includes the efforts to establish a forest stand, to treat that stand through maturity, and to harvest the merchantable logs from the stand. Stand establishment involves preparation of the site for planting and planting of seedlings on the harvested site. Intermediate stand treatments to enhance growth and productivity usually involve either thinning or fertilization or both.

Timber harvesting generally consists of five components: felling (severing the standing tree from the stump), processing (often called bucking, limbing and/or topping and involving removal of non-merchantable limbs and tops and cutting of the tree into merchantable and transportable log lengths), secondary transportation (often called skidding on gentle slopes and yarding on steep slopes, this transportation step moves trees or logs from the point of felling to a loading point near a haul road), loading (moving logs from decks to haul vehicles), and primary transportation (generally hauling of logs from the woods to a process point). Although all functions are performed in the woods setting, the specific order and location of processing operation will vary by region and by harvesting system within a region. Transportation of logs from the woods to the process point is often considered part of the harvesting operation. The costs and consumption rates for primary transportation are included in the summary statistics of this chapter, but consistent with the protocol for SimaPro analysis, emission factors associated with primary transportation are included with the manufacturing modules for lumber, plywood, or oriented strand board (OSB).

System boundaries for forest resource activities in the Southeast United States are illustrated in Figure 1.1. Inputs to the system include site preparation activities to prepare for planting, the human effort required to plant seedlings, fertilizer used during stand growth, and the fuel and lubricants needed to operate the harvesting systems. The primary output product for this analysis is a log destined for a sawmill, plywood, or OSB plant. A primary co-product is pulpwood logs, used in the manufacture of pulp and paper. The other co-product, non-merchantable slash is generally left at a landing and disposed of through mechanical activities or prescribed fire.

Factors involved in growth of the seedlings were modeled as input to the system, but were not considered to be within the system boundary. These factors include the fertilizer used in seedling growth and the electrical energy required to operate forest nursery pumps and to power the growing operations, and to keep seedlings cool until planting.

Although harvesting operations in the Pacific Northwest can be found on both gentle and steep terrain, they are more likely to involve steeper slope conditions than in the Southeast. Steep slope harvesting will usually involve cable yarding as the method of secondary transportation. Cable yarders stays on haul roads and moves logs to the landing through a series of cables stretched from the road to the end of a harvesting corridor. The steep slopes also limit the use of mechanized felling systems, so felling operations are generally done with a person operating a chainsaw – often called manual felling. Limited decking areas at a landing will dictate processing of the trees into log lengths near the stump of the felled tree, so processing operations (bucking, limbing, and topping) are also done by a person operating a chainsaw located in the woods. This changes the order of operations in the system. Processing follows immediately after felling. The secondary transportation step (yarding) will move logs rather than whole trees to the landing.

System boundaries for forest resource activities in the Pacific Northwest are illustrated in Figure 1.2. Inputs and outputs from the system are similar to those in the southeast. In the Pacific Northwest, very little pulpwood is produced in the woods. Most of the feedstock for pulp and paper mills comes from the residual material from the manufacturing plants for the primary wood products (lumber and plywood). The slash resulting from non-merchantable material is generally left on site and is disposed of through a variety of site preparation techniques.

Stand re-establishment activities in both regions will generally involve some type of site preparation and subsequent hand planting of seedlings by planting crews. Additional stand management activities may include pre-commercial thinning and fertilization. Pre-commercial thinning operations are more common in the Pacific Northwest. Intensive fertilization schedules are a more common practice in the Southeast.

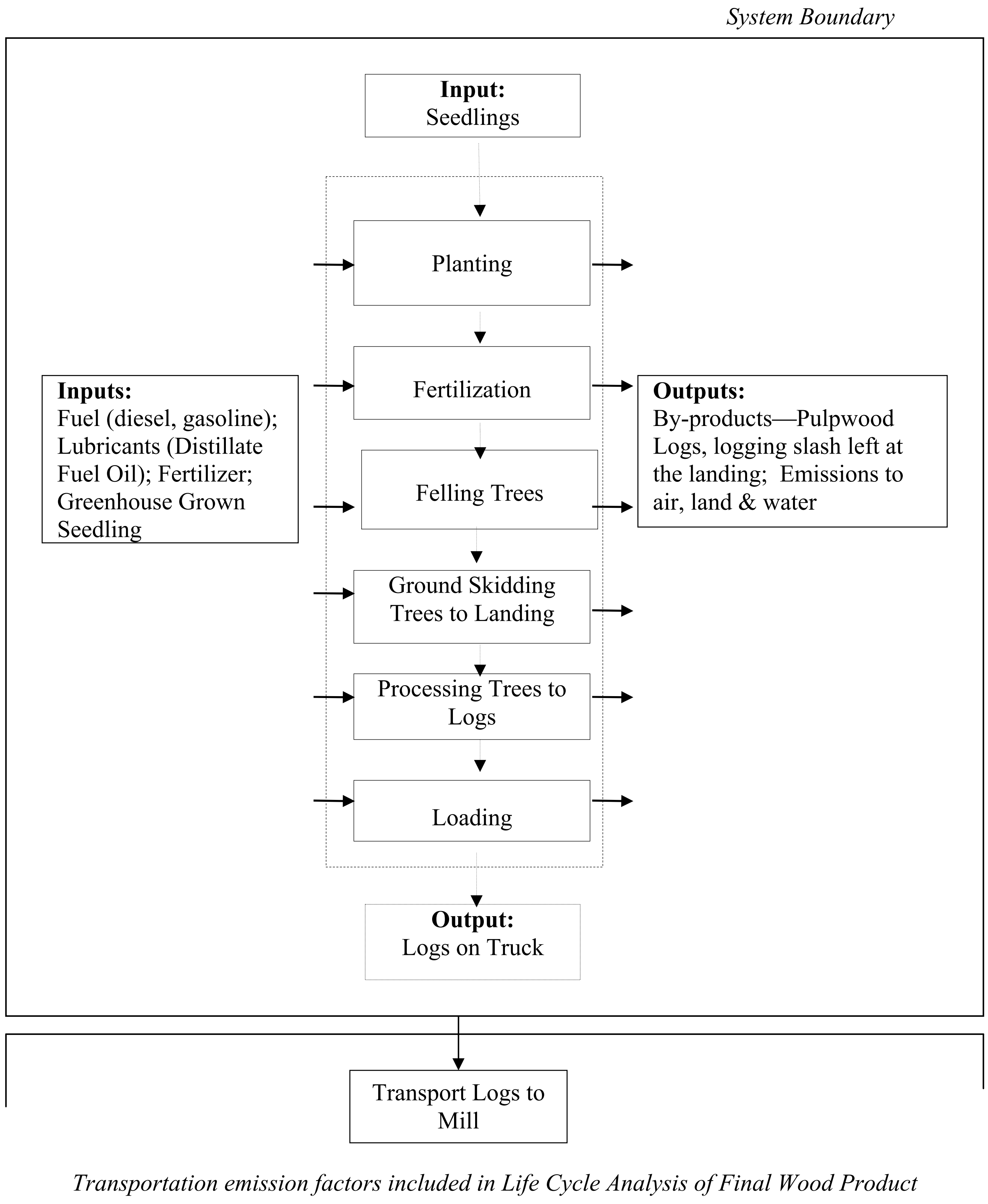
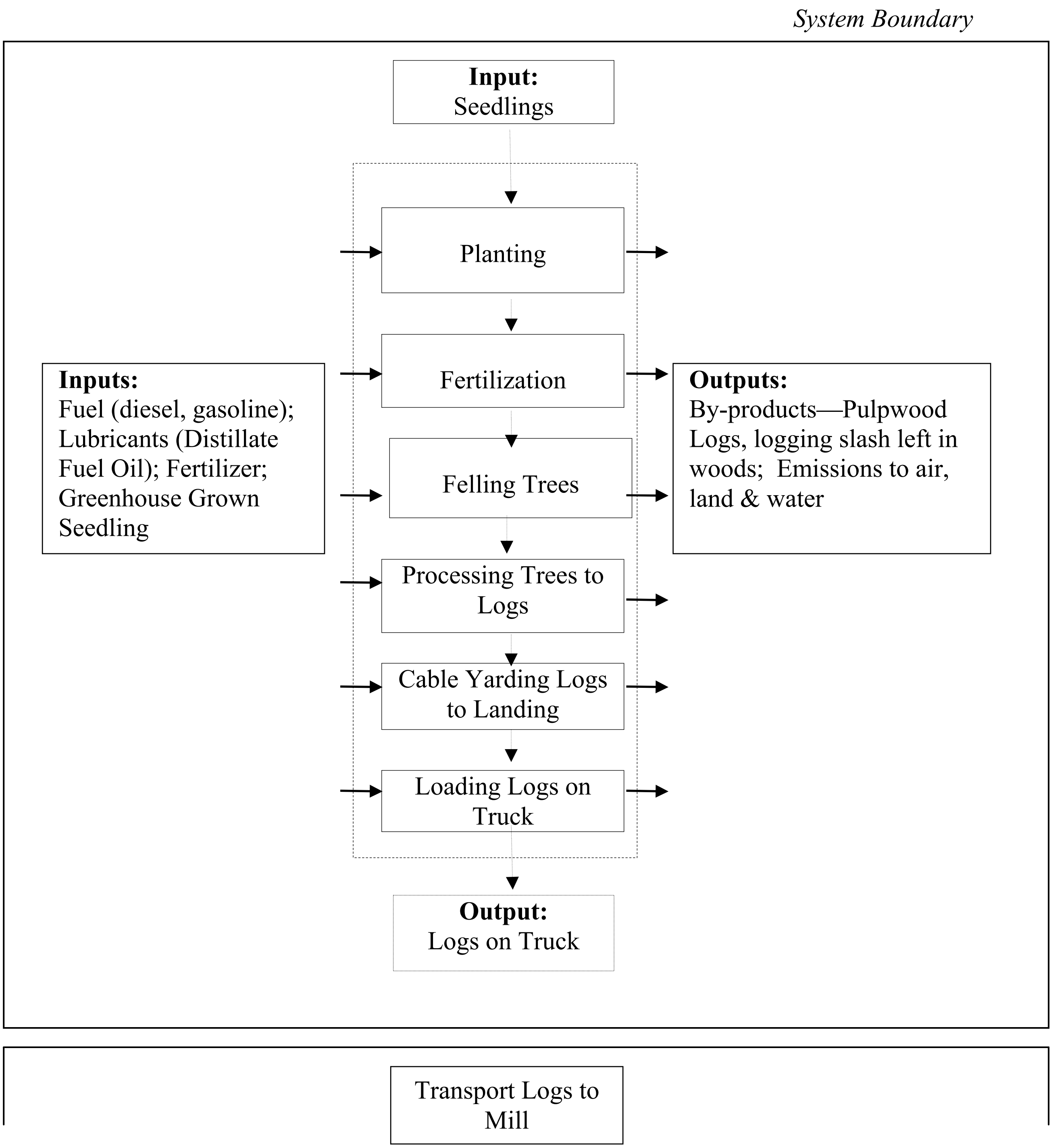


Figure 1.1. **System boundaries and process flow for forest stand establishment and harvesting for southeast region.**



Transportation emission factors included in Life Cycle Analysis of Final Wood Product

Figure 1.2. **System boundaries and process flow for forest stand establishment and harvesting for the Pacific Northwest region.**

2.0 METHODOLOGY

Biomass Volume Yields per Unit Area

Regional scenarios for timber production were structured to describe conditions associated with the growth, removal, and reestablishment of trees in the forest resource module. The scenarios were regionally defined, one reflecting conditions in the Pacific Northwest, specifically the west side of Oregon and Washington, and the other reflecting conditions for the southeastern United States, with data centered in North Carolina. These regions represent the predominant timber producing regions within the United States.

This specific analysis involves scenarios for the Southeastern US and Pacific Northwest regions. These were structured from three general combinations of management intensity (forest treatment regime) and site productivity for each region. The management intensities ranged from little intervention on low site productivity lands to higher management intensities involving combinations of fertilization and thinning on high productivity lands. Associated with each combination of management intensity and site productivity was an estimated yield of biomass. Management options were focused on private forest lands that generally involved planting, intermediate forest management activities such as fertilization and thinning, and a final harvest at the rotation age of the forest. Vegetation growth for the scenarios was simulated through established growth and yield vegetation simulators developed for each respective region. The simulation models produced estimates of standing and harvested biomass along with many other stand attributes at selected points in time through the rotation age of the forest stand for selected site and management intensities. Volumes of harvested biomass in the form of logs were passed on as resources to the manufacturing segments for lumber, plywood, or oriented strand board (OSB). Volumes of logs destined for pulp and paper manufacture were treated as co-products of the forest resource module

A single estimate of the average volume per unit area for a region was developed by weighting each of the three combinations of site productivity and management intensity to represent the acreage distribution under current management practices as a Base Case. Acreage distributions of management intensity and site class were determined through expert opinion and subsequent analysis of US Forest Service data available from the Resource Planning Assessment database (Mills 2001). The Forest Service information categorizes the number of private forest acres in each region by site classification and management intensity. Each of the management intensity and site classes used in the Forest Service analysis were associated with and represented by one of the three general management intensity combinations described above. In this way, the weighting of acres by management regime approximated the same distribution as represented in the RPA. This has been characterized as a Base Case (see Appendix 1), and a weighted average from the three site / management combinations is used to represent the region.

The allocation of acreage to management intensity / site productivity class represented a base case for each region. In the Southeast, 37% of industrial and non-industrial private forestlands were classified in the lowest productivity class, 58% in the middle productivity class, and 5% in the highest class. In the Pacific Northwest, 42% of the lands were classified in the lowest productivity/management class, 46% in the middle class, and 12% in the highest productivity class.

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In the Pacific Northwest, all the harvested volume is first delivered to sawmill or plywood plants. Residual chips are generated from the lumber and plywood manufacturing process. Direct delivery of pulpwood from the woods was not assumed to represent a significant part of the harvested volume. This affects the commercial volume removed from the woods and the volume left on site after harvest. Average yield for the base case was 501 cubic meters / hectare (7159 cubic feet / acre). This volume increased to 581 cubic m

Vegetation simulators common to the respective regions were also used in conjunction with established research to estimate the units of biomass by tree component – stem, roots, branches and foliage. Estimates of tree biomass by component were used to estimate the standing and removed carbon pool over time.

Site Preparation and Stand Establishment

Forest stand establishment and timber harvesting activities include site preparation for planting after harvest, planting of seedlings, forest management activities over the life of the stand including fertilization and thinning, and harvesting of the mature stand. Cost, production and emission factors associated with site preparation and forest stand establishment were developed from information in existing studies and were integrated with information on subsequent stand treatments and final harvesting to develop overall factors associated with the log delivered to a lumber mill, plywood plant or OSB mill.

Specific activities in these areas vary for the two regions of the country. For example, site preparation activities in the Southeast are more intensive than in the Pacific Northwest and involve extensive use of mechanical equipment. Southeast forests are generally not thinned before they reach commercial size and have multiple fertilizer treatments. Managed forests in the Pacific Northwest will likely receive a pre-commercial thinning, but only one fertilizer treatment. Southeast forests are usually planted with bare-root seedlings. Forests in the Pacific Northwest are planted with containerized seedlings. In both cases, the seedlings are grown in forest nursery operations, but those in the Pacific Northwest utilize more temperature control activities associated with use of a greenhouse.

These differences were recognized in the development of the site preparation and planting scenarios for the two regions. Site preparation and planting factors for the Southeast were developed from published studies on forest nursery (South and Zwolinski 1996) and site preparation production and fuel consumption rates (Frazier et al. 1981). Cost and fuel consumption factors were developed as a rate per seedling and were then multiplied by the number of planted seedlings per unit area (hectare or acre) specified to determine costs and fuel consumption rates per unit area. Calculated rates per unit area were divided by the final harvested volume per unit area to establish the contribution of site preparation, seedlings and planting to the costs and consumption factors per unit of harvested volume.

Factors for the Pacific Northwest were developed from personal communication with forest nursery managers (Wenny 2003) and a developed manuscript on greenhouse operations (Schlosser et al. 2002). The individual rates per seedling were again multiplied by the number of seedlings planted per unit area (hectare or acre) to determine the total cost and fuel consumption rates associated with the final forest stand. These factors were divided by the final harvest volume to determine their contribution on the basis of unit volume of harvested log.

Seedlings in both regions were assumed to be planted by hand. Therefore, the only fuel factors associated with planting are related to travel to and from the planting site.

The level and type of fertilization was a factor of the region and the intensity level of management within the region. In the Southeast region, fertilization regimes were developed for both the mid intensity and high intensity scenarios. There was no fertilization in the low intensity option. Fertilization differences between the mid and high intensity options were primarily in the frequency of application. The high intensity option involved fertilization every four years over the 25 year life of the stand. The mid intensity option involved fertilization at years two and sixteen. The fertilizer mixture included nitrogen, potassium and phosphorus. Stand treatment options for the Southeast were developed by Lee Allen of the North Carolina Tree Nutrition Cooperative (2001).

Intermediate stand treatments in the Pacific Northwest included less fertilization, but added precommercial thinning. Fertilization was only done in years 20, 30 and 40 in the high intensity option. Precommercial thinning was done in both the mid and high intensity options at year 15. These management scenarios were developed at the University of Washington from growth and yield information available to their stand modeling researchers (Lippke and Comnick 2002).

Rates of fuel consumption for stand establishment and management activities and the per-acre rates of fertilization are shown in Table 2.1.

Table 2.1. Seedling, Site Preparation, Planting and Fertilization Consumption

	Southeast Region			**Pacific Northwest Region**		
	Low Intensity	**Medium Intensity**	**High Intensity**	**Low Intensity**	**Medium Intensity**	**High Intensity**
	Fuel Consumption (Gal / Acre)			**Fuel Consumption (Gal / Acre)**		
Greenhouse & Seedling	5.46	5.46	5.46	2.62	3.93	3.93
Site Preparation	2.16	7.86	14.18	0.00	0.00	0.00
Planting	0.71	0.71	0.71	0.41	0.41	0.41
Precommercial Thin	0.00	0.00	0.00	0.96	0.96	0.96
Total	8.32	14.02	20.34	3.98	5.29	5.29
	Pounds / Acre over Rotation			**Pounds / Acre over Rotation**		
Nitrogen						
In Seedlings	0.125	0.125	0.125	0.038	0.057	0.057
On Site	0	236	636	0	0	354
Phosphate						
In Seedlings	0.006	0.006	0.006	0.063	0.095	0.095
On Site	0	40	115	0	0	60
Potassium						
In Seedlings	0.075	0.075	0.075	0.154	0.232	0.232
On Site	0	0	0	0	0	0

Timber Harvesting

Harvesting production, cost and fuel consumption rates were assimilated from existing studies of harvesting equipment typical of the systems used to harvest sites both in the southeastern United States and the Pacific Northwest. These studies included both published information and personal interviews with timber harvesting contractors (Biltonen 2002, Hochrein and Kellogg 1988, Jorgenson 2002, Keegan et al. 1995, Kellogg and Bettinger 1995, Kellogg et al. 1996, Lawson 2002, Ledoux 1984, Reynolds 2002, Stevens and Clarke 1974). The costs, production and consumption rates were developed for equipment options within each component of the system. Harvesting systems were developed as combinations of these harvesting components. Although there are many combinations of harvesting equipment and systems that can be used for harvesting timber, this analysis assumes the use of the most common system for a region within the assumed slope classification of the harvested sites.

In the southeast region, this involves the use of mechanized harvesting systems operating on relatively gentle terrain. A mechanized system utilizes a felling device mounted on a woods tractor that travels through the stand to cut the trees and implies use of another machine that can delimb and process trees into logs. The processing operation for this type of system generally takes place at the landing. Thus, whole trees are moved to the landing through the secondary transportation operation and are then processed into logs. Two general systems were used. A smaller feller-buncher and grapple skidder were used for thinning. A larger, more capital-intensive system was used for final harvest. Since whole trees are moved to the landing with both systems, the removed carbon from the site includes both the stem and the crown.

Harvesting systems selected for the Pacific Northwest included logging systems that utilize hand felling and the movement of the material to the landing with cable based systems. Cable based systems keep the primary machinery on harvest roads, and are commonly used to harvest steep slopes. In cable systems, trees are typically felled and bucked into logs at the point of felling so limbs, tops and other unmerchantable materials are left in the woods. Since limbs and tops of the trees are left on the site, removed carbon for Pacific Northwest systems includes only the carbon associated with the stem.

Cost, production and fuel and lubrication consumption rates for the selected systems are shown in Table 2.2. The total cost and fuel consumption was calculated for each forest management activity, including commercial thinning and final harvest. The averaged costs and fuel consumption rates were then calculated as the total divided by the total merchantable volume removed. The rates shown in Table 2.1 are also used in SimaPro as the basis for emissions associated with the harvesting operations.

General Assumptions

- The data collection, analysis, and assumptions followed protocols as defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)--Research Guidelines for Life Cycle Inventories" dated April 18, 2001.
- SimaPro 5.0.9, a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to perform the life cycle analysis. Developed in the Netherlands by PRé Consultants B.V., SimaPro5 contains a US database for a number of materials, including paper products, fuels, and chemicals. Franklin Associates (FAL) provides an additional US database.

Output reported from Forest Resources Module

- Product quantity – total cubic volume of logs destined for lumber, plywood and OSB plants and total cubic volume produced as pulpwood
- Consumed resources – fuel, lubricants, and fertilizer through the site preparation, stand establishment, intermediate management treatments, and final harvest
- Costs associated with stand establishment and harvesting
- Emissions – Air emissions related to site preparation, stand establishment, intermediate management treatments, and final harvest
- Total Standing Carbon Pool – at rotation age and as an average across the rotation
- Carbon Removed from the Site

Table 2.2. Timber Harvesting System Production, Costs, and Consumption

		Production Rate CCF / SMHR	Production Cost $ / CCF	Diesel Use Gal / CCF	Lubricant Use Gal / CCF
System 1: Southeast Thinning System					
Felling:	Small Feller Buncher	17.28	$ 5.03	0.31	0.01
Skidding:	Small Wheeled Skidder	3.24	$ 16.98	0.95	0.02
Processing:	Stroke Delimber	25.92	$ 3.86	0.22	0.00
Loading:		8.64	$ 6.94	0.58	0.01
Subtotal	**Stump to Truck**		$ 32.81	2.06	0.04
Hauling:		2.59	$ 34.56	3.14	0.06
System Total			**$ 67.37**	**5.20**	**0.09**
System 2: Southeast Final Harvest System					
Felling:	Large Feller Buncher	22.03	$ 4.40	0.27	0.00
Skidding:	Medium Grapple Skidder	4.05	$ 18.52	1.19	0.02
Processing:	Stroke Delimber	25.92	$ 3.86	0.22	0.00
Loading		8.64	$ 6.94	0.58	0.01
Subtotal	**Stump to Truck**		$ 33.72	2.26	0.04
Hauling		2.59	$ 34.56	3.14	0.06
System Total			**$ 68.28**	**5.40**	**0.10**
System 3: Pacific Northwest – Cable Thinning					
Felling:	Hand Felling	2.49	$ 11.22	0.08	0.00
Yarding:	Large Yarder - Partial	7.78	$ 16.72	1.80	0.03
Loading		8.64	$ 6.94	0.58	0.01
Subtotal	**Stump to Truck**		$ 34.89	2.46	0.04
Hauling		2.59	$ 45.47	4.13	0.07
System Total			**$ 80.36**	**6.59**	**0.12**
System 4: Pacific Northwest - Clearcut					
Felling:	Hand Felling	2.49	$ 11.22	0.08	0.00
Yarding:	Large Yarder - Clearcut	10.79	$ 10.19	1.19	0.02
Loading		8.64	$ 6.94	0.58	0.01
Subtotal	**Stump to Truck**		$ 28.36	1.84	0.03
Hauling		2.59	$ 45.47	4.13	0.07
System Total			**$ 73.83**	**5.98**	**0.11**

SMHR = scheduled machine hour, includes productive time and delays
CCF = 100 cubic feet of solid wood

3.0 SIMAPRO MODELING OF STAND ESTABLISHMENT AND HARVESTING

Models developed for SimaPro used the same protocol and energy assumptions as models developed for lumber and plywood manufacture. The model is patterned after the system flowchart illustrated in Figures 1.1 and 1.2.

Individual models were developed for tree seedlings in each of the regions. These served as a base for a process called a “reforested acre”. A reforested acre process was developed for each intensity level of management within each region and included the input of the seedling and the activities of planting, precommercial thinning, and fertilization. The levels of activity for each of the management intensity levels within a region are reflected in the rates of application shown in Table 2.1.

Processes were also developed for each piece of equipment utilized in the thinning and harvest operations as outlined in Table 2.2. These processes included the fuel and lubrication consumption rates shown in Table 2.2 and the cost rates for fixed, operating and labor costs. The process developed for a reforested acre was combined with the processes associated with each piece of harvesting equipment into an overall process representing a harvested sawlog for each combination of region and management intensity.

The weighted average of the three management intensity levels within a region was combined in Product Assemblies within SimaPro. Outputs from these product assemblies were used in subsequent stages of processing to incorporate the forest resource activities in the outputs for lumber, plywood and OSB products.

4.0 CARBON PRODUCTION AND REMOVAL

In the Southeast carbon estimates were developed through the NUTREM2 model (NCSFNC 2000) developed and used in the region.

The annual production of carbon in the stem was estimated at 50% of the biomass of the stem. Carbon in the branches is estimated at 21% of stem biomass. Biomass and the related carbon in the foliage and roots were also developed from the NUTREM2 model. Standing carbon estimates were developed from the estimate of total tree volume generated in the NUTREM2 model coupled with adjustments for the age of the stand. Carbon in branches and course roots were again estimated as a function of stem carbon. Carbon in foliage was set equal to the annual production of carbon. Carbon in fine roots was calculated as twice the annual carbon production in fine roots.

Carbon removed is calculated as the difference between carbon in the year before activity and carbon after the activity plus any accumulation during the year of activity. As noted in the harvesting section, removed carbon includes carbon in both the stem and crown.

In the Northwest, carbon budgets are constructed from tree lists describing standard inventory data for individual trees, e.g., species, diameter, and crown ratio. These tree lists are derived from the FVS growth model (Wykoff 1986). They include tree characteristics at five-year intervals as predicted by the model. From these data, timber volume and the biomass of leaves, roots, and stem are estimated using published allometric equations (Gholz et al. 1979). The equations take the following form:

$$y = ae^{b*dbh}$$

where y is the mass or volume being predicted, dbh is the diameter at breast height, and a and b are species-specific parameters. Stem volume is multiplied by specific gravity of each species to estimate stem mass. Masses of carbon in each tissue are estimated by multiplying tissue mass by species-specific carbon concentrations. The need for species-specificity in these parameters is obvious from the substantial species differences in allometric equations (Gholz et al. 1979), specific gravity (Panshin and de Zeeuw 1970), and carbon concentrations (Vertregt and Penning de Vries 1987). The carbon amounts are then summed over the several parts of the tree. Per-tree estimates are expanded to a per-acre basis using standard forest inventory techniques (Marshall and Waring 1986, Monserud and Marshall 1999). Carbon accumulation in biomass is estimated by the changes in carbon standing stocks as estimated by the above procedure.

The model will predict tree mortality, which releases carbon from the canopy and other above ground pools. It also describes the mortality of tree parts as biomass of a particular part declines during the subsequent time steps. Finally, the model estimates the mass of parts of the tree not hauled offsite during harvesting. All of these dying tissues are assigned to pools of decomposing material. Species-specific estimates of decomposition rate are used to estimate losses of carbon to the atmosphere. The equations take the following form:

$$x_t = x_0(1 - k * t)$$

where x_t is the weight at time t, x_0 is initial weight, k is a species- and tissue-specific constant describing proportional weight loss per year, and t is time in years (Aber and Melillo 1991). The mass of decomposing material is estimated as the sum of mortality in the most recent interval and the residual mass of decomposing material (x_t) from previous time steps. The masses of decaying material are summed over all species and tissue types.

While standing carbon represents an estimate of carbon in the standing tree based on the estimate of biomass, the rates of decomposition of down material, down foliage, or roots from harvested trees are not well documented for either the Southeast or Northwest. Future work will focus on further development of information in this area.

The general assumption in both the Southeast and Northwest is that fine roots grow and decompose at about the same rate. This means they do not add net carbon to the system. What is not known, however, is the degree of carbon release from the decomposed fine roots in the soil and whether the net release of fine root carbon will be different over the 30 or 100-year rotation of the forest from the carbon released in a non-managed stand. This represents an area for future investigation.

Carbon information for both regions includes the standing carbon inventory just prior to harvest at the rotation age and an estimate of removed carbon through forest management activities, both intermediate thinning and the final harvest. The results do not address soil carbon or the effect of forest management activities on total soil carbon. A more complete treatment of changes in carbon levels over time is included in Module N of the report.

5.0 SOUTHEAST EXAMPLE

Scenarios developed for the Southeast represent a composite of stands from the extensive database managed by the Forest Nutrition Cooperative at North Carolina State University (Hafley et al. 1982, Buford 1991). The corresponding carbon analysis was done with the related NUTREM2 model (NCSFNC 2000) with carbon factors based on data in the SETRES database common to the Southeastern United States.

The three scenarios represent combinations of the site index and corresponding level of management intensity. The first reflects non-industrial private forests (NIPF) with low intensity management that might be implemented by the small landowner. The second reflects high intensity management on NIPF lands and/or low intensity management on industrial lands. The third scenario reflects high intensity management on industry lands. Specific assumptions associated with these three scenarios are outlined in Table 5.2 (at the end of the section).

The increasing levels of site productivity and management intensity result in an increase in the volume of wood fiber produced per acre, but also reflect a change in the type of product produced. Three product categories were identified for the southeast, pulpwood, chip and saw, and sawtimber. Chip and saw material represents smaller diameter trees that are processed through a specific type of sawmill that produces both lumber and pulpwood chips. Sawtimber represents a higher value product with more of the material eventually ending up as lumber. In the summary tables for this analysis, chip and saw material was considered to be part of the lumber component of production. The production from the low intensity areas is divided between pulpwood and chip and saw material. In the management scenario involving medium intensities, the percentage of volume in pulpwood remains about the same, but more of the lumber component is shifted from chip and saw to sawtimber. With higher intensity management, even more of the volume is shifted to the sawtimber category.

These three site / management scenarios were averaged to develop a composite average for the region. Weighting for the composite average was determined through analysis of a general RPA survey of the region conducted by the US Forest Service (Mills 2001). This survey determined the number of acres within each combination of site index and management intensity. The numbers of combinations of site index / management intensity were larger than the three specific scenarios created for this analysis. The acreages determined in the RPA analysis were matched to one of the scenarios and totaled. Specific details of the process and the resulting acreages are contained in Appendix 1.

Two cases were structured. One emulates the current conditions as determined by the analysis of RPA information for current conditions. The second considers the impact of shifting to a higher intensity level of management on lands with the higher site indices.

The resulting analysis for the Base Case for the southeast is shown in Table 5.3 (at the end of the section). Results under the scenario with higher intensity management are shown in Table 5.4 (at the end of the section). In both cases the one way hauling distance represents the average surveyed distance for the region from harvest site to lumber mill. The shift to the higher intensity scenario increased the production of merchantable volume from 222 cubic meters / hectare (3174 cubic feet / acre) to 291 cubic meters / hectare (4163 cubic feet / acre). The percent of the volume categorized for lumber increased from 34.9% to 44.1%. In addition, more of the lumber volume produced in the higher intensity scenario was categorized in the sawtimber category rather than in a chip-n-saw category.

General comparisons of cost, fuel consumption and nitrogen fertilizer requirements are shown in Table 5.1.

Table 5.1. Comparison of sawlog volume, harvest costs, fuel consumption and nitrogen use per cubic meter of produced sawlogs for base case and alternate case in the Southeastern United States

	Base Case	Alternate Case	Units
Sawlog Volume	222	291	cubic meters / hectare
Cost to Truck	11.81	11.91	dollars / cubic meter
Cost to Mill	26.50	27.59	dollars / cubic meter
Diesel Consumption			
In Seedlings	.515	.578	liters / cubic meter
To Truck	2.93	3.02	liters / cubic meter
To Mill	4.20	4.20	liters / cubic meter
Total	7.65	7.79	liters / cubic meter
Nitrogen	.852	1.88	kilograms / cubic meter

The increased cost and fuel consumption required to produce the sawlog volume in the higher intensity scenario is generally offset by the increased volume. Costs and consumption rates per unit of sawlog volume are very close for the two scenarios. The exception is the requirement for fertilizer, illustrated in Table 5.1 by the requirement for nitrogen. The high requirement for fertilization is required in the southeast is required to obtain the additional growth over the relative short rotation (25 years) of the forest.

Detailed results for each of the management intensity levels are presented in Tables A2.1 and A2.2 of Appendix 2. These tables show both the results of the individual management intensities and the weighted average for the base and alternate cases.

The method used to allocate acreage from the RPA to one of the three intensity classifications did not match the assessment of forestry professionals of the region (Allen 2001). They estimated an acreage distribution of 20% of the acres to the low intensity class, 60% to the middle intensity class, and 20% to the highest intensity class. With this distribution of acreage, average volume yield would be 244 cubic meters / hectare (3488 cubic feet / acre) with 36.8% of the volume allocated to the lumber category. The difference in acreage allocation reflects the difficulty of reducing 15 classifications of site index and management intensity to the three used as the scenarios in this analysis. The comparative analysis between the base and alternative cases still represents a valid comparison of the impacts of higher intensity management.

Tables 5.3 and 5.4 show estimates of the standing and removed carbon at the end of the rotation age, an average of annual amounts standing carbon over the rotation of the stand, and the carbon removed through thinning and harvesting activities. The values are expressed as units of carbon weight per unit of area.

Results of the Sima Pro analysis for this scenario are discussed in Section 7.

Figures A3.1 and A3.2 shown in Appendix 3 illustrate the annual production of carbon for the base case and alternative case, respectively. It is obvious from these graphs that the rate of carbon production in each component of the stand slows with increasing age of trees in the stand. The inventory of the standing carbon pool over the duration of the rotation is shown in Figure A3.3 (Appendix 3) for the Base Case and Figure A3.4 (Appendix 3) for the Alternative case. The carbon inventory levels just before harvest in Figures A3.3 and A3.4 will correspond to the carbon inventory values shown in Tables 5.3 and 5.4. The average of standing carbon pools are shown to be 38,279 pounds/acre for the Base Case and 39,527 for the more intensive management of the Alternative Case.

Table 5.2. Southeastern (SE) US Scenarios: Specific Assumptions for three management scenarios applied to private forest lands in the Southeastern US.

Ownership / Prescription	NIPF / Low Intensity	NIPF / High Intensity or Industrial / Low Intensity	Industrial / High Intensity
Site Index	58	67	80
Planting Density (Trees per acre)	726	726	726
Fertilization	None	Years 2, 16	Years 2,5,9,13,17,21
First Thinning - Cubic Feet	0	896	845
at year		*17*	*13*
Second Thinning - Cubic Feet	0	0	832
at year			*19*
Final Harvest – Cubic Feet	3,145	2,507	2,932
at year	*30*	*25*	*25*
Total Yield / Acre – Cubic Feet	3,145	3,403	4,609
Rotation Age	30 years	25 years	25 years
Percent Sawlog	3.2 %	20.2 %	42.7 %
Percent Chip-n-Saw	34.9 %	11.2 %	8.9 %
Percent Pulpwood	61.9 %	68.6 %	48.4 %
Percent Area in Class for Base Case	37%	58%	5%
Percent Area in Class for Alternative Case	0%	37%	63%

Table 5.3. Southeastern US: Cost and Energy Consumption – Base Case representing a weighted average of the three management intensity levels

Southeastern US Scenarios	**25**	**Year Rotation**
Percent of Private Land Area in Site / Management Category		
NIPF Low Intensity	**37.0%**	
Industrial Low Intensity	**58.0%**	
Industrial High Intensity	**5.0%**	
Average One Way Haul Distance	**57.0**	**Miles**
	91.7	**Kilometers**

Harvesting Systems:

NIPF Low Intensity	Small Feller Buncher / Skidder / Processor
Industrial Low Intensity	Large Feller Buncher / Medium Skidder / Large Processor
Industrial High Intensity	Large Feller Buncher / Medium Skidder / Large Processor

	Average Harvesting Factors English Units			**Average Harvesting Factors Metric Units**	
	Volume removed in thinning and final harvest				
Volume		**3.17E+03**	**Cubic Feet / Acre**	**2.22E+02**	**Cubic Meters / Hectare**
% Lumber		**34.9%**		**34.9%**	
% Pulpwood		**65.1%**		**65.1%**	
	Note: Lumber includes both Sawtimber and Chip and Saw Volumes				
System Costs					
Prep, Plant,	**$**	**224**	**Dollars per Acre**	**$ 553**	**Dollars per Hectare**
Pre Com Thin	$	.071	Dollars / Cubic Foot	$ 2.490	Dollars / Cubic Meter
Stump to	**$**	**1,062**	**Dollars per Acre**	**$ 2,623**	**Dollars per Hectare**
Truck	$	.334	Dollars / Cubic Foot	$ 11.810	Dollars / Cubic Meter
Hauling		**57**	**Miles**	**91.7**	**Kilometers**
Truck to	**$**	**1,097**	**Dollars per Acre**	**$ 2,710**	**Dollars per Hectare**
Mill	$	0.346	Dollars / Cubic Foot	$ 12.202	Dollars / Cubic Meter
Total Cost	**$**	**2,382**	**Dollars per Acre**	**$ 5,886**	**Dollars per Hectare**
	$	0.751	Dollars / Cubic Foot	$ 26.502	Dollars / Cubic Meter

Table 5.3. Southeastern US Base Case (Continued)

	Average Harvesting Factors English Units		Average Harvesting Factors Metric Units	
Electric, Fuel and Lubricant Consumption				
Seedling, Site Prep, Plant, Precommercial Thin				
Fuel	**1.22E+01**	**Gallons / Acre**	**1.14E+02**	**Liters / Hectare**
	3.85E-03	Gallons / Cubic Foot	5.15E-01	Liters / Cubic Meter
Lubricants	**2.20E-01**	**Gallons / Acre**	**2.06E+00**	**Liters / Hectare**
	6.94E-05	Gallons / Cubic Foot	9.27E-03	Liters / Cubic Meter
Electric	**1.14E+01**	**Kwh / Acre**	**1.01E+02**	**MJ / Hectare**
	3.58E-03	Kwh / Cubic Foot	4.55E-01	MJ / Cubic Meter
Stump to Truck				
Fuel (Diesel)	**6.97E+01**	**Gallons / Acre**	**6.52E+02**	**Liters / Hectare**
	2.20E-02	Gallons / Cubic Foot	2.93E+00	Liters / Cubic Meter
Lubricants	**1.25E+00**	**Gallons / Acre**	**1.17E+01**	**Liters / Hectare**
	3.95E-04	Gallons / Cubic Foot	5.28E-02	Liters / Cubic Meter
Hauling	**5.70E+01**	**Miles**	**91.7**	**Kilometers**
Fuel (Diesel)	**9.97E+01**	**Gallons / Acre**	**9.33E+02**	**Liters / Hectare**
	3.14E-02	Gallons / Cubic Foot	4.20E+00	Liters / Cubic Meter
Lubricants	**1.79E+00**	**Gallons / Acre**	**1.68E+01**	**Liters / Hectare**
	5.65E-04	Gallons / Cubic Foot	7.56E-02	Liters / Cubic Meter
Total Planting and Harvest Operation				
Fuel	**1.82E+02**	**Gallons / Acre**	**1.70E+03**	**Liters / Hectare**
	5.72E-02	Gallons / Cubic Foot	7.65E+00	Liters / Cubic Meter
Lubricants	**3.27E+00**	**Gallons / Acre**	**3.06E+01**	**Liters / Hectare**
	1.03E-03	Gallons / Cubic Foot	1.38E-01	Liters / Cubic Meter

Table 5.3. Southeastern US Base Case (Continued)

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
Fertilizer				
Nitrogen	**1.69E+02**	**Pounds / Acre**	**1.89E+02**	**Kilograms / Hectare**
	5.32E-02	Pounds / Cubic Foot	8.52E-01	Kilograms / Cubic Meter
Phosphate	**2.90E+01**	**Pounds / Acre**	**3.25E+01**	**Kilograms / Hectare**
	9.12E-03	Pounds / Cubic Foot	1.46E-01	Kilograms / Cubic Meter
Potassium	**7.50E-02**	**Pounds / Acre**	**8.41E-02**	**Kilograms / Hectare**
	2.36E-05	Pounds / Cubic Foot	3.78E-04	Kilograms / Cubic Meter

Carbon Pools at End of Rotation				
Average of Standing Carbon Pools over Rotation				
Stem	2.27E+04	**Pounds / Acre**	2.54E+04	**Kilograms / Hectare**
Crown	7.44E+03	**Pounds / Acre**	8.34E+03	**Kilograms / Hectare**
Roots	8.14E+03	**Pounds / Acre**	9.12E+03	**Kilograms / Hectare**
Total	***3.83E+04***	**Pounds / Acre**	**4.29E+04**	**Kilograms / Hectare**
Standing Carbon Prior to Harvest				
Stem	3.97E+04	**Pounds / Acre**	4.45E+04	**Kilograms / Hectare**
Crown	1.20E+04	**Pounds / Acre**	1.34E+04	**Kilograms / Hectare**
Roots	1.34E+04	**Pounds / Acre**	1.51E+04	**Kilograms / Hectare**
Total	***6.51E+04***	**Pounds / Acre**	**7.30E+04**	**Kilograms / Hectare**
Removed Through Thinnings and Final Harvest				
Stem	5.04E+04	**Pounds / Acre**	5.65E+04	**Kilograms / Hectare**
Crown	1.43E+04	**Pounds / Acre**	1.60E+04	**Kilograms / Hectare**
Roots	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Total	***6.47E+04***	**Pounds / Acre**	**7.25E+04**	**Kilograms / Hectare**

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

Table 5.4. Southeastern US: Cost and Energy Consumption – Alternative Case representing a shift to higher intensity management by increasing the percent acreage in the highest two intensity categories

Southeastern US Scenarios	**25**	**Year Rotation**
Percent of Private Land Area in Site / Management Category		
NIPF Low Intensity	**0.0%**	
Industrial Low Intensity	**37.0%**	
Industrial High Intensity	**63.0%**	
Average One Way Haul Distance	**57.0**	**Miles**
	91.7	**Kilometers**

Harvesting Systems:

NIPF Low Intensity	Small Feller Buncher / Skidder / Processor
Industrial Low Intensity	Large Feller Buncher / Medium Skidder / Large Processor
Industrial High Intensity	Large Feller Buncher / Medium Skidder / Large Processor

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
	Volume removed in thinning and final harvest			
Volume	**4.16E+03**	**Cubic Feet / Acre**	**2.91E+02**	**Cubic Meters / Hectare**
% Lumber	**44.1%**		**44.1%**	
% Pulpwood	**55.9%**		**55.9%**	
	Note: Lumber includes both Sawtimber and Chip and Saw Volumes			
System Costs				
Prep, Plant,	**$ 410**	**Dollars per Acre**	**$ 1,013**	**Dollars per Hectare**
Pre Com Thin	$ 0.099	Dollars / Cubic Foot	$ 3.478	Dollars / Cubic Meter
Stump to	**$ 1,404**	**Dollars per Acre**	**$ 3,469**	**Dollars per Hectare**
Truck	$ 0.337	Dollars / Cubic Foot	$ 11.908	Dollars / Cubic Meter
Hauling	**57**	**Miles**	**91.7**	**Kilometers**
Truck to	**$ 1,439**	**Dollars per Acre**	**$ 3,555**	**Dollars per Hectare**
Mill	$ 0.346	Dollars / Cubic Foot	$ 12.202	Dollars / Cubic Meter
Total Cost	**$ 3,252**	**Dollars per Acre**	**$ 8,037**	**Dollars per Hectare**
	$ 0.781	Dollars / Cubic Foot	$ 27.589	Dollars / Cubic Meter

Table 5.4. Southeastern US Alternate Case (Continued)

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
Electric, Fuel and Lubricant Consumption				
Seedling, Site Prep, Plant, Precommercial Thin				
Fuel	**1.80E+01**	**Gallons / Acre**	**1.68E+02**	**Liters / Hectare**
	4.33E-03	Gallons / Cubic Foot	5.78E-01	Liters / Cubic Meter
Lubricants	**3.24E-01**	**Gallons / Acre**	**3.03E+00**	**Liters / Hectare**
	7.79E-05	Gallons / Cubic Foot	1.04E-02	Liters / Cubic Meter
Electric	1.14E+01	**Kwh / Acre**	**1.01E+02**	**MJ / Hectare**
	2.73E-03	Kwh / Cubic Foot	3.47E-01	MJ / Cubic Meter
Stump to Truck				
Fuel (Diesel)	**9.39E+01**	**Gallons / Acre**	**8.78E+02**	**Liters / Hectare**
	2.26E-02	Gallons / Cubic Foot	3.02E+00	Liters / Cubic Meter
Lubricants	**1.69E+00**	**Gallons / Acre**	**1.58E+01**	**Liters / Hectare**
	4.06E-04	Gallons / Cubic Foot	5.43E-02	Liters / Cubic Meter
Hauling	**5.70E+01**	**Miles**	**9.17E+01**	**Kilometers**
Fuel (Diesel)	**1.31E+02**	**Gallons / Acre**	**1.22E+03**	**Liters / Hectare**
	3.14E-02	Gallons / Cubic Foot	4.20E+00	Liters / Cubic Meter
Lubricants	**2.35E+00**	**Gallons / Acre**	**2.20E+01**	**Liters / Hectare**
	5.65E-04	Gallons / Cubic Foot	7.56E-02	Liters / Cubic Meter
Total Planting and Harvest Operation				
Fuel	**2.43E+02**	**Gallons / Acre**	**2.27E+03**	**Liters / Hectare**
	5.83E-02	Gallons / Cubic Foot	7.79E+00	Liters / Cubic Meter
Lubricants	**4.37E+00**	**Gallons / Acre**	**4.09E+01**	**Liters / Hectare**
	1.05E-03	Gallons / Cubic Foot	1.40E-01	Liters / Cubic Meter

Table 5.4. Southeastern US Alternate Case (Continued)

	Average Harvesting Factors English Units		Average Harvesting Factors Metric Units	
Fertilizer				
Nitrogen	**4.88E+02**	**Pounds / Acre**	**5.47E+02**	**Kilograms / Hectare**
	1.17E-01	Pounds / Cubic Foot	1.88E+00	Kilograms / Cubic Meter
Phosphate	**8.73E+01**	**Pounds / Acre**	**9.78E+01**	**Kilograms / Hectare**
	2.10E-02	Pounds / Cubic Foot	3.36E-01	Kilograms / Cubic Meter
Potassium	**7.50E-02**	**Pounds / Acre**	**8.41E-02**	**Kilograms / Hectare**
	1.80E-05	Pounds / Cubic Foot	2.89E-04	Kilograms / Cubic Meter

Carbon Pools at End of Rotation				
Average of Standing Carbon Pools over Rotation				
Stem	2.34E+04	**Pounds / Acre**	2.62E+04	**Kilograms / Hectare**
Crown	7.98E+03	**Pounds / Acre**	8.94E+03	**Kilograms / Hectare**
Roots	8.20E+03	**Pounds / Acre**	9.20E+03	**Kilograms / Hectare**
Total	***3.96E+04***	**Pounds / Acre**	**4.44E+04**	**Kilograms / Hectare**
Standing Carbon Prior to Harvest				
Stem	4.06E+04	**Pounds / Acre**	4.56E+04	**Kilograms / Hectare**
Crown	1.25E+04	**Pounds / Acre**	1.41E+04	**Kilograms / Hectare**
Roots	1.38E+04	**Pounds / Acre**	1.55E+04	**Kilograms / Hectare**
Total	*6.70E+04*	**Pounds / Acre**	**7.51E+04**	**Kilograms / Hectare**
Removed Through Thinnings and Final Harvest				
Stem	6.41E+04	**Pounds / Acre**	7.18E+04	**Kilograms / Hectare**
Crown	1.84E+04	**Pounds / Acre**	2.06E+04	**Kilograms / Hectare**
Roots	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Total	***8.25E+04***	**Pounds / Acre**	**9.24E+04**	**Kilograms / Hectare**

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

6.0 PACIFIC NORTHWEST EXAMPLE

The scenarios developed for the western United States were structured in a manner similar to those for the southeast. Three general combinations of site index and management intensity were developed to reflect a range of conditions and management ranging from low intensities common to NIPF lands to higher intensities of management more common to high site index lands managed by the forest industry. Specific assumptions associated with these three combinations are outlined in Table 6.2 (at the end of the section). The distribution of acres assigned to each of these categories is developed as it was for the southeast. Details of the development are also shown in Appendix 1.

Two cases were developed for western forests, one reflecting current conditions and one estimating the impact of higher intensities of management on lands with higher site indices. In these cases, the merchantable volume is first delivered to sawmills and residual chips are generated from the lumber manufacturing process. Direct delivery of pulpwood from the woods was not assumed to represent a significant part of the volume. This affects the commercial volume removed from the woods and the volume left on site after harvest. The sites were assumed to be on steep slopes requiring the use of cable yarding systems. Cable systems most often work with log-length recovery meaning the tops and branches are left on site.

Results for the base case are shown in Table 6.3 (at the end of the section). Those for the higher intensity example are shown in Table 6.4 (at the end of the section). The average one way hauling distance in both cases reflects the average surveyed distance from harvest site to lumber mill. Average yield for the base case was 501 cubic meters / hectare (7159 cubic feet / acre). This volume increased to 581 cubic meters per hectare (8301 cubic feet / acre) under the higher intensity alternative.

General comparisons of cost, fuel consumption and nitrogen fertilizer requirements are shown in Table 6.1. As was the case for the Southeast Region, the increased cost and fuel consumption required to produce the sawlog volume in the higher intensity scenario is generally offset by the increased volume. Costs and consumption rates per unit of sawlog volume are very close for the two scenarios. The requirement for nitrogen as illustrated in Table 6.1 is higher for the alternate scenario than for the base scenario, but the amounts are significantly lower that for the Southeast region. Detailed results for each of the management intensity levels are presented in Tables A2.3 and A2.4 of Appendix 2. These tables show both the results of the individual management intensities and the weighted average for the base and alternate cases.

Results of the Sima Pro analysis for this scenario are addressed in Section 7.

Carbon pools for the two alternatives are shown at the bottom of Tables 6.3 and 6.4, illustrating standing and removed carbon at the end of the rotation age, an average of annual amounts standing carbon over the rotation of the stand, and the carbon removed through thinning and harvesting activities.

Standing carbon estimates for the Pacific Northwest cases, 82,366 pound/acre average for the Base Case and 85,885 for the more intensive management of the Alternative Case, are shown in their respective tables (6.3 and 6.4). The changes in the standing carbon pool are shown in Figure A3.5 for the Base Case and Figure A3.6 for the Alternate Case, both shown in Appendix 3. The final carbon values in Tables 6.3 and 6.4 correspond to the highest points on the graphs in Figures A3.5 and A3.6.

Table 6.1. Comparison of sawlog volume, harvest costs, fuel consumption and nitrogen use per cubic meter of produced sawlogs for base case and alternate case in the Pacific Northwest region of the United States

	Base Case	Alternate Case	Units
Sawlog Volume	501	581	cubic meters / hectare
Cost to Truck	11.38	11.56	dollars / cubic meter
Cost to Mill	28.69	28.71	dollars / cubic meter
Diesel Consumption			
In Seedlings	.0885	.0801	liters / cubic meter
To Truck	2.85	2.90	liters / cubic meter
To Mill	5.53	5.53	liters / cubic meter
Total	8.46	8.50	liters / cubic meter
Nitrogen	.0951	0.246	kilograms / cubic meter

There is consistency between the results developed for the Southeast and those developed for the Pacific Northwest (Table 5.1). The costs to the truck in the Southeast are $11.81 per cubic meter for the base case and $11.91 per cubic meter for the alternate case. Comparable costs in the Pacific Northwest are 11.38 and 11.56 respectively. Production of sawlogs per unit of area is higher in the Pacific Northwest, but harvesting system costs are also higher because of the use of cable yarders. Diesel consumption to the truck in the southeast is 2.93 liters per cubic meter for the base case and 3.02 liters per cubic meter in the alternate case. This compares to 2.85 liters per cubic meter for the base case in the Pacific Northwest and 2.90 liters per cubic meter for the alternate case. The application rate of fertilizer is greater for the high intensity options in the southeast than in the northwest as reflected in Tables 5.1 and 6.1.

Table 6.2. Pacific Northwest (PNW) Scenarios: Specific Assumptions for three levels of management intensity in the Pacific Northwest

Management Intensity Class **Prescription**	**3** **Low Intensity**	**2** **Medium Intensity**	**1** **High Intensity**
Site Index	86	114	130
Planting Density (Trees per acre)	400	600	600
Genetics and Fertilization	None	None	Years 20,30,40
Pre-commercial Thinning (Trees per acre)	None	Year 15 *300*	Year 15 *275*
Commercial Thinning Cubic Feet *at year*	0	1,151 30	1,153 *25*
Final Harvest – Cubic Feet *at year*	6,186 *45*	5,851 *45*	10,017 *45*
Total Yield / Acre – Cubic Feet	6,186	7,002	11,171
Percent Sawlogs	100 %	100 %	100 %
Rotation Age	45 years	45 years	45 years
Percent Area in Class for Base Case	42 %	46 %	12 %
Percent Area in Class for Alternative Case	24 %	40 %	36 %

Table 6.3. Pacific Northwest (PNW): Cost and Energy Consumption – Base Case representing a weighted average of the three management intensity levels

Pacific Northwest Scenarios	**45**	**Year Rotation**
Percent of Private Land Area in Site / Management Category		
Low Productivity / Mgmt Intensity	**42.0%**	
Mid Productivity / Mgmt Intensity	**46.0%**	
High Productivity / Mgmt Intensity	**12.0%**	
Average One Way Haul Distance	**75.0**	**Miles**
	120.7	**Kilometers**

Harvesting Systems:

Hand Fell and Buck at Stump
Cable Yarding to Landing
Load and Haul

	Average Harvesting Factors English Units			**Average Harvesting Factors Metric Units**		
	Volume removed in thinning and final harvest					
Volume		**7.16E+03**	**Cubic Feet / Acre**		**5.01E+02**	**Cubic Meters / Hectare**
% Lumber		**100.0%**			**100.0%**	
% Pulpwood		**0.0%**			**0.0%**	
System Costs						
Prep, Plant,	**$**	**255**	**Dollars per Acre**	**$**	**630**	**Dollars per Hectare**
Pre Com Thin	$	0.036	Dollars / Cubic /Foot	$	1.257	Dollars / Cubic Meter
Stump to	**$**	**2,307**	**Dollars per Acre**	**$**	**5,700**	**Dollars per Hectare**
Truck	$	0.322	Dollars / Cubic /Foot	$	11.378	Dollars / Cubic Meter
Hauling		**75**	**Miles**		**120.7**	**Kilometers**
Truck to	**$**	**3,255**	**Dollars per Acre**	**$**	**8,044**	**Dollars per Hectare**
Mill	$	0.455	Dollars / Cubic /Foot	$	16.056	Dollars / Cubic Meter
Total Cost	**$**	**5,817**	**Dollars per Acre**	**$**	**14,374**	**Dollars per Hectare**
	$	0.813	Dollars / Cubic /Foot	$	28.691	Dollars / Cubic Meter

Table 6.3. Pacific Northwest Base Case (Continued)

	Average Harvesting Factors English Units		Average Harvesting Factors Metric Units	
Electric, Fuel and Lubricant Consumption				
Seedling, Site Prep, Plant, Precommercial Thin				
Fuel	**4.74E+00**	**Gallons / Acre**	**4.43E+01**	**Liters / Hectare**
	6.62E-04	Gallons / Cubic Foot	8.85E-02	Liters / Cubic Meter
Lubricants	**8.53E-02**	**Gallons / Acre**	**7.98E-01**	**Liters / Hectare**
	1.19E-05	Gallons / Cubic Foot	1.59E-03	Liters / Cubic Meter
Electric	**2.17E+01**	**Kwh / Acre**	**1.93E+02**	**MJ / Hectare**
	3.03E-03	Kwh / Cubic Foot	3.85E-01	MJ / Cubic Meter
Stump to Truck				
Fuel (Diesel)	**1.53E+02**	**Gallons / Acre**	**1.43E+03**	**Liters / Hectare**
	2.13E-02	Gallons / Cubic Foot	2.85E+00	Liters / Cubic Meter
Lubricants	**2.75E+00**	**Gallons / Acre**	**2.57E+01**	**Liters / Hectare**
	3.84E-04	Gallons / Cubic Foot	5.13E-02	Liters / Cubic Meter
Hauling	**7.50E+01**	**Miles**	**120.7**	**Kilometers**
Fuel (Diesel)	**2.96E+02**	**Gallons / Acre**	**2.77E+03**	**Liters / Hectare**
	4.13E-02	Gallons / Cubic Foot	5.53E+00	Liters / Cubic Meter
Lubricants	**5.33E+00**	**Gallons / Acre**	**4.98E+01**	**Liters / Hectare**
	7.44E-04	Gallons / Cubic Foot	9.95E-02	Liters / Cubic Meter
Total Planting and Harvest Operation				
Fuel	**4.53E+02**	**Gallons / Acre**	**4.24E+03**	**Liters / Hectare**
	6.33E-02	Gallons / Cubic Foot	8.46E+00	Liters / Cubic Meter
Lubricants	**8.16E+00**	**Gallons / Acre**	**7.63E+01**	**Liters / Hectare**
	1.14E-03	Gallons / Cubic Foot	1.52E-01	Liters / Cubic Meter

Table 6.3. Pacific Northwest Base Case (Continued)

	Average Harvesting Factors English Units		Average Harvesting Factors Metric Units	
Fertilizer				
Nitrogen	**4.25E+01**	**Pounds / Acre**	**4.77E+01**	**Kilograms / Hectare**
	5.94E-03	Pounds / Cubic Foot	9.51E-02	Kilograms / Cubic Meter
Phosphate	**7.28E+00**	**Pounds / Acre**	**8.16E+00**	**Kilograms / Hectare**
	1.02E-03	Pounds / Cubic Foot	1.63E-02	Kilograms / Cubic Meter
Potassium	**1.99E-01**	**Pounds / Acre**	**2.23E-01**	**Kilograms / Hectare**
	2.78E-05	Pounds / Cubic Foot	4.46E-04	Kilograms / Cubic Meter
Carbon Pools at End of Rotation				
Average of Standing Carbon Pools over Rotation				
Stem	5.81E+04	**Pounds / Acre**	6.51E+04	**Kilograms / Hectare**
Crown	1.11E+04	**Pounds / Acre**	1.25E+04	**Kilograms / Hectare**
Roots	1.32E+04	**Pounds / Acre**	1.47E+04	**Kilograms / Hectare**
Total	***8.24E+04***	**Pounds / Acre**	**9.23E+04**	**Kilograms / Hectare**
Standing Carbon Prior to Harvest				
Stem	1.24E+05	**Pounds / Acre**	1.39E+05	**Kilograms / Hectare**
Crown	1.99E+04	**Pounds / Acre**	2.23E+04	**Kilograms / Hectare**
Roots	2.89E+04	**Pounds / Acre**	3.24E+04	**Kilograms / Hectare**
Total	***1.73E+05***	**Pounds / Acre**	**1.93E+05**	**Kilograms / Hectare**
Removed Through Thinnings and Final Harvest				
Stem	1.40E+05	**Pounds / Acre**	1.56E+05	**Kilograms / Hectare**
Crown	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Roots	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Total	***1.40E+05***	**Pounds / Acre**	**1.56E+05**	**Kilograms / Hectare**

Stem Carbon:	**Carbon in Stem + Bark**
Crown Carbon:	**Carbon in Branches + Foliage - Litter**
Roots:	**Carbon in Course and Fine Roots**

Table 6.4. Pacific Northwest (PNW): Costs and Energy Consumption – Alternative Case representing a shift to higher intensity management by increasing the percent acreage in the highest two intensity categories

Pacific Northwest Scenarios	**45**	**Year Rotation**
Percent of Private Land Area in Site / Management Category		
Low Productivity / Mgmt Intensity	**24.0%**	
Mid Productivity / Mgmt Intensity	**40.0%**	
High Productivity / Mgmt Intensity	**36.0%**	
Average One Way Haul Distance	**75.0**	**Miles**
	120.7	**Kilometers**

Harvesting Systems:

Hand Fell and Buck at Stump
Cable Yarding to Landing
Load and Haul

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
	Volume removed in thinning and final harvest			
Volume	**8.31E+03**	**Cubic Feet / Acre**	**5.81E+02**	**Cubic Meters / Hectare**
% Lumber	**100.0%**		**100.0%**	
% Pulpwood	**0.0%**		**0.0%**	

System Costs						
Prep, Plant,	**$**	**259**	**Dollars per Acre**	**$**	**639**	**Dollars per Hectare**
Pre Com Thin	$	0.031	Dollars / Cubic /Foot	$	1.099	Dollars / Cubic Meter
Stump to	**$**	**2,718**	**Dollars per Acre**	**$**	**6,717**	**Dollars per Hectare**
Truck	$	0.327	Dollars / Cubic /Foot	$	11.555	Dollars / Cubic Meter
Hauling		**75**	**Miles**		**120.7**	**Kilometers**
Truck to	**$**	**3,777**	**Dollars per Acre**	**$**	**9,333**	**Dollars per Hectare**
Mill	$	0.455	Dollars / Cubic /Foot	$	16.056	Dollars / Cubic Meter
Total Cost	**$**	**6,754**	**Dollars per Acre**	**$**	**16,689**	**Dollars per Hectare**
	$	0.813	Dollars / Cubic /Foot	$	28.710	Dollars / Cubic Meter

Table 6.4. Pacific Northwest Alternate Case (Continued)

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
Electric, Fuel and Lubricant Consumption				
Seedling, Site Prep, Plant, Precommercial Thin				
Fuel	**4.98E+00**	**Gallons / Acre**	**4.65E+01**	**Liters / Hectare**
	5.99E-04	Gallons / Cubic Foot	8.01E-02	Liters / Cubic Meter
Lubricants	**8.96E-02**	**Gallons / Acre**	**8.38E-01**	**Liters / Hectare**
	1.08E-05	Gallons / Cubic Foot	1.44E-03	Liters / Cubic Meter
Electric	2.32E+01	**Kwh / Acre**	**2.06E+02**	**MJ / Hectare**
	2.79E-03	Kwh / Cubic Foot	3.55E-01	MJ / Cubic Meter
Stump to Truck				
Fuel (Diesel)	**1.80E+02**	**Gallons / Acre**	**1.69E+03**	**Liters / Hectare**
	2.17E-02	Gallons / Cubic Foot	2.90E+00	Liters / Cubic Meter
Lubricants	**3.24E+00**	**Gallons / Acre**	**3.03E+01**	**Liters / Hectare**
	3.90E-04	Gallons / Cubic Foot	5.22E-02	Liters / Cubic Meter
Hauling	**7.50E+01**	**Miles**	**1.21E+02**	**Kilometers**
Fuel (Diesel)	**3.43E+02**	**Gallons / Acre**	**3.21E+03**	**Liters / Hectare**
	4.13E-02	Gallons / Cubic Foot	5.53E+00	Liters / Cubic Meter
Lubricants	**6.18E+00**	**Gallons / Acre**	**5.78E+01**	**Liters / Hectare**
	7.44E-04	Gallons / Cubic Foot	9.95E-02	Liters / Cubic Meter
Total Planting and Harvest Operation				
Fuel	**5.29E+02**	**Gallons / Acre**	**4.94E+03**	**Liters / Hectare**
	6.36E-02	Gallons / Cubic Foot	8.50E+00	Liters / Cubic Meter
Lubricants	**9.51E+00**	**Gallons / Acre**	**8.90E+01**	**Liters / Hectare**
	1.15E-03	Gallons / Cubic Foot	1.53E-01	Liters / Cubic Meter

Table 6.4. Pacific Northwest Alternate Case (Continued)

	Average Harvesting Factors English Units		**Average Harvesting Factors Metric Units**	
Fertilizer				
Nitrogen	**1.27E+02**	**Pounds / Acre**	**1.43E+02**	**Kilograms / Hectare**
	1.53E-02	Pounds / Cubic Foot	2.46E-01	Kilograms / Cubic Meter
Phosphate	**2.17E+01**	**Pounds / Acre**	**2.43E+01**	**Kilograms / Hectare**
	2.61E-03	Pounds / Cubic Foot	4.18E-02	Kilograms / Cubic Meter
Potassium	**2.13E-01**	**Pounds / Acre**	**2.39E-01**	**Kilograms / Hectare**
	2.57E-05	Pounds / Cubic Foot	4.11E-04	Kilograms / Cubic Meter
Carbon Pools at End of Rotation				
Average of Standing Carbon Pools over Rotation				
Stem	6.30E+04	**Pounds / Acre**	7.06E+04	**Kilograms / Hectare**
Crown	1.15E+04	**Pounds / Acre**	1.28E+04	**Kilograms / Hectare**
Roots	1.44E+04	**Pounds / Acre**	1.62E+04	**Kilograms / Hectare**
Total	***8.89E+04***	**Pounds / Acre**	**9.96E+04**	**Kilograms / Hectare**
Standing Carbon Prior to Harvest				
Stem	1.40E+05	**Pounds / Acre**	1.56E+05	**Kilograms / Hectare**
Crown	2.10E+04	**Pounds / Acre**	2.36E+04	**Kilograms / Hectare**
Roots	3.30E+04	**Pounds / Acre**	3.70E+04	**Kilograms / Hectare**
Total	***1.94E+05***	**Pounds / Acre**	**2.17E+05**	**Kilograms / Hectare**
Removed Through Thinnings and Final Harvest				
Stem	1.59E+05	**Pounds / Acre**	1.78E+05	**Kilograms / Hectare**
Crown	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Roots	0.00E+00	**Pounds / Acre**	0.00E+00	**Kilograms / Hectare**
Total	***1.59E+05***	**Pounds / Acre**	**1.78E+05**	**Kilograms / Hectare**

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

7.0 SIMA PRO ANALYSIS

SimaPro 5.0.9, a software package designed for analyzing the environmental impact of products during their whole life cycle, was used to perform the life cycle analysis and to generate emission factors and to analyze the relative contribution of the various site preparation and harvesting processes to emissions. Developed in the Netherlands by PRé Consultants B.V., SimaPro5 contains a US database for a number of materials, including paper products, fuels, and chemicals. Franklin Associates (FAL) provides an additional US database. The relative contribution of site preparation and harvesting processes to utilized the Eco-indicator 99 (E) / Europe EI 99 E/E method incorporated within SimaPro.

The source of fuel used to generate the electricity used in the manufacturing process is important in determining the type and amount of impact in the LCA, but is a relatively small component of the forest management process. In 2000 the dominant form of electricity generation in the Pacific Northwest region was hydro, representing 74.3% of the total, followed by natural gas at 12.3% and coal at 8.1%. In the SimaPro (LCA software) impact analysis, no impacts are associated with hydro-generated electricity; however, combusting of coal will contribute significant impact values. The dominant form of fuel source in the southeast region was coal, representing 45.56% of the total, followed by natural gas at 23.03% and nuclear at 21.57%. In the SimaPro 5.0 analysis using the FAL database, combusting of coal contributes significant impact values, as does nuclear and petroleum, whereas natural gas and hydroelectric power contributes relatively less. These assumptions are consistent with those used in the manufacturing processes for lumber and plywood and are described in more detail in those modules.

Factors for fertilizers used in seedling development and in forest management were derived from existing database factors within the FAL database. Potassium fertilizer was considered as an input from nature. Nitrogen and phosphate fertilizers were considered as inputs from what SimaPro labels as the "technosphere", reflecting a manufacturing process to produce these fertilizers.

Assumptions relative to diesel fuel and gasoline were consistent with those used in the analysis of the primary wood products of lumber, plywood and oriented strand board. They were derived from the FAL database. Diesel fuel was the primary power source for all site preparation and harvesting equipment except chainsaws and the vehicles used to transport crews to and from the forest stand. Lubricant consumption in harvesting equipment generally consists of hydraulic oils and general lubricants required for the hydraulic systems and moving parts of the harvesting equipment. Lubricants are not consumed through combustion, but are replaced through regular maintenance activities. Used lubricating fluids were assumed to be recycled.

The primary direct emissions from forest management activities will be through the air emissions created through the combustion of diesel and gasoline engines. Air emissions for all operations required to produce logs loaded on trucks are shown for base and alternate cases studied for both regions in Table 7.1. Emissions from seedling growth and planting represented a very small portion of the total for the forest management activity, and the total emissions for the forest management activities were a small component of the overall emission factors associated with the primary wood products.

Factors associated with the transportation of the harvested logs to the primary manufacturing center were included with the analysis and factors of the manufacturing center. The emissions to the air shown in Table 7.1 do not include those associated with diesel combustion associated with this primary transportation activity.

The factors shown in the tables represent the combined effect of fuel combustion and fertilization. The non-fossil CO2 emissions shown in the table are assumed to be derived from biomass and are therefore have a neutral impact in the overall life cycle analysis.

SimaPro allows the selection of several developed methods for measuring relative impacts of developed processes. The method selected for the forest resource module was Eco-indicator 99 (E) / Europe EI 99 E/E. This method incorporates measures of impact of the total process on developed measures such as fossil fuels, respiratory inorganics, climate change, and carcinogens. Contribution to these factors is measured in method-derived indices that assess the impact on human health, plant species and energy replacement needs. While each of these impact areas have direct measurements, the method also combines these factors into a single dimensionless index reflecting the total impact of the process. The single factor is a direct result of the assumptions used in developing and weighting the indicator, but can be used to illustrate the relative differences between the various forest management treatment options. The single factor analysis for each of the processes in the planting, site preparation, intermediate site treatments, and final harvesting activity to overall emission factors are shown for the high intensity levels for both of the harvest regions in Figures 7.1 and 7.2.

The contribution of each of the individual processes to the factor is shown for each of the forest management options and regions in Figures 7.3 to 7.8. The primary contributor to the overall impact factor for all scenarios is the combustion of diesel equipment. Within that category, the largest individual contributor is the equipment used for the secondary transportation of the cut logs or trees from the woods to the landing. This is followed closely by the diesel consumption used in the loading logs on trucks. Graphs for the high intensity scenarios show a significant contribution from natural gas related to the process called the reforested acre. This reflects the contribution that the fertilizer applications make to the final product.

A summary of the total impact factor for each of the management intensities and regions and for the weighted averages by region for the base and alternate cases are shown in Table 7.2. The higher factors for the southeast region generally reflect the increased use of mechanized site preparation and the high levels of fertilization intensity.

Table 7.1. Projected Emissions to the Air for both regions and both the base and alternate case – using SimaPro Eco-indicator 99 (E) / Europe EI 99 E/E

	SE Base	SE Alternate	PNW Base	PNW Alternate
	Kilograms / Cubic Meter of Harvested Log			
aldehydes	1.69E-04	1.77E-04	1.49E-04	1.51E-04
ammonia	3.19E-04	7.38E-04	3.74E-05	8.69E-05
CO	7.70E-02	7.45E-02	1.03E-01	1.02E-01
CO2	3.99E-01	9.50E-01	3.24E-02	9.71E-02
CO2 (fossil)	9.25E+00	9.71E+00	8.02E+00	8.12E+00
CO2 (non-fossil)	2.51E-03	3.00E-03	1.96E-03	2.03E-03
dust (SPM)	2.11E-04	5.01E-04	1.71E-05	5.12E-05
formaldehyde	2.44E-03	2.47E-03	2.18E-03	2.20E-03
methane	6.29E-03	1.27E-02	1.71E-03	2.47E-03
N2O	2.34E-03	5.54E-03	1.90E-04	5.69E-04
NO2	7.63E-04	1.88E-03	6.21E-05	1.84E-04
non methane VOC	3.78E-02	4.66E-02	3.00E-02	3.12E-02
NOx	1.67E-01	1.71E-01	1.46E-01	1.47E-01
organic substances	1.16E-04	1.31E-04	9.57E-05	9.82E-05
particulates (PM10)	1.15E-02	1.18E-02	1.02E-02	1.03E-02
particulates (unspecified)	7.38E-04	8.72E-04	5.19E-04	5.40E-04
SO2	1.94E-03	4.80E-03	1.57E-04	4.66E-04
SOx	4.38E-02	7.56E-02	1.97E-02	2.36E-05
VOC	3.22E-05	7.63E-05	2.61E-06	7.80E-06
	Pounds / Cubic Foot of Harvested Volume			
aldehydes	1.06E-05	1.10E-05	9.30E-06	9.41E-06
ammonia	1.99E-05	4.61E-05	2.34E-06	5.42E-06
CO	4.81E-03	4.65E-03	6.41E-03	6.37E-03
CO2	2.49E-02	5.93E-02	2.02E-03	6.06E-03
CO2 (fossil)	5.78E-01	6.06E-01	5.00E-01	5.07E-01
CO2 (non-fossil)	1.57E-04	1.87E-04	1.22E-04	1.27E-04
dust (SPM)	1.32E-05	3.13E-05	1.07E-06	3.20E-06
formaldehyde	1.52E-04	1.54E-04	1.36E-04	1.38E-04
methane	3.92E-04	7.94E-04	1.06E-04	1.54E-04
N2O	1.46E-04	3.46E-04	1.19E-05	3.55E-05
NO2	4.76E-05	1.17E-04	3.88E-06	1.15E-05
non methane VOC	2.36E-03	2.91E-03	1.87E-03	1.95E-03
NOx	1.04E-02	1.07E-02	9.10E-03	9.19E-03
organic substances	7.23E-06	8.18E-06	5.97E-06	6.13E-06
particulates (PM10)	7.21E-04	7.34E-04	6.37E-04	6.44E-04
particulates (unspecified)	4.61E-05	5.44E-05	3.24E-05	3.37E-05
SO2	1.21E-04	3.00E-04	9.83E-06	2.91E-05
SOx	2.73E-03	4.72E-03	1.23E-03	1.47E-06
VOC	2.01E-06	4.76E-06	1.63E-07	4.87E-07

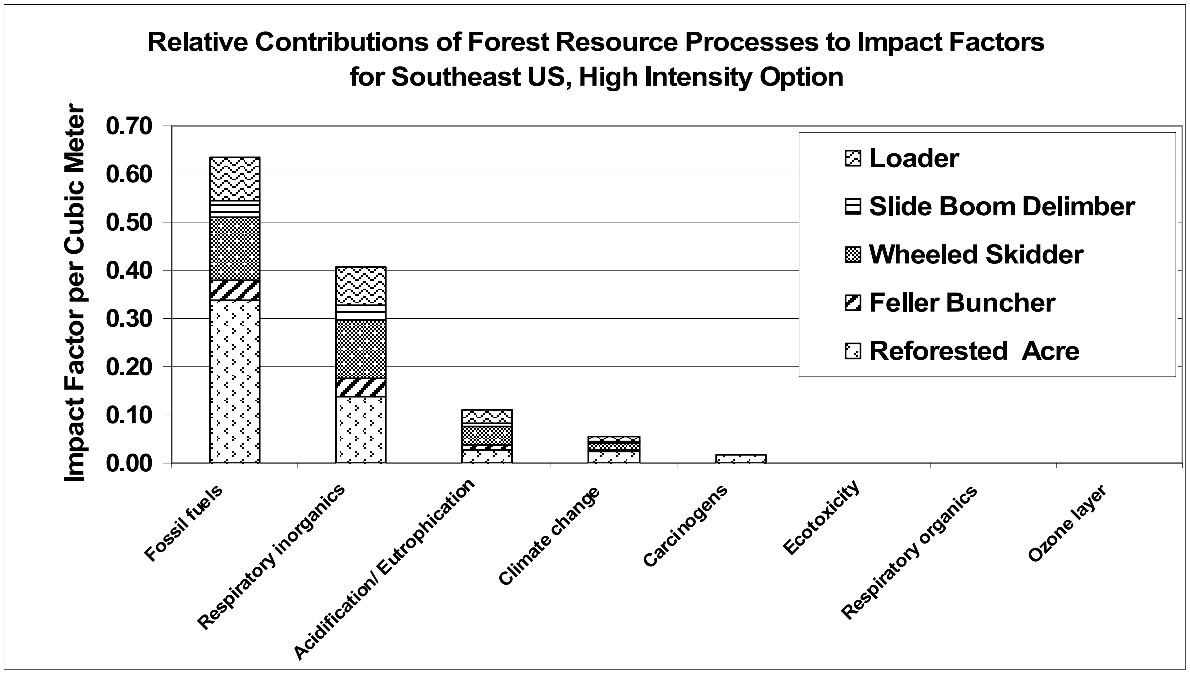

Figure 7.1. SimaPro impact factor breakdown by impact area as generated by the Eco-indicator 99 (E) / Europe EI 99 E/E method for the Southeast US, high intensity management option.

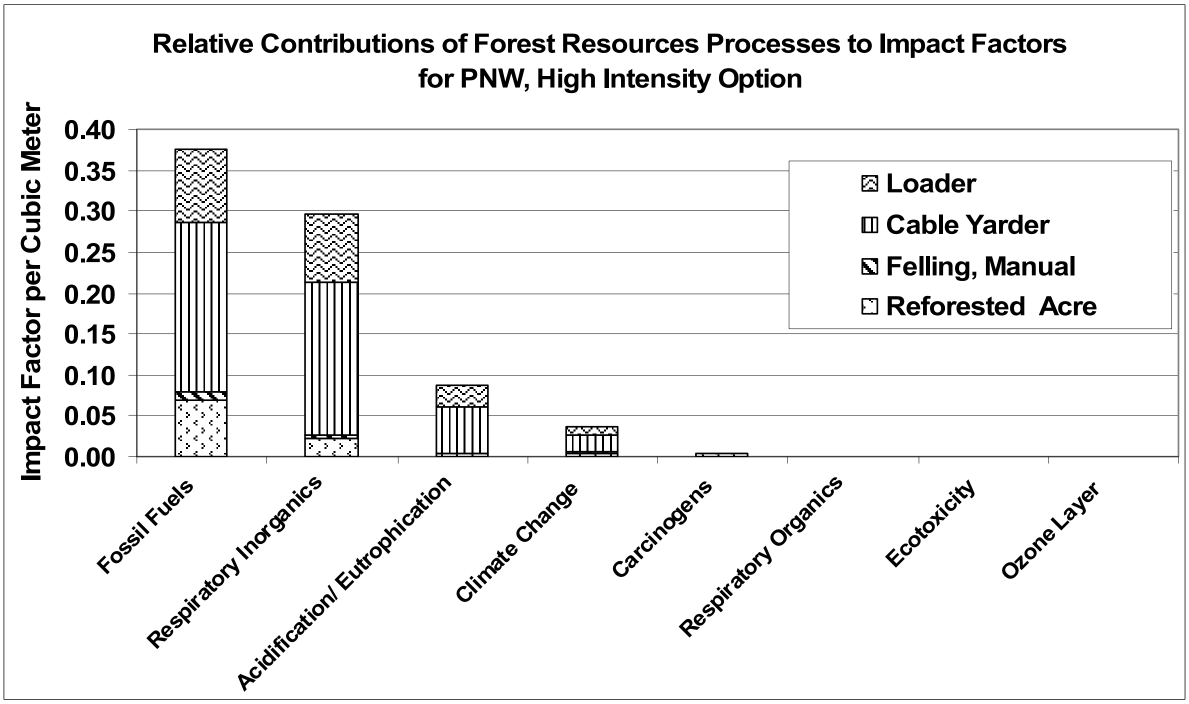

Figure 7.2. SimaPro impact factor breakdown by impact area as generated by the Eco-indicator 99 (E) / Europe EI 99 E/E method for the PNW, high intensity management option.

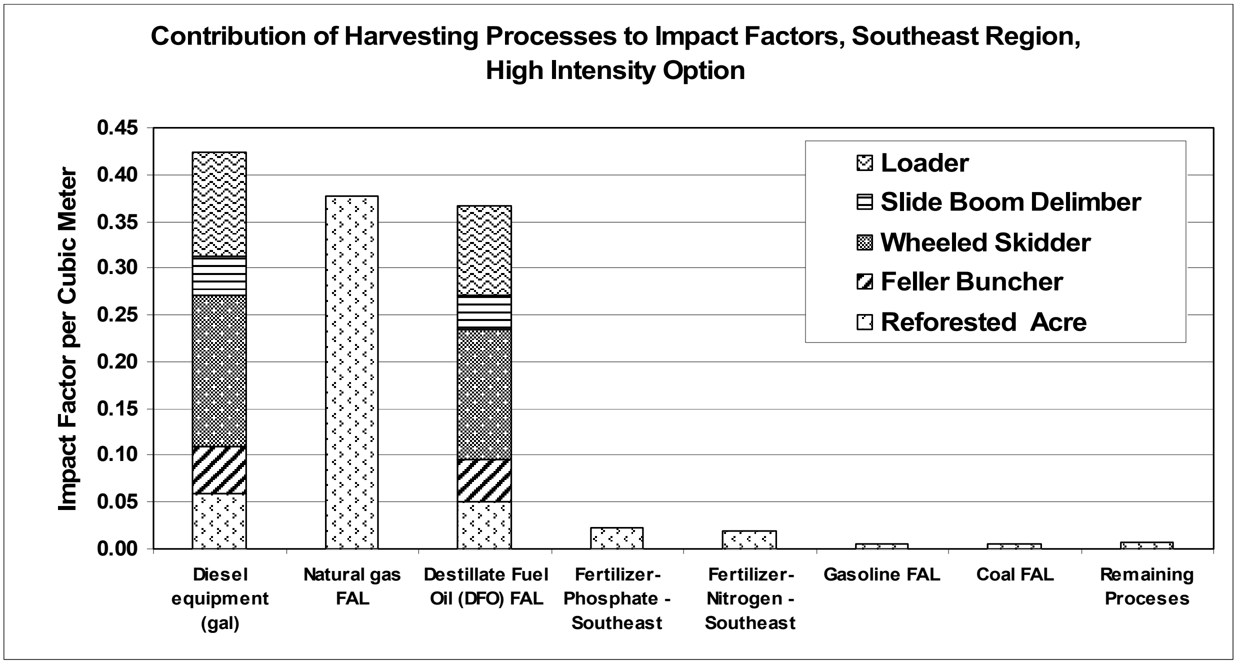

Figure 7.3. **Contribution of forest management processes to impact factors for the Southeast Region with High Intensity Management**

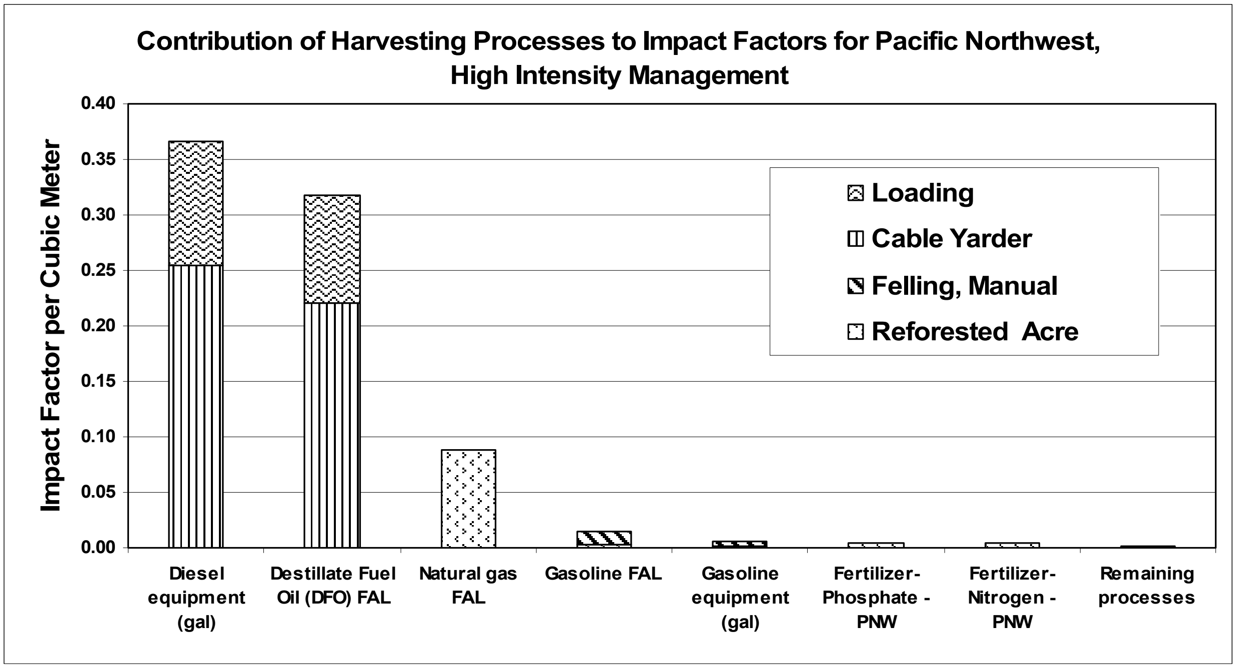

Figure 7.4. **Contribution of forest management processes to impact factors for the Pacific Northwest with High Intensity Management**

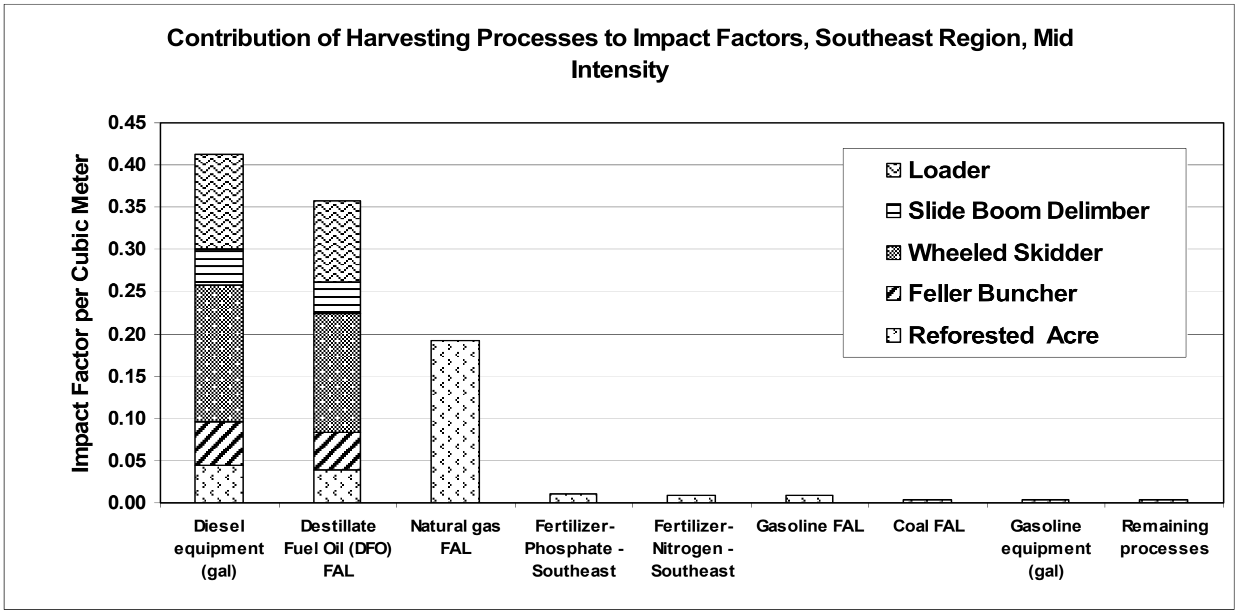

Figure 7.5. Contribution of forest management processes to impact factors for the Southeast Region with management intensity at a medium level.

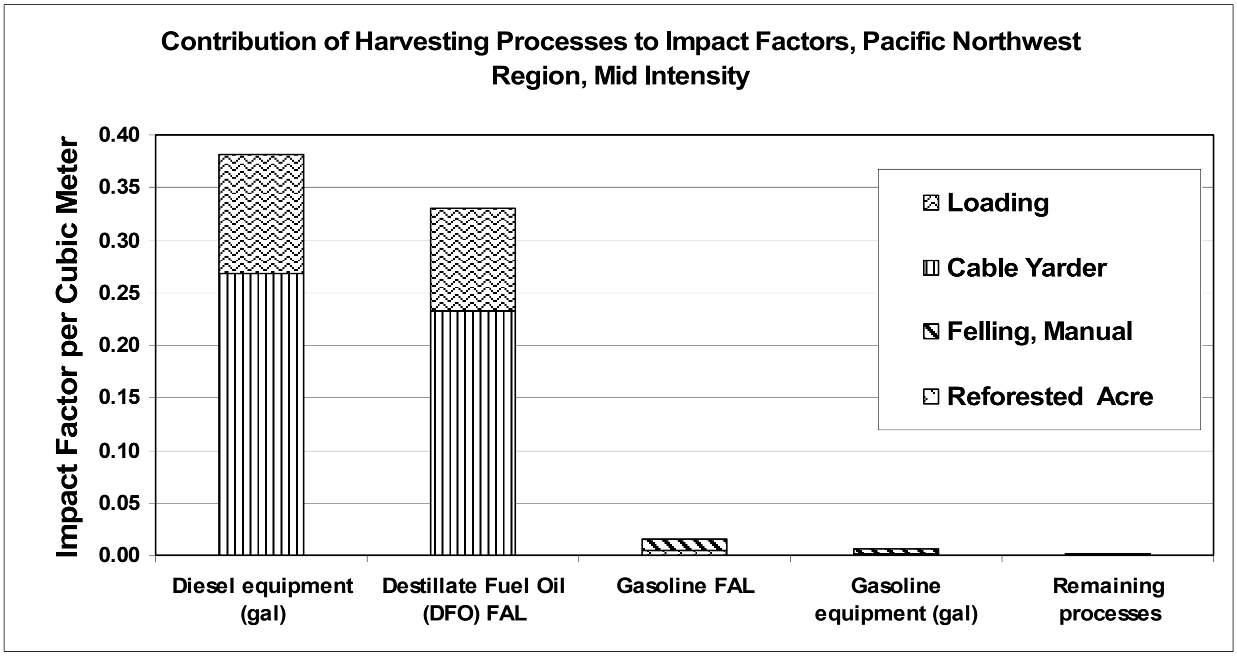

Figure 7.6. Contribution of forest management processes to impact factors for the Pacific Northwest with management intensity at a medium level.

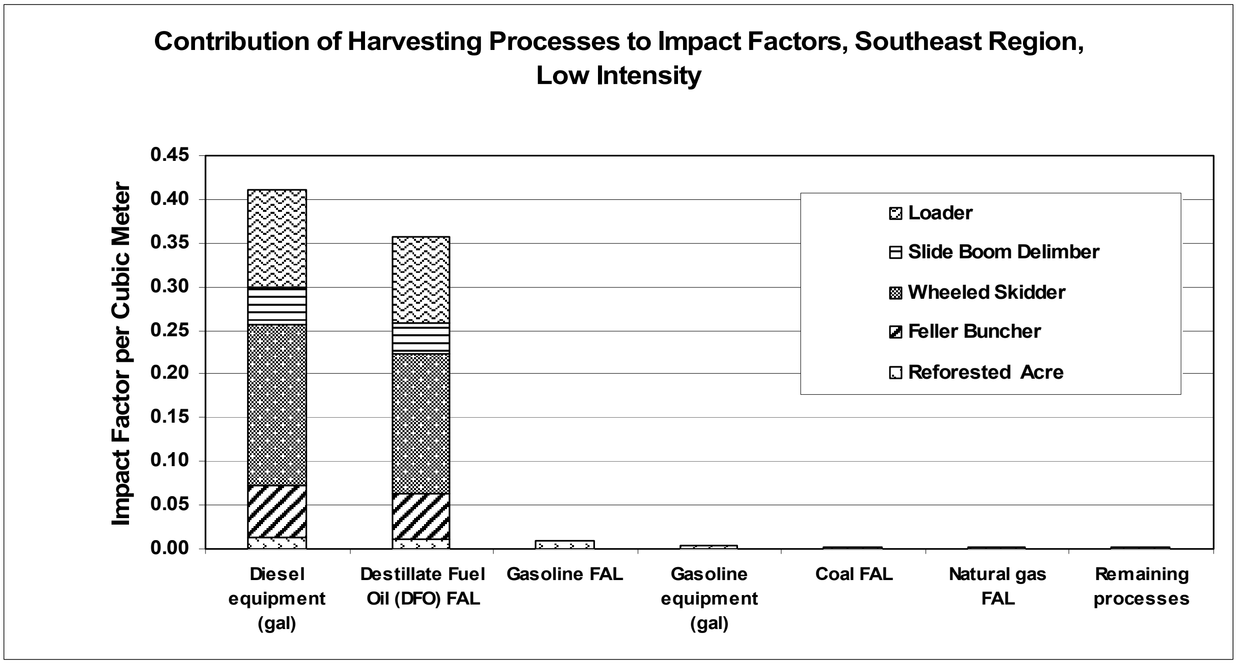

Figure 7.7. Contribution of forest management processes to impact factors for the Southeast Region with management at the lowest level of intensity.

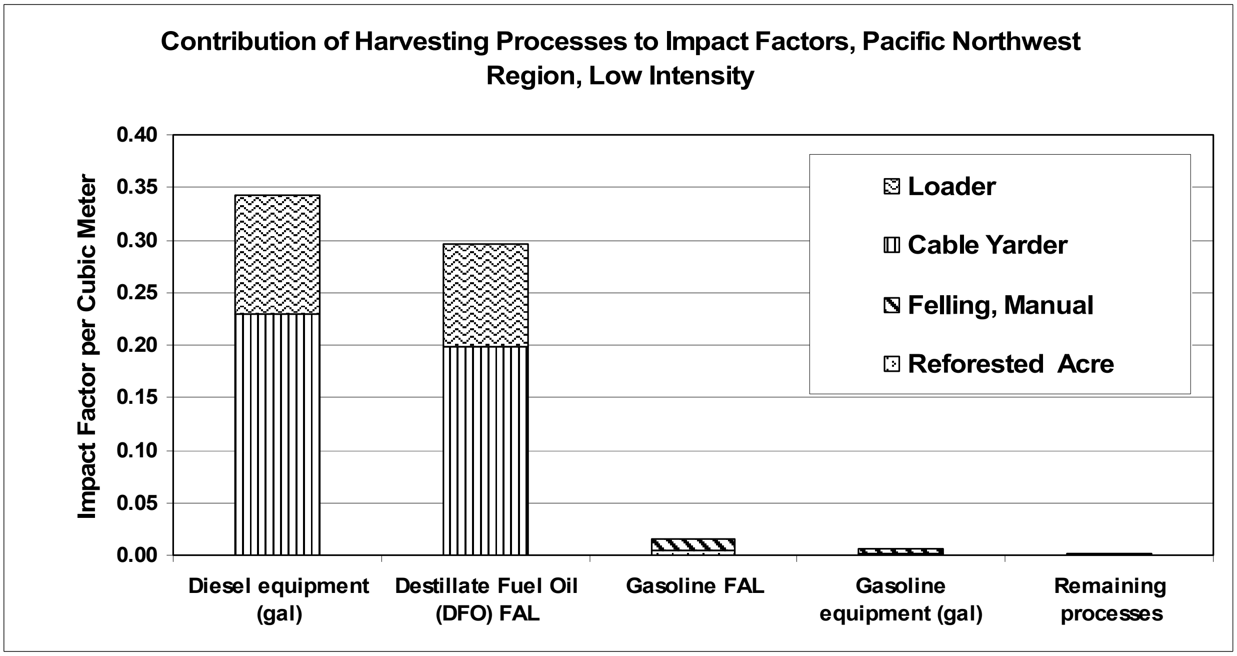

Figure 7.8. Contribution of forest management processes to impact factors for the Pacific Northwest with management at the lowest level of intensity.

Table 7.2. Comparison of overall impact factor by management scenario and region as developed through the Eco-indicator 99 (E) / Europe EI 99 E/E method of SimaPro.

	Impact Factor per Cubic Meter		
Single Factor Measurement	**SE**	**Percent Difference**	**PNW**
High Intensity	1.227	*53%*	0.802
Mid Intensity	1.002	*37%*	0.734
Low Intensity	0.785	*19%*	0.661
Average for Base Case	0.932	*31%*	0.713
Average for Alternate Case	1.144	*54%*	0.742
Percent Increase for Alternate	*19%*		*4%*

SimaPro, Eco-indicator 99 (E) / Europe EI 99 E/E

8.0 FUTURE WORK AND DATA QUALITY

The methods and approach used to reduce the multiple site index / management intensity classifications of each region listed in the RPA to the three scenarios developed for each region require additional review and assessment. The three management scenarios within each region could be benchmarked against other known data for the region and perhaps calibrated to be more representative of the region.

Indices of the other co-products associated with forest management activities developed for the Pacific Northwest in Module O account for reserved acreage adjacent to the managed stands but could be more directly integrated into this analysis and extended to cover the southeast. In particular, the analysis of different rotations and management intensities applied at the region scale in Module O were not integrated with the site index and management intensity information, but rather, each treatment was applied to arbitrary blocks of acres.

Fuel consumption data for the selected harvesting systems is generally based on the horsepower of the machines used within those systems. The fuel consumption calculations show consistency across the range of equipment used and should have a fairly high degree of reliability. Lubricant consumption was calculated as a percent of fuel consumption. This assumption generalizes the consumption rate and fails to distinguish between individual equipment characteristics. Use of a single type of harvesting system for a region was necessary to decrease the number of harvesting options considered within the module, but there are many combinations of equipment that can be used to harvest trees. The assumption of steep slope settings in the Pacific Northwest dictated the use of cable logging systems, but this added to costs associated with northwest harvesting operations. There are also sites in the northwest that could be harvested with mechanized, ground-based harvesting systems.

Region specific data on the level of resource consumption during seedling growth, site preparation and stand establishment is limited. Estimates for these values were developed using a limited set of published data and through direct inquiries of forest nursery managers. The inquiries of nursery operators indicate there are some imbedded chemical requirements in seedlings, but a negligible amount of energy. Most seedling nurseries in the northwest and southeast use small amounts of heating and cooling. Most of the cooling costs are incurred in keeping seedlings ready for planting. Stand establishment requirements were based on planting rates for seedlings and the distance of the stands from the mill. When seedling growth and planting is combined with the timber harvesting operation, emission flows are dominated by the fuel consumption required for harvesting the timber.

Carbon models must be reviewed for consistency between regions and for consistent application of both production and decomposition functions. For example, it is time consuming if not overly complex to calibrate growth models for appropriate responses across broad region like the Pacific Northwest and Southeast. Other data issues related to carbon production, decomposition and release were noted in the general discussion of the methods for estimating carbon. A more general approach to modeling carbon flows associated with forest stand growth and harvesting is included in Module N.

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APPENDIX 1: MANAGEMENT INTENSITY DESCRIPTION FOR BASE CASE AND ALTERNATE MANAGEMENT SCENARIO

MANAGEMENT INTENSITY FOR BASE-CASE AND MANAGEMENT ALTERNATIVE

Three management intensity regimes were analyzed for each region, Southeastern (SE) and Pacific Northwest (PNW) US. The three regimes reflect a range of current practices from (1) very intensive as practices that might be justified on lands with high site productivity indices, (2) medium intensity practices that are common for industry but also practiced by some non-industrial landowners, or (3) relatively non-intensive practices that are used frequently on lands with low site productivity, especially for the non-industrial private owner. The three regimes reflect a combination of site index and management intensity.

The product volumes, emissions, and co-products associated with each of these regimes was weighted in proportion to the number of acres receiving each treatment to derive estimates for an average acre under current practices. These results are referred to as the Base-Case. Re-weighting the results with more acres allocated to more intensive practices provides a realistic estimate of products and co-products that would be associated with future improved practices consistent with current technology, thus allowing an examination of the difference between a Base-Case and more intensive alternatives.

While the range of management practices can be defined with many more intermediate treatments, these three regimes for each region define a logical range of management intensities and are sufficient to approximate the impact of current and future practices. Results for each of the three regimes define a logical set of outputs for the combination of management intensity and site productivity as defined primarily by the annual fiber yield growing on the sites. When weighted by the percentage of acres with comparable yields, the combined scenario represents an average yield from the managed lands of the region. The shift of a greater percentage of the land to categories involving more intensive management can demonstrate the impact of such a shift on product yield and other co-products. Reserve acres, often represented by public lands, are not included in this phase of the analysis. These lands are included in Module O where consideration is given to ecological co-products that can only be determined at a landscape scale.

MANAGEMENT STRATIFICATION FOR THE SOUTHEAST:

The Base-Case for the SE was defined from the management intensity assumptions used in the 2000 Resources Planning Act Assessment (RPA). The 10 SE Region management intensity classes for forest industry (FI) lands and 6 classes for non-industry private forestry (NIPF) lands were assigned to the most representative of our three regimes.

Table A1.1 presents the three MI regimes used in this analysis for the Southeast in terms of site index, rotation age, planting density and the frequency of thinning and fertilization. Attachment 1 describes the 10 forest industry and 6 non-industrial private forestry classes of management intensity as used in the RPA for the Southeast.

Table A1.1. Representative Management Intensity and site class regimes for the Southeast

Management Intensity Class	3	2	1
Ownership / Prescription	**NIPF / Low Intensity**	**NIPF / High Intensity or Industrial / Low Intensity**	**Industrial / High Intensity**
Site Index	58	67	80
Planting Density (Trees per acre)	726	726	726
Fertilization	None	Years 2, 16	Years 2,5,9,13,17,21
First Thinning - Cubic Feet	0	896	845
at year		*17*	*13*
Second Thinning - Cubic Feet	0	0	832
at year			*19*
Final Harvest - Cubic Feet	3,145	2,507	2,932
at year	*30*	*25*	*25*
Total Yield / Acre – Cubic Feet	3,145	3,403	4,609
Rotation Age	30 years	25 years	25 years
Ave. Volume Growth/yr	105 cu ft.	136 cu ft.	184 cu ft.

The distribution of acres by site classification provided in the RPA is shown in Table A1.2.

Table A1.2. Distribution of acres by land productivity class in 2000

Site Class Height Index	3 <56	2 56 – 70	1 >70		
	Millions of Acres and Percent			Total	Percent of Total
Forest Industry	.61	10.69	4.22	15.51	53.9 %
Percent	*4 %*	*69 %*	*27 %*	*100 %*	
NIPF	0.47	8.63	4.17	13.27	46.1 %
Percent	*4 %*	*65 %*	*31 %*	*100 %*	
Total	1.08	19.32	8.38	28.78	
Percent	*4 %*	*67 %*	*29 %*	*100 %*	100 %

By contrast, the acreages assigned to each regime as defined by the site index / management intensity developed in Table A1.1 are shown in Table A1.3. The range in yield used to assign acres to the lowest management intensity class was lowered from 120, the nominal midpoint of our two lowest management classes, to 103, in order for the resulting distribution to correspond more closely to expert opinion. The nominal midpoint applied to the RPA tables of growth resulted in too many acres assigned to the low intensity class. Adjusting the RPA growth tables for the volume of thinnings removed and lowering the range of yields assigned to the lowest intensity class produced an acceptable distribution.

Table A1.3. Distribution of Southeast acres by Management Intensity Class

Management Intensity	**3**	**2**	**1**		
Average Yield CuFt / Year	105	136	184		
Range of Yield CuFt / Year	< 103	103-161	> 161		
	Millions of Acres			**Total for Class**	**Percent of Total**
Forest Industry	1.21	12.89	1.42	15.51	53.9%
Percent	*8%*	*83%*	*9%*	*100%*	
NIPF	9.43	3.84	0	13.27	46.1%
Percent	*71%*	*29%*	*0%*	*100%*	
Total	10.64	16.72	1.42	28.78	100%
Percent	*37%*	*58%*	*5%*	*100%*	

With this adjustment, Table A1.3 illustrates that in the Base-Case, most forest industry lands are being managed in the middle intensity class yet the vast majority of NIPF lands are in the lowest intensity class

By contrast, Table A1.2 indicates that 27% of the forest industry lands and 31% of NIPF lands have the potential to reach the higher yields associated with the highest level of management intensity. The implication is that many lands are currently managed less intensively than they could be and perhaps less than is economic if owners were more comfortable with the long-term nature of management investments.

As an alternative to the Base-Case, acres are reassigned to the next higher management intensity as a possible future scenario. The acreage allocation associated with this management alternative is shown in Table A1.4.

Table A1.4. Acres associated with more management activity (more intensive management on 95% of the acres)

Management Intensity	3	2	1		
Average Yield CuFt / Yr	105	136	184		
Range of Yield CuFt / Yr	<103	103-161	>161		
	Millions of Acres			Total for Class	Percent of Total
Forest Industry	0	1.21	14.31	15.51	53.9 %
Percent	0 %	8 %	92 %	100 %	
Change from base	-8 %	-75 %	+ 83 %		
NIPF	0	9.43	3.84	13.27	46.1 %
Percent	41 %	59 %	0 %	100 %	
Change from base	- 71 %	+42%	+29 %		
Total	0	10.64	1.81	28.78	100 %
Percent	0 %	37 %	63 %	100 %	
Change from base	- 37 %	-21 %	+58 %		

This management alternative reduces the acres in the least intensive management to zero, a 37 percentage point reduction. These acres are instead moved into the medium intensity class which is still reduced by 21 points as all of the acres allocated to medium intensity management in the Base-Case are moved into the high intensity class. The high intensity class is increased to 63% for a 58 percentage point increase. While this is just one of many scenarios reflecting changes in management intensity that could be developed as a feasible alternative, increased management intensity on most acres is anticipated over a period of years as more owners adopt the best practices of today.

The annual growth for the average SE region acre increases from 127 cubic feet per acre per year in the Base-Case to 167 in the Alternative Case, a 31% increase. Growth in the Base-Case is at the low end of the mid-range management intensity class, or 96% of the annual growth increment for management intensity 2, rising to 105% in the more intensive management alternative.

MANAGEMENT STRATIFICATION FOR PACIFIC NORTHWEST:

Similar to the approach taken for the SE, the management intensity assumptions used for the PNW in the most recent USFS Resource Planning Assessment (RPA) were assigned to the most representative of our three regimes. Table A1.5 presents the three MI classes used in this analysis for the PNW region. Attachment 2 describes the 5 forest industry and 4 non-industrial private forest classes used in the 2000 RPA for the PNW.

Table A1.5. Representative Management Intensity and site class regimes for the Pacific Northwest

Management Intensity Class	3	2	1
Ownership / Prescription	**Low Intensity**	**Medium Intensity**	**High Intensity**
Site Index	86	114	130
Planting Density (Trees per acre)	400	600	600
Genetics and Fertilization	None	None	Years 20,30,40
Pre-commercial Thinning	None	Age 15	Age 15
(Trees per acre)		300	275
Commercial Thinning - Cubic Feet	0	1,151	1,153
at year		*30*	*25*
Final Harvest - Cubic Feet	6,186	5,851	10,017
at year	*45*	*45*	*45*
Total Yield / Acre – Cubic Feet	6,186	7,002	11,171
Ave. Volume Growth/yr	137 cu ft.	156 cu ft.	248 cu ft.

The distribution of acres by site classification is shown in Table A1.6.

Table A1.6. Distribution of acres by land productivity class in 2000

Site Class **Height Index**	**3** <100	**2** 100 – 120	**1** >120		
	Millions of Acres and Percent			**Total**	**Percent of Total**
Forest Industry	.77	1.51	1.52	3.81	66 %
Percent	*20 %*	*40 %*	*40 %*	*100 %*	
NIPF	0.61	.78	.52	1.92	34 %
Percent	*32 %*	*41 %*	*27 %*	*100 %*	
Total	1.39	2.29	2.04	5.72	
Percent	*24 %*	*40 %*	*36 %*	*100 %*	100 %

By contrast, the acreages assigned to each regime as defined by the site index / management intensity developed in Table A1.5 are shown in Table A1.7.

Table A1.7. Distribution of Pacific Northwest acres by Management Intensity Class

Management Intensity	**3**	**2**	**1**		
Average Yield Cubic Feet / Year	137	156	248		
Range of Yield Cubic Feet / Year	< 150	150-208	> 208		
	Millions of Acres			**Total for Class**	**Percent of Total**
Forest Industry	1.21	1.96	0.64	3.81	66.6%
Percent	*32%*	*52%*	*17%*	*100%*	
NIPF	1.17	.67	0.07	1.92	33.4%
Percent	*61%*	*35%*	*4%*	*100%*	
Total	2.38	2.63	.71	5.72	100%
Percent	*42%*	*46%*	*12%*	*100%*	

Table A1.7 illustrates that in the Base-Case, most forest industry lands are being managed to produce the yields associated with management intensity class 2. The yields on NIPF lands place the majority of these lands into management intensity class 3. Very few NIPF acres meet the yield criteria for the highest management intensity classification.

By contrast, Table A1.6 indicates that 40% of the forest industry lands and 27% of NIPF lands have the potential to reach the higher yields associated with the highest level of management intensity. The implication is that many lands are currently managed less intensively than they could be and perhaps less than is economic if owners were more comfortable with the long-term nature of management investments. An alternative to the Base-Case moves some of the lands to a higher productivity level through the application of more intensive management.

Data from the RPA was used to determine acres that might be compatible with a shift from to a higher level of management intensity and the resulting increase in yield. This represents an alternative scenario for the region associated with a higher level of management intensity. The acreage allocation associated with this management alternative is shown in Table A1.8.

Table A1.8. Acres associated with more management activity (more intensive management on 41% of the acres)

Management Intensity	**3**	**2**	**1**		
Average Yield Cubic Feet / Yr	137	156	248		
Range of Yield Cubic Feet / Yr	< 150	150-208	> 208		
	Millions of Acres			**Total for Class**	**Percent of Total**
Forest Industry	.72	1.56	1.52	3.81	66.6 %
Percent	19 %	41 %	40 %	100 %	
Change from base	- 13 %	-11 %	+23 %		
NIPF	.64	.76	.52	1.92	46.1 %
Percent	33 %	40 %	27 %	100 %	
Change from base	- 28 %	+ 5 %	+23%		
Total	1.36	2.32	2.04	5.72	100 %
Percent	24 %	40 %	36 %	100 %	
Change from base	- 18 %	+ 15 %	+ 23 %		

This management alternative reduces the acres in the least intensive management regime by 18%. Within the middle management regime, 23% are moved up to management intensity 1, resulting in a net increase of 15% for acres in the middle regime. The shift is a little more dramatic by ownership, with a 28% reduction in the lowest intensity management on NIPF. This is just one of many scenarios reflecting changes in management intensity that could be developed as a feasible alternative. It is not an extreme case and could be reasonably expected over a period of years as more owners adopt the best practices of today.

The annual growth for the average PNW region acre increases from 159 cuft per acre per year in the Base-Case to 185 in the Alternative Case, a 16% increase. Growth in the Base-Case is 11% below the center of the range represented by the medium management intensity rising to 3% above under the more intensive Alternative Case. These alternatives are useful in developing a perspective for change and sensitivity analysis for each region while noting that the management practices and growing conditions are quite different in each region. The increase in growth for the Pacific Northwest Alternative Case is only half the increase for the Southeast Alternative but is directly proportional to the lower percentage of acres that were moved to higher management levels.

ATTACHMENT 1: 2000 RPA MANAGEMENT INTENSITY AND SITE CLASS DEFINITIONS

Southeast (SE)

SE Site Classes:

1 - High, Site Index >70, base age 25

2 - Medium, Site Index 56-70, base age 25

3 - Low, Site Index 55 or less, base age 25.

FIA definitions of site based on site productivity class:

1-high, sites capable of producing 85+ cubic feet per acre per year (SE) at max. MAI and 120+ in the SC. This is FIA site classes 1-4 in the SE but 1-3 for the SC (SC was stratified differently because measurement systems were different).

2-medium, FIA site classes 5 for SE (50-84 cuft/ac/yr), and 4,5 for SC (50-119 cuft/ac/yr)

3-low, FIA site classes 6 for both SE and SC. Producing 20-49 cu.ft./ac/year

SE Forest Industry Management Intensity Classes (MI):

The first two intensities represented older established stands. The others are for current and future regeneration. Across the 3 site classes, the management options can be summarized as:

1. planted traditional--regular planting stock with some fertilization and stocking control;
2. MIC-1 plus commercial thinning;
3. planted low--genetically improved stock, managed for mixed pulp wood and sawtimber, no stocking control or fertilization;
4. MIC-3 plus commercial thinning;
5. planted medium--genetically improved stock, with stocking control or fertilization;
6. MIC-5 plus commercial thinning;
7. planted high--genetically improved stock, high intensity management using both stocking control and fertilization;
8. MIC-7 plus commercial thinning;
9. planted high-plus--advanced genetics while using aggressive weed control and fertilization;
10. MIC-9 plus commercial thinning;

11. Short rotation aggressive pulp plantations and reserves are not considered

SE NIPF owner Management Intensity Classes
(same activities as 1…6 above, with slightly lower growth rates):

1. Low--regular planting stock with some fertilization and stocking control;

2. Low, plus commercial thinning;

3. Medium--genetically improved stock, managed for mixed pulp wood and sawtimber, no stocking control or fertilization;

4. Medium, plus commercial thinning;

5. High--genetically improved stock, with stocking control or fertilization;

6. High, plus commercial thinning;

ATTACHMENT 2: 2000 RPA MANAGEMENT INTENSITY AND SITE CLASSIFICATIONS

Pacific Northwest (PNW)

PNW Site Classes:

Managed yields were developed with the Douglas-fir simulator (DFSIM). There is one non-managed or custodial scenario developed with empirical data and four managed scenarios developed with DFSIM. The ATLAS site productivity classes were determined with the following DFSIM site index parameters:

1. High--Site index 130 (50 yrs. BH)
2. Medium--Site index 110
3. Low--Site index 90 (Management intensity 5, commercial thinning, was not developed for low sites.)

FIA definitions of site based on site productivity classes:

<u>Douglas-fir and all other types.</u>

- High: 165 or more,
- Medium: 120 - 164, and
- Low: 20 - 119 net cubic feet per acre per year

<u>Western Hemlock</u>

- High: 225 or more,
- Medium: 120 -224, and
- Low: 20 – 119 net cubic feet per acre per year.

PNW Management Intensity Classes (MI):

1. A custodial approach to management. The yield tables were derived from empirical growth information calculated from the FIA field plots. For comparison, DFSIM was run under the assumption for natural regeneration. Generally, the growth yield tables were slightly lower than the simulator and plot harvests produced lower values than the simulator. Those lower values, however, do represent projections of what was found on the measured field plots.

2. A step above custodial management, it includes the establishment of plantations. The yield tables were produced by DFSIM. Acres regenerated under ATLAS were projected to have 100 percent of the DFSIM yield volume. Average projected harvest volumes were near the yield table values, reflecting the simulation of actual conditions.

    Planted to 400 TPA

3. Goes further and adds precommercial thinning. Here the average projected harvest volumes were close to the yield table values.

   Planted to 600 TPA.

   Treatment: Precommercial Thinning to 275 TPA at age 15.

4. Goes further and represents regeneration with genetically improved planting stock and a fertilization. A double/triple fertilization was done to represent the a combination of planting with genetically improved planting stock and 1 fertilization treatment (age 40). Due mostly to the influence of actual acres having less volume than the input yields, the projected harvest volumes were generally at or below the input yields.

   Planted to 600 TPA.

   Treatment: Precommercial thinning to 275 TPA at age 15.

   Fertilization--high sites: age 20, 30, and 40 with 200 lbs. nitrogen/acre.

   Fertilization--medium sites: age 30 and 40 with 200 lbs. nitrogen/acre.

5. The same as MI4 with the addition of s commercial thinning that occurred at age 32 for high sites and age 37 for medium sites. Fertilization occurs as it does for MI4, within a few years of commercial thinning and about 5 years prior to the earliest final harvest age. A little less than one third of the basal area was removed in each thinning regime. (Medium and High Sites only.)

   Planted to 600 TPA.

   Treatment: Precommercial thinning to 275 TPA at age 15.

   Fertilization--high sites: age 20, 30, and 40 with 200 lbs. nitrogen/acre.

   Fertilization--medium sites: age 30 and 40 with 200 lbs. nitrogen/acre.

   Commercial thinning: set to age 30 for high

APPENDIX 2: DETAIL OF COST AND ENERGY CONSUMPTION FOR SOUTHEAST AND PACIFIC NORTHWEST MANAGEMENT SCENARIOS

Table A2.1. Southeastern US: Cost and Energy Consumption for all Management Scenarios in Base Case

Southeastern US Scenarios	**25 or 30**	**Year Rotation**
Base Year for Comparison	**25**	**Years**
Average One Way Haul Distance	**57**	**Miles**

Harvesting Systems:

NIPF Low Intensity	Small Feller Buncher / Skidder / Processor
Industrial Low Intensity	Large Feller Buncher / Medium Skidder / Large Processor
Industrial High Intensity	Large Feller Buncher / Medium Skidder / Large Processor

	NIPF / Low Intensity	**NIPF / High Intensity or Industrial / Low Intensity**	**Industrial / High Intensity**	**Average**	
Percent in Classification	37%	58%	5%		
Volume	**3,145**	**3,403**	**4,609**	**3,368**	**Cubic Feet / Acre**
Rotation Age	**30**	**25**	**25**		**Years**
Avg per Year	**105**	**136**	**184**	**127**	**CuFt/Acre/Year**
Avg Volume	**2,621**	**3,403**	**4,609**	**3,174**	**CuFt/Ac @ 25**
% Lumber	**38.1%**	**31.4%**	**51.6%**	**34.9%**	
% Pulpwood	**61.9%**	**68.6%**	**48.4%**	**65.1%**	

Note: Lumber includes both Sawtimber and Chip and Saw Volumes

System Costs					
Seedling,					
Site Prep,	**$ 127.00**	**$ 262.00**	**$ 497.00**	**$ 223.80**	**Dollars per Acre**
Plant, Thin	$ 0.048	$ 0.077	$ 0.108	$ 0.068	Dollars / Cubic Foot
Stump to	**$ 860**	**$ 1,148**	**$ 1,554**	**$ 1,062**	**Dollars per Acre**
Truck	$ 0.328	$ 0.337	$ 0.337	$ 0.334	Dollars / Cubic Foot
Hauling	**57**	**Miles**			
Truck to	**$ 906**	**$ 1,176**	**$ 1,593**	**$ 1,097**	**Dollars per Acre**
Mill	$ 0.346	$ 0.346	$ 0.346	$ 0.346	Dollars / Cubic Foot
Total Cost	**$ 1,766**	**$ 2,324**	**$ 3,147**	**$ 2,158**	**Dollars per Acre**
	$ 0.674	$ 0.683	$ 0.683	$ 0.679	Dollars / Cubic Foot

Table A2.1. Southeastern US Base Case (continued)

	NIPF / Low Intensity	NIPF / High Intensity or Industrial / Low Intensity	Industrial / High Intensity	Average	
Electric, Fuel and Lubricant Consumption					
Seedling, Site Prep, Plant, Thin					
Fuel	**8.32**	**14.02**	**20.34**	**12.23**	**Gallons / Acre**
	0.0032	0.0041	0.0044	0.0038	Gallons / Cubic Foot
Lubricants	**0.15**	**0.25**	**0.37**	**0.22**	**Gallons / Acre**
	0.00006	0.00007	0.00008	0.00007	Gallons / Cubic Foot
Electricity	**11.36**	**11.36**	**11.36**	**11.36**	KwH / Acre
	0.0043	0.0033	0.0025	0.0037	KwH / Cubic Foot
Stump to Truck					
Fuel (Diesel)	**53.9**	**76.8**	**104.0**	**69.7**	**Gallons / Acre**
	0.0206	0.0226	0.0226	0.0218	Gallons / Cubic Foot
Lubricants	**1.0**	**1.4**	**1.9**	**1.3**	**Gallons / Acre**
	0.0004	0.0004	0.0004	0.0004	Gallons / Cubic Foot
Hauling	**57**	**Miles**			
Fuel (Diesel)	**82.3**	**106.9**	**144.8**	**99.7**	**Gallons / Acre**
	0.0314	0.0314	0.0314	0.0314	Gallons / Cubic Foot
Lubricants	**1.5**	**1.9**	**2.6**	**1.8**	**Gallons / Acre**
	0.0006	0.0006	0.0006	0.0006	Gallons / Cubic Foot
Total Planting and Harvest Operation					
Fuel (All)	**144.6**	**197.7**	**269.1**	**181.6**	**Gallons / Acre**
	0.0552	0.0581	0.0584	0.0570	Gallons / Cubic Foot
Lubricants	**2.6**	**3.6**	**4.8**	**3.3**	**Gallons / Acre**
	0.0010	0.0010	0.0011	0.0010	Gallons / Cubic Foot

Table A2.1. Southeastern US Base Case (continued)

	NIPF / Low Intensity	NIPF / High Intensity or Industrial / Low Intensity	Industrial / High Intensity	Average	
Fertilizer					
Nitrogen	**0.125**	**236.125**	**636.125**	**168.805**	**Pounds / Acre**
	0.0000	0.0694	0.1380	0.0472	Pounds / Cubic Foot
Phosphate	**0.006**	**40.006**	**115.006**	**28.956**	**Pounds / Acre**
	0.0000	0.0118	0.0250	0.0081	Pounds / Cubic Foot
Potassium	**0.075**	**0.075**	**0.075**	**0.075**	**Pounds / Acre**
	0.0000	0.0000	0.0000	0.0000	Pounds / Cubic Foot

Carbon Pools at End of Rotation

	Average Annual Standing Carbon Pools over Rotation				
Stem	25,367	20,812	24,906	22,702	**Pounds / Acre**
Crown	7,984	6,995	8,554	7,439	**Pounds / Acre**
Roots	9,086	7,491	8,623	8,138	**Pounds / Acre**
Total	***42,437***	***35,298***	***42,083***	***38,279***	**Pounds / Acre**
Standing Carbon Prior to Harvest					
Stem	42,659	37,563	42,453	39,693	**Pounds / Acre**
Crown	12,502	11,538	13,122	11,974	**Pounds / Acre**
Roots	14,179	12,897	14,343	13,444	**Pounds / Acre**
Total	***69,341***	***61,997***	***69,918***	***65,111***	**Pounds / Acre**
Removed Through Thinnings and Final Harvest					
Stem	42,659	53,697	70,158	50,436	**Pounds / Acre**
Crown	11,945	15,261	20,216	14,282	**Pounds / Acre**
Roots	-	-	-	-	**Pounds / Acre**
Total	***54,603***	***68,958***	***90,374***	***64,717***	**Pounds / Acre**
	16.28	*15.78*	*15.22*	*15.94*	*Pounds / Cubic Foot*

Pounds / cubic foot based on stem volume divided by merchantable cubic feet

Percent of Full Rotation Harvested			
	83.33%	100.00%	100.00%

Stem Carbon: **Carbon in Stem + Bark**

Crown Carbon: **Carbon in Branches + Foliage - Litter**

Roots: **Carbon in Course and Fine Roots**

Table A2.2. Southeastern US: Cost and Energy Consumption for all Management Scenarios in Alternate Case

Southeastern US Scenarios	**25 or 30**	**Year Rotation**
Base Year for Comparison	**25**	**Years**
Average One Way Haul Distance	**57**	**Miles**

Harvesting Systems:

NIPF Low Intensity	Small Feller Buncher / Skidder / Processor
Industrial Low Intensity	Large Feller Buncher / Medium Skidder / Large Processor
Industrial High Intensity	Large Feller Buncher / Medium Skidder / Large Processor

	NIPF / Low Intensity	**NIPF / High Intensity or Industrial / Low Intensity**	**Industrial / High Intensity**	**Average**	
Percent in Classification	0%	37%	63%		
Volume	**3,145**	**3,403**	**4,609**	**4,163**	**Cubic Feet / Acre**
Rotation Age	**30**	**25**	**25**		**Years**
Avg per Year	**105**	**136**	**184**	**167**	**CuFt/Acre/Year**
Avg Volume	**2,621**	**3,403**	**4,609**	**4,163**	**CuFt/Ac @ 25**
% Lumber	**38.1%**	**31.4%**	**51.6%**	**44.1%**	
% Pulpwood	**61.9%**	**68.6%**	**48.4%**	**55.9%**	

Note: Lumber includes both Sawtimber and Chip and Saw Volumes

System Costs					
Seedling, Site Prep, Plant, Thin	**$ 127.00**	**$ 262.00**	**$ 497.00**	**$ 410.05**	**Dollars per Acre**
	$ 0.048	$ 0.077	$ 0.108	$ 0.096	Dollars / Cubic Foot
Stump to Truck	**$ 860**	**$ 1,148**	**$ 1,554**	**$ 1,404**	**Dollars per Acre**
	$ 0.328	$ 0.337	$ 0.337	$ 0.337	Dollars / Cubic Foot
Hauling	**57**	**Miles**			
Truck to Mill	**$ 906**	**$ 1,176**	**$ 1,593**	**$ 1,439**	**Dollars per Acre**
	$ 0.346	$ 0.346	$ 0.346	$ 0.346	Dollars / Cubic Foot
Total Cost	**$ 1,766**	**$ 2,324**	**$ 3,147**	**$ 2,842**	**Dollars per Acre**
	$ 0.674	$ 0.683	$ 0.683	$ 0.683	Dollars / Cubic Foot

Table A2.2. Southeastern US Alternate Case (continued)

	NIPF / Low Intensity	NIPF / High Intensity or Industrial / Low Intensity	Industrial / High Intensity	Average	
Electric, Fuel and Lubricant Consumption					
Seedling, Site Prep, Plant, Thin					
Fuel	**8.32**	**14.02**	**20.34**	**18.00**	**Gallons / Acre**
	0.0032	0.0041	0.0044	0.0043	Gallons / Cubic Foot
Lubricants	**0.15**	**0.25**	**0.37**	**0.32**	**Gallons / Acre**
	0.00006	0.00007	0.00008	0.00008	Gallons / Cubic Foot
Electricity	**11.36**	**11.36**	**11.36**	**11.36**	KwH / Acre
	0.0043	0.0033	0.0025	0.0028	KwH / Cubic Foot
Stump to Truck					
Fuel (Diesel)	**53.9**	**76.8**	**104.0**	**93.9**	**Gallons / Acre**
	0.0206	0.0226	0.0226	0.0226	Gallons / Cubic Foot
Lubricants	**1.0**	**1.4**	**1.9**	**1.7**	**Gallons / Acre**
	0.0004	0.0004	0.0004	0.0004	Gallons / Cubic Foot
Hauling	**57**	**Miles**			
Fuel (Diesel)	**82.3**	**106.9**	**144.8**	**130.8**	**Gallons / Acre**
	0.0314	0.0314	0.0314	0.0314	Gallons / Cubic Foot
Lubricants	**1.5**	**1.9**	**2.6**	**2.4**	**Gallons / Acre**
	0.0006	0.0006	0.0006	0.0006	Gallons / Cubic Foot
Total Planting and Harvest Operation					
Fuel (All)	**144.6**	**197.7**	**269.1**	**242.7**	**Gallons / Acre**
	0.0552	0.0581	0.0584	0.0583	Gallons / Cubic Foot
Lubricants	**2.6**	**3.6**	**4.8**	**4.4**	**Gallons / Acre**
	0.0010	0.0010	0.0011	0.0010	Gallons / Cubic Foot

Table A2.2. Southeastern US Alternate Case (continued)

	NIPF / Low Intensity	NIPF / High Intensity or Industrial / Low Intensity	Industrial / High Intensity	Average	
Fertilizer					
Nitrogen	**0.125**	**236.125**	**636.125**	**488.125**	**Pounds / Acre**
	0.0000	0.0694	0.1380	0.1126	Pounds / Cubic Foot
Phosphate	**0.006**	**40.006**	**115.006**	**87.256**	**Pounds / Acre**
	0.0000	0.0118	0.0250	0.0201	Pounds / Cubic Foot
Potassium	**0.075**	**0.075**	**0.075**	**0.075**	**Pounds / Acre**
	0.0000	0.0000	0.0000	0.0000	Pounds / Cubic Foot

Carbon Pools at End of Rotation					
Average Annual Standing Carbon Pools over Rotation					
Stem	25,367	20,812	24,906	23,391	**Pounds / Acre**
Crown	7,984	6,995	8,554	7,977	**Pounds / Acre**
Roots	9,086	7,491	8,623	8,204	**Pounds / Acre**
Total	***42,437***	***35,298***	***42,083***	***39,572***	**Pounds / Acre**
Standing Carbon Prior to Harvest					
Stem	42,659	37,563	42,453	40,643	**Pounds / Acre**
Crown	12,502	11,538	13,122	12,536	**Pounds / Acre**
Roots	14,179	12,897	14,343	13,808	**Pounds / Acre**
Total	***69,341***	***61,997***	***69,918***	***66,988***	**Pounds / Acre**
Removed Through Thinnings and Final Harvest					
Stem	42,659	53,697	70,158	64,067	**Pounds / Acre**
Crown	11,945	15,261	20,216	18,383	**Pounds / Acre**
Roots	-	-	-	-	**Pounds / Acre**
Total	***54,603***	***68,958***	***90,374***	***82,450***	**Pounds / Acre**
	16.28	*15.78*	*15.22*	*15.43*	*Pounds / Cubic Foot*

Pounds / cu ft based on stem volume divided by merchantable cubic feet

Percent of Full Rotation Harvested

	83.33%	100.00%	100.00%

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

Table A2.3. Pacific Northwest: Cost and Energy Consumption for all Management Scenarios in Base Case

Pacific Northwest Scenarios	**45**	**Year Rotation**
Base Year for Comparison	**45**	**Years**
Average One Way Haul Distance	**75**	**Miles**
Harvesting Systems:		
Low Productivity / Mgmt Intensity	Hand Fell and Buck at Stump	
Mid Productivity / Mgmt Intensity	Cable Yarding to Landing	
High Productivity / Mgmt Intensity	Load and Haul	

	Low Intensity	**Medium Intensity**	**High Intensity**	**Average**	
Percent in Classification	42%	46%	12%		
Volume	**6,186**	**7,002**	**11,171**	**7,159**	**Cubic Feet / Acre**
Rotation Age	**45**	**45**	**45**		**Years**
Avg per Year	**137**	**156**	**248**	**159**	**CuFt/Acre/Year**
Avg Volume	**6,186**	**7,002**	**11,171**	**7,159**	**CuFt/Ac @ 45**
% Lumber	**100.0%**	**100.0%**	**100.0%**	**100.0%**	
% Pulpwood	**0.0%**	**0.0%**	**0.0%**	**0.0%**	

System Costs					
Seedling,					
Site Prep,	**$ 243.34**	**$ 263.34**	**$ 263.34**	**$ 254.94**	**Dollars per Acre**
Plant, Thin	$ 0.039	$ 0.038	$ 0.024	$ 0.037	Dollars / Cubic Foot
Stump to	**$ 1,754**	**$ 2,462**	**$ 3,646**	**$ 2,307**	**Dollars per Acre**
Truck	$ 0.284	$ 0.352	$ 0.326	$ 0.320	Dollars / Cubic Foot
Hauling	**75**	**Miles**			
Truck to	**$ 2,813**	**$ 3,184**	**$ 5,079**	**$ 3,255**	**Dollars per Acre**
Mill	$ 0.455	$ 0.455	$ 0.455	$ 0.455	Dollars / Cubic Foot
Total Cost	**$ 4,567**	**$ 5,646**	**$ 8,725**	**$ 5,562**	**Dollars per Acre**
	$ 0.738	$ 0.806	$ 0.781	$ 0.775	Dollars / Cubic Foot

Table A2.3. Pacific Northwest Base Case (continued)

	Low Intensity	Medium Intensity	High Intensity	Average	
Electric, Fuel and Lubricant Consumption					
Seedling, Site Prep, Plant, Thin					
Fuel	**3.98**	**5.29**	**5.29**	**4.74**	**Gallons / Acre**
	0.0006	0.0008	0.0005	0.0007	Gallons / Cubic Foot
Lubricants	**0.07**	**0.10**	**0.10**	**0.09**	**Gallons / Acre**
	0.00001	0.00001	0.00001	0.00001	Gallons / Cubic Foot
Electricity	**16.81**	**25.22**	**25.22**	**21.69**	KwH / Acre
	0.0027	0.0036	0.0023	0.0031	KwH / Cubic Foot
Stump to Truck					
Fuel (Diesel)	**114.1**	**164.5**	**241.5**	**152.6**	**Gallons / Acre**
	0.0184	0.0235	0.0216	0.0212	Gallons / Cubic Foot
Lubricants	**2.1**	**3.0**	**4.3**	**2.7**	**Gallons / Acre**
	0.0003	0.0004	0.0004	0.0004	Gallons / Cubic Foot
Hauling	**75**	**Miles**			
Fuel (Diesel)	**255.7**	**289.4**	**461.7**	**295.9**	**Gallons / Acre**
	0.0413	0.0413	0.0413	0.0413	Gallons / Cubic Foot
Lubricants	**4.6**	**5.2**	**8.3**	**5.3**	**Gallons / Acre**
	0.0007	0.0007	0.0007	0.0007	Gallons / Cubic Foot
Total Planting and Harvest Operation					
Fuel (All)	**373.8**	**459.3**	**708.6**	**453.3**	**Gallons / Acre**
	0.0604	0.0656	0.0634	0.0632	Gallons / Cubic Foot
Lubricants	**6.7**	**8.3**	**12.8**	**8.2**	**Gallons / Acre**
	0.0011	0.0012	0.0011	0.0011	Gallons / Cubic Foot

Table A2.3. Pacific Northwest Base Case (continued)

	Low Intensity	Medium Intensity	High Intensity	Average	
Fertilizer					
Nitrogen	**0.038**	**0.057**	**354.057**	**42.53**	**Pounds / Acre**
	0.0000	0.0000	0.0317	0.0038	Pounds / Cubic Foot
Phosphate	**0.063**	**0.095**	**60.095**	**7.28**	**Pounds / Acre**
	0.0000	0.0000	0.0054	0.0007	Pounds / Cubic Foot
Potassium	**0.154**	**0.232**	**0.232**	**0.20**	**Pounds / Acre**
	0.0000	0.0000	0.0000	0.0000	Pounds / Cubic Foot
Carbon Pools at End of Rotation					
Average of Standing Carbon Pools over Rotation					
Stem	55,521	55,710	76,083	58,075	**Pounds / Acre**
Crown	11,405	10,520	12,547	11,135	**Pounds / Acre**
Roots	12,396	12,653	17,745	13,156	**Pounds / Acre**
Total	***79,322***	***78,882***	***106,376***	**82,366**	**Pounds / Acre**
Standing Carbon Prior to Harvest					
Stem	122,114	109,326	184,638	123,735	**Pounds / Acre**
Crown	21,632	17,068	25,021	19,939	**Pounds / Acre**
Roots	27,960	25,639	44,505	28,878	**Pounds / Acre**
Total	***171,707***	***152,033***	***254,164***	**172,552**	**Pounds / Acre**
Removed Through Thinnings and Final Harvest					
Stem	119,622	140,312	206,075	139,514	**Pounds / Acre**
Crown	-	-	-	-	**Pounds / Acre**
Roots	-	-	-	-	**Pounds / Acre**
Total	***119,622***	***140,312***	***206,075***	**139,514**	**Pounds / Acre**
	19.34	*20.04*	*18.45*	*19.55*	Pounds / Cubic Foot

Pounds / cubic foot based on stem volume divided by merchantable cubic feet

Percent of Full Rotation Harvested

	Low Intensity	Medium Intensity	High Intensity
	100.00%	100.00%	100.00%

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

Table A2.4. Pacific Northwest: Cost and Energy Consumption for all Management Scenarios in Alternate Case

Pacific Northwest Scenarios	**45**	**Year Rotation**
Base Year for Comparison	**45**	**Years**
Average One Way Haul Distance	**75**	**Miles**
Harvesting Systems:		
Low Productivity / Mgmt Intensity	Hand Fell and Buck at Stump	
Mid Productivity / Mgmt Intensity	Cable Yarding to Landing	
High Productivity / Mgmt Intensity	Load and Haul	

	Low Intensity	**Medium Intensity**	**High Intensity**	**Average**		
Percent in Classification	24%	40%	36%			
Volume	**6,186**	**7,002**	**11,171**	**8,307**	**Cubic Feet / Acre**	
Rotation Age	**45**	**45**	**45**		**Years**	
Avg per Year	**137**	**156**	**248**	**185**	**CuFt/Acre/Year**	
Avg Volume	**6,186**	**7,002**	**11,171**	**8,307**	**CuFt/Ac @**	**45**
% Lumber	**100.0%**	**100.0%**	**100.0%**	**100.0%**		
% Pulpwood	**0.0%**	**0.0%**	**0.0%**	**0.0%**		

System Costs					
Seedling,					
Site Prep,	**$ 243.34**	**$ 263.34**	**$ 263.34**	**$ 258.54**	**Dollars per Acre**
Plant, Thin	$ 0.039	$ 0.038	$ 0.024	$ 0.033	Dollars / Cubic Foot
Stump to	**$ 1,754**	**$ 2,462**	**$ 3,646**	**$ 2,718**	**Dollars per Acre**
Truck	$ 0.284	$ 0.352	$ 0.326	$ 0.326	Dollars / Cubic Foot
Hauling	**75**	**Miles**			
Truck to	**$ 2,813**	**$ 3,184**	**$ 5,079**	**$ 3,777**	**Dollars per Acre**
Mill	$ 0.455	$ 0.455	$ 0.455	$ 0.455	Dollars / Cubic Foot
Total Cost	**$ 4,567**	**$ 5,646**	**$ 8,725**	**$ 6,495**	**Dollars per Acre**
	$ 0.738	$ 0.806	$ 0.781	$ 0.781	Dollars / Cubic Foot

Table A2.4. Pacific Northwest Alternate Case (continued)

	Low Intensity	Medium Intensity	High Intensity	Average	
Electric, Fuel and Lubricant Consumption					
Seedling, Site Prep, Plant, Thin					
Fuel	**3.98**	**5.29**	**5.29**	**4.98**	**Gallons / Acre**
	0.0006	0.0008	0.0005	0.0006	Gallons / Cubic Foot
Lubricants	**0.07**	**0.10**	**0.10**	**0.09**	**Gallons / Acre**
	0.00001	0.00001	0.00001	0.00001	Gallons / Cubic Foot
Electricity	**16.81**	**25.22**	**25.22**	**23.20**	KwH / Acre
	0.0027	0.0036	0.0023	0.0029	KwH / Cubic Foot
Stump to Truck					
Fuel (Diesel)	**114.1**	**164.5**	**241.5**	**180.2**	**Gallons / Acre**
	0.0184	0.0235	0.0216	0.0216	Gallons / Cubic Foot
Lubricants	**2.1**	**3.0**	**4.3**	**3.2**	**Gallons / Acre**
	0.0003	0.0004	0.0004	0.0004	Gallons / Cubic Foot
Hauling	**75**	**Miles**			
Fuel (Diesel)	**255.7**	**289.4**	**461.7**	**343.4**	**Gallons / Acre**
	0.0413	0.0413	0.0413	0.0413	Gallons / Cubic Foot
Lubricants	**4.6**	**5.2**	**8.3**	**6.2**	**Gallons / Acre**
	0.0007	0.0007	0.0007	0.0007	Gallons / Cubic Foot
Total Planting and Harvest Operation					
Fuel (All)	**373.8**	**459.3**	**708.6**	**528.5**	**Gallons / Acre**
	0.0604	0.0656	0.0634	0.0636	Gallons / Cubic Foot
Lubricants	**6.7**	**8.3**	**12.8**	**9.5**	**Gallons / Acre**
	0.0011	0.0012	0.0011	0.0011	Gallons / Cubic Foot
Fertilizer					
Nitrogen	**0.038**	**0.057**	**354.057**	**127.49**	**Pounds / Acre**
	0.0000	0.0000	0.0317	0.0114	Pounds / Cubic Foot
Phosphate	**0.063**	**0.095**	**60.095**	**21.69**	**Pounds / Acre**
	0.0000	0.0000	0.0054	0.0019	Pounds / Cubic Foot
Potassium	**0.154**	**0.232**	**0.232**	**0.21**	**Pounds / Acre**
	0.0000	0.0000	0.0000	0.0000	Pounds / Cubic Foot

Table A2.4. Pacific Northwest Alternate Case (continued)

	Low Intensity	Medium Intensity	High Intensity	Average	
Carbon Pools at End of Rotation					
Average of Standing Carbon Pools over Rotation					
Stem	55,521	55,710	76,083	62,999	**Pounds / Acre**
Crown	11,405	10,520	12,547	11,462	**Pounds / Acre**
Roots	12,396	12,653	17,745	14,424	**Pounds / Acre**
Total	***79,322***	***78,882***	***106,376***	**88,885**	**Pounds / Acre**
Standing Carbon Prior to Harvest					
Stem	122,114	109,326	184,638	139,508	**Pounds / Acre**
Crown	21,632	17,068	25,021	21,026	**Pounds / Acre**
Roots	27,960	25,639	44,505	32,988	**Pounds / Acre**
Total	***171,707***	***152,033***	***254,164***	**193,522**	**Pounds / Acre**
Removed Through Thinnings and Final Harvest					
Stem	119,622	140,312	206,075	159,021	**Pounds / Acre**
Crown	-	-	-	-	**Pounds / Acre**
Roots	-	-	-	-	**Pounds / Acre**
Total	***119,622***	***140,312***	***206,075***	**159,021**	**Pounds / Acre**
	19.34	*20.04*	*18.45*	*19.30*	Pounds / Cubic Foot

Pounds / cubic foot based on stem volume divided by merchantable cubic feet

Percent of Full Rotation Harvested

	Low Intensity	Medium Intensity	High Intensity
	100.00%	100.00%	100.00%

Stem Carbon: **Carbon in Stem + Bark**
Crown Carbon: **Carbon in Branches + Foliage - Litter**
Roots: **Carbon in Course and Fine Roots**

APPENDIX 3: CHANGES IN CARBON POOLS WITH TIME

Appendix 3 contains figures that illustrate the changes in annual production of carbon and in standing carbon inventories through the life of the stands. Carbon levels were developed by tree component for each of the Southeastern US and Pacific Northwest scenarios. A weighted average for each of the regions was calculated from the annual scenario results. The values plotted represent the weighted averages.

The weighted average reflects carbon values for years 1 through 25 for the Southeastern scenarios and years 1 through 45 for those in the Pacific Northwest. Although the low intensity scenario in the Southeast has a rotation age of 30 years, the first 25 years of that rotation were used in developing the weighted average.

Figures A3.1 and A3.2 portray annual carbon production in the Southeast for the base case and alternative case. The figures show that the rate of carbon production increases through the first 15 years of the rotation, illustrate the decrease in carbon production immediately following thinning, and then shows a steady state of carbon production through the remaining years of the rotation.

The resulting standing carbon pools are illustrated in Figures A3.3 and A3.4 for the Southeastern US. The pools show a steady increase in standing carbon with dips at the point of the commercial thinning and a final decrease at harvest time. The carbon remaining after harvest represents the carbon in foliage and roots that are not removed from the site.

Figures A3.5 and A3.6 illustrate the standing carbon pools for the Pacific Northwest. The patterns are similar to those for the southeast. The flattened areas in the middle of the rotation reflect the commercial thinning activities. The carbon remaining after harvest represents carbon in roots, branches and the non-merchantable portion of the stem.

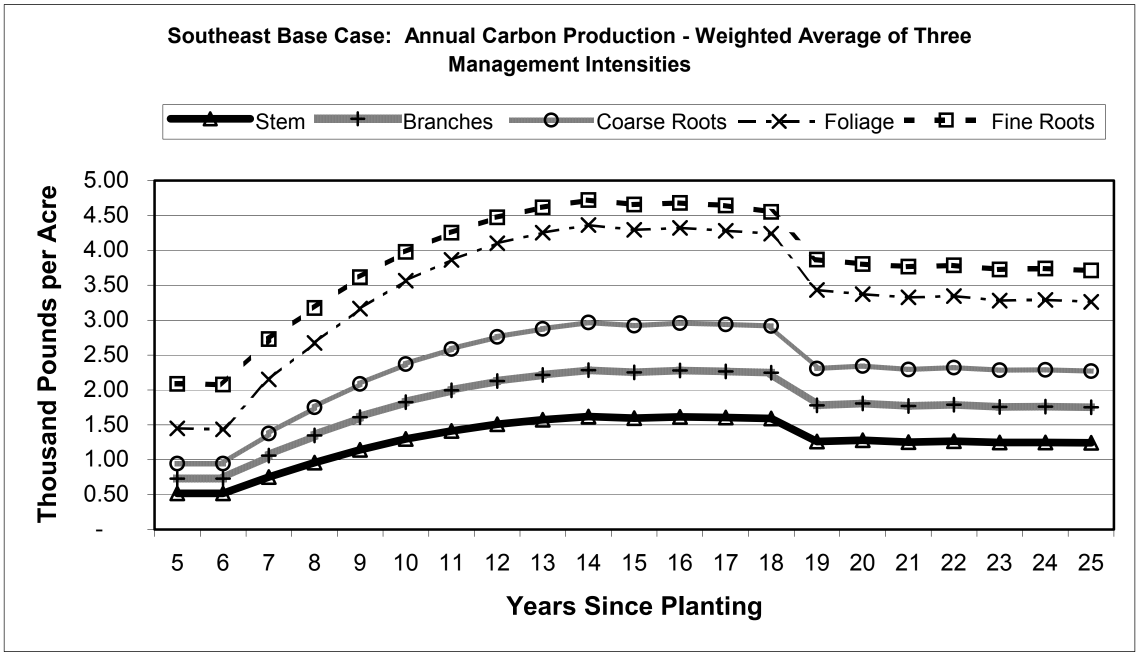

Figure A3.1. **Annual Carbon Production for Southeastern US Conditions –Base Case Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications.

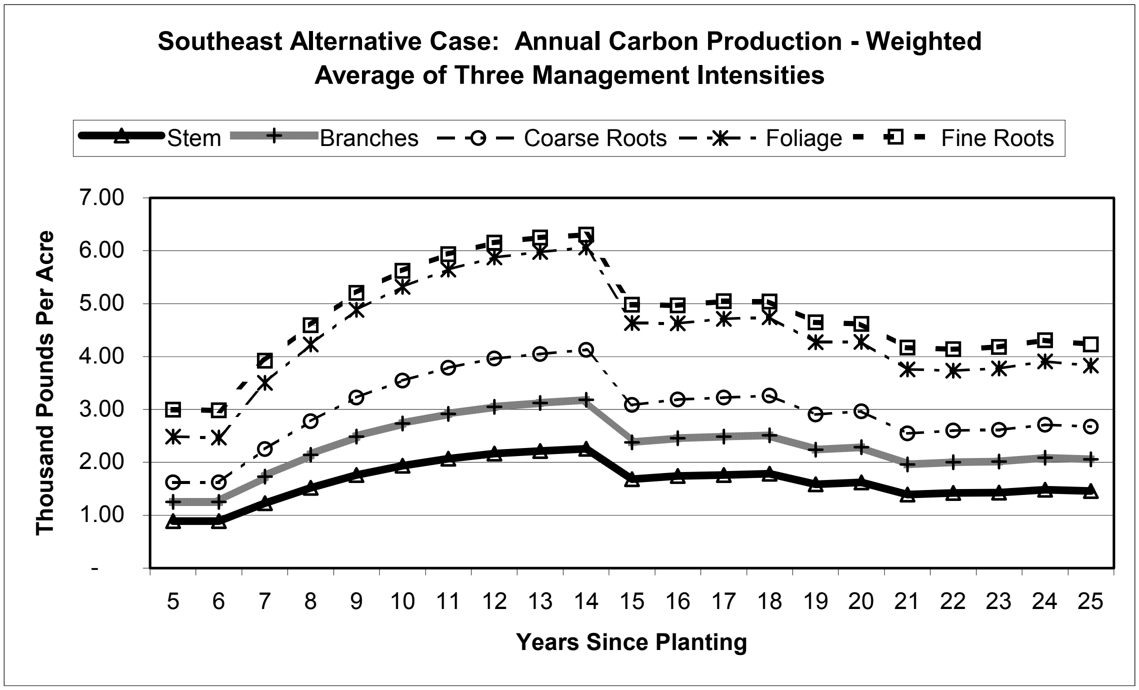

Figure A3.2. **Annual Carbon Production for Southeastern US Conditions – Alternative Case Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications.

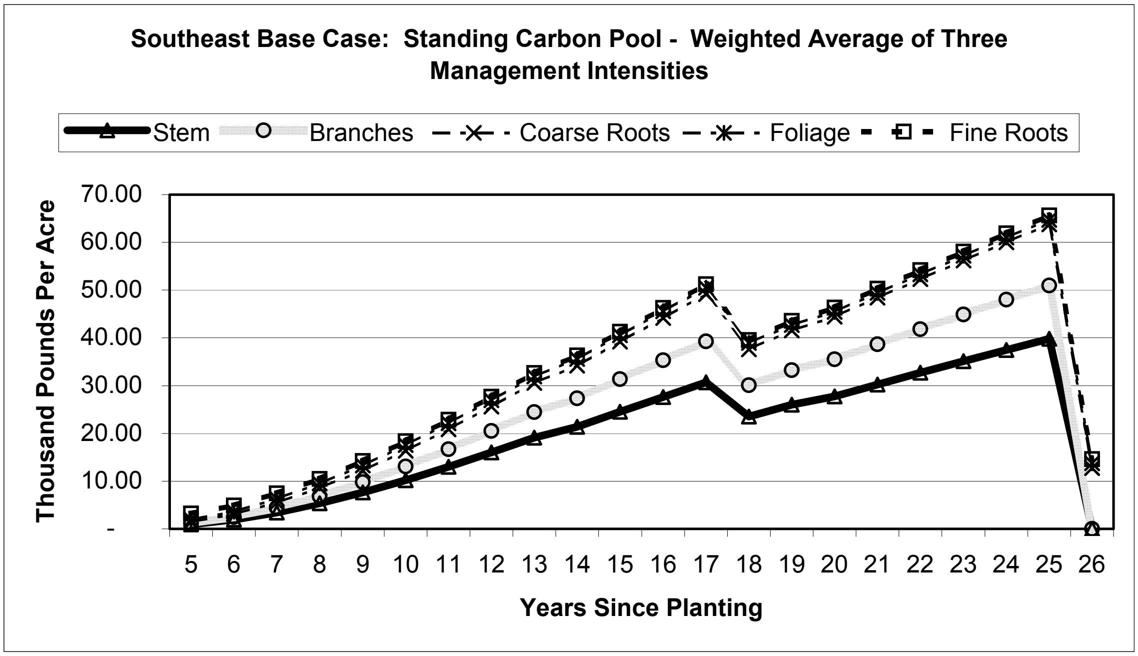

Figure A3.3. **Standing Carbon Pool for Southeastern US Conditions – Base Case Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications

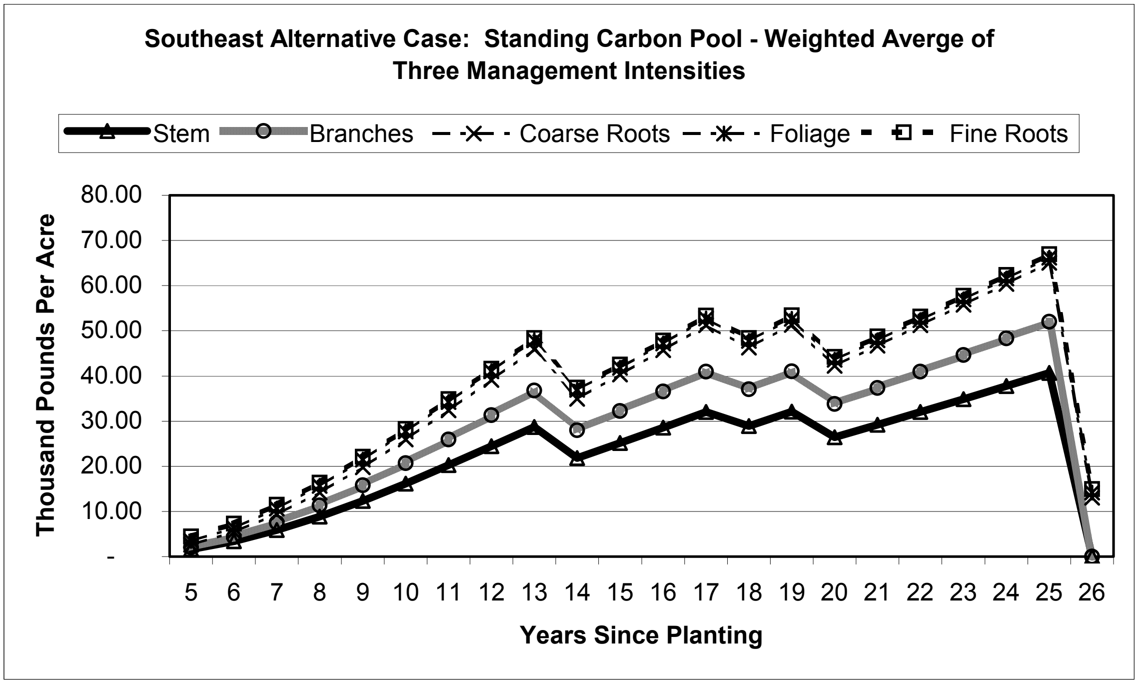

Figure A3.4. **Standing Carbon Pool for Southeastern US Conditions --- Alternative Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications

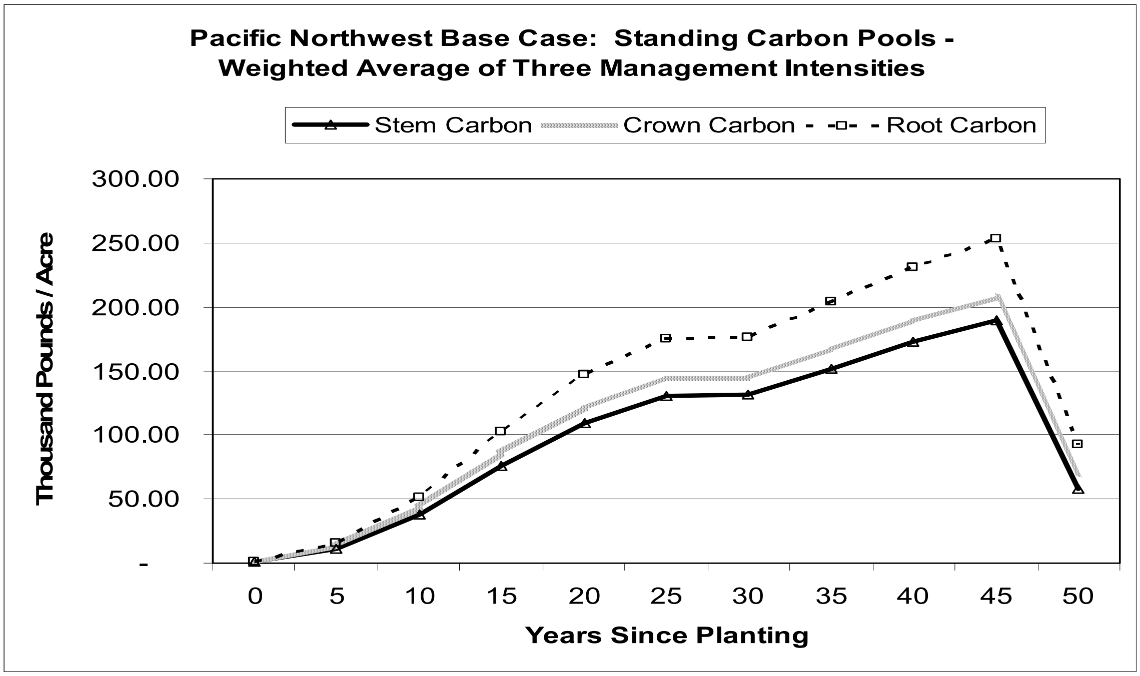

Figure A3.5. **Standing Carbon Pool for Pacific Northwest Conditions – Base Case Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications.

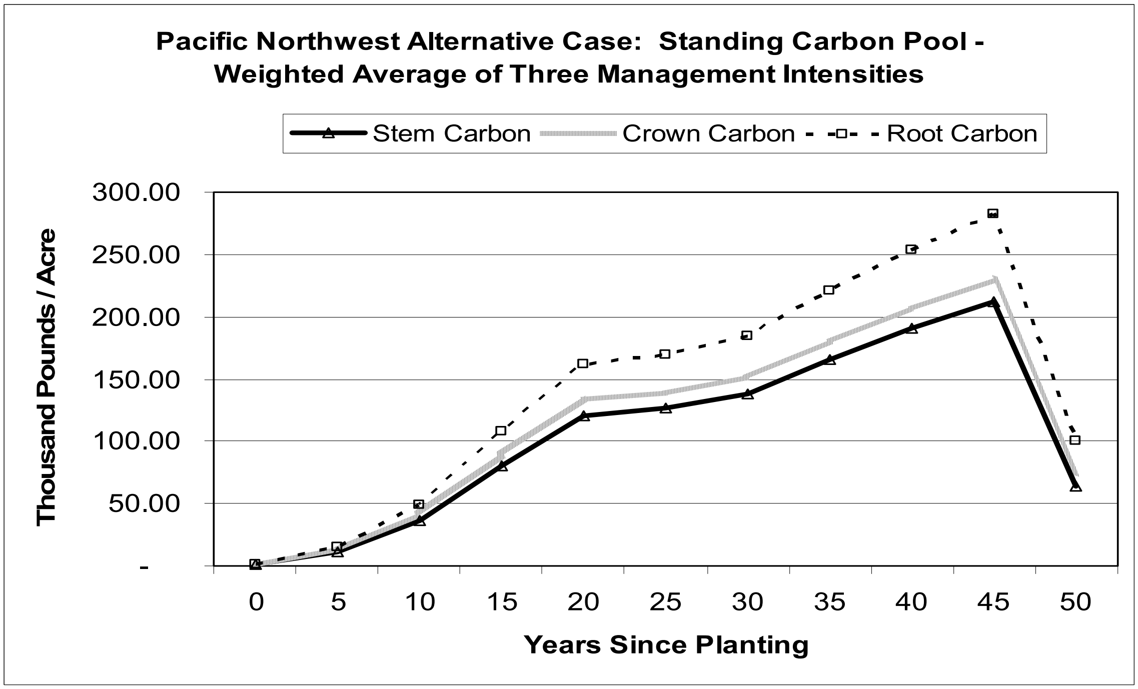

Figure A3.6. **Standing Carbon Pool for Pacific Northwest Conditions --- Alternative Scenario**
Notes: Developed as a weighted average of three site productivity / management intensity classifications