UNIVERSITY OF MINNESOTA

CENTER FOR TRANSPORTATION STUDIES

RESEARCH REPORT

IDENTIFYING POTENTIAL SITES FOR ENERGY PRODUCTION FROM WOODY BIOMASS

College of Natural Resources

Dietmar Rose • Syed A. Husain

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
CTS 97-01		

4. Title and Subtitle	5. Report Date
Identifying Potential Sites for Energy Production from Woody Biomass	December 1997
	6.

7. Author(s)	8. Performing Organization Report No.
Dietmar Rose	

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
College of Natural Resources University of Minnesota St. Paul, MN 55108	
	11. Contract (C) or Grant (G) No. (C) (G)

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Center for Transportation Studies 200 Transportation and Safety Building 511 Washington Ave SE Minneapolis, MN 55455	Final Report 1996
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This study examined the economic potential of producing short-rotation hybrid poplar on agricultural lands enrolled in the Conservation Reserve Program (CRP) to support biomass requirements of two proposed powerplants and to supplement industrial timber requirements in Minnesota. Timber product demands at six aggregated traditional forest markets and biomass demands at two power plant locations currently under consideration were considered over a hundred year planning horizon.

The modeling effort consisted of a spatial and dynamic optimization model with a built in harvest scheduling model, a forest growth model, and a transportation model based on the actual road network. Initially, the model was used to derive optimal wood energy cost and supply schedules using only agricultural lands. The model was then expanded to include forest lands and the timber requirements of the forest industries within the state. Forest lands were modeled under environmentally restricted and unrestricted management practices to determine the cost of environmental mitigation. The scheduling model identified supply schedules reflecting the optimal location of timber and biomass production for each demand center under several land base and cost assumptions. The marginal cost of delivered timber products, location and quantity of forest and agricultural lands harvested, and total costs of meeting the demand target goals in each planning period are also estimated.

17. Document Analysis/Descriptors	18. Availability Statement
Energy production Timber products	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	108	

Identifying Potential Sites for Energy Production from Woody Biomass

Prepared by

Dietmar W. Rose

College of Natural Resources
University of Minnesota
St. Paul 55108

Syed A. Husain

College of Natural Resources
University of Minnesota
St. Paul 55108

May 1997

Published by

Center for Transportation Studies
200 Transportation and Safety Building
511 Washington Ave. S.E.
Minneapolis, MN 55455

Funding Acknowledgments

This research was made possible with major funding provided by the Center for Transportation Studies and the Consortium for Plant Biotechnology Research. Support from the California Electric Power Research Institute, Minnesota Power and Light, the Potlatch Corporation, Biose Cascade Corporation, and the Blandin Paper Company is also acknowledged.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Maps

Executive Summary

This study examined the economic potential of producing short-rotation hybrid poplar on agricultural lands enrolled in the Conservation Reserve Program (CRP) to support biomass requirements of two proposed powerplants and to supplement industrial timber requirements in Minnesota. Timber product demands at six aggregated traditional forest markets and biomass demands at two power plant locations currently under consideration were considered over a hundred year planning horizon.

The modeling effort consisted of a spatial and dynamic optimization model with a built in harvest scheduling model, a forest growth model, and a transportation model based on the actual road network. Initially, the model was used to derive optimal wood energy cost and supply schedules using only agricultural lands. The model was then expanded to include forest lands and the timber requirements of the forest industries within the state. Forest lands were modeled under environmentally restricted and unrestricted management practices to determine the cost of environmental mitigation. The scheduling model identified supply schedules reflecting the optimal location of timber and biomass production for each demand center under several land base and cost assumptions. The marginal cost of delivered timber products, location and quantity of forest and agricultural lands harvested, and total costs of meeting the demand target goals in each planning period are also estimated. The following are the key findings of this study:

- Delivered fuelwood costs were shown to be in a range which makes it an attractive renewable energy alternative.

- Transportation costs impact the competitiveness of individual producers and result in locational advantages for some and disadvantages for others. The two power plant sites examined in the research, Alexandria and Granite Falls, appear to be poor choices in view of this study.

- Fuel wood needs by the identified powerplants are met from forest lands, mostly the relatively abundant northern hardwood covertype, and wood is transported relatively large distances from the point of wood production to the consumption centers in Alexandria and Granite Falls. This results in more cross traffic on rural roads than necessary under better siting decisions for powerplants and for wood production.

- Since it turns out that the power plants modeled in this study would most cost effectively acquire fuelwood from existing forest lands, substantial savings could be achieved if the plants are located in the northern part of the state where major concentrations of the forest lands exist, rather than the currently proposed southwestern locations

- Short-rotation hybrid poplar wood grown on agricultural lands almost exclusively is transported to forest industrial demand centers far away from the wood production sites as an aspen substitute.

- Land use decisions and policies affecting these decisions in the agriculture and forestry sectors have significant impacts on truck traffic on rural highways as well as on the cost of transporting associated commodities.

- Public pressures for more environmental mitigation of timber harvesting impacts are increasing and are creating severe supply bottlenecks. The study has identified these bottlenecks in terms of where and when they can be expected to occur and have helped identify locations where management intensification might have the greatest benefits in terms of reduced road impacts, transportation costs, and income opportunities for rural farmers.

- Wood production opportunities for specific townships and agricultural lands were identified. Commercial forest lands near these agricultural sites need to be examined as candidates for management intensification. If the associated management investments were made, it might change the opportunities identified for farmers to produce wood.

- The results indicate that industrial demand for all timber products analyzed in this study can be satisfied over the planning horizon, if additional agricultural lands are devoted to poplar production. The addition is made necessary because of aspen, for which existing industrial requirements cannot be sustained over the planning horizon if only existing forest lands are used.

- The combination of restricted forest and agricultural lands results in higher marginal costs than the combination of unrestricted forest and agricultural lands. The difference in these marginal costs shows the opportunity cost of environmental mitigation.

Chapter 1. Introduction

1.1 Background

Consistent increases in market and non-market demands for natural resources are compelling decision makers to rethink current natural resource management policies. This is particularly true for the forest and electric power industries in Minnesota. The demand for forest products has grown substantially in recent years and is expected to continue to grow well into the next century. Public concerns over forest industry expansion and its perceived negative impacts on the environment stimulated preparation of a Generic Environmental Impact Statement [1] which indicated potential constraints in meeting existing and future timber demands in the state. There is a particular shortage expected in aspen production, due to the unequal age distribution of currently growing timber.

Electricity is traditionally produced from non-renewable resources such as coal, natural gas, petroleum, or nuclear energy. Since energy production from these fuels can result in environmental externalities such as emissions of sulphur and carbon, there is an increasing public interest in the possibility of using substitute fuels such as biomass. The use of biomass energy for large scale electricity production is not a new idea. It was throughly examined, for example, during the oil crisis of the mid seventies. This idea was rejected at that time because it was considered cost ineffective when compared to fossil fuels or nuclear energy. Now, thirty years later, biomass energy production is once again gaining public attention. The present study, examines the relationship of the forest and electric power industries by focusing on the use of wood as either a biomass fuel or as a traditional timber product.

Most industry analysts contend that economies of scale require power plants to be relatively large, with correspondingly large fuel requirements. Because biomass production costs are generally low in relation to transportation costs, the latter are a major factor in the potential financial feasibility of electricity generation from biomass. New power generating plants could make use of existing wood supplies, but there is a potential "domino" effect. Using wood for energy production could shift wood supply patterns, deplete long term wood supplies, and potentially even add more pressure on the existing forest inventory.

Increasing demand for wood has resulted in higher timber prices over the recent years. Wood fired power plants would add to this demand and thus further increase timber prices. In order to neutralize these increased demands and prices, it is being advocated that short rotation woody crops (SRWCs) be produced on marginal agricultural lands such as those set aside under the Conservation Reserve Program (CRP). These lands, it is argued, have the potential to provide both fuelwood and timber, thereby reducing harvest pressures on traditional forest lands. This could provide farmers with an additional cash crop assuming that markets will exist. Soil erosion and water contamination concerns might also be reduced because of the relatively long rotation periods associated with SRWCs and reduced reliance on pesticides and herbicides which contribute to water contamination.

Production of SRWCs on agricultural lands might permit some land owners to diversify their crop operations. This is particularly relevant in the light of the 1996 farm bill which incorporates several reforms and structural changes in the United States agricultural policy. In short, agricultural subsidies are to be phased out by 2003. Over that period farmers are free to plant whatever they desire and still receive income subsidies.

The CRP was initiated under the Food Security Act of 1985. Some forty million cropland acres were removed from production for a ten year period. Landowners were given a one time cost share for the establishment of conservation practices and annual contract payments for ten years. Most of these acres will come out of contract by 1999, perhaps to be returned to annual crop production. In the absence of price support programs, this increased production might result in lower crop prices which can have substantial national and international consequences. And because some of the CRP acreage is highly erodible, its return to annual cropping could result in an increase in soil erosion and surface water contamination.

Proponents argue that growing SRWCs on agricultural lands, particularly those which are adjacent to the current forest lands and not highly erodible as energy or fiber plantations might have a positive impact on the economy as well as on the environment. But before energy production plants are built and large investments into farm-grown woody biomass are made, it must be understood how such developments would fit with the existing economic and environmental conditions.

1.2 Study Objectives

In this research, we examine spatial and dynamic interactions among forest resources, agricultural land, and timber and biomass consumers. The linking of agricultural and forestry land resources and production decisions adds a new dimension to previous planning efforts. Expected future timber products demand in six forest markets are modeled for ten 10-year planning periods using forest land and agricultural lands. Then biomass demands for two 100 MW power plants are added. Two sets of forest management options representing traditional and environmentally restricted management practices are used, along with hybrid poplar production on agricultural lands. Estimates of transportation costs are generated using actual road distances between analysis areas and the market locations. This research also generated estimates of delivered biomass costs using only agricultural land parcels under several cost and production assumptions.

A subset of CRP lands is used to represent agricultural lands in Minnesota. These lands are used not because they are any different from traditional croplands, but because by being in the program, we know their characteristics such as location, productivity, and reservation prices. There are three primary objectives pursued in this study.

1. Estimate the delivered fuelwood costs, and the location and acreage of agricultural lands required to fuel two 100 MW power plants.

2. Determine marginal costs, and the location and acreage of lands harvested in each planning period to meet expected timber product requirements, when (1) only commercial forest lands managed under traditional management practices are available for harvest, (2) only commercial forest lands with environmentally accepted management practices are available for harvest, (3) both agricultural and commercial forest lands managed under traditional and environmentally efficient management alternatives are available for harvest.

3. Investigate the impact of biomass demands on the unrestricted and environmentally restricted forest lands, agricultural lands, and timber product markets.

1.3 An Overview of the Study

The plan for the rest of this study is as follows. Chapter 2 presents a background on several components of the research: the land base, SRWC production and harvest technology, and Minnesota's overall timber supply structure. In chapter 3, a discussion of forest management and harvest scheduling model with multiple markets and products is presented. Other modeling components associated with the determination of transportation costs, the assumptions used to model forest growth over time, and application of specific forest management alternatives are also discussed. Chapter 4 provides a complete description of the extensive data collection and data manipulations necessary to calibrate the scheduling and cost models. This location specific data represents the attributes of both forest and agricultural sectors. Chapter 5 presents the results of fuelwood production scenarios using agricultural lands alone. These results reflect the future costs of meeting fuelwood requirements for two potential power plants located in Minnesota. The results are generated by using a combination of linear optimization and cash flow analysis techniques.

Results for all other management scenarios reflecting both forest and agricultural lands are presented in chapter 6. Also, a comparison between scenarios in terms of shadow prices and acreage harvested in each planning period is presented. Chapter 7 concludes with a discussion of policy implications of this research.

6

Chapter 2: Background

2.1 The Conservation Reserve Program

The CRP resulted from public awareness and concern over declining farm prices, huge domestic and international crop surpluses, reduced crop exports, and farm closures reported in the 1970's. These concerns were further enhanced by the assertion that certain traditional crop management practices resulted in soil erosion and other environmental externalities such as the destruction of wildlife habitat, water and air quality, and future soil productivity. Combined lobbying by the agricultural interest groups and environmental interest groups played an important role in the establishment of such a large scale land retirement program. CRP was first authorized by the Food Security Act of 1985 and was then extended by the Food, Agriculture, Conservation, and Trade Act of 1990. The USDA's Farm Service Agency (FSA) is responsible for the implementation of CRP.

Enrollment in CRP programs began in 1986 and continued until 1992, through thirteen sign-up periods. Congress set a target of 40 to 45 million acres nationwide, but only 39 million acres were eventually enrolled. It was specified in the bill that no more than 25 percent of a given county's cropland can be enrolled in the program but there are some exceptions to this rule. Most of these enrollments occurred during 1986-1988 [2]. Annually CRP contract payments cost the federal government almost $1.7 billion.

In order to qualify for enrollment in the CRP, landowners had to remove land from agricultural production for a period of ten years in exchange for annual payments and a one time 50 percent cost-share for establishment of a suitable permanent cover. Only those lands which met pre-specified eligibility criteria could be enrolled. If two-thirds of a field were eligible, then the whole field could be enrolled. Annual payment levels were to be determined by a bidding process, under which landowners bid the minimum amount they would accept annually to retire their eligible cropland from production. The government would choose the lowest bids to meet the target acreage and, therefore, achieve its targets cost effectively. As it turned out, this procedure worked only in the first couple of sign-ups. After that landowners knew the maximum acceptable payment amount for their area, so the bid process was reduced to a flat-rate offer scheme [3]. In most areas annual contract payments were comparable to the annual payment a landowner would receive if the land was rented for cropping [3].

In Minnesota, the peak CRP enrollment was about 1.8 million acres, with an annual cost of $105 million [3]. The contracts on most of this acreage will expire by 1999. Landowners will have to once again decide on the future management and use of these lands.

In the context of this study we assume that all such landowners could grow SRWCs such as hybrid poplar which could be sold to potential power plants or the forest industry. It is understood that there could be a substantial amount of risk associated with such an endeavor but if proper management and establishment procedures are adopted, these risks could be minimized and the potential gains could be large.

2.2 Short Rotation Woody Crops

The history of poplar culture in Europe and Middle East can be traced back to the later part of the sixteenth century. In the United States research records on hybrid poplar date as far back as 1942, but its use was largely limited to windbreaks and landscape trees [4]. Serious research on hybrid poplar as well as other short rotation woody crops (SRWC) did not begin until the late seventies when oil shortages forced policy makers to seek domestic substitutes for imported petroleum products.

The U.S. Department of Energy (DOE) sponsored several research programs to develop and analyze the potential of biomass energy production. The primary objective of these programs was to identify species and production techniques which were capable of producing large amounts of wood in a relatively short time [5].

Considerable progress was made in the development and management of SRWC technology during the late seventies and early eighties. However, this technology was never commercially implemented because of high production costs and uncertainty associated with SRWC biomass production. It was anticipated that relatively small reductions in the production and harvesting costs along with an increase in the fossil fuel prices or hardwood chip values would result in the wide adoption of this technology in the near future [6].

Species

SRWC operations can be defined as the production of trees for harvest within ten to twelve years or less depending upon the management practices employed. The recommended attributes of these species are rapid juvenile growth, wide site adaptability, disease resistance, and pest resistance. Good coppice regrowth and resprouting are also considered desirable but not essential.

Presently, species exhibiting these traits include silver maple (*Acer saccharinum*), sweetgum (*Liquidambar styraciflua*), sycamore (*platanus occidentalis*), black locust (*Robinia pseudoacacia*), *Eucalyptus* species or hybrids, and poplar (*Populus*) species or hybrids. In some parts of the United States other genera such as willows (*Salix supp.*), alders (*Alnus supp.*), mesquite (*Prosopis Supp.*), and the Chinese Tallow tree (*Sapium sebiferum*) are also being considered [7].

Poplars and their hybrids can be grown in most of the country, but eucalyptus plantations are limited to Hawaii, southern Florida, and some parts of California [7]. Poplars also have an additional advantage due to their ease of propagation by stem cuttings and/or tissue culture, whereas most eucalyptus have to be planted as seedlings.

Yield Potential

In the United States, hybrid poplar and eucalyptus have shown exceptionally high yield rates ranging between 8.9 and 19.1 dry tons/acre/year, but these high yield rates have been only achieved in small plot research trials with selected clones. Experimental yields of SWRCs are two to five times more than those observed in the natural forest stands. On a dry weight basis, biomass yields are comparable with many annual crops. In several research trials annual growth rates of above ground leafless biomass in the range of 4 to 7.5 dry tons/acre/year have been achieved [8]. Some researchers suggest that if current efforts in breeding and biotechnology are maintained, yields as high as 7 to 13 dry tons/acre/year are possible within a short time [9]. However, these high yields would require use of good croplands, which would be more costly to divert from annual crop production. Table 2.1 shows the current and the expected yields for different regions of the United States.

Table 2.1: SRWC Current and Expected Yields by U.S. Regions

	Yields: Dry Tons/Acre/Year		
Region	Current[1]	Current Maximum[2]	Projected
Northeast	4	7	6.7
South/Southeast	4	7	8
Midwest/Lake	4.9	7	8.9
Northwest	7.6	19.3	13.4
Subtropics	7.6	12.3	13.4

Notes: [1]Estimates based on large research production plots.
[2]Maximum yields observed in small plot research trials.
Source: [9]

Further increases in yields are not limited by either the availability of sunlight or the rates of photosynthesis for the most parts of the United States. In fact, based on the average annual solar radiation and the maximum conversion efficiency of green plants (6.6 percent), the theoretical maximum whole plant yield is almost 100 dry ton/acre/year [10]. However, the maximum observed whole plant yield has been 50 dry tons/acre/year in temperate climates [10,11]. The discrepancy between the observed and the theoretically possible yields is attributed to water and nutrient limitations, disease and pest problems, and to genetic makeup characteristics that result in plants that allocate large amounts of carbon to the root zone [9].

Site Selection

SRWCs such as hybrid poplar grow particularly well on deep, well-drained, light textured fertile soils with sufficient soil moisture. Light textured soils such as silt loam and sandy loams are also well suited, but heavier textured soils with significant amounts of clay can be productive as well, given adequate drainage.

Another important consideration is the slope of the plantation site. In order to reduce erosion, control losses of fertilizer and other agricultural chemicals through runoff, and to allow easy access for planting and harvesting equipment, it is generally recommended that SRWC plantation sites not be placed on slopes steeper than eight percent. Sites with steeper slopes would require costly special erosion control measures such as grass strips and alternative cultivation methods, along with specialized planting and harvesting equipment.

Plantation Spacing

Tree spacing does not have a significantly large impact on SRWC yields provided that the trees are grown long enough to reach their maximum annual growth rate and harvested just before the start of competition related mortality. However, spacing decisions can affect establishment costs, economically optimal rotation ages, and tree sizes at the harvest age. Therefore, spacing decisions should be made on the basis of specific assumptions regarding the type of clones used, the site quality, the expected tree size at harvest, and the desired rotation age.

Since the beginning of research on SRWCs, both the plantation spacing distance and the length of rotation have increased. This increase can be attributed to several reasons: (1) higher planting densities have higher up-front establishment costs, (2) yields of closely spaced regenerated coppice are not significantly higher than those of single rotation plantations planted at wider spacings, and (3) conventional harvesting equipment and infrastructure are designed to deal with large diameter trees associated with wider spacings and longer rotation cycles. During the last few years advances have been made in the development of small diameter harvesting systems but as of yet these systems have not yet been extensively field tested. For these reasons, current research has mostly focused on clonal screening and yield evaluation on plantations planted at 8 feet by 8 feet spacings, (680 trees/acre) [2].

Production and Harvesting Costs

The data on the production and harvesting costs of SRWCs is limited, especially from actual field operations. Studies conducted by Oak Ridge National Laboratory (ORNL), Natural Resource Research Institute (NRRI), and Electric Power Research Institute (EPRI) use engineering cost accounting approaches. These studies estimate the costs of harvesting and handling to be between $2/dt to $19/dt. Transportation costs are modeled to vary by the average hauling distance, and not by actual hauling distances. This variability in the estimated SRWC production and harvest costs translates into fuelwood costs ranging between $1/MBtu to $4/MBtu, depending upon the researcher's assumptions [12].

The higher cost estimates are associated with the use of traditional harvesting technologies which are available but not completely suitable for the harvest of SRWCs. These technologies were designed for large diameter trees and forested landscapes. The lower cost estimates are based on assumptions which reflect continued agricultural subsidies, high biomass yields, and the use of new harvesting technologies which avoid expensive operations like skidding and loading by directly placing harvested trees on the trailers. A detailed comparison of production and harvesting costs for SRWCs used in several different studies is presented by Hughes and Wiltsee [12].

Disease Incidence and Control

A great many insects and microbial pests can pose problems for SRWCs [13]. The North Central Experiment Station (NCES) has established a network of *Populus* plantations across a five state region in the north-central U.S. to identify yield potential and disease susceptibility of several poplar clones [14,2]. Since 1987, 91 clones have been tested: 52 were dropped from further research because they did not show adequate growth and disease resistance. The most damaging disease at all sites was Septoria Canker, which results in stem breakage as well as tree death [14].

Researchers currently recommended that only widely tested clones be planted and that untested clones be avoided, even if they promise greater yield potential. Hybrid poplar clones are genetically identical, so it is possible that a serious outbreak of disease could damage or destroy entire plantations. In order to avoid such risks, researchers recommend that a variety of suitable clones should be planted at a given site in separate blocks. Furthermore, close monitoring for disease incidence, particularly in the establishment years, is necessary.

Water Quality and Soils

Conversion of agricultural lands to SRWCs can result in better soil structure, organic matter content, and water quality than is achieved by some annual cropping practices. However, the extent of these improvements will depend on the particular changes in the crop management techniques. The root system developed by the SRWCs is much more extensive than most annual crops and therefore, it adds organic matter to the soil, slows erosion and helps in reducing soil compaction [15]. It is estimated that soils in agricultural row crops when converted to woody crops can accumulate as much as 1 ton/acre/year of organic matter over 10- 20 years [16]. Table 2.2 provides a comparison of typical erosion and agricultural chemical use levels for selected food and woody crops.

Table 2.2: Typical Erosion Levels and Agricultural Chemical Use of Selected Food and SRWCs

Crop	Erosion t/ac/yr	Nitrogen lbs/ac/yr	Phosphorus lbs/ac/yr	Potassium lbs/ac/yr	Herbicide lbs/ac/yr
Corn	9.7	120	53.4	71.3	2.7
Soybeans	3.2	8.9	31.2	62.3	1.6
SRWCs	0.9	53.4	8.9	71.3	0.3

Source: [7]

In general, woody crops require fewer fertilizers and pesticides than most annual crops reducing but not entirely avoiding the risk of ground water and surface water contamination. As with annual crops, nitrate leaching is reduced if fertilizer applications do not exceed soil nutrient requirements. The only exception is the establishment phase of the SRWCs when the nutrient leaching may not meet the Environmental Protection Agency (EPA) recommendations [17].

SRWCs require more water than annual agricultural crops. In fact, hybrid poplar can grow in standing water for a limited amount of time [2]. Therefore, land rendered incapable of producing agricultural crops due to high water levels might be usable for woody crop production.

SRWCs can also be planted to reduce damage to riparian ecosystems caused by the adjacent intensive agricultural practices. These plantations can serve as run-off filters between riparian areas and conventional agricultural sites. These run-off filters can capture soil lost due to erosion and absorb nutrients and pesticides which would otherwise contaminate the water bodies.

Wildlife Habitat and Biodiversity

The effect of SRWC plantations on wildlife habitat and biodiversity is expected to be mostly positive. Although these crops do not provide the same level of diversity found in most forest and prairie ecosystems, in comparison to annual row crop operation they do provide a greater level of diversity in terms of plant and animal species. If the potential of SRWCs is realized and large plantations are established, it is expected to increase landscape diversity, edge habitats, shelter, and food sources for the wildlife [9]. An additional benefit of these plantations could be that their utilization for feedstock energy can defer the harvesting of natural forests and as a result increase wildlife habitat within the natural forests. Growing short rotation high yield crops produces large amounts of feedstock on a relatively smaller amount of land. It has been observed that some agricultural systems have detrimental impact on wildlife species because they eliminate and fragment habitat and decrease available cover and food supplies. The strategic placement of SRWC plantations in these systems and next to existing woodlands can create corridors for wildlife movement and improve overall habitat conditions. Studies done by the Audubon Society have shown that these plantations can serve as temporary habitat for a wide range of birds including some rare species [6].

Carbon Mitigation

Carbon mitigation benefits of SRWCs not only depend on the amount of land converted to these crops but also on factors such as the amount of fossil fuel inputs they replace, the conversion efficiency rates, and the type of fuels displaced. A recent study [9] estimated that if SRWCs were used to displace coal to produce electricity, current U.S. carbon emissions would be reduced by about five percent annually. The authors considered all carbon emissions associated with the production, harvesting, and transportation cycle of woody crops but did not consider the possible benefits derived by carbon sequestration in the soil and in the standing trees. The specific assumptions included a land base of 28 million hectares, annual yield rates of 22 dry Mg/hectare, and conversion efficiency rate of 42 percent. Until recently, the conversion rate of 42 percent for wood was considered unrealistic, but production technologies such as the Whole Tree Energy™ [18] system may achieve such rates.

2.3 Whole Tree Energy Power Production

During the eighties a new technology for electricity production patented as Whole Tree Energy™ (WTE) was developed by the Energy Performance Systems, Inc. Minneapolis, Minnesota. This technology uses a direct combustion process in which whole trees are harvested, transported, dried, and then used as fuel for electricity production. The basic idea was to develop a wood-fired power generating system which would be economically and technically compatible with traditional large scale power plant.

A significant attribute of WTE systems is its avoidance of conventional harvesting operations such as wood chipping and skidding [17]. Furthermore, the plant design does not require any pulverizing and crushing equipment which are an essential component of a coal fired power plant.

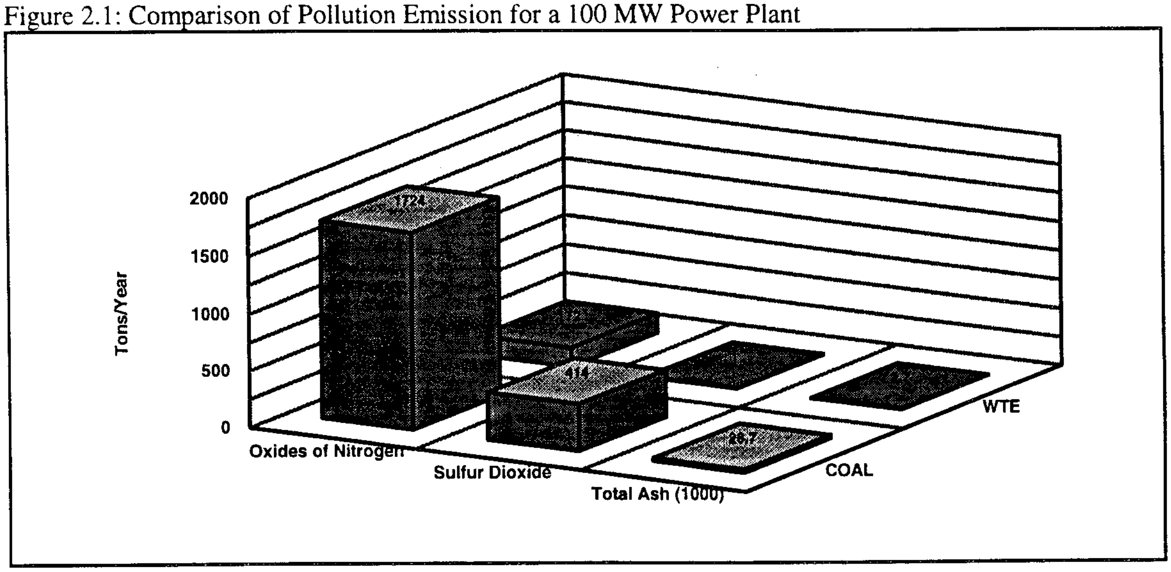
It is claimed that the WTE plant would cost 25 percent less than a coal plant [18]..

A study of the economic and engineering design of WTE concluded that WTE is both technically and economically feasible [19]. The total capital requirements for the establishment of a 100 MW plant would be approximately $134 million, and annual operating costs would be $19 million. Total production costs would average $190/kW-yr.

In comparison to coal, WTE sulfur emission would be minimal because there is hardly any sulfur in wood. The reductions in oxides of nitrogen would also be significant because of low fuel nitrogen content and low thermal nitrogen oxide generation. The reduction in ash content is also expected to be large. Figure 2.1 shows a comparison of these pollutants between WTE and coal for a 100 MW power plant [18].

Under WTE technology, whole trees are harvested and delivered to the plant where they are stacked in a dome approximately 650 feet in diameter and 200 feet in height. Necessary equipment includes a crane to unload and stack trees, an under-pile air distribution system, and a conveyor for transporting wood to the boiler. Ambient air in the dome is kept at 130 ° F to reduce the moisture content of the wood. After about a month, dry wood is transported by conveyor into the furnace.

Figure 2.1: Comparison of Pollution Emission for a 100 MW Power Plant



Source: [21]

The furnace receives loads of trees 35 feet long, four feet high and eight feet wide. This fuel enters in the furnace every four minutes in about six ton batch loads. The dimensions of the furnace chamber are 28 feet tall, 35 feet wide and 13 feet deep.

Burning is a three step process which ensure almost complete combustion of wood. The first step keeps temperatures at around 900 ° F at the grate and about 2400 ° F at the top of the stack.. In the second step, released volatiles mix with the over fire air above the stacks and burn at almost 2700° F. The third step involves the burning of the char which falls through the grate. This complete process increases the furnace efficiency and reduces the emission of volatile particles.

2.4 Minnesota Generic Environmental Impact Statement

Minnesota forests occupy approximately 17 million acres, about one-third of the state. Almost 89 percent of this land is classified as productive timberland. The forest sector provides approximately 165,000 direct and indirect jobs, with an annual value added output of approximately $13 billion [20].

Minnesota's forest industries have experienced a substantial growth during this decade and are expected to expand even further during the next decade. In response to public concerns regarding these industry expansions and their impact on the environment, the Minnesota Environmental Quality Board (EQB) funded Minnesota's first Generic Environmental Impact Statement (GEIS) in 1992. The main objectives of this study were to (1) identify and evaluate the economic, environmental and social impacts of increased timber harvesting and management activities and (2) recommend mitigative strategies to over come any potential negative impacts [4]. In the GEIS, traditional timber management alternatives were expanded by including site specific mitigation strategies designed to enhance wildlife, biodiversity, water quality and recreational activities.

Part of the GEIS was an examination of all forest activities in Minnesota through use of an integrated natural resource scheduling system to assess the economic, social, and environmental impacts of all forest management activities in Minnesota. Detailed location-specific management schedules were first developed without specific constraints on timber management for a 60-year planning horizon and for three distinct timber demand scenarios. Each schedule was examined by experts in various resource disciplines for its impacts on natural resources. Recommendations for mitigation of negative impacts on wildlife, water, recreation, soils, and bio-diversity were developed and were translated into specific management restrictions. Optimal management schedules that reflected these mitigating actions provided the basis for assessing the trade-offs among different levels of resource protection. The detailed results for the Minnesota GEIS are contained in a series of technical reports and background papers available from the EQB and in Jaako Pöyry [1].

Three levels of harvest were simulated: the current actual harvest of 4.0 million cords/year; a level of 4.9 million cords/ year estimated to occur within 5 years if proposed industry expansions occurred; and the estimated "maximum" annual volume of timber sustainable for harvest statewide of 7 million cords/year. Six pulpwood markets and 10 product classes were assessed. Quantities demanded at major market centers were set for each planning period to reflect the requirements of the mills at each location. Quantities were adjusted over time to reflect different projections under each cutting level scenario of how new industries would become established or how existing mill capacity would be expanded in a market area. This flexibility permits analysis of the impacts of new markets and assessment of their relative competitiveness to existing markets. The spatial allocation of timber management activities on the basis of economic efficiency increased the realism of the impact analyses because the latter required spatial and temporal detail to be realistic.

The GEIS predicted significant aspen shortages corresponding to all demand scenarios. These shortages were over come by assuming that northern hardwoods can be substituted for about 25 percent of the aspen demand. Even so, the shadow prices for aspen rose over $80 per cord in the latter planning periods.

The present research builds from some of the GEIS modeling approach. It extends the number of markets to include biomass power plants and it adds a whole new production base in the form of SRWCs on agricultural lands.

Chapter 3. Model and Modeling Components

3.1 Introduction to Forest Scheduling Models

Harvest scheduling problems in forest management are generally solved by two specific approaches: tactical planning and strategic planning. In tactical planning, detailed management alternatives based on higher levels of spatial detail are examined for relatively shorter planning horizons. Tactical planning models become computationally difficult and expensive when the length of the planning horizon is increased. If the objective is to examine overall sustained yields and other long term goals, then strategic planning is used. Strategic planning models use highly aggregated data which makes its computation feasible. The trade-off is that stands with similar physical and economic characteristics are aggregated over large areas, with a loss of site specific data and spatial resolution [30].

Harvest scheduling problems have been solved in a number of ways, including linear programming (LP), dynamic programming, binary search, and shadow price search methods [31]. The use of any specific method depends on the objectives of the analyst. If higher spatial resolution and site specific data are of importance then linear programming is generally used. It allows for the inclusion of several constraints while maximizing or minimizing a specific objective function. Linear programming is extremely effective in achieving optimal solutions for relatively small problems but as the problem size increases the formulation and the computation becomes increasingly difficult. This is particularly true for statewide harvest scheduling problems which can have millions of decision variables and constraints.

Harvest scheduling problems can also be solved by a relatively simple and cost effective heuristic approach known as the binary search method. This method can be used for longer planning horizons but it does not allow for the consideration of more than one decision variable such as harvest level in each planning period. The only two choices available to the planner are either to increase or decrease the harvest level. In other words it does not account for harvest of multiple product types and their interactions. Other decisions such as management prescriptions for initial harvest or thinnings and regeneration alternatives have to be generated externally and then input into the simulation process.

The harvest scheduling algorithm utilized in this study was developed by Hoganson and Rose in 1989. This algorithm is primarily based on linear programming but overcomes it limitations by using a heuristic approach based on dynamic programming. This algorithm combines the strategic and tactical planning approaches and allows the analyst to incorporate greater level of site specific data and spatial resolution in the modeling process over longer planning horizons.

The computation size of harvest scheduling model depends on the number of product types, analysis areas, markets and planning periods considered in the formulation. The computational solution becomes more and more difficult as the level of detail incorporated in the model is increased because of the multiplicative effect on the number of constraints and decision variables. A scheduling problem with enough detail to ensure a realistic solution can result in millions of decision variables and thousands of constraints. This can make the problem economically and computationally difficult, if not impossible to solve. These problems are generally avoided by using high levels of data aggregation which can compromise the authenticity of the solution obtained.

Hoganson and Rose [32,33] developed a multi-product and multi-period forest management and harvest scheduling model known as DUALPLAN. This model has the ability to solve large forest management problems and allows for a much greater level of detail than the traditional forest management models such as FORPLAN. DUALPLAN was later modified to recognize alternative market location and implemented as a computer software program DTRAN [34].

3.2 Harvest Scheduling Model DTRAN

DTRAN is based on a linear programming formulation, which takes advantage of the primal-dual relationships. The solution technique of DTRAN can be best understood by considering the following harvest scheduling model formulation:

$$Primal \qquad \underset{X}{Minimize} \sum_{i=1}^{I}\sum_{j=1}^{Ji} C_{ij}X_{ij}$$

$$S.T$$

$$\sum_{i=1}^{I}\sum_{j=1}^{Ji} V_{ijptm}X_{ij} \geq D_{ptm} \qquad \forall ptm$$

$$\sum_{j=1}^{Ji} X_{ij} \leq A_i \qquad \forall i$$

$$X_{ij} \geq 0 \qquad \forall ij$$

Where:

A_i = the number of acres of stand type I that are present in the initial period.

C_{ij} = discounted cost of assigning an acre of stand type I to prescription j. This includes all additively separable costs such as production, harvesting and transportation.

D_{ptm} = exogenous demand for product p, in time period t, for market m.

I = number of stand types.

J_i = number of management options for stand type I.

V_{ijptm} = the per acre yield of product p, in time period t, for market m from stand type I, if management option j is implemented.

X_{ij} = number of acres of stand type I assigned to management option j.

The first set of constraints requires the product output levels (demands) to be achieved in each planning period for each market. The second set ensures that the acres in a given analysis area are greater than or equal to the sum of acres assigned to each of its possible management options. Each analysis area has one constraint and it protects against over allocation of land base. The non-negativity of the decision variables is satisfied by the third set of constraints. The product output level constraints are generally less than the analysis area constraints, but they are significant in terms of holding the problem together, for without them, the problem for each analysis area could be solved independently.

The Lagrange multipliers associated with the output level constraints reflect the cost of producing one additional unit of product type p, in time period t, for market m. These multipliers can be interpreted as the shadow prices or marginal costs of production. They include all direct and indirect costs associated with the production and shipment of a given product. There is a direct relationship between these marginal costs and the product output levels. Generally, an increased level for product outputs will result in increased marginal costs and vice versa. The Lagrange multipliers associated with the initial area constraints are the estimates of the change in the cost of producing required output levels if an additional unit of land corresponding to a given stand type were available.

Hoganson and Rose [32,33] approach for both DUALPLAN and DTRAN is based on the concept of Lagrangian relaxation. They argue that the maintenance of strict feasibility for harvest scheduling models as required by the concepts of linear programming imposes an undue burden on the computational facilities with little gain. Their rationale is that product demands for the future planning periods are approximations at best and therefore, if slight deviation from these output levels provide a close to optimal solution, then it should be an acceptable solution. The DTRAN strategy can be best explained by examining the dual of the forest management scheduling problem developed above:

$$Dual(1) \qquad \underset{\phi\ \lambda}{Maximize} \sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{m=1}^{M} D_{ptm}\lambda_{ptm} - \sum_{i=1}^{I} A_i\phi_i$$

$S.T$

$$\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{m=1}^{M} V_{ijptm}\lambda_{ptm} - \phi_i \leq C_{ij} \qquad \forall\ ij$$

$$\lambda_{ptm} \geq 0 \qquad \forall\ ptm$$

$$\phi_i \geq 0 \qquad \forall\ i$$

Where:

p = number of product types.

t = number of planning periods.

m = number of markets.

λ_{ptm} = Lagrange multiplier associated with the primal problem output level constraints.

ϕ_I = Lagrange multiplier associated with the primal problem initial area constraints.

This formulation can be explained as the problem of a principal who wants to purchase all the land from the landowners and in return sell them the outputs from the land. The principal's problem is to determine the price for each output in each planning period for each market (λ_{ptm}) and the compensation to offer for the purchase of each stand type (ϕ_I), so that profits are maximized. The principal's offer price for the purchase of stand types should be such that the landowners consider it profitable to sell the land instead of managing it themselves.

Comparing the primal with the dual formulation shows that the Lagrange multipliers of the primal problem become the decision variables of the dual, and the decision variables of the primal (X_{ij}) become the Lagrange multiplier for the dual. The strategy employed by DTRAN is to make use of this relationships between the primal and the dual in its solution process. It assumes that economic intuition and forecasts outside the model provide some estimates about the future product prices -

all the λ_{ptm} variables in the above formulation. This assumption reduces the dual to the following:

$$Dual(2) \qquad \underset{\phi}{Minimize} \sum_{i=1}^{I} A_i \phi_i$$

$$S.T$$

$$\phi_i \geq \sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{m=1}^{M} V_{ijptm} - C_{ij} \qquad \forall\, ij$$

$$\phi_i \geq 0 \qquad \forall\, i$$

This problem can be explained as the principal's problem who wants to minimize land purchase costs. Each constraint represents a lower bound on ϕ_I. This problem can be easily solved by choosing the lowest bound for each ϕ_I. Even though there are J_i constraints on each ϕ_I, since they all represent lower bounds, so all but the lowest will be redundant. The right hand side of each constraint is simply a cash flow analysis of its corresponding management option evaluated by using estimates of shadow prices for each product type. This constraint basically states that the marginal value of each analysis area should be at least as much as the value of any of its management alternatives when evaluated by using shadow prices λ_{ptm}. The actual simulation approach of DTRAN is to follow these steps:

(1) Use outside the model economic forecasts to predict marginal cost of production for each product, in each market, for each planning period i.e., λ_{ptm}

(2) Use these estimates of λ_{ptm} to solve for the remaining dual variables ϕ_I in Dual (2).

(3) Find the X_{ij}'s in the primal problem that correspond to the optimal dual solution. This solution may not necessarily be feasible.

(4) Calculate the product output levels for the primal solution found in step (3) and test it for feasibility. If the product output levels are close to the desired output levels stop, the primal solution will be a near feasible optimal solution. Otherwise go to step (5).

(5) Re-estimate the shadow prices λ_{ptm} by examining the relationship between the product output levels determined in step 4 and the prior shadow price estimates. Make appropriate changes and return to step (2).

DTRAN requires the estimation of certain variables outside the model. Costs, product types and product quantities from each analysis area under a given set of management options over the entire planning horizon need to be estimated. For the present study these estimates are generated by a prescription writer, explained in the next section. Transportation costs between each analysis area and all markets are also estimated outside DTRAN. The system used to accomplish this task is discussed in section 3.4.

3.3 Prescriptions Writer

Scheduling models such as DTRAN require detailed input in terms of physical and economic flows associated with all the management options for a given analysis area for all the planning periods. The physical flows provide information about the timing, quantity, and type of product that can be harvested from a certain analysis area managed under a specific set of management alternatives or prescriptions. The economic flows represent the associated production and harvesting costs. For the model discussed in the previous section, wood volumes (V_{ijptm}) and the production and harvesting components of C_{ij} are determined by the prescription writer.

Management options are defined by the analyst: minimum and maximum rotation ages, types and timing of thinning and harvesting, types of regeneration (natural or artificial), and the costs associated with each activity. The range of management options available for a given analysis area may vary by initial stand age, stand conditions, product specifications, growth and yield relationships, and other economic, environmental, and ecological reasons. It is necessary that all possible options must be specified in a scheduling model before it can determine which options can optimally meet the forest wide objectives.

RxWrite [35], a set of software programs compatible with DTRAN, was used to develop all the management prescriptions necessary for calibrating DTRAN. The prescription writer simulates harvesting and three types of thinnings: from above, from below, and random. For thinning or selective cutting, RxWrite simulates growth of the remaining trees. It utilizes all stand-level inventory data including individual tree records. The Stand and Tree Evaluation and Modeling System (STEMS) which was developed by the USDA Forest Service [36] is used to simulate tree growth over time. A wide range of options concerning thinning intensity, timing and frequency can also be specified by the decision maker. Standard regeneration tree lists, applied following clear cutting, can vary by cover type, site index, and type of regeneration. The transition of stands after clear cutting through natural regeneration is modeled using an empirical matrix of cover type transition probabilities.

Once all the system parameters were set, the model was used to simulate sets of specified management options for a given stand or group of stands. The output from these simulations was converted into input files for later use by DTRAN.

3.4 Transportation Modeling

Transportation costs are calculated and input into DTRAN using GISTRAN [37]. This model provides estimates of transportation costs from each analysis areas to each defined market. Two databases are used in GISTRAN: one containing all major links in Minnesota's transportation network and one that contains the location of all markets and production analysis areas. All locations (roads, analysis areas and markets) are identified by Universe Transverse Mercator (UTM) coordinates.

The GISTRAN road network for the state of Minnesota was developed from digital line graphs made by the U.S. Geological Survey from 1:2,000,000 scale maps. These scale maps provided the road network and political boundary data [38]. The data set associated with 1:2,000 scale maps is in several data sets and in three categories: transportation, boundaries, and roads. GISTRAN data was taken from the trails and roads data set [37]. The road network information, last updated in 1980, includes all Interstate, U.S., and state highways but no secondary roads. The Elbers Equal Area Conic projection coordinates in the digital line graphs were converted into the UTM coordinate system, zone 15, which covers most of Minnesota [37]. For this study, GISTRAN was updated to include all the forest as well as agricultural analysis areas, the new biomass power plant demand sites, and the road network for the entire state.

In GISTRAN, the lowest cost routes from each analysis area to each market in the study area are generated by using Dijkstra algorithm [39]. The algorithm, based on graph theory, finds the shortest path from one node (road intersection) to all other nodes in the network. A complete description of the Dijkstra algorithm can be found in Horowitz and Sahni [40].

In order to calculate the distance from an analysis area to the nearest point on the road network, the identifier of the closest arc (road segment), the distance to the closest arc, and the distance from the nearest point on the closest arc to the beginning of the closest arc were calculated. This procedure, which is largely automated, can be summarized in the following five steps [41].

(1) Calculate the distance from each analysis area to each node in the road network and make a list of 16 closest nodes.

(2) Make a list of arcs incident on these nodes.

(3) For each arc in the list, calculate the distance from the analysis area to each point along the arc and make an ordered list of eight closest pairs of adjacent points.

(4) Calculate the perpendicular distance from the analysis area to the line segment defined by each pair of adjacent points in the list.

(5) If the plot is closer to the current arc, update nearest arc information.

Once all the relevant distances are determined, then the calculation of transportation costs is straightforward. These costs then become the third component of C_{ij} in the harvest scheduling model.

GISTRAN also can display the procurement zone boundaries based on the shadow prices generated by the scheduling model. Furthermore, it can display product volumes and timings associated with optimal management alternatives for a given analysis area.

3.5 Modeling Overview

DTRAN and related software developed in the College of Natural Resources at the University of Minnesota over the last decade allows the analyst to incorporate transportation costs and other harvest scheduling activities under diverse management options over long planning horizons is paramount. While problems at each level of planning differ for the area involved, the relevant time frame, the level of detail, the level of uncertainty, and the management level at which decisions are made, there are significant linkages among the different levels. From the bottom up, operational constraints limit the feasible set of alternatives in tactical planning, and tactical constraints affect what is possible at the strategic level. Forest plans may turn out to be infeasible because the cumulative effects of operational level constraints were not accounted. They should, therefore, be included explicitly in the model. Similarly, constraints can be imposed from the top down. Strategic and tactical planning goals can only be accomplished if specific actions that are taken on the ground are influenced by those goals. The feasibility and cost of management actions are ultimately determined at the operational level, and the impacts of lower level constraints must be passed back up to the higher levels of planning [42]. Thus, while the separation of decisions at different levels of planning is practical and useful, the linkages between each level must also be maintained.

DTRAN overcomes several of the major problems of linear programming, such as the need for data aggregation, the associated problems of model sensitivity, and the difficulty in linking strategic with tactical and operational planning. Essentially the method decomposes a Model I or II formulation [43] of forest management scheduling problems into smaller problems and uses simple search techniques and an economic interpretation of the problem to search for the values of key variables that tie the problem together. Considerable operational detail can be recognized. Higher level planning constraints are imposed on lower level solutions through the explicit recognition of the values of the dual variables that correspond to the higher level constraints.

The decomposition approach can be interpreted as a hierarchical planning method. A hierarchical approach provides a useful way to break up large problems into pieces that are relatively independent, to reduce complexity, and to simplify the solution process [43,44]. A forest-wide planning model with production targets is linked with a stand-level management model that is applied to each stand in the forest. At the forest-wide level, the problem of satisfying the tactical constraints of meeting mill wood requirements over time is solved. At the stand (analysis area) level, the problem of selecting an optimal prescription is solved. The two problem levels are tied together through the recognition at the stand level of the values of the dual variables associated with the forest-wide constraints; at the tactical level the requirement of (near) operational feasibility is maintained through iterative re-evaluation of the marginal costs of production until the aggregation of the stand-level solutions meets the forest-wide objectives. The method provides the advantage of recognizing detail at the appropriate level, as does the hierarchical approach, and also the assurance that the solutions provided will be optimal to the global problem encompassing all levels.

The DTRAN algorithm iterates between the solution of thousands of operational problems and the re-estimation of the dual variable values representing higher level constraints. The approach can be interpreted as a Lagrangian relaxation method where decomposition occurs naturally through spatial disaggregation of the forest into management areas and stands. A key to the success of the algorithm is the analyst's understanding of the management problem to search for the key dual variables rather than relying on sub-gradient methods associated with general Lagrangian relaxation techniques.

Associated with each constraint is a dual variable. The dual variable for an analysis area constraint reflects the value of having an additional acre in the analysis area. This can also be interpreted as the marginal value of an additional acre in the analysis area. The dual variables associated with the flow constraints indicate the marginal cost of meeting each flow requirement. The key to the Hoganson/Rose algorithm is the fact that, if the values of the dual variables associated with the flow constraints are known, then it is easy to solve for the values of the dual variables associated with the analysis area constraints. The DTRAN algorithm uses heuristic search techniques to successively improve estimates of the dual variables corresponding to the flow constraints until an acceptable solution is found, one that satisfies the flow constraints within some acceptable user-defined tolerance.

An infinite planning horizon can be modeled implicitly by assuming that the dual values of flows for periods beyond the explicit planning horizon are equal to the dual variable estimates for the final period for the corresponding product. This approach does not guarantee long run sustainability, however. Because the first few periods of the model are the only periods that are likely to be implemented in practice, a planning horizon can be deemed to be "long enough" if extending the planning horizon further does not change the plan for the first period. The use of the dual variable estimates to value flows beyond the explicit time horizon allows the analyst to meet this test in most applications with a relatively short explicit time horizon.

Another advantage of the algorithm is its intuitive interpretation. The dual variable values estimate the marginal cost of meeting the production targets specified by the product flow constraints. One can then assess these marginal costs to determine whether it is acceptable for the targeted output level. If the costs are not acceptable, the demand targets could be lowered or new, lower-cost ways to achieve current targets must be found. In addition, the shadow prices derived for a given problem can be used for marginal analysis of additional projects not considered in the original run. As long as the additional projects are not likely to be applied on a large scale, their inclusion should not significantly influence the values of the dual variables associated with forest-wide constraints. Even if new projects are proposed for large scale application, the dual variable values for earlier runs can be used to test their viability. If new prescriptions are not more cost effective than those already being considered, they will not be selected by the model even if included in a new run.

Previous applications of DTRAN algorithm were set up to minimize the cost of meeting output flow constraints which typically correspond to the wood requirements of existing and projected mills in a region, or to allowable cut targets. In general there will be less uncertainty projection of wood production targets than there would be about projections of wood prices. This type of formulation is ideally suited for analyzing the costs and environmental trade-offs associated with different output levels or analyzing the feasibility of specific industrial expansions. That is what the present research does - it analyzes the effects of expanding the wood supply by planting SRWCs on agricultural lands and of diversifying the product demand by adding biomass power plants to the set of traditional timber production targets.

Chapter 4: Study Data and Assumptions

4.1 Study Area

For this research, commercial forest lands in northern Minnesota are represented by the 1990 Forest Inventory and Analysis (FIA) data of the United States Department of Agriculture (USDA) Forest Service and the Minnesota Department of Natural Resources (DNR). The FIA data represents over 13.5 million acres of forest land contained in 37 northern counties. Existing forests in southern portion of the state, mostly mixed hardwood stands and relatively small forest businesses, are not included. Data on lands enrolled in the Conservation Reserve Program was obtained from the Minnesota Department of Agriculture (MDA). The CRP lands are distributed over most of the state and cover an area of over 1.8 million acres. A detailed description of both databases will be presented later in this chapter.

4.2 Market Locations

Six aggregated forest product markets and two potential electric power plant locations are considered in this study. Aggregated forest product markets are assumed to be located in Brainerd, Bemidji, Cook, Duluth, Grand Rapids, and International Falls. These locations represent the concentration of major forest industries in Minnesota and were first modeled for the Minnesota GEIS.

The power plant locations considered are Alexandria and Granite Falls. These locations were specifically chosen because they appear to meet the potential requirements for the establishment of biomass operated power plants, as spelled out by EPRI [22]. Any location considered for the establishment of a 100 MW power plant should meet the following basic criteria:

(1) It should be outside any air quality non-attainment zones and Class 1 air resource regions. This will avoid competition with the existing industrial sector pollution.

(2) There should be no air space height restrictions at the proposed plant sites that may be violated by the building or smokestack construction.

(3) There should be an adequate road and highway access to the plant site during and after its construction.

(4) Access to natural gas pipe lines is recommended. Natural gas can serve as an economical backup or alternate fuel supply in case of bio-fuel shortage or price escalation.

(5) Plant sites require an area of about 200-400 acres. Actual plant facilities can occupy as much as 75-100 acres. It is recommended that areas with wetlands and endangered species be avoided in order to minimize environmental impacts.

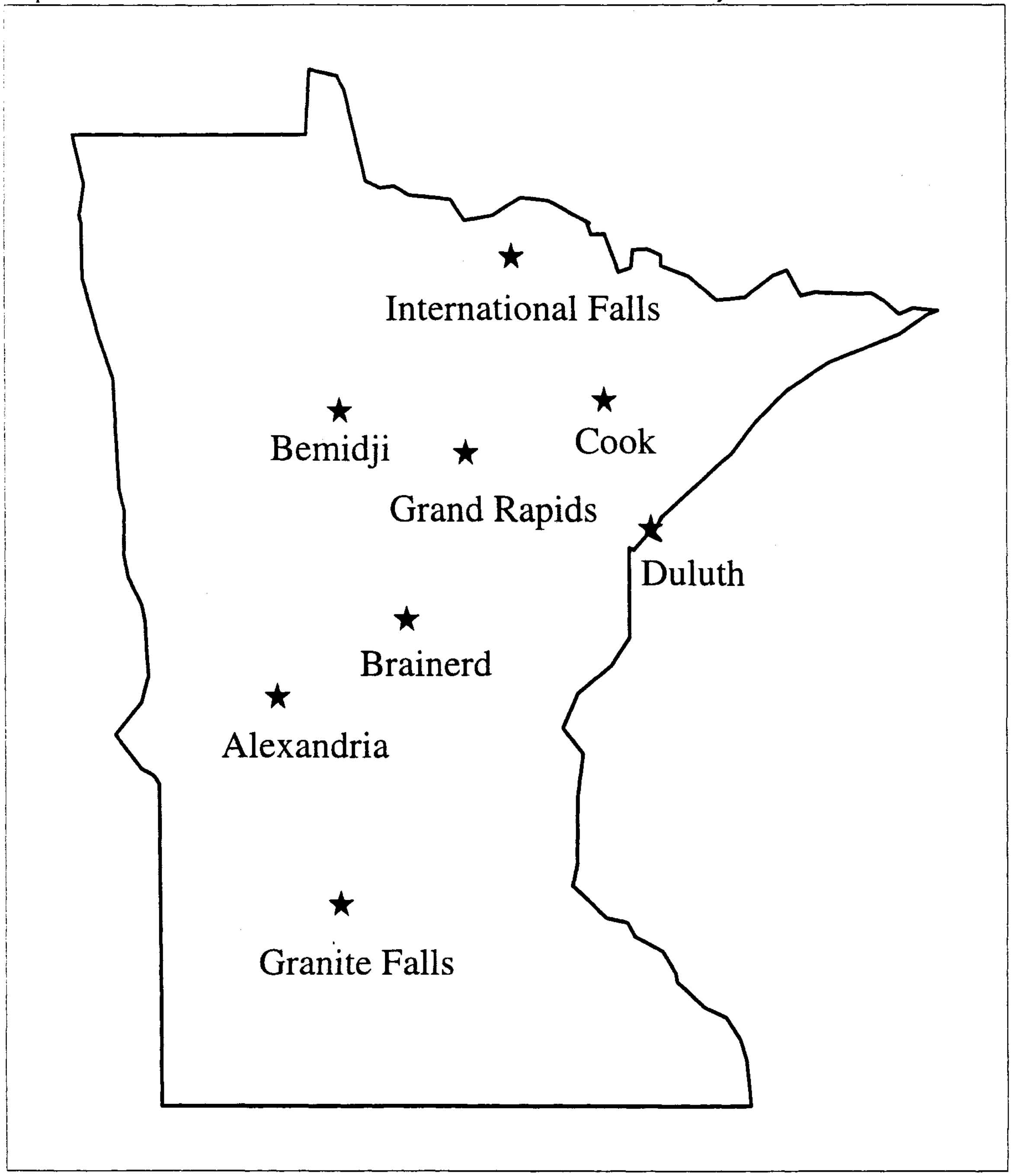
(6) Access to electric transmission lines at voltages of 69 KV or more is necessary for a 100 MW power plant. Plant costs and its impacts can be further reduced if access to substations is available.

(7) There should be abundant supply of surface and ground water. Water is necessary for everyday plant operations such as steam production and equipment cooling.

(8) Water treatment systems are necessary to treat the used water to within acceptable discharge standards and then released into surface water systems.

The locations of forest product markets and the power plants are displayed in Map 4.1.

Map 4.1: Location of Forest Markets and Power Plants Modeled in this Study



4.3 Timber Products Demand

The timber product requirements modeled in this study are similar to those modeled in the Minnesota GEIS medium scenario [1]. These demands reflect the raw material requirements of the existing forest industries as well as those which are projected to begin production in 1997. Table 4.1

shows the summary of modeled timber products demand by market. For this research, these demands are treated as exogenous to the market and enter as the constraint constants in the harvest scheduling model detailed in the previous chapter. The aggregated aspen product set reflects the demand for both aspen sawlogs and pulpwood. The demand for pine pulpwood and pine bolts and sawlogs was modeled separately because of differences in their prices and physical qualities. Since the demand for pine bolts and sawlogs in individual markets is relatively small therefore only the total demand of 240.66 thousand cords[1] was modeled in this study. The spruce product set represents the demand for spruce bolts and pulpwood. The northern hardwoods sets reflect the demand for sawlogs, pulpwood and red oak sawlogs. The blanks in the above table

Table 4.1: Aggregated Annual Timber Product Demands by Market (Thousands of Cords)

PRODUCT\MARKET	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls	TOTAL
Aspen	580	319	203	590	519	458	2669
Pine Pulpwood	57.78	-	-	162.78	-	42.78	263.34
Spruce	-	100	-	379.5	163.5	-	643
Northern Hardwoods	89	198	59	355	69	49	819
Pine Bolts and Sawlogs	102.61	27.61	27.61	27.61	27.61	27.61	240.66
TOTAL	829.39	644.61	289.6	1514.9	779.11	577.39	4635

indicate either insignificant or no demand at a given market. Complete details of product types and product sets modeled in this research are presented in Appendix A.

For biomass power plant demand called fuelwood in this study, many types of wood are suitable. On average, a 100 MW power plant running at 80 percent efficiency rate (292 days per year) will require approximately 350 thousand dry tons of wood annually. Backup fuels such as

[1] A cord is generally defined as 128 cubic feet of stacked wood including the bark and air space. Divide by 79 to convert cubic feet of wood into cords.

natural gas are assumed to be used during the rest of the year.

4.4 Agricultural Land Database

The farm land data set for this study was obtained from the Minnesota Department of Agriculture (MDA). This tabular database was created by each county's Farm Services Agency (FSA) office by running a standard query on county CRP records in September of 1994. Aerial photographs kept at Soil and Water Conservation Districts (SWCD) as well as this database are currently being utilized by MDA in an ongoing project to digitize CRP lands in Minnesota.

According to FSA's summary statistics, there were 1,834,411 acres enrolled in the Minnesota before the implementation of the "Early Release Program" in 1995. This program provided a one time opportunity for the landowners to release their land from further CRP contract obligations and was independent of the actual expiration date of their contracts. Only those landowners whose CRP land parcels were scheduled for release in 1996 were given an option to extend their contracts by one year. The exact figures for early release acreage as well as contract extensions are not available, but it is estimated that approximately 60-70 thousand acres were released.

The MDA tabular database has records for 1,705,441 acres, about 93 percent of the acreage reported by FSA. The difference is attributed to missing data, non-updated county level records on which the standard query was done, or the discrepancies related to the matching of aerial photographs to the records in the database.

Attributes

The following attributes are included in the database:

- Parcel Identification Number: A seven digit alpha-numeric number indicating the three digit county FIPS number and a four digit sequential parcel number.

- Farm Number: Farm number assigned by the county CFSA office.
- Tract Number: Land tract number as indicated on the aerial photographs.
- Field Number: Different fields within the same farm.
- Conservation Practice Number: The number 1-23 of the conservation practice applied on enrolled acres for each parcel of land.
- Contract End Year: The year when the CRP contract expires for a given parcel of land.
- Acreage: The acreage of each enrolled parcel.
- Rent Rate: The per acre annual rent rate for each parcel.
- Highly Erodible Land Indicator: Land parcels designated as highly erodible either due to steep slopes or soil characteristics which make these lands unsuitable for any kind of cropping activity.
- Wetland Indicator: Land parcels which are partially or completely wetlands.
- Wetland Converted Indicator: Land parcels which were wetlands but were converted to farmlands.
- Contract Number: The CRP contract number assigned to each parcel.
- Land Capability Class (LCC): Natural Resource Conservation Service (NRCS) Land Capability Classes I through VIII.
- Land Capability Subclass (LCSC): Natural Resource Conservation Service (NRCS) Land Capability Subclass defining the type of limitation on a given parcel of land.
- Description: Legal description of the location of each parcel.
- Township: Civil township where each parcel is located.

Data Truncation

Statewide totals for acreage in major land categories such as highly erodible lands and their distribution in wetlands and converted wetlands is presented in Table 4.2. The acreage reported as highly erodible (830,000 acres) was excluded from further analysis. Steep slopes or other severe soil limitations associated with these lands render them unsuitable for any

Table 4.2: Major Agricultural Land Categories and Their Distribution (Acres)

Highly Erodible Lands (YES) 829,788 acres			
Attributes/Indicator	Yes	No	Unknown
Wetlands Indicated	468,289	265,054	96,445
Wetlands Converted	6,720		
Highly Erodible Lands (NO) 786,095 acres			
Attributes/Indicator	Yes	No	Unknown
Wetlands Indicated	419,800	286,173*	80,122*
Wetlands Converted	2,157*		
Highly Erodible Lands (UNKNOWN) 89,558 acres			
Attributes/Indicator	Yes	No	Unknown
Wetlands Indicated	21,765	8,383*	59,410*
Wetlands Converted	2,119*		

Notes: * indicates agricultural lands included in the analysis

type of farming activity, including tree growth. Those lands classified as unknown (90,000 acres) were not excluded from the analysis, except for wetlands. Wetlands are said to provide several environmental and economic benefits and their destruction can have significant long term impact on the ecosystem itself. Therefore, acreage consisting of confirmed non-converted wetlands (420,000 and 22,000) was also excluded.

These exclusions left the agricultural land database with 438,364 acres, about 26 percent of the original database. This portion of the agricultural land data will be modeled in this study for possible planting to hybrid poplar. No other presently agricultural lands will be considered for such use.

Geographical Location of CRP Parcels

The geographical location of each CRP parcel within a given county was determined by the legal description, farm number, and tract number attributes of the database. Ideally, this information would have been noted in the township attribute of the data set, but for most counties this attribute was either incomplete or empty. By using several sources such as Minnesota plat books, county aerial photographs, copies of actual CRP parcel record sheets, and with the assistance of county FSA offices, each CRP parcel was successfully assigned to the correct civil township.

Land Characteristics

NRCS land capability class (LCC) and land capability sub-class (LCSC) measures indicate the suitability of a soil to support a particular crop and the corresponding crop management limitations. LCC are indicated by Roman numerals I through VIII, with class I being the least limited and class VIII being the most limited for crop production. The following are the standard definitions of LCC:

Class I	Soils have few limitations that restrict their use.
Class II	Soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.
Class III	Soils have severe limitations that reduce the choice of plants, require special conservation practices, or both.
Class IV	Soils have very severe limitations that reduce the choice of plants, require very careful management, or both.
Class V	Soils are subject to little or no erosion but have other limitations, impractical to remove, that limit their use largely to pasture, woodland, or wildlife habitat.
Class VI	Soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture, woodland, or wildlife habitat.
Class VII	Soils have very severe limitations that make them unsuited to cultivation and that restrict their use largely to pasture, woodland or wildlife habitat.
Class VIII	Soils and landforms have limitations that preclude their use for commercial plants and restrict their use to recreation, wildlife habitat, water supply, or esthetic purposes.

LCSC are soil groups within a land capability class and they are indicated by adding a letter to the LCC numeral. There are four such classifications as described below:

E The main limitation is risk of erosion.

W Water in or on the soil is the main limitation.

S Soil is the limitation because it is shallow, droughty or stony.

C This represents climatic limitations such as very cold or very dry.

Soils in LCC I do not have any subclasses and soils in LCC V cannot have E as a limitation. Combination of these classes and subclasses are widely used by analysts to estimate crop yields and prescribe appropriate management systems for specific soils.

Statewide acreage of this study's agricultural land base by LCC and LCSC are presented in Table 4.3. Note that the majority of the land is in LCC III, LCC II, and LCC IV respectively. The least amount of acreage is associated with LCC VIII and LCC I respectively. Data on land capability classes is missing for 41,664 acres and is represented by LCC "O". Similarly, missing data on subclasses is indicated by subclass "M" (32,322 acres).

Table 4.3: Distribution of Agricultural Lands by LCC and LCSC

LCC	LCSC	ACRES	LCC TOTAL ACRES
I	None	76	76
II	C	3,237	
II	E	48,206	
II	S	20,708	
II	W	78,340	
II	M	1,795	152,286
III	C	623	
III	E	58,463	
III	S	50,638	
III	W	65,566	
III	M	1,988	177,277
IV	C	153	
IV	E	10,166	
IV	S	36,438	
IV	W	14,729	
IV	M	544	
VI	E	833	62,031
VI	S	3,329	
VI	W	232	4,394
VII	E	382	
VII	S	235	617
VIII	W	20	20
O	E	4,362	
O	S	1,523	
O	W	7,784	13,669
O	M	27,995	27,995
TOTAL		438,364	438,364

Notes: M indicates unknown or missing LCSC data.

O indicates unknown or missing LCC data.

LCC and LCSC Data Aggregation

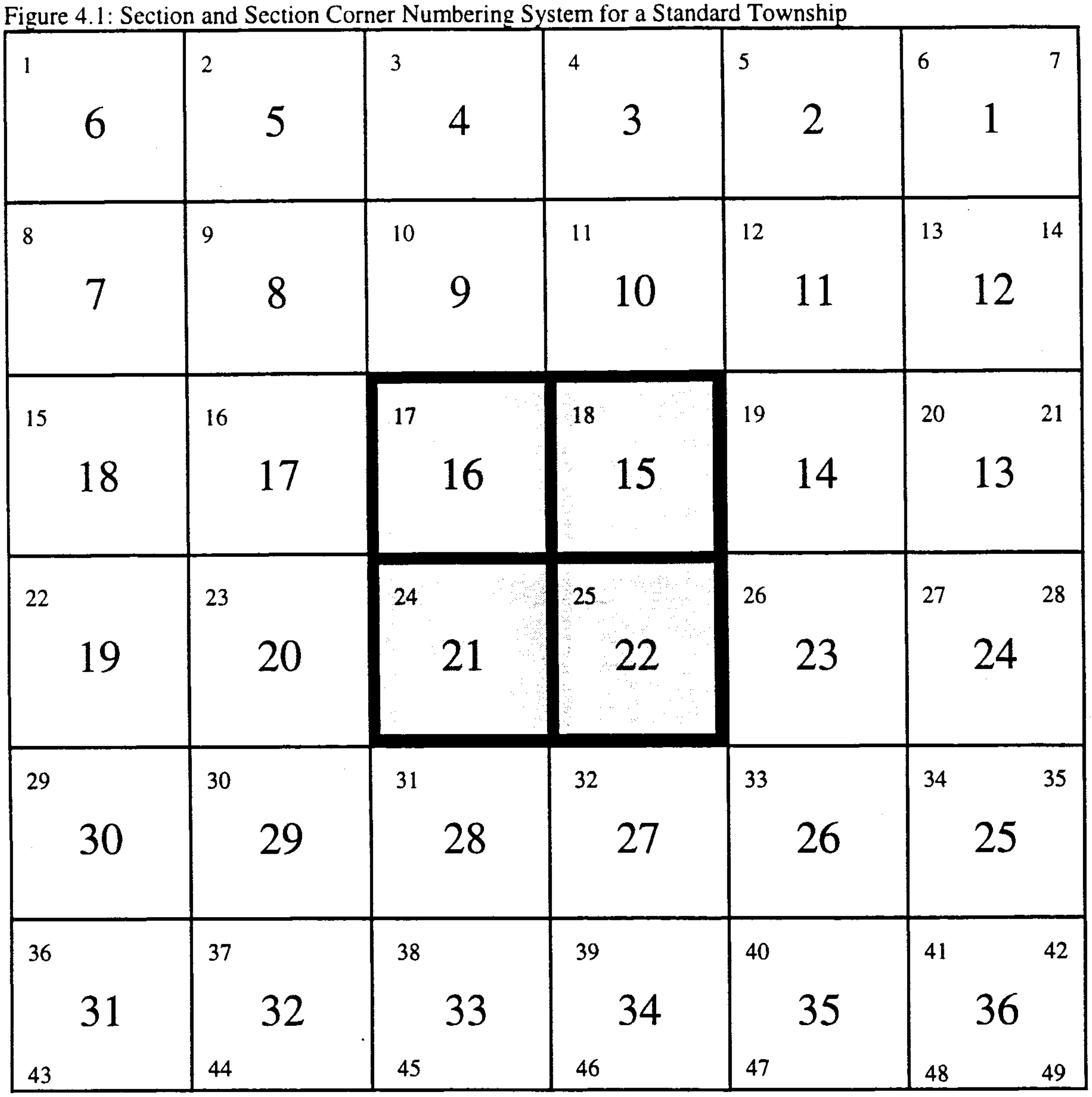
Data on combinations of land capability classes and subclasses was aggregated on the basis of geographical location of the CRP parcels. The acreage of all land parcels within the same township with exactly the same combinations of land class and subclass was aggregated to calculate the total acreage of that combination for the specified township. This aggregation reduced the number of records in the database from 11,531 to 3,107 and therefore, increased the efficiency of the empirical estimation in terms of estimation time and computer memory requirements. Essentially, then a "land parcel" for this study's purposes is all lands in a township that share a common LCC and LCSC.

Location of Townships

The UTM coordinate system was used to represent the location of the aggregated land parcels within a township. Each parcel was treated as if it was located at the geographic center of the township. These coordinates provided the linkage between the land parcels and the transportation network (GISTRAN) used in this analysis. UTMs were calculated using a software known as SECTIC-24K, developed by the Minnesota Land Management Information Center.

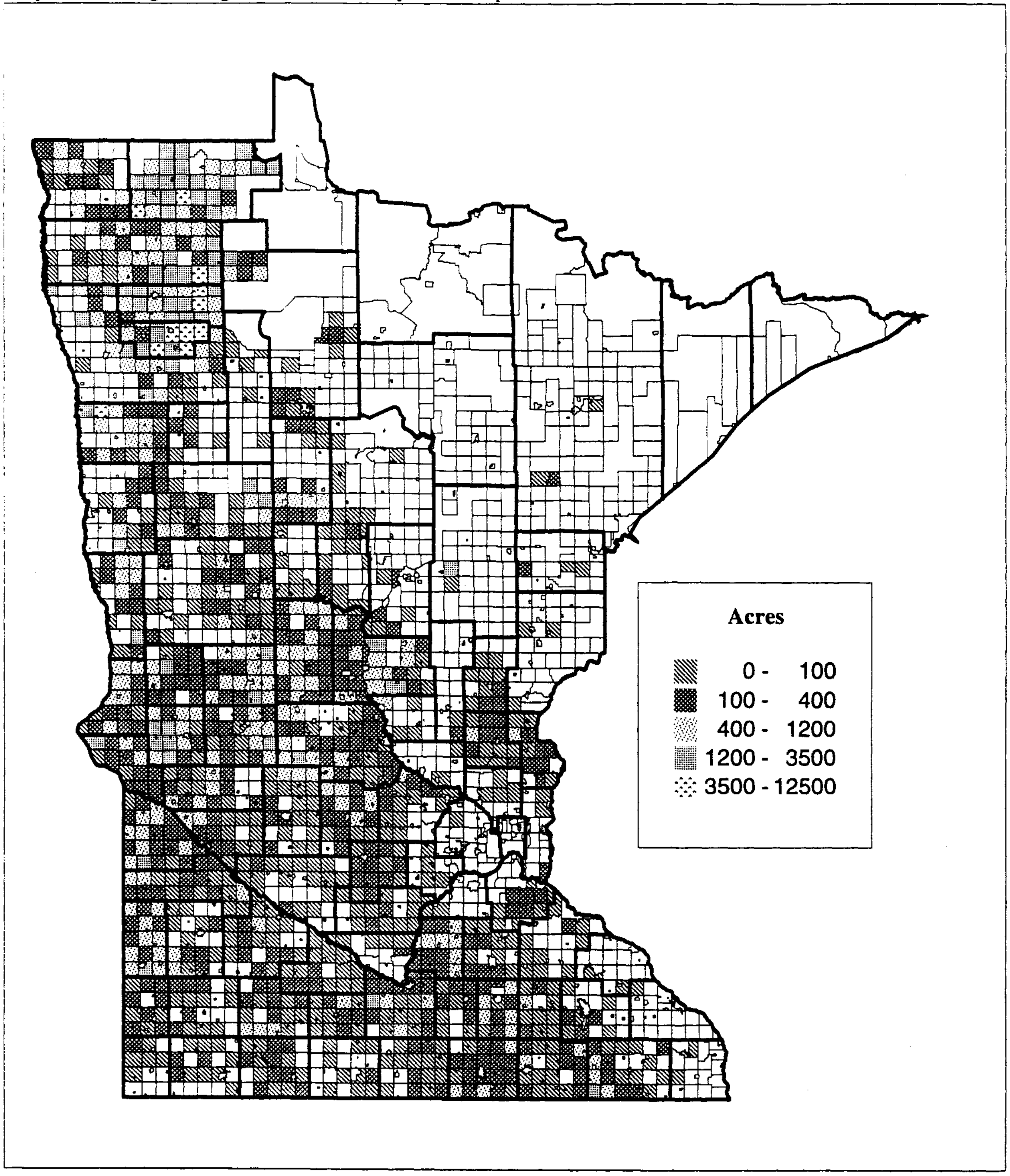
SECTIC-24K is based on a digital file of the Public Land Survey section corners of Minnesota, recorded from the latest U.S. Geological Survey's 1:24,000 7.5-minute quadrangle maps. The program extracts section corner tics by county name, quad or township name in either UTM or Latitude/Longitude coordinate systems. It also permits conversions between different coordinate systems. Most of Minnesota is located in UTM zone 15 with some parts located in UTM zone 14 and 16. These two zones were also converted to UTM zone 15 coordinates for this research. The accuracy of these projections is plus or minus 40 feet from identifiable objects. This is the national map accuracy standard for 1:24,000-scaled maps. Due to non-availability of specific locational data and computational limitations, it was assumed that all acreage within a given township is located in the center of that township. In effect, then, the unit of analysis for this study is a representative farm with homogeneous characteristics. Each township may have one or more such farms, depending upon the soil capability classes and subclasses within it. Figure 4.1 depicts a standard township

Figure 4.1: Section and Section Corner Numbering System for a Standard Township



with 36 sections and 49 section corners representing an area of 36 square miles. The center is depicted by the shaded area representing sections 15, 16, 22 and 23 respectively. The tic common to all four of these sections is 25 and it represents the exact center of a township. UTM coordinates for tic 25 were extracted to define the location of CRP parcels in a given township. Map 4.2 shows the acreage of CRP lands by township considered in this analysis.

Map 4.2: Acreage of Agricultural Lands by Township



4.5 Opportunity Cost of Landowner's Participation

In chapter 5, we will consider the effects of modeling two different estimates of agricultural landowners opportunity costs. If landowners who now have CRP contracts decide to grow hybrid poplars, then they give up the chance to use the land for other purposes. Because they were in the

CRP, they have already shown that the CRP annual payment are larger than their opportunity cost, otherwise, they would not have enrolled. The former CRP contract payments can then be considered as one proxy for the opportunity cost of timber production. Landowners also could rent their lands to other farmers at annual cash rental rates. Therefore, cash rental rates can also be considered as a proxy for the opportunity cost of SRWC production.

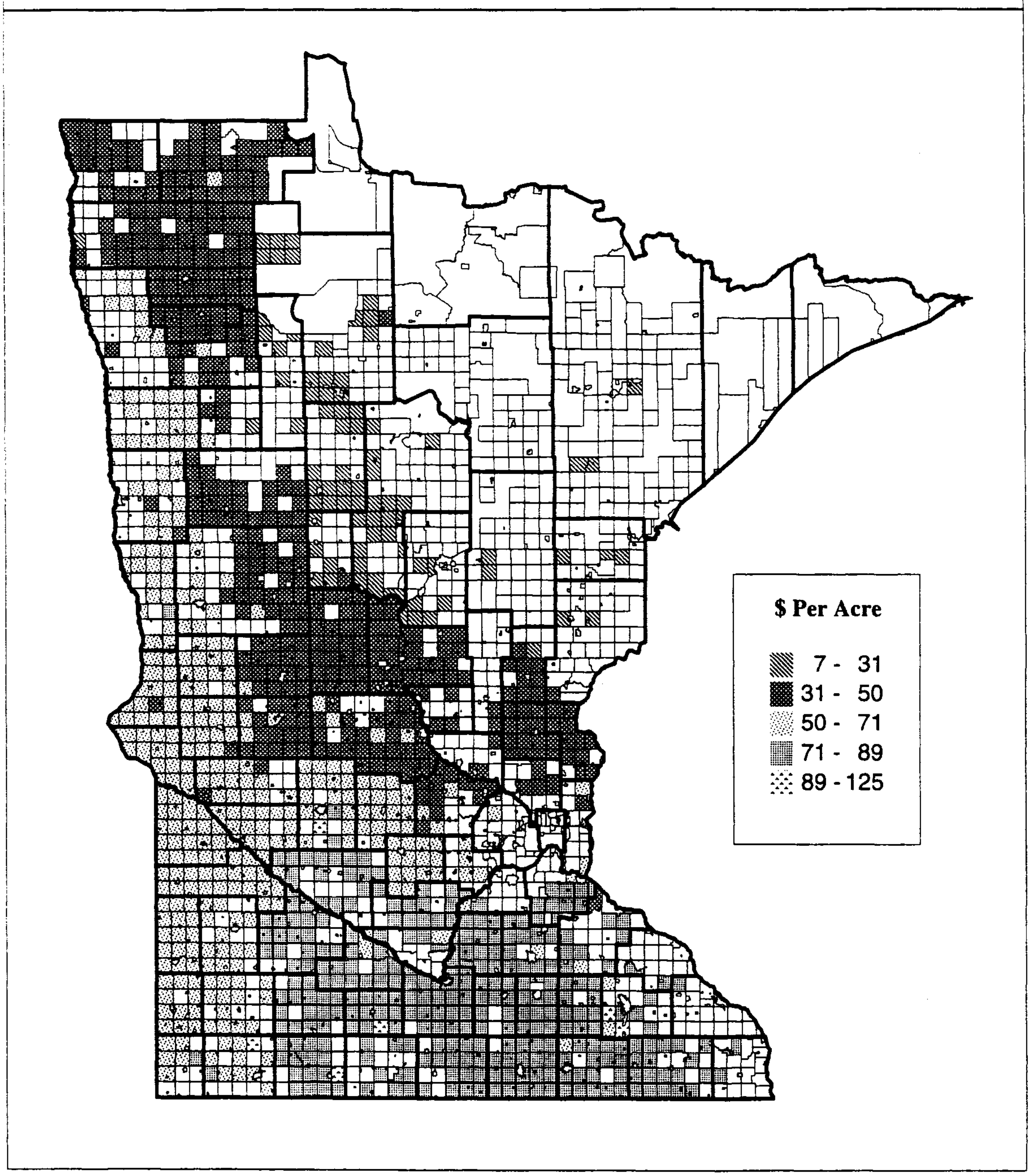
The measures of these proxy variables can be considered as the reservation value below which landowners will not decide to grow trees. Landowners will invest in a SRWC production system only if the discounted net returns from this investment are greater than the discounted land rent or CRP contract payments received over the poplar production cycle. Clearly, it is important to include one of these proxy variables in the production cost. Procedures for the estimation of each parcels's average annual CRP contract payments and annual cash rents on the agricultural lands considered in this study are developed below.

CRP Contract Payments

CRP contract payments were estimated from those reported in the database attribute "land rent", which is simply the fixed annual per-acre payment that the landowners received for placing their lands into the program . Average annual payments were calculated for each individual combination of land capability classes and subclasses within each township. If the payment was unknown for a particular combination, then the average of all other combinations present in that township was used for the missing rate. In a few townships where land rent information was missing for all combinations, the average for the whole county for each missing combination was used.

Average CRP payments for all townships are presented in map 4.2. These payments range from \$17 to \$ 125 per acre and follow a clear pattern. Highest CRP land rents are associated with good agricultural lands in the south and south-western portion of the state. As one moves toward north-central and north-west, the payments start to decline. There are very few agricultural lands enrolled in CRP in the north-east, primarily because it is mostly forest land. This gradient in observed payment rates is an artifact of the original CRP payment mechanism, described in Taff [23].

Map 4.3: Annual CRP Payment Rates by Townships ($/Acre)



Cash Rental Rates

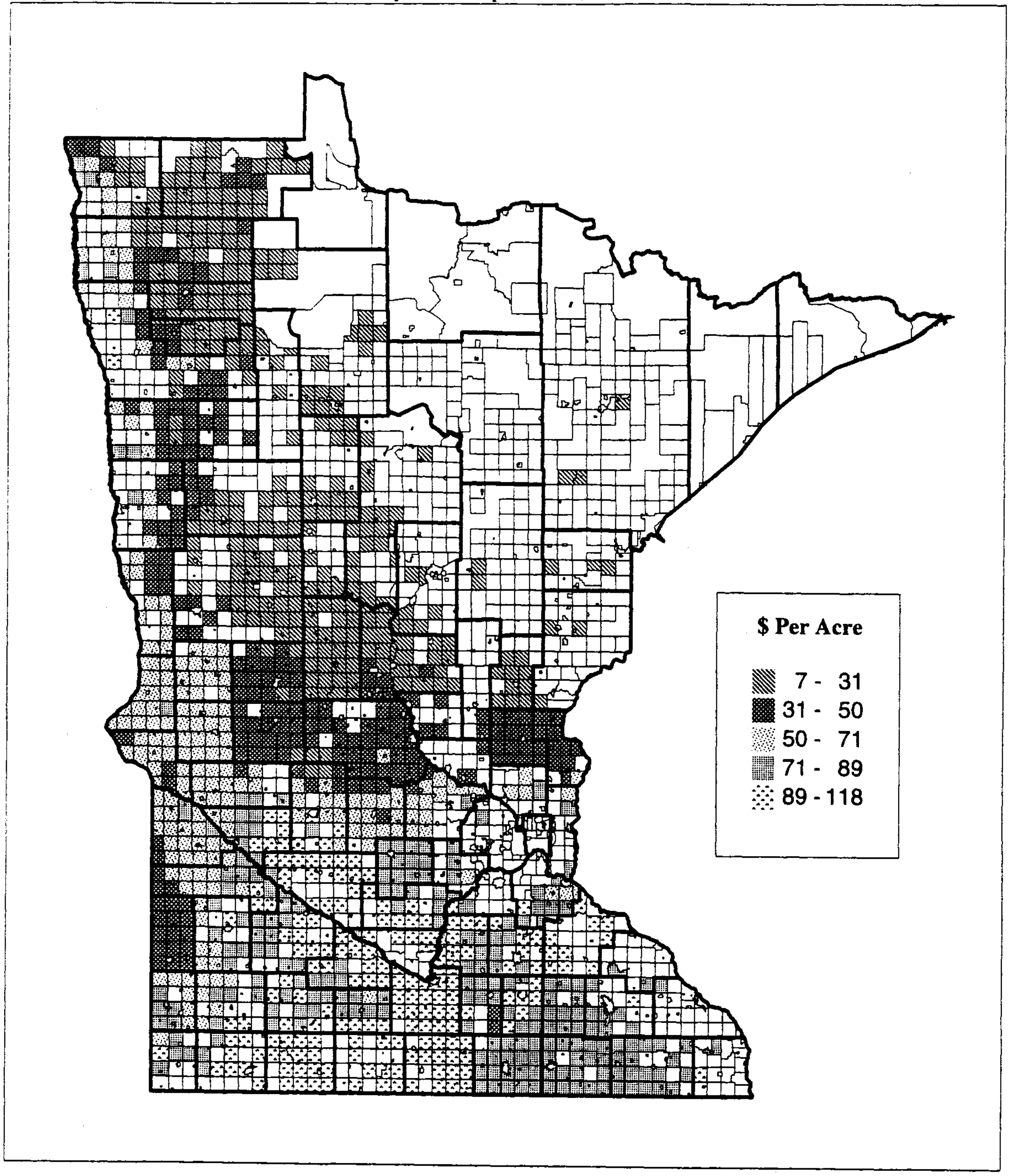
An alternative proxy for the reservation price for agricultural lands is cash rental rates. These per-acre rental rates were calculated for each township from the 1995 estimates of average market value of tillable land (AMVTL), total agricultural tillable land (TATL) and the capitalization rate for a specified region. Capitalization rate is defined as the average estimated cash rent as a percentage of the county assessor's estimated market value of the farmland. Estimates of county level AMVTL and TATL were reported by Lazarus [24]. For this research, the following relationship was used to calculate the per acre cash rental rates for each civil township:

(AMVTL/TATL) * CAPRATE = RENT/ACRE

If any of the above variables were missing for a particular township, then the average of that variable was calculated from the neighboring townships. In cases where variables were missing for all townships within a county, then the average of that variable was calculated from the surrounding counties. Estimated per acre rental rates for all the townships are presented in map 4.3.

The patterns observed in map 4.2 also appear here. Lower rental rates are associated with poorer agricultural lands in the north-central and northern regions. In general, these rates are lower than CRP contract payments calculated in the previous section.

Map 4.4: Estimated Annual Cash Rents by Township ($/Acre)



4.6 Minnesota Forest Inventory Analysis Database

The data representing the forest sector in this research was taken from the latest North Central Forest Inventory and Analysis (NCFIA) project conducted by the USDA Forest Experiment Stations [25]. This is the latest form of disaggregated forest data available for Minnesota. The northern portion of the state is represented by 11,184 individual sample plots. Each plot represents about 1,000 to 1,500 similar acres. In all, over 13 million acres are represented in the data set. All similar stands represented by a given sample plot are treated identically in the model and are considered as a single analysis area. Management activities are assumed to occur uniformly across each analysis area. In practice, of course, this assumption may not be correct because of the heterogeneity within a given analysis area or if the number of analysis areas is not significant. However, large data sets can sufficiently smooth the results to provide a strong statistical basis for this assumption. The following is a description of the key attributes of this data set:

- Plot Identification Number: A unique stand identification number which is used to link the database to other stand attributes.
- FIA Unit Numbers: 1: Aspen Birch Unit, 2: Northern Pine Unit, 3: Central Hardwood Unit and 4: Prairie Unit.
- County: Name of the county where the analysis area is located.
- Ownership: Type of land ownership such as public or private.
- Covertype: Description of the forest cover type.
- Stand Size: Area of a given stand in acres.
- Stand Age: Age of a given stand.
- Site Index: A measure of the quality of a given stand, in terms of tree height at specified time intervals.
- Tree List: A list of tree species along with the diameter at breast height information.
- UTM Coordinates: The location of a given analysis area in terms of UTM coordinates.

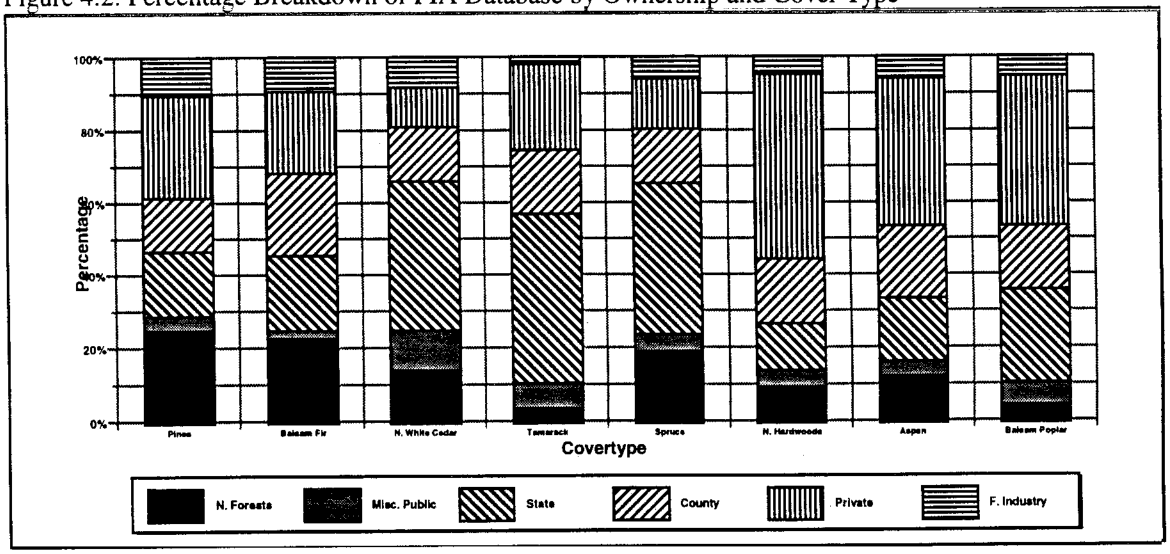
The FIA data set also provides detailed information about forest land ownership, cover type, and age class distribution. The summary of major ownership classes by cover types are presented in

Table 4.4. The acreage of aspen and northern hardwoods is substantially greater than any other cover type. Although the forest industry is the largest consumer of timber, it owns the least amount of land. Most of the forest land in northern Minnesota is publicly owned. The private ownership is about 36 percent and the Superior and Chippewa National Forest own about 13 percent of the total land. Figure 4.2 shows the actual percentages of ownership by cover type.

Table 4.4: Distribution of FIA Database by Ownership and Cover Type (Acres)

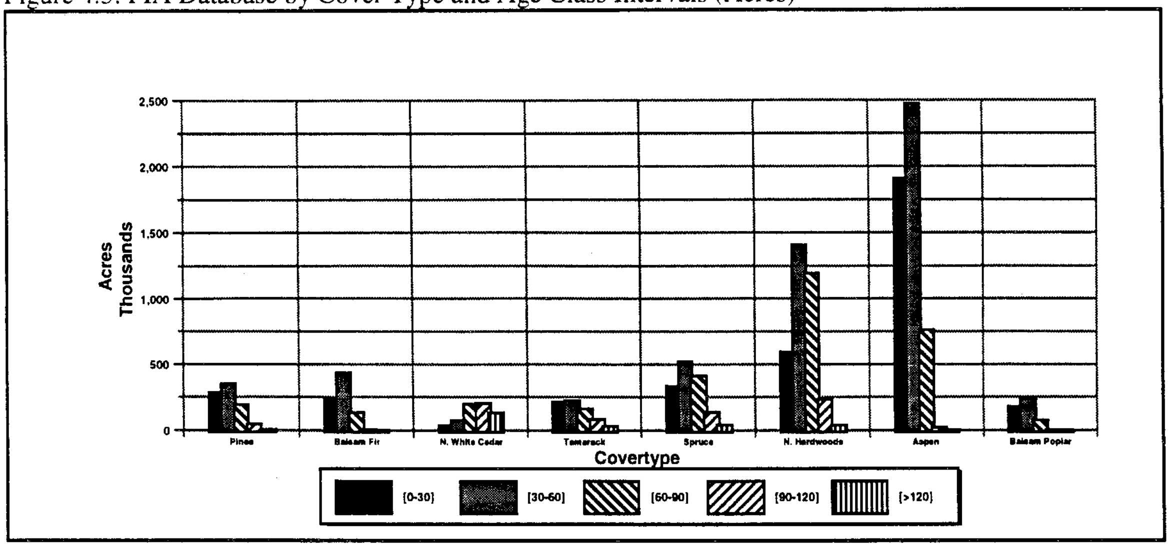
	COVER TYPE								
OWNER	Pines	Balsam Fir	N. White Cedar	Tamarack	Spruce	N. Hardwoods	Aspen	Balsam Poplar	**TOTAL**
N. Forests	220100	185900	92200	29800	282000	345600	642100	23400	**1821100**
Misc. Public	38800	20000	71300	46500	65900	148200	222500	29800	**643000**
State	158000	167000	267500	334000	599400	435200	887200	127700	**2976000**
County	129200	181900	97700	127800	218100	615300	1034100	88500	**2492600**
Private	248800	182500	70700	170700	200700	1786500	2086200	206700	**4952800**
F. Industry	86400	71900	49000	9100	75500	138900	293400	25700	**749900**
TOTAL	**881300**	**809200**	**648400**	**717900**	**1441600**	**3469700**	**5165500**	**501800**	**13635400**

Figure 4.2: Percentage Breakdown of FIA Database by Ownership and Cover Type



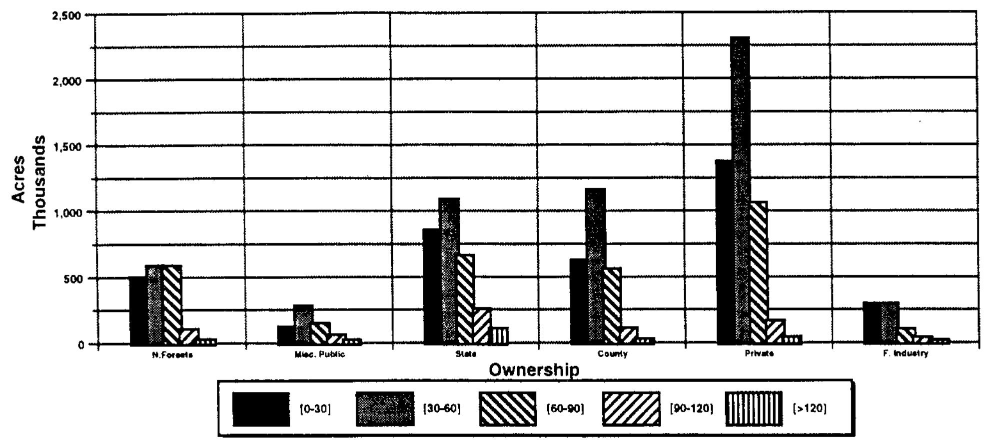
An important attribute for the modeling process is the stand cover type and age class, which suggest the quantity and quality of timber products harvested from a given stand. Therefore, reasonably accurate estimates of initial age class distributions are essential for reliable results. The cover type and age class intervals data are shown in Figure 4.3. The age class imbalance for aspen, currently being debated in the forest sector, is evident in the figure. Almost two million acres of aspen are in the [0-30] year age class and about three quarters of a million acres are in the [60-90] year age class. Approximately 1.5 million acres of northern hardwoods are over 60 years of age. A significant portion of these hardwoods are considered low quality timber and not presently consumed by the forest industry.

Figure 4.3: FIA Database by Cover Type and Age Class Intervals (Acres)



The age class distribution by ownership is presented in Figure 4.4. Acreage in the [0-30] year class is significant for all the ownership groups. There is no significant acreage in the over 90 year age group except for the state ownership. Out of all ownership groups, the national forests show the most uniform age class distribution, at least for the first three age class intervals.

Figure 4.4: FIA Database by Ownership and Age Class Intervals (Acres)



Truncated FIA Database

In the Minnesota GEIS, wildlife, recreation, water, soils, and biodiversity experts were given a detailed description of forest management activities based on an initial set of simulations. These descriptions included the timing and location of all scheduled forest management activities and their impact on the forest inventory at each planning interval. The experts analyzed the stand-level management schedules using discipline-specific models and provided recommendations on how to avoid adverse environmental impacts associated with each harvest level. Their recommendations resulted in the assignment of all commercial forest lands to one of the following five treatment categories:

(1) Normal: Plots for which all standard silvicultural options were acceptable. This category represents complete FIA data set.

(2) Buffered: Plots within a certain distance of water, where no clear cutting and only random thinnings at specified time intervals were allowed.

(3) Extended: Plots on which minimum harvest age was increased.

(4) Old Growth: Plots on which harvesting was not allowed at all.

(5) Reserved: Plots which were not available for harvesting activity for economic, environmental, and social reasons.

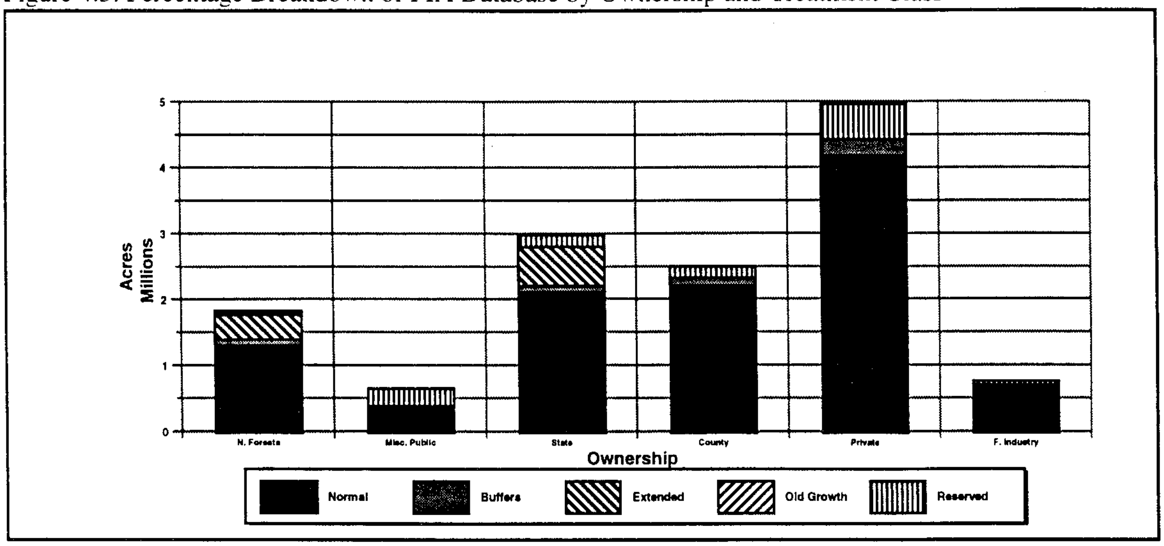
The summary of acres by ownership and treatment class is presented in Table 4.5. Later in this study, two types of forest management prescriptions are modeled: "unrestricted" and environmentally "restricted". For the restricted management simulations, the FIA database was truncated by 1,028,000 acres, consisting of over one thousand analysis areas that fell into the reserved treatment classification. Furthermore, no-clear-cutting constraints were imposed on forest lands in buffered and old growth treatment classes. These constraints are especially restrictive because thinnings or selective cuttings are generally more expensive than clear cutting on a per unit basis.

Table 4.5: Distribution of FIA Database by Ownership and Treatment Class (Acres)

Owner/Treatment	Normal	Buffers	Extended	Old Growth	Reserved	Total
N. Forests	1315800	112900	364900	27500	0	1821100
Misc. Public	402600	10200	0	0	230200	643000
State	2127200	99800	597300	0	151700	2976000
County	2224300	141800	0	0	126500	2492600
Other Private	4188400	263600	0	0	500800	4952800
F. Industry	723700	7400	0	0	18800	749900
Total	10982000	635700	962200	27500	1028000	13635400

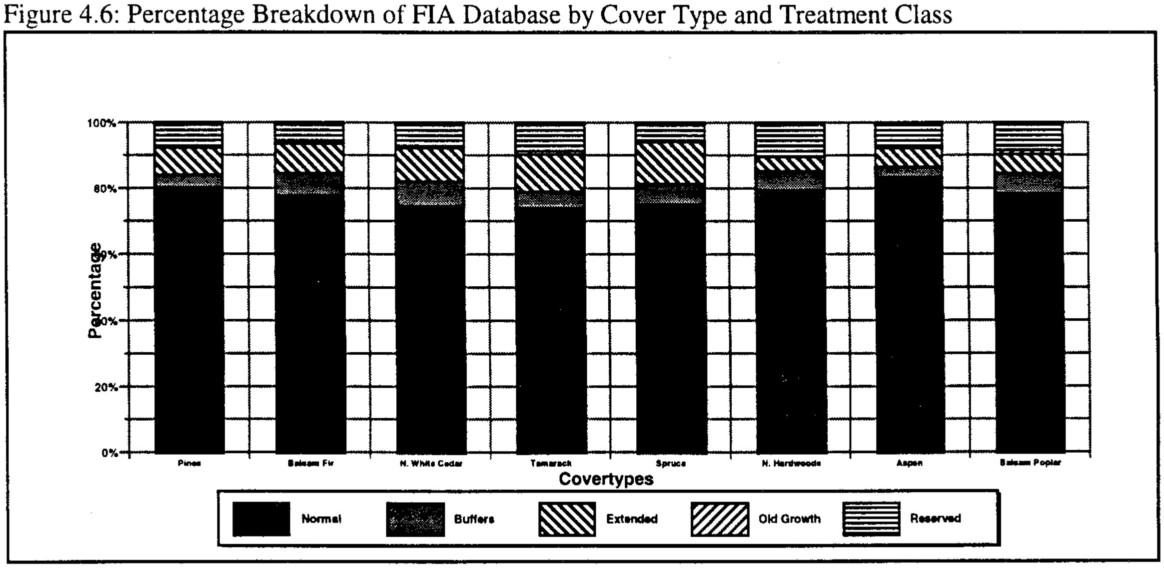
Availability of forest lands for harvesting varies by owner. Small private owners have varying management objectives and income needs. Environmental concerns also exclude timber production on much of the public forest land. Availability was implemented in the model by randomly removing stands from the forest base with availability varying by ownership. Figure 4.5 shows the percentage breakdown of treatment by ownership. Notice that about 27 percent of miscellaneous public lands are reserved while no land is reserved in the national forests. Extended rotations are generally applied on the state and the national forest lands. Buffered lands in all ownership categories are less than five percent. There are no old growth limitations in any category except the national forests.

Figure 4.5: Percentage Breakdown of FIA Database by Ownership and Treatment Class



The percentage breakdown of treatment class by cover type is presented in Figure 4.6. Notice that acreage in the reserved category is almost uniform across all cover types and the variability is less than 5 percent at best. The buffered areas also exhibit uniformity across cover types with less than 2 percent variability. About 5 percent of spruce and balsam poplar, 2 percent of northern hardwoods, and about 10 percent of all other cover types are under extended rotations.

Figure 4.6: Percentage Breakdown of FIA Database by Cover Type and Treatment Class



Additional statistics on FIA data are presented in Appendix B, including cover type, age class, and ownership by county.

4.7 Hybrid Poplar

For this study, agricultural landowners are modeled as if they face a choice: (1) don't grow trees and rent the land or (2) grow hybrid poplar and sell it to potential power plants and/or to forest product markets. Since hybrid poplar and aspen have similar product characteristics, it is assumed that they can be substituted for each other in all markets. In compliance with existing practices, an 8 X 8 spacing and an optimal rotation age of 10 years is assumed.

Yield Rates

On going research on intensively managed plantations provides some reliable information on the production potential of short-rotation hybrid poplar clones. In Minnesota, yield rates are expected to range between 2 to 5 dry tons/acre/year, according to soil and climatic conditions. These estimates are mostly derived from a network of research plantations which were established in a five state region of the north central U.S during the 1980s [14]. In the present study, yield rates are modeled as a function of NRCS land capability classes and subclasses, rainfall, and soil types. In general, soils with a higher productivity rating (a lower LCC number) for agricultural crops will also be more suitable for hybrid poplar. However, this link is not expected to hold for soils with poor drainage conditions, because hybrid poplar still tends to grow well under such conditions [2].

For the purposes of this study, hybrid poplar yield rates for all agricultural land parcels were determined by consultation with researchers at the US Forest Service hybrid poplar project at Rhinelander, Wisconsin. Table 4.6 shows the potential yield rates, acreage and the corresponding land capability classes and subclasses. The average for the entire study area was 3.5 dry tons per acre (one dry ton is approximately equal to one cord). There are 10 different yield levels which reflect all the land capability class and sub-class combinations. The minimum and the maximum yields considered are 2.2 and 5 dry tons respectively.

Table 4.6: Estimated Annual Yield Rates for Hybrid Poplar on Agricultural Lands

LCC & LCSC	ACRES	DRY TONS PER ACRE/YEAR
0	4362	3
0M	27994	3.5
0S	1523	3
0W	7784	4.5
1	76	5
2C	3237	3.2
2E	48206	3.2
2M	1795	3.6
2S	20708	3.2
2W	78340	4.9
3C	623	3.2
3E	58463	3.2
3M	1988	3.6
3S	50638	3.2
3W	65566	4.9
4C	153	3.2
4E	10166	3.2
4M	544	3.6
4S	36438	3.2
4W	14729	4.9
6E	833	3.2
6S	3329	3.2
6W	232	3.9
7E	382	2.2
7S	235	2.2
8W	20	4
TOTAL/AVERAGE	438364	3.54

Notes: M indicates unknown or missing LCSC data.
O indicates unknown or missing LCC data.

Production Costs

Estimates of variable production costs for hybrid poplar production were obtained from the

Natural Resources Research Institute (NRRI), based on actual cost data associated with a network of plantations in Minnesota and Wisconsin. Table 4.7 shows the break down of these production costs for the first three years of operation. In general most expenses incurred in the production of hybrid poplar occur during the establishment phase. After successful establishment usually there are no other significant costs until harvest. The only exception might be in case of disease which may result in additional costs but are not modeled in this study.

Table 4.7: Production Cost Estimates for Hybrid Poplar

ACTIVITY	UNIT	COST	YEAR
Clip/Mow	$/Acre	7.50	0
Herbicide	$/Acre	20.00	0
Plow	$/Acre	13.42	0
Disk	$/Acre	14.00	0
Plant Cover	$/Acre	7.50	0
Cover Seed	$/Acre	3.00	0
Harrow	$/Acre	10.00	1
Planting	$/Acre	34.00	1
Cutting	$/Acre	68.00	1
Herbicide	$/Acre	20.00	1
Cultivation	$/Acre	11.19	1
Herbicide	$/Acre	24.00	2
Fertilization	$/Acre	30.00	3
Land Rent	$/Acre	variable	1-10

Source: [2]

4.8 Harvest and Transportation Costs

Harvest and transportation costs are extremely significant components of the timber production process. In general, transportation costs are approximately one third of the total costs associated with the procurement of timber. In some cases these costs can be actually higher than the stumpage value (the price of uncut timber) of a given stand. Despite this, transportation costs are often not considered in the timber management and modeling studies. This omission can be justified because a given timber stand might produce several products, each of which may have several market destinations. Incorporating multiple products and market locations along with the traditional complexities of long term planning usually makes the transportation problem unmanageable in the context of harvest scheduling. The Minnesota GEIS was the first large scale study in the United States to successfully deal with these complex issues [20].

Forest harvesting costs vary by several factors which makes their estimation difficult. The location, condition, area, volume, and harvest type (thinning or clear cutting) are some of the factors which influence harvesting costs. Generally these factors differ on a stand by stand basis and therefore, using a fixed per acre estimate of harvesting costs in the modeling process is generally not realistic.

In the GEIS, a specific harvest cost model was implemented which accounted for factors such as clear-cut or thinning, average tree size, volume per acre, off road distance, and total volume harvested. This model was specifically designed for the forest harvest conditions encountered in Minnesota. The same approach was used in the present study, as summarized in Table 4.8. The model starts with a base harvest cost of $22 per cord, which is then adjusted to reflect stand characteristics. All stands are individually assessed by the model and the output is used as the harvesting cost estimates. The resulting estimated harvesting costs ranged between 16 and 29 dollars per cord for thinning and between 11 and 22 dollars per cord for clear cutting.

Table 4.8: A Timber Harvesting Cost Model

VARIABLES	DEFINITION	EQUATIONS	RANGE
A_1	Thinning (0=No, 1=Yes)	1	Either Thinning or Clear-cut, Not Both
A_2	Clear-cut (0=No, 1=Yes)	0	Either Thinning or Clear-cut, Not Both
A_3	Avg. Tree Size (ft^3)	6	1-20 ft^3
A_4	Avg. Off Road Distance (ft)	400	0-2000 ft
A_5	Volume Per Acre Removed (cords/acre)	10	4-40 cords/acre
A_6	Total Logging Chance Volume (cords)	100	15-450 cords
A_7	Tree Size Effect	$=A_1*(161.9-18.64*A_3+1.525*A_3^2-0.041*A_3^3)+A_2*(123.7-12.42*A_3+0.828*A_3^2-0.0198*A_3^3)$	
A_8	Transport Distance Effect	$=A_1*(104+0.007*A_4)+A_2*(54.1+0.007*A_4)$	
A_9	Volume Per Acre Effect	$=A_1*(140.6-5.62*A_5+0.3225*A_5^2-0.006*A_5^3)+A_2*(74.1-0.059728*A_5)$	
A_{10}	Logging Chance Volume Effect	$=A_1*(134.6-0.4865*A_6+0.0018*A_6^2-0.000002183*A_6^3)+A_2*(98.1-0.375*A_6+0.001228*A_6^2-0.0000013068*A_6^3)$	
A_{11}	Overall Weighting Factor	$=(2*A_7+A_8+A_9+A_{10})/5$	
A_{12}	Base Wood Cost ($/cord)	22	
	Factored Wood Cost ($/cord	$A_{11}*A_{12}/100$	

Source:[26]

In addition to the above production costs, a loading cost of $4.75 per cord and a one way transportation cost of $0.15 per cord per mile is applied to all harvested products. The transportation costs are assumed to be the same regardless of the road type.

Two separate estimates of harvest costs for hybrid poplar were generated. One reflects the traditional harvesting technology, and the other represents the whole tree harvesting systems which avoid expensive operations such as wood chipping and partial skidding [27]. In Minnesota, data on hybrid poplar harvesting costs is rare because most of the large scale plantations are still below harvesting age. Therefore, this study utilized harvesting cost estimates generated by the Oak Ridge National Laboratories (ORNL) for the Great Lakes region [28]. Appropriate adjustments were made to reflect the regional conditions and specific assumptions of this research. The accuracy of the adjusted harvest cost estimates was determined by using the above harvesting cost model as well as discussions with the experts in this field. The following are the adjusted harvest costs for hybrid poplar in Minnesota:

- Conventional Harvest: $450 per acre and an additional loading and processing cost of 4.75 per dry ton.
- Whole Tree Harvest: $270 per acre and an additional loading and processing cost of 4.75 per dry ton.

The whole tree harvest costs are 40 percent lower than the conventional costs primarily because unlike conventional harvesting, whole tree harvesting does not require additional on site processing such as wood chipping.

The model is calibrated so that hybrid poplar sold as pulpwood in the forest markets will be harvested conventionally because these markets generally require additional on-site processing. Hybrid poplar sold to power plants will be harvested and processed with the whole tree harvesting technology.

4.9 Density of Cover Types

Power plant fuelwood requirements are generally stated in dry tons because it is assumed that any type of wood has about the same energy content per unit weight, provided that the moisture content is identical. Chemical properties for different tree species are roughly the same, given identical moisture content. But tree species do differ by their moisture content at harvest. Therefore, their energy content per unit of weight are also different. One pound of wood at zero percent moisture content is equivalent to about 8600 Btu (British thermal units). Table 4.9 shows the volumes, specific gravities and densities at zero percent moisture content of major tree species in Minnesota. The specific gravities were used to determine the densities for individual tree species [29] and the volumes were used to calculate weighted densities for similar tree species groups. These weighted densities for different cover types were used in the model to determine the most cost effective combinations of cover types to be allocated to the power plants.

Table 4.9: Weighted Densities for Minnesota Tree Species Groups

SPECIES	SP. GRAVITY lbs/ft³	DENSITY lbs/ft³	VOLUME cords	WTD. DENSITY lbs/ft³
E. White Pine	0.35	21.8	261642	
Red Pine	0.46	28.7	581621	
Jack Pine	0.43	26.8	560139	
All Pines			**1393402**	**26.65**
White Spruce	0.36	22.5	295108	
Black Spruce	0.42	26.2	745825	
All Spruce			**1040933**	**25.15**
White Oak	0.68	42.5	645287	
Bur Oak	0.64	40	12248	
N. Red Oak	0.63	39.3	816814	
N. Pin Oak	0.63	39.3	12248	
Black Oak	0.61	38.1	12248	
All Oak			**1498845**	**40.67**
Big Tooth Aspen	0.39	24.3	278351	
Quaking Aspen	0.36	23.7	3809323	
All Aspen			**4087674**	**23.74**
Basswood	0.37	23.1	691130	
Black Walnut	0.55	34.3	14163	
Black Cherry	0.50	31.2	15684	
Butter Nut	0.38	23.7	11145	
American Elm	0.50	31.2	89361	
Slippery Elm	0.53	33.1	89361	
Rock Elm	0.63	39.3	89361	
Black Maple	0.57	35.6	201499	
Sugar Maple	0.63	39.3	172056	
Red Maple	0.54	33.7	201499	
Silver Maple	0.47	29.3	172056	
Black Ash	0.49	30.6	699328	
Green Ash	0.56	35.0	186502	
All N. Hardwoods			**2633145**	**30.44**
Hybrid Poplar	**0.36**	**22.5**	**0**	**22.5**
Balsam Poplar	**0.35**	**21.8**	**961739**	**21.8**

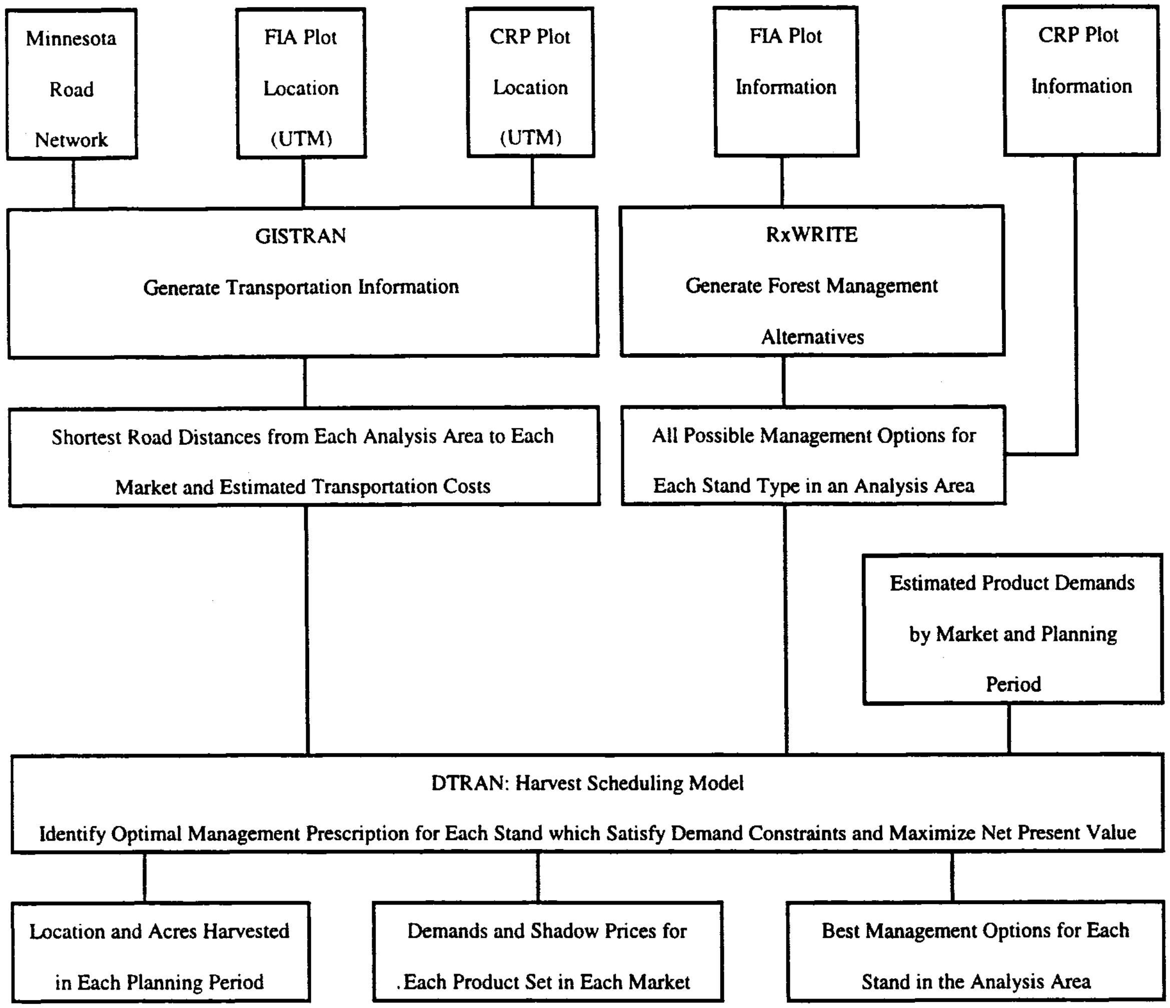
4.10 Management Prescriptions

As discussed in chapter 3, management prescriptions are a set of alternatives which are defined by the analyst for each analysis over the planning horizon. In this study, RxWrite was used to define and implement these management alternatives. Anywhere from 20-80 management options were evaluated for each analysis area. The number of options used for a specific stand varied by the initial age class, site index, and regeneration type. In general, younger stands have more management alternatives than the older stands. The number of prescription also increases then the forest stands are assigned to different treatment classes, to reduce the environmental impacts of harvesting. This is because the stands assigned to a specific treatment class were only linked to regeneration options for that treatment class. In other words, stands with extended rotations were linked to regeneration alternatives with extended rotations only. The details of silvicultural options employed in this study are presented in Appendix C.

4.11 Schematic Overview of Modeling Framework

Given the data discussed in this chapter and the modeling system presented in chapter 3, we are in a position to link the data to the models. Figure 4.7 presents a flowchart of this linkage. All location information for the markets, forest analysis areas, and agricultural analysis areas are evaluated by GISTRAN. It uses a road network to determine the transportation distance and costs for all product flows. The management alternatives for forest lands are analyzed by RxWrite. The output is the volume of each product produced under a given management alternative and its expected costs. The management alternatives for agricultural lands were determined outside RxWrite. The output from GISTRAN and RxWrite is input into DTRAN along with the exogenous product demands for all the markets in each planning period. DTRAN determines the best management alternative for each analysis area and determines the location of all harvested acres. DTRAN also estimates the present value of shadow prices for each product type, in each market and planning period.

Figure 4.7: A Flowchart of Modeling and Data Components



In Chapter 5, the results of fuelwood production scenarios using only agricultural lands are presented. The DTRAN modeling system was not used to generate these independent fuelwood production scenarios. Chapter six presents the results of employing DTRAN to examine the complete set of product and resource base scenarios.

Chapter 5: Fuelwood Production on Agricultural Lands

5.1 Fuelwood Production

In this chapter, the estimates of delivered fuelwood costs for each 100 MW potential power plant, located in Granite Falls and Alexandria are presented. These estimates were calculated using a combination of linear optimization techniques and the principles of cash flow analysis. The discounted fuelwood costs from each analysis area to each power plant were calculated using a single 10 year planning period and a real discount rate of 4 percent. We used only a single planning period in this part of the analysis because we assumed that the management options would not change in the subsequent periods. It was further assumed that the only fuelwood source available to the power plants would be hybrid poplar produced on agricultural lands considered in this study. The differential effects of using two types of harvesting costs, reflecting either traditional harvesting technology (chipped wood) or whole tree harvesting systems (unchipped wood), were examined. Alternative estimates of the opportunity cost of land in each township were represented by annual CRP contract payments and annual cash rents. The combination of the above assumptions and the plant locations resulted in eight scenarios:

1 - Alexandria with chipped wood and CRP payment rates.

2 - Granite Falls with chipped wood and CRP payment rates.

3 - Alexandria with unchipped wood and CRP payment rates.

4 - Granite Falls with unchipped wood and CRP payment rates.

5 - Alexandria with chipped wood and cash rents.

6 - Granite Falls with chipped wood and cash rents.

7 - Alexandria with unchipped wood and cash rents.

8 - Granite Falls with unchipped wood and cash rents.

5.2 Delivered Fuelwood Costs

The results for all of the above independent scenarios are presented in Table 5.1. Approximately 90-100 thousand acres of land capable of producing about 3.5 million dry tons of wood would be required to fuel each power plant for the entire planning period. The average present value costs of delivered (to the plant gate) fuelwood range between $29/dt to $40/dt, depending upon the assumptions used. Table 5.1 also shows the maximum and the minimum costs per dry ton. The maximum cost can be interpreted as the marginal cost of delivered fuelwood because it is the cost associated with the last unit of fuelwood delivered to a given power plant. The minimum costs are simply the cost of fuelwood delivered from a location with the lowest overall cost.

Table 5.1: Final Results for All Independent Fuelwood Supply Scenarios

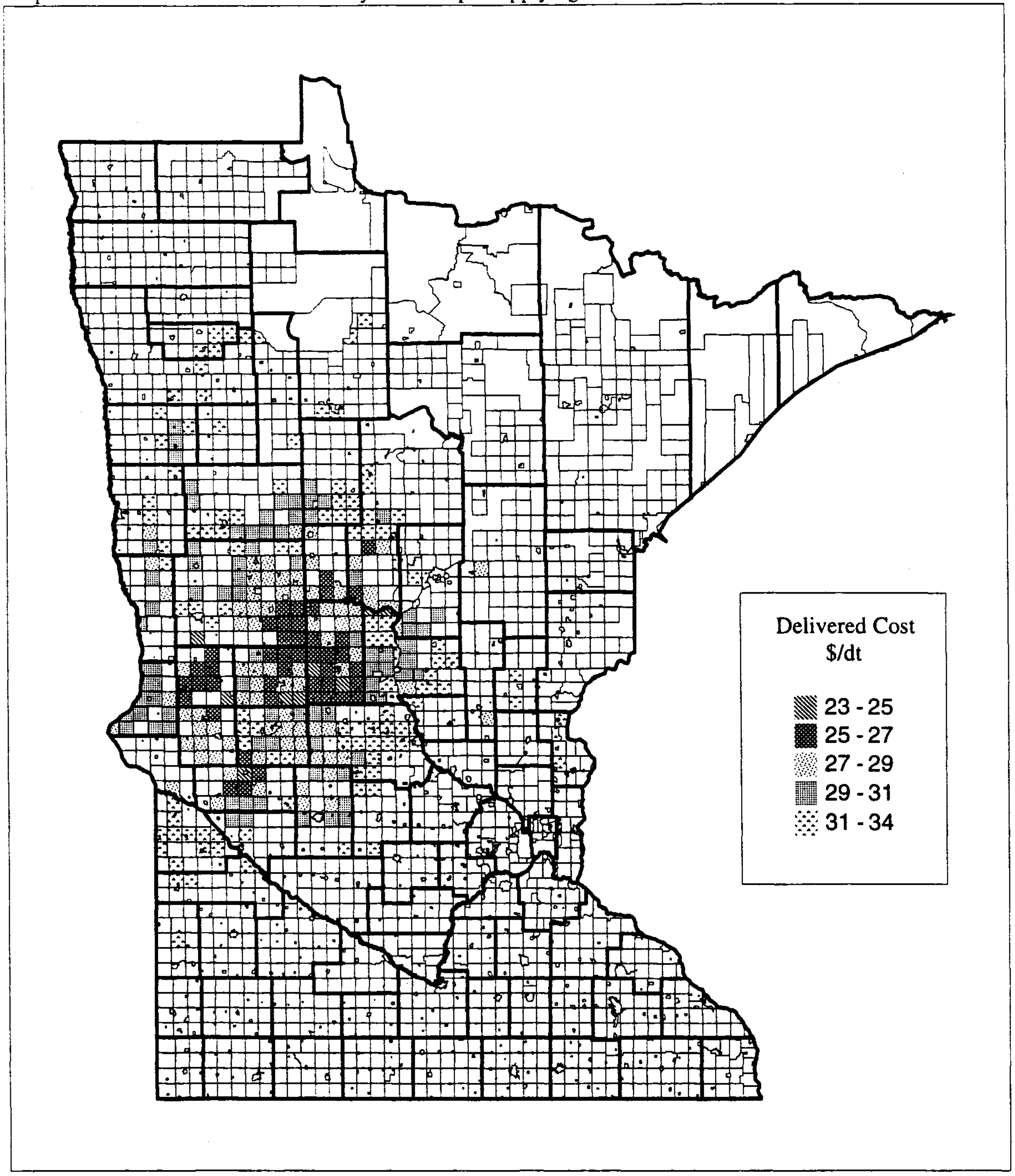
Scenario	Acres	Dry Tons	Total Cost ($)	Average $/DT	Minimum $/DT	Maximum $/DT	Average $/MBtu
1	90,224	3,500,846	123,277,554	34.81	23.21	38.53	2.02
2	97,968	3,501,236	138,864,972	39.63	26.04	43.66	2.30
3	94,546	3,501,769	112,071,938	31.86	20.73	35.68	1.85
4	98,809	3,502,947	127,014,242	36.25	23.56	39.99	2.11
5	93,772	3,523,321	114,540,105	32.01	19.59	35.79	1.86
6	99,288	3,503,062	131,027,536	37.86	25.92	41.74	2.20
7	97,349	3,558,199	104,142,209	28.99	17.11	33.28	1.69
8	99,813	3,505,489	119,043,920	34.37	23.44	38.02	2.00

Systems that use unchipped wood and estimated cash rents as the proxy for the opportunity cost of land result in the least cost scenarios for both power plants. This is because the estimated cash rents are generally lower than the CRP payment rates and also because of the differences in the costs of harvesting technologies used. Whole tree harvesting costs are about 40 percent lower than the traditional chipped wood harvesting. Agricultural lands can be used to meet the fuelwood requirements of a power plant in Alexandria if the plant pays an average cost of $29/dt ($1.69/MBtu), provided that the landowners use whole tree harvesting technology and consider cash rents as their opportunity cost for land.

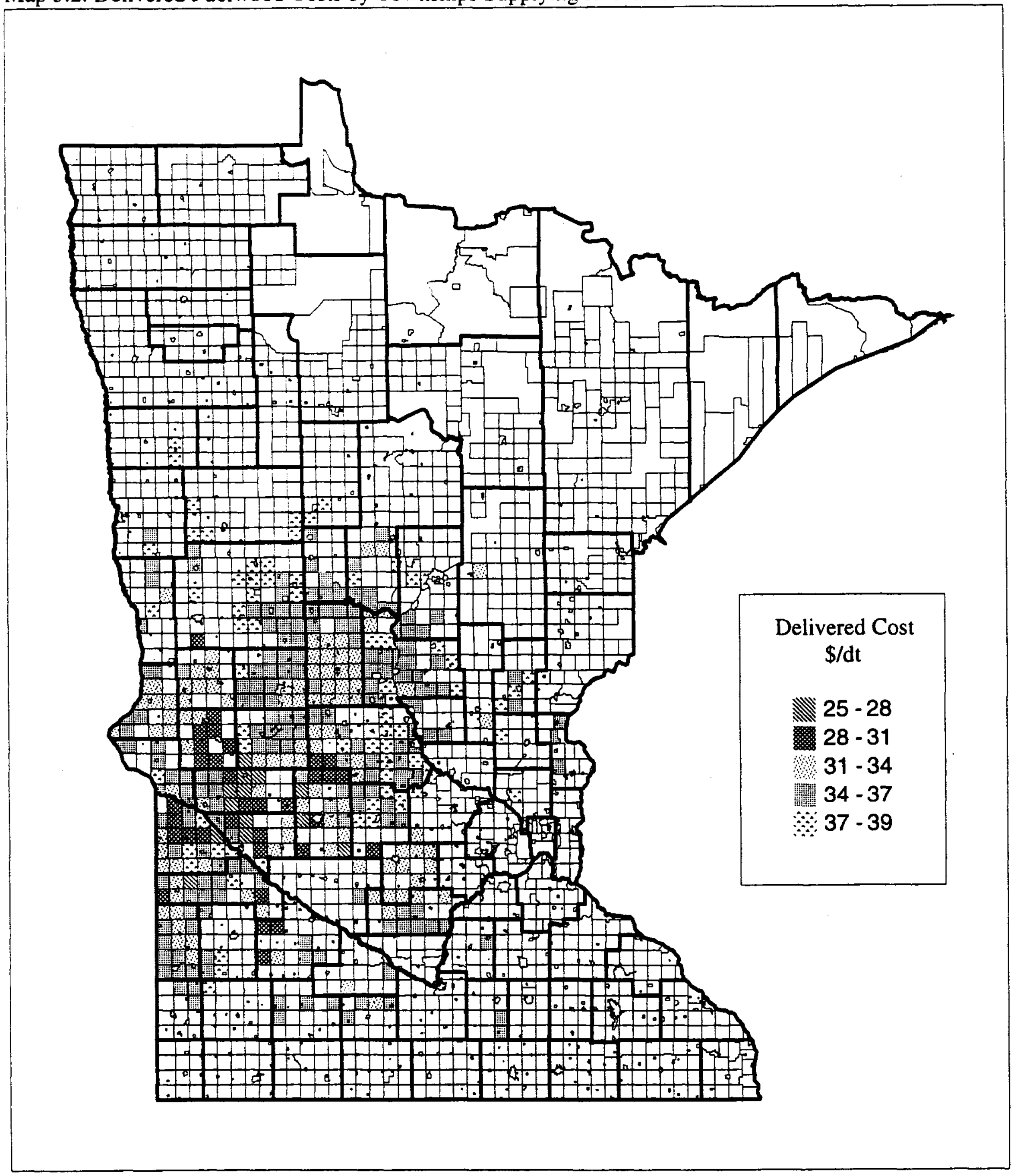
Under all scenarios, the delivered fuelwood costs at Alexandria are on average about $5/dt lower than Granite Falls. This is simply because those agricultural lands closer to Granite Falls generally fall into the category of good agricultural lands with relatively higher opportunity costs. These high land rents translate into higher production costs which make it more cost effective to transport fuelwood from lands that are further away but have lower rents. The yields on lands closer to Granite Falls are not so high that they can off-set their higher opportunity costs. The average distance between production sites and Granite Falls is about 90 miles, and for Alexandria it is approximately 60 miles.

Map 5.1 shows the weighted average fuelwood delivery costs for all townships which supply fuelwood to Alexandria in the scenario 7 (unchipped wood, cash rents). The cost estimates associated with each yield rate in a given township were weighted by the number of acres to determine the total average costs for a given township. In most townships, delivered costs range between $25/dt ($1.45/MBtu) and $34/dt ($1.98/MBtu). Townships in the west and north-central part of the state deliver the majority of the fuelwood. No fuelwood is supplied from the southern part of the state primarily because of the higher opportunity costs in that area. The range of fuelwood traveling distance is between 4 and 188 miles, with an average distance of 62 miles. The maximum distance reflects shipments from a few townships in the north and north-western parts of the state; most distances are much shorter.

Map 5.1: Delivered Fuelwood Costs by Townships Supplying to Alexandria under Scenario 7



The lowest cost fuelwood delivery scenario at the Granite Falls location is also that in which landowners use cash rents to determine their opportunity cost of participation and employ a whole tree harvesting system. The average delivered fuelwood cost is estimated at $34/dt ($2/MBtu). The weighted average costs of delivered fuelwood to Granite Falls are presented in Map 5.2. Again, Map 5.2: Delivered Fuelwood Costs by Townships Supplying to Granite Falls under Scenario 8



higher land opportunity costs result in most of the fuelwood being shipped from the central and west-central part of the state, in spite of the fact that other agricultural lands are closer to Granite Falls. The delivered fuelwood costs for majority of the townships supplying to Granite Falls are between $31/dt ($1.80/MBtu) and $39/dt ($2.27/MBtu) and some townships have costs within $25/dt

($1.45/MBtu) and $31/dt ($1.80/MBtu). The transportation distances vary by as much as 7 to 211 miles, with an average distance of 91 miles. The longest hauling distances are associated with two townships in the Norman County, in the north-western corner of the state.

Table 5.1 shows that scenarios which employ traditional harvesting techniques and use CRP payment rates as opportunity cost of land result in substantially higher fuelwood costs. In these scenarios, the fuelwood costs at Alexandria and still lower than Granite Falls because of the locational advantages. The location and fuelwood cost estimates of townships supplying fuelwood for these scenarios are presented in Appendix D.

5.3 Combined Fuelwood Production Scenarios

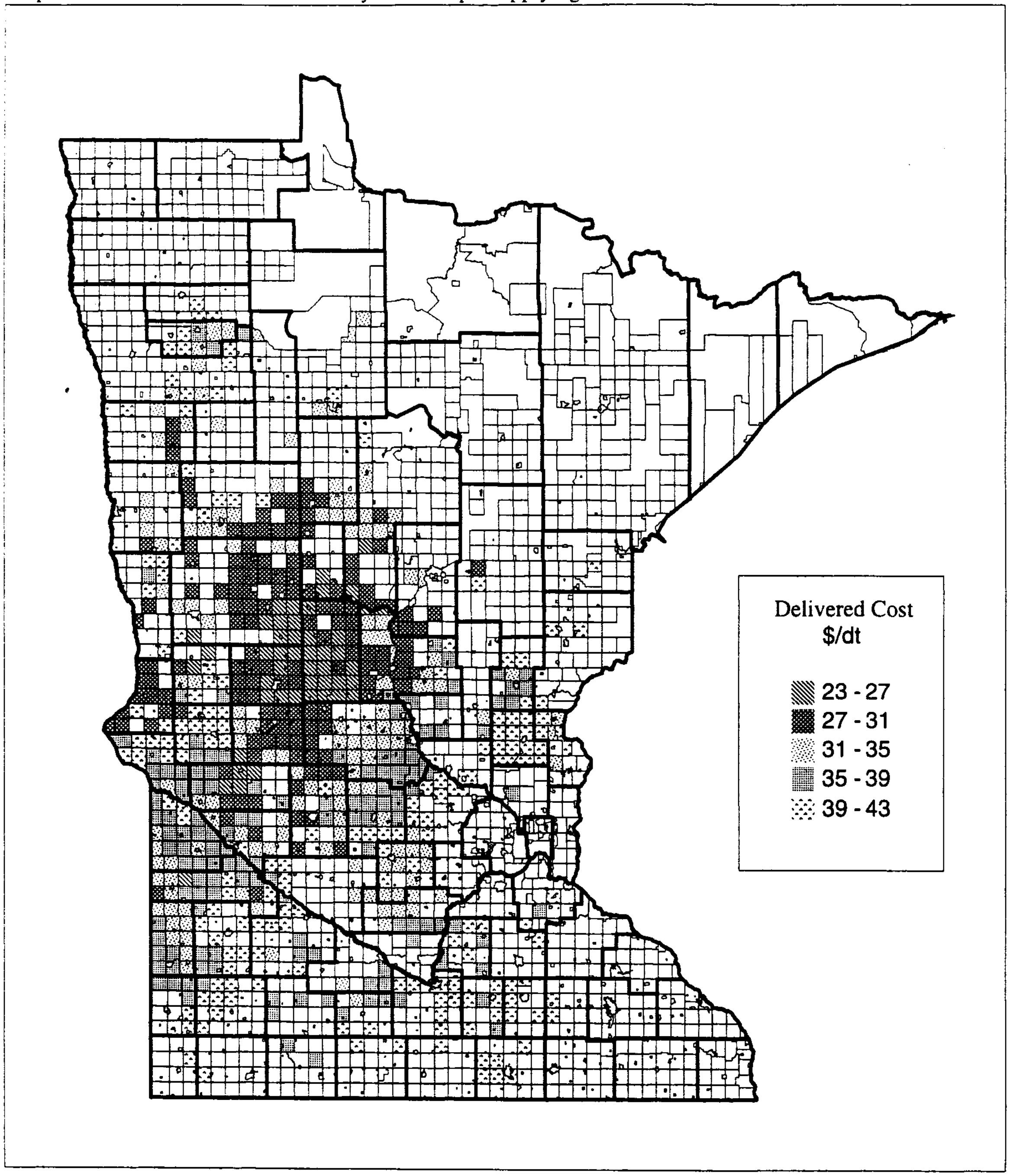
In this set of simulations, it is assumed that power plants at both locations are in operation. As before, landowners who chose to grow poplar ship only to these power plants, and only wood from agricultural lands is used for energy. The least cost deliveries changes from the previous set of runs because some owners can shift their delivery targets when both plants are in operation. The results for this scenario are presented in Table 5.2. These results demonstrate that the least cost option is if whole tree harvesting is used and if cash rents reflect the landowners opportunity cost of participation. The combined estimates of delivered fuelwood range between $17/dt ($1/MBtu) and $43($2.5/MBtu), with an average of $33.71/dt ($1.96/MBtu). The present value of total delivered costs associated with this scenario is nearly $242 million spread over the ten years. The total fuelwood costs at Alexandria are about $30 million lower than an identical plant located at Granite Falls. Map 5.3 illustrates the location and the weighted average of fuelwood costs by townships when both plants are in operation. The combined fuelwood requirements result in the inclusion of more townships in the southern region than either single power plant scenario. The main concentration of townships supplying fuelwood are in the central and the west-central part of the state. The weighted average delivered fuelwood costs by township range between $23/dt and $43/dt. The average fuelwood traveling distance to Alexandria is about 61 miles and nearly 89 miles to Granite Falls.

Table 5.2: Final Results for Combined Fuelwood Supply Scenarios

Scenario	Acres	Dry Tons	Total Cost ($)	Average $/DT	Minimum $/DT	Maximum $/DT	Average MBtu/DT
1	93,953	3,512,659	114,541,791	31.98	19.59	35.96	1.86
2	94,642	3,500,531	146,143,970	40.95	27.37	45.72	2.38
COMBINED	**188,595**	**7,013,190**	**260,685,761**	**37.11**	**19.59**	**45.72**	**2.16**
3	97,857	3,583,023	105,333,426	28.91	17.11	33.32	1.68
4	94,751	3,523,042	136,292,723	37.76	24.89	42.84	2.20
COMBINED	**192,608**	**7,106,065**	**241,626,149**	**33.71**	**17.11**	**42.84**	**1.96**
5	91,802	3,524,347	125,135,190	35.07	23.21	38.78	2.04
6	98,419	3,500,948	150,429,620	42.11	26.91	46.96	2.45
COMBINED	**190,221**	**7,025,295**	**275,564,810**	**39.15**	**23.21**	**46.96**	**2.28**
7	95,652	3,505,627	113,074,097	31.96	20.73	35.88	1.86
8	96,149	3,518,397	140,479,584	38.92	24.43	44.15	2.26
COMBINED	**191,801**	**7,024,024**	**253,553,681**	**35.81**	**20.73**	**44.15**	**$2.57**

The other three scenarios reflecting the combination of chipped wood and CRP payment rate assumptions result in noticeably higher costs. The maps of supply location and delivered cost estimates for each of these scenarios are presented in Appendix E.

Map 5.3: Delivered Fuelwood Costs by Townships Supplying to Both Power Plants under Scenario 7 and 8



5.4 Summary of Results

The agricultural lands examined here could support two 100 MW power plants in Minnesota and return to the landowners more income than their modeled alternative uses. This is only possible if the power plants are willing to pay more than the estimated delivered costs for fuelwood. Given the assumptions of this research, the average delivered fuelwood costs for all single scenarios range between \$1.69/MBtu and \$2.30/MBtu. The present value of total fuelwood costs are between \$104 and \$139 million over the planning entire planning period. The average fuelwood costs for the combined scenarios are between \$1.96/MBtu and \$2.57/MBtu. All combined as well as single power plant scenarios indicate that fuelwood supply costs at Alexandria are lower than Granite Falls.

Most of the townships which are in this analysis could provide fuelwood to either power plant, so if both power plants are in operation, then the landowners will sell to the highest bidder. This could result in a bidding war between the power plants and can substantially increase their fuelwood price in the short run, provided both plants must meet their supply needs only with wood from agricultural lands.

These estimates for fuelwood costs are still higher than power plants now pay for coal (\$1/MBtu). They are also higher than power plants might have to pay if they compete for wood in existing Minnesota forest product markets. We turn to this possibility in the next chapter.

Coal fired power plants produce relatively higher amounts of sulphur, ash and CO_2 emissions. If we consider the environmental costs of these externalities, only then wood fired power plant technologies such as whole tree burning can become economically feasible. The recent changes in the legislation such as the monitoring of CO_2 emissions from power plants and subsidies for bio-energy operated power plants including carbon credits are steps in the right direction and can help make large scale electricity production by burning wood a reality in the near future.

Chapter 6: Joint Production Results and Discussion

6.1 Simulation Design

In this chapter we analyze 16 forest product types aggregated into 21 product sets reflecting the demand for timber products at six markets and fuelwood demand at two power plant locations (Appendix A). The scheduling problems were modeled for ten 10-year planning periods. It was assumed that harvest occurs at the beginning of each planning period, and a real discount rate of 4 percent was used for all simulations. In all, eight simulations were analyzed, divided into two broader management categories, unrestricted and restricted for environmental reasons. Only part of the results are presented in this chapter. See the appendix for complete simulation listings.

Unrestricted Scenarios: For unrestricted harvest scenarios we assume that all commercial forest lands in the FIA data set described in Chapter 4 are available for harvest under generally accepted management practices. The objective was to minimize the cost of meeting the exogenous timber demand targets without any specific consideration for environmental impacts of harvesting. The commercial forest land base modeled for these scenarios comprised of 11,184 analysis areas representing over 13 million acres of forest land. The agricultural land base consisted of 3,107 analysis areas covering almost 440 thousand acres. Four scenarios were considered under this category:

Run 1: The demand for timber products at six traditional wood markets drawing only from commercial forest lands.

Run 2: Both timber demand and fuelwood demand for two power plants drawing only from commercial forest lands.

Run 3: Timber products demand drawing from both commercial forest lands and agricultural lands.

Run 4: Both fuelwood and timber demands drawing from both agricultural and commercial forest lands.

Restricted Scenarios: For restricted scenarios, commercial forest lands were modeled as if they were managed under the more restrictive conditions detailed in Chapter 4. These management restrictions were modeled after the Minnesota GEIS to reduce the negative environmental impacts of timber harvesting. The main restriction required that over a million acres of forest lands be excluded from any harvesting activity. These lands were considered unsuitable for timber harvesting because they provided services other than just timber. Other restrictions involved increased rotation ages, no clear cutting, and selective thinnings in certain analysis areas, but did not result in these areas being completely excluded. For these runs, the agricultural land base and the timber demand targets were the same as in the unrestricted scenarios:

Run 5: The demand at timber markets was met only by the restricted commercial forest lands.

Run 6: Both timber product and fuelwood demand targets were met from restricted commercial forest lands alone.

Run 7: Timber products demand was met from both restricted forest lands and agricultural lands.

Run 8: Both fuelwood and timber demands were met from both agricultural and restricted commercial forest lands.

6.2 Computation of Simulations

Unlike the power plant scenarios examined in the previous chapter, the more complex scenarios outlined above were analyzed by DTRAN, the forest management and harvest scheduling model described in Chapter 3. DTRAN was run on a 200 megahertz Dell Pentium microcomputer with 64 megabytes of random access memory (RAM) and a fixed disk space of 2 gigabytes running under a MS-DOS operating system.

The output for each run provided the estimates of product shadow prices, deviations from product demand targets, the location and amount of acres harvested, and the variable costs associated with each planning period and market. Every simulation had 220 product flow constraints, reflecting the demand for each product set in each market and planning period. Each simulation was run until an acceptable solution was found. The runs were judged acceptable when the deviations from the product demand targets in all markets and planning periods were within 5 percent. There were two exceptions to this rule: (1) when the demand targets for a given product were not met because of actual physical supply shortages, and (2) when the flow for a given product flip flops between iterations even with very small changes in the shadow prices. In some cases, a change of less than a penny between iterations could in fact change the procurement zone for a given product. This is because DTRAN does not allow stand splitting. If a product is harvested from a given stand, it goes to the market offering the highest price.

In general, each simulation was run for five to six hundred iterations. In the simulations with no physical timber supply shortages, 200-205 of the 220 constraints were met within a 5 percent deviation, and the remaining constraints within a 15 percent deviation.

6.3 Simulation Results

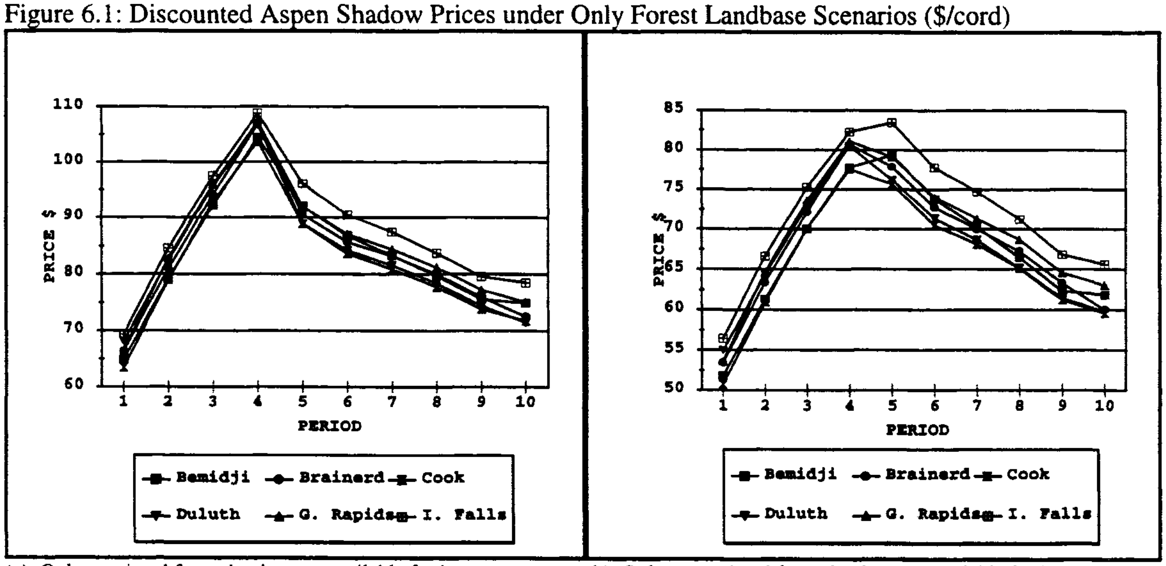
The estimated shadow prices for products at various levels of production over time is the most direct output of the scheduling model. These marginal costs reflect the required production levels, the initial inventory, and changes over time in the inventory as a result of management activities. Differences in production costs between alternate model runs measure the trade-offs of changing forest product demands and management constraints. The shadow prices for product types in the restricted runs are generally expected to be higher than those for the same products in the unrestricted runs, because of the smaller acreage on which production is allowed and because of higher per unit costs on these lands. This difference then, is one estimate of the relative cost of imposing environmental restrictions on the forests. The addition of agricultural lands to the production set is expected to help meet timber product demands, particularly in those planning periods where enough timber is not available from the traditional forest lands. The addition of power plants to the demand mix is expected to increase the role of agricultural lands.

Shadow price increases reflect shortages in specific timber products brought on by age class imbalances in the inventory. Simulation results for aspen, for which the age class imbalance is most pronounced in Minnesota, are presented in the following section.

6.4 Aspen

Even if there is no power plant demand, the demand targets for aspen products in any of the six markets could not be met when only traditional forest lands were available for harvest. Figure 6.1(a) and (b) illustrates the aspen discounted shadow prices for the six markets and planning periods when only restricted and unrestricted commercial forest lands were available for harvest. The

Figure 6.1: Discounted Aspen Shadow Prices under Only Forest Landbase Scenarios ($/cord)

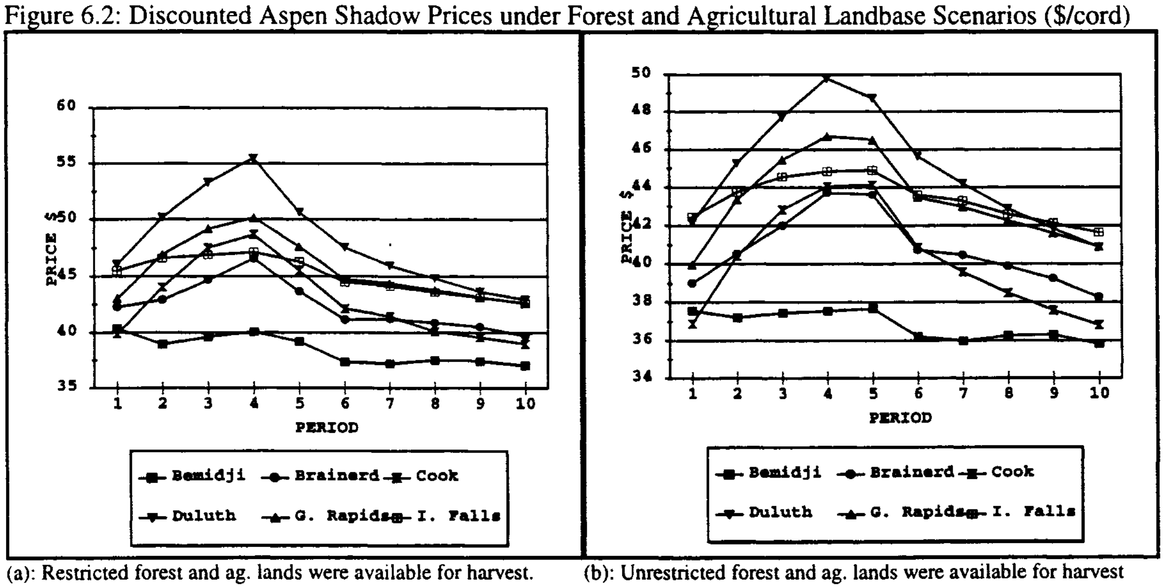


(a): Only restricted forest lands were available for harvest.

(b): Only unrestricted forest lands were available for harvest shadow prices in all markets rise over the first five periods, then begin to decline. In spite of relatively high shadow prices, the average deviations from the demand goals in all markets and initial planning periods was as much as 30 percent. This case demonstrates the situation where demand is not met because of actual physical supply limitations. Further increase in shadow prices at any given market does not ensure additional product supply. In such situations, shadow prices are meaningless, in that they do not reflect the actual marginal costs of delivered products.

The introduction of agricultural lands for hybrid poplar production changes the results substantially. Since there is little difference between the physical and chemical properties of aspen and hybrid poplar, they can be modeled as if their markets were identical. Figure 6.2 (a) and (b) depicts the discounted aspen shadow prices when agricultural lands are added to the restricted and unrestricted forest lands. As before, only the six timber markets are buying wood. The inclusion of

Figure 6.2: Discounted Aspen Shadow Prices under Forest and Agricultural Landbase Scenarios ($/cord)

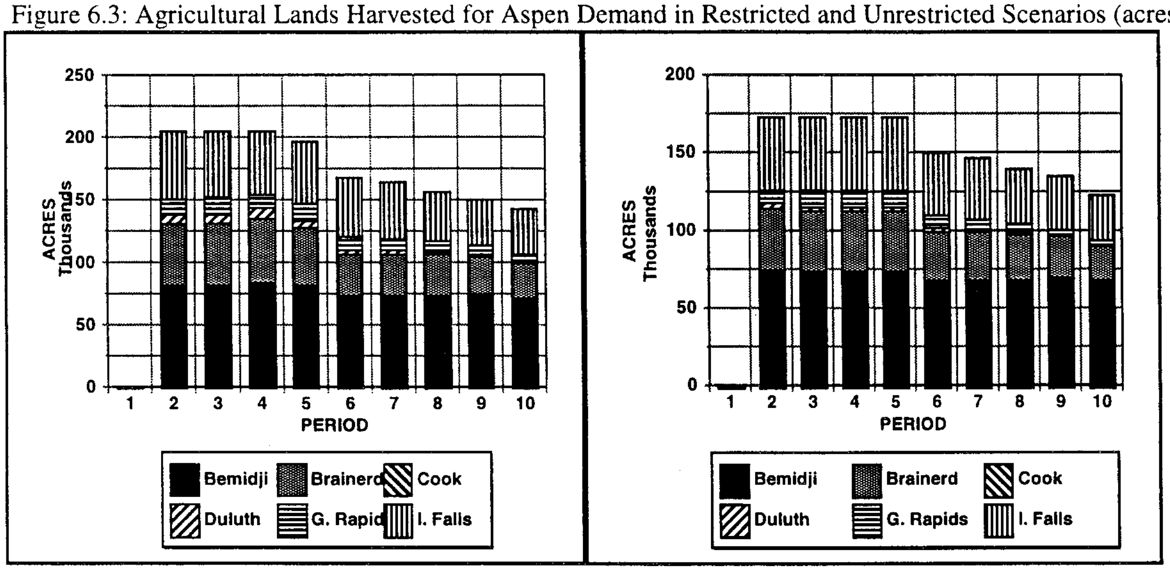


(a): Restricted forest and ag. lands were available for harvest. (b): Unrestricted forest and ag. lands were available for harvest

agricultural lands substantially reduces aspen shadow prices for both scenarios. The demand targets for all markets and planning periods are satisfied. Shadow prices for both scenarios generally rise for the first four periods before they begin to steadily decline, but their patterns are not uniform across markets. In general, the prices associated with the unrestricted scenario are nearly five dollars per cord less than the restricted scenario.Those markets that bought wood from agricultural lands generally exhibit the lowest shadow prices. As a rule, these markets are located closer to agricultural lands with low opportunity costs and high yield rates.

Figure 6.3 (a) and (b) shows the acreage of these lands utilized to meet aspen product demands for all planning period and markets. No agricultural land is harvested in the first planning period because the rotation for hybrid poplar is ten years and therefore it will not be available for harvest until the beginning of the second planning period. In both management scenarios, the lowest

Figure 6.3: Agricultural Lands Harvested for Aspen Demand in Restricted and Unrestricted Scenarios (acres)



(a): Restricted forest and ag. lands were available for harvest.   (b): Unrestricted forest and ag. lands were available for harvest

shadow prices are associated with Bemidji, primarily because it is located closer to large acreage of agricultural lands with relatively low opportunity costs. About 70-80 thousand acres of these lands are used to meet the demands at the Bemidji market in each planning period. In Figure 6.2, it was observed that the highest shadow prices are associated with Duluth and Grand Rapids markets, which receive most of their aspen supply from commercial forest lands. The agricultural lands allocated to Duluth and Grand Rapids markets is relatively insignificant. The only market which does not receive any supply from these lands is Cook. This market is located in the north-eastern part of the state. There are very few agricultural lands in the vicinity of this market and therefore, all its aspen requirements are met by the abundant aspen stands located nearby.

The breakdown of agricultural lands utilized to meet aspen demands in all markets and planning periods for both restricted and unrestricted scenarios is presented in Table 6.1 and Table 6.2, respectively. The restricted case requires approximately 20 thousand additional acres than the unrestricted case over the entire planning horizon. This is true because more restrictive management

Table 6.1: Acreage of Agricultural Lands Harvested to Meet Aspen Demand for the Restricted Scenario

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	83082	82643	84569	83351	74298	74382	74467	75506	73263	**705561**
Brainerd	0	50307	50097	51649	45241	34147	34170	33547	30685	28438	**358281**
Cook	0	0	0	0	0	0	0	0	0	0	**0**
Duluth	0	6126	7799	7877	5443	3821	2622	1818	1302	944	**37752**
G. Rapids	0	12962	12473	11300	13715	9614	9518	8690	7069	5448	**90789**
I. Falls	0	52177	51642	49259	48563	45801	43367	37805	35472	34282	**398368**
TOTAL	**0**	**204654**	**204654**	**204654**	**196313**	**167681**	**164059**	**156327**	**150034**	**142375**	**1590751**

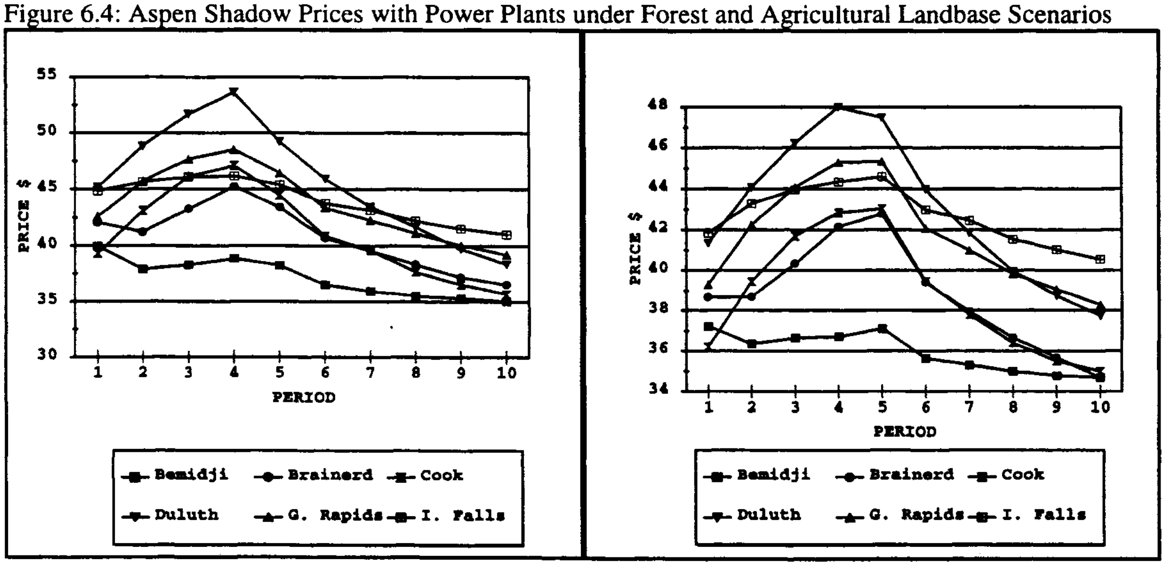
Table 6.2: Acreage of Agricultural Lands Harvested to Meet Aspen Demand for the Unrestricted Scenario

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	76142	74374	74311	74330	69011	69469	69777	69940	69027	**646381**
Brainerd	0	38731	38767	38811	38822	30873	30374	28859	27447	21762	**294446**
Cook	0	0	0	0	0	0	0	0	0	0	**0**
Duluth	0	3609	3620	3620	3609	2425	1818	944	739	585	**20969**
G. Rapids	0	8580	10450	10469	10450	8744	7110	5195	3724	3601	**68323**
I. Falls	0	45293	45144	45144	45144	38672	37577	34383	33069	27458	**351884**
TOTAL	**0**	**172355**	**172355**	**172355**	**172355**	**149725**	**146348**	**139158**	**134919**	**122433**	**1382003**

practices on the forest lands including the exemption of over a million acres from any type of harvest activity are modeled under the restricted scenario. It is interesting to note that after the first four periods the harvested acreage of agricultural lands starts to decline, reflecting the fact that the age class imbalance of aspen stands will begin to improve in about 40 years. As a result, its ability to provide industrial quality aspen becomes more stable. Because, hybrid poplar produced on agricultural lands is generally more expensive than aspen produced on forest lands, the model always picks aspen stands over poplar provided that aspen is physically available. This is the main reason for the reduction in agricultural acres harvested during the later planning periods for both scenarios.

Discounted aspen shadow prices when the fuelwood requirements for the two power plants are also imposed on the model are presented in Figure 6.4 (a) and (b) for the restricted and unrestricted forest land scenarios. In general the shadow prices associated with the unrestricted scenario are almost \$5-\$7/cord lower than the restricted scenario. Comparison with Figure 6.2 suggests that the aspen shadow prices are not substantially impacted by the inclusion of power plant fuelwood requirements. The model does not allocate significant quantities of aspen to the power

Figure 6.4: Aspen Shadow Prices with Power Plants under Forest and Agricultural Landbase Scenarios



(a): Restricted forest and ag. lands were available for harvest. (b): Unrestricted forest and ag. lands were available for harvest

plants because aspen has a relatively less energy content when compared to other forest cover types such as northern hardwoods. In a few cases, it turns out, aspen shadow prices in Figure 6.4 are actually lower than those observed when demand from power plants was not included (Figure 6.3). This is because a designated cover type such as "northern hardwoods" also contains small percentages of other species like aspen. Therefore, if northern hardwoods are now harvested to meet new power plant demands, they also produce aspen products which would otherwise not be available. These so called "by products" can result in price reductions and also reduce the allocation of agricultural lands for aspen products.

Table 6.3 shows the acreage of agricultural lands harvested for aspen in restricted scenario but with power plants (Table 6.2). The acreage harvested for each market and planning period are generally the same as in the case of no power plants. The main difference is at the Brainerd market for which the acreage of agricultural lands is substantially reduced. Almost ten thousand acres which were previously being allocated to this market are now being allocated to other markets or power plants. The target demands at Brainerd are still met at about the same shadow prices because of the internal scheduling changes which utilize the byproduct aspen generated from the harvest of other

Table 6.3: Agricultural Lands Harvested to Meet Aspen Demand for the Restricted Scenario with Power Plants (acres)

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	80185	79806	79242	79825	70487	68465	66062	60157	54381	**638610**
Brainerd	0	39631	41155	45086	39318	29595	23991	17727	13208	11527	**261238**
Cook	0	0	0	0	0	0	97	0	97	0	**194**
Duluth	0	5529	7204	7204	5242	2569	1411	686	430	430	**30705**
G. Rapids	0	12962	12366	11300	12218	7822	5428	4447	1967	2046	**70556**
I. Falls	0	50540	50005	50005	48469	39045	37577	33218	24958	19783	**353600**
TOTAL	**0**	**188847**	**190536**	**192837**	**185072**	**149518**	**136969**	**122140**	**100817**	**88167**	**1354903**

cover types for fuelwood requirements. Brainerd is specifically targeted because it is closest to the agricultural lands with high opportunity costs. The general trend in the land allocation remains the same as before, with high acreage harvested in the first four periods followed by a steady decline.

Table 6.4 presents the acreage of agricultural lands harvested for the unrestricted scenario with power plants. These harvested acreage are generally lower than those observed in the unrestricted scenario without power plants (Table 6.2) particularly for Brainerd market.

Table 6.4: Agricultural Lands Harvested to Meet Aspen Demand for the Unrestricted Scenario with Power Plants (acres)

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	73360	72338	71639	71595	66886	60060	54333	54249	51119	**575579**
Brainerd	0	29534	29081	30143	30580	26331	18417	13441	11368	6578	**195473**
Cook	0	0	0	0	0	0	0	97	0	91	**188**
Duluth	0	2436	2436	2436	2425	1738	836	482	430	420	**13639**
G. Rapids	0	7764	9609	9622	9240	5236	2779	1967	2064	1752	**50033**
I. Falls	0	39045	39045	38896	38896	34873	34434	25006	19783	17641	**287619**
TOTAL	**0**	**152139**	**152509**	**152736**	**152736**	**135064**	**116526**	**95326**	**87894**	**77601**	1122531

In summary, projected aspen demand targets for all markets cannot be met by wood from commercial forest lands alone, particularly in the first five planning periods. The targets can be met only by the addition of agricultural lands as a source of additional wood. This holds whether or not timber production on forest lands is restricted for environmental reasons. Shadow prices range between \$37 and \$56 per cord for the restricted scenario and within \$35 and \$50 per cord for the unrestricted scenario. In both cases highest prices are observed in Duluth market, and the lowest prices are observed in the Bemidji market. The maximum amount of agricultural lands harvested in any given period is nearly 205 thousand acres in the restricted scenario, and 172 thousand acres in the unrestricted case. These high acreages are associated with the initial four planning periods. The least amount of acreage harvested is about 142 thousand acres and 122 thousand acres corresponding to the restricted and unrestricted scenarios, respectively.

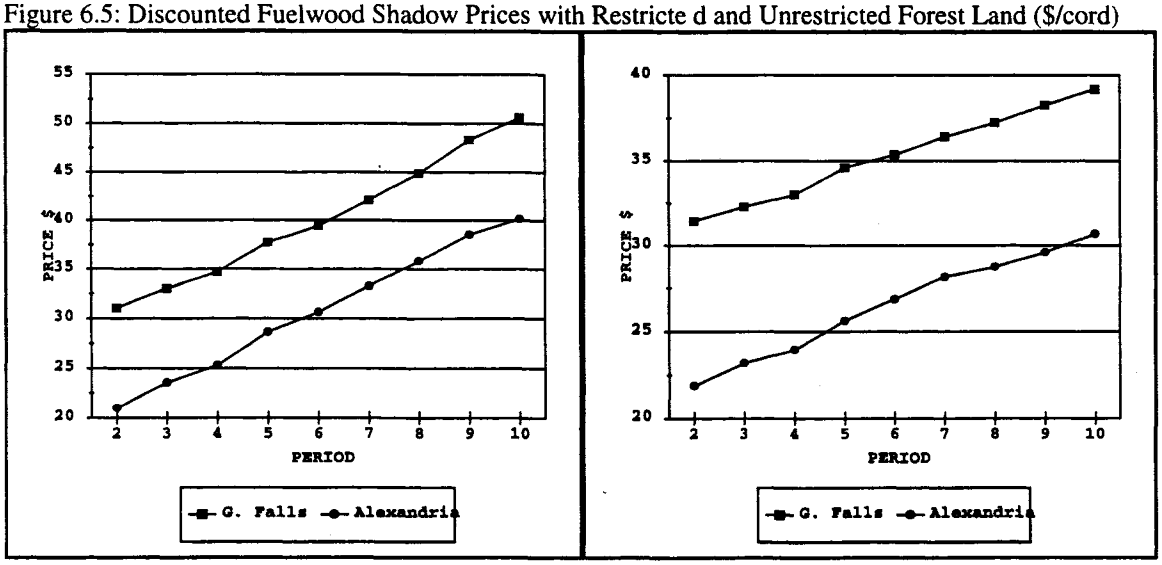
Aspen demands in all market and planning periods are still achieved when fuelwood requirements are also incorporated in the model, as long as agricultural lands stay in production. The shadow prices for the restricted (\$35 to \$54 per cord) and unrestricted cases (\$35 to \$48 per cord) remain approximately the same as observed earlier. The acreage of agricultural lands harvested for the Brainerd market is significantly lower than in the case of no power plants. The maximum and minimum acreage harvested in any planning period for the restricted case is almost 189 thousand acres and 88 thousand acres, respectively. In the unrestricted case the highest and the lowest amount of acreage harvested is approximately 152 thousand acres and 78 thousand acres, respectively.

6.5 Supplying the Power Plants

Now consider the changes in the system when we add additional wood demands of two 100 MW power plants, located in Alexandria and Granite Falls. It was assumed that these power plants will start production in the beginning of the second planning period and each plant will require 350 thousand dry tons of wood annually or 3.5 million dry ton in each planning period after the first period.

Even if only forest lands produced fuelwood, the demands for both power plants in each planning period were met in both management scenarios. The discounted shadow prices of fuelwood under the restricted and unrestricted forest lands are presented in Figure 6.5 (a) and (b).

Figure 6.5: Discounted Fuelwood Shadow Prices with Restricte d and Unrestricted Forest Land ($/cord)

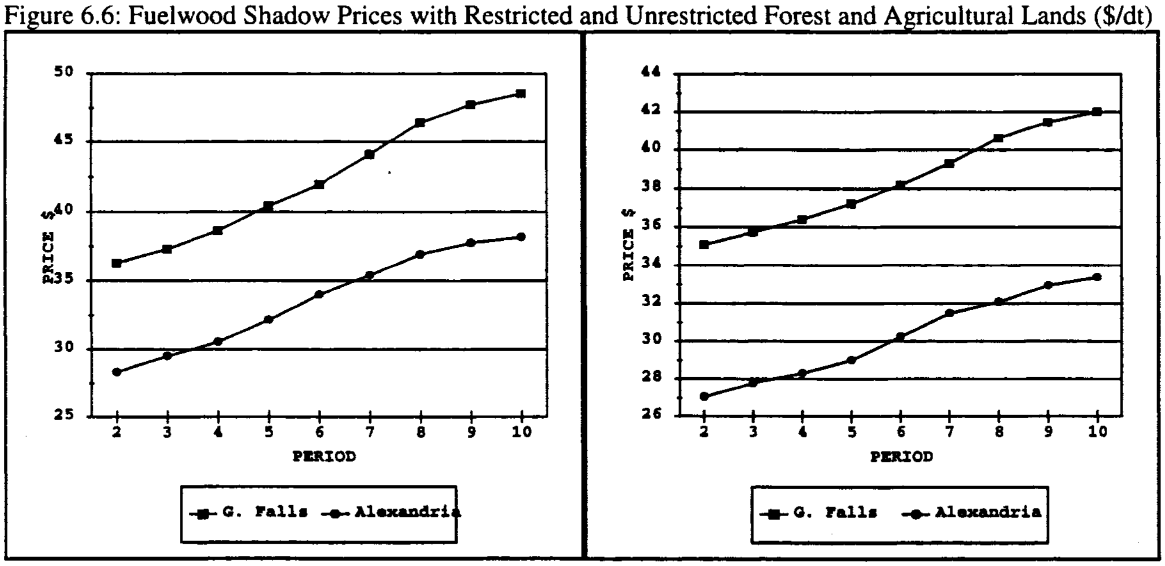


(a) Restricted forest lands were available for harvest. (b) Unrestricted forest lands were available for harvest.

The shadow prices in Alexandria are approximately $10/dt lower than those observed for Granite Falls. This is primarily because Alexandria is located closer to the commercial forest lands than Granite Falls. In the restricted case the shadow prices at Alexandria range between $21/dt and $40/dt and at Granite Falls within $32/dt and $52/dt. The range of these prices is slightly lower in the unrestricted case with Granite Falls between $32-$40 per dry and Alexandria within $21-$31 per dry ton. The shadow prices in both cases steadily increase over the entire planning horizon. The low prices in the earlier periods reflect the use of northern hardwoods which have a high energy content but low industrial value. Increasing shadow prices over the planning horizon indicate that the supply of northern hardwoods becomes more and more limited in each successive planning period.

Similar price trends are observed when agricultural lands can also help meet target demands. The shadow prices associated with these scenarios are presented in Figure 6.6 (a) and (b). The price difference between Alexandria and Granite Falls is about $10/dt and relatively uniform across the planning horizon. In general, the shadow prices associated with the unrestricted scenario are lower than the restricted case, but the difference is not large.

Figure 6.6: Fuelwood Shadow Prices with Restricted and Unrestricted Forest and Agricultural Lands ($/dt)

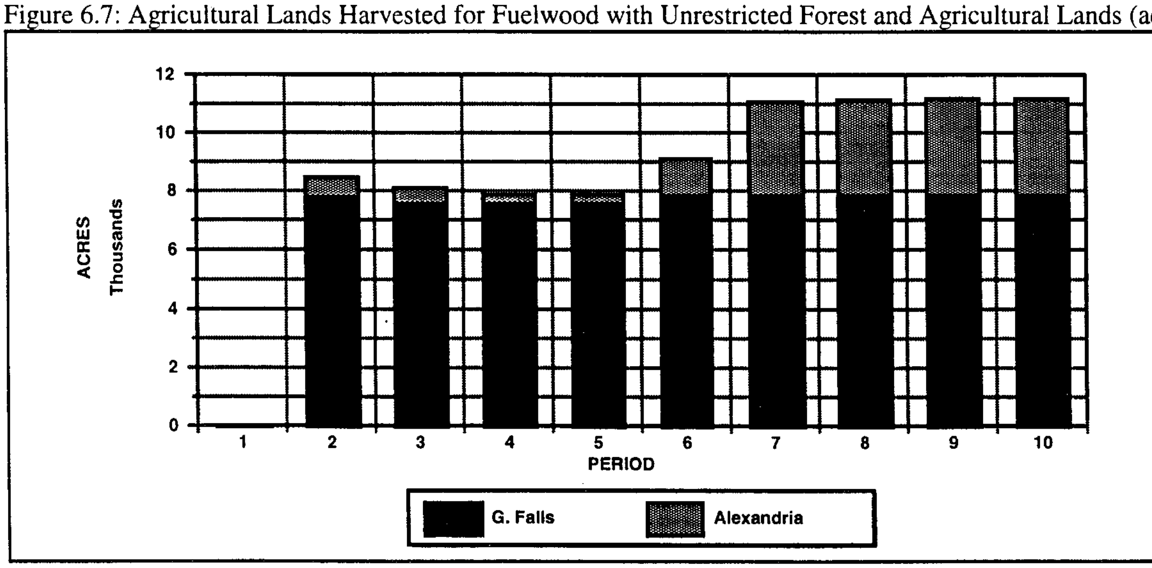


(a) Restricted forest and ag. lands were available for harvest.

(b) Unrestricted forest and ag. lands were available for harvest.

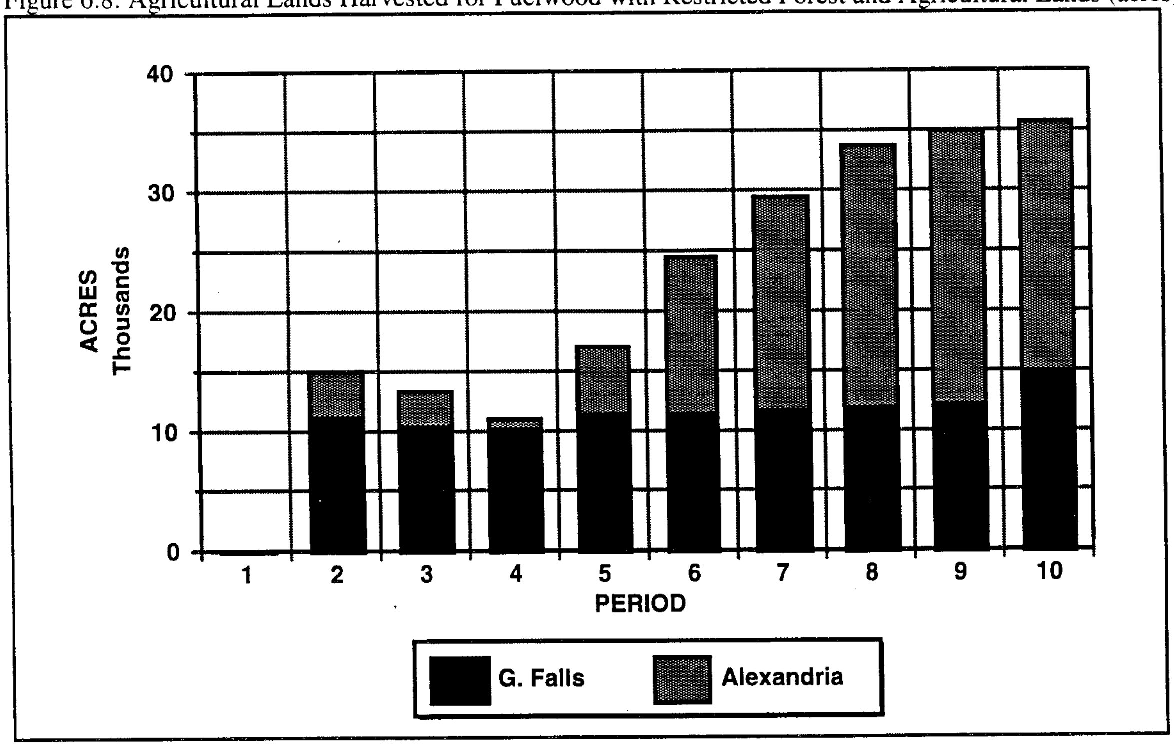
The acreage of agricultural lands harvested to meet fuelwood requirements were not substantial in the unrestricted scenario. Most of the poplar produced on these lands goes to traditional forest markets, not to the power plants. Figure 6.7 illustrates that for both power plants only eight thousand acres were allocated in the initial planning periods and approximately eleven thousand acres in the later planning period. This increase in acreage harvested during the later periods reflects the restricted supply of hardwoods from the forest lands. Most of the fuelwood produced on these lands goes to the Granite Falls because it is relatively distant from the forest lands and closer to the agricultural lands. About eight thousand acres are harvested in each planning period for Granite Falls. In comparison, the allocation of agricultural lands to Alexandria is insignificant at least in the first five planning periods. But as the fuelwood supply from the forest lands begins to tighten, the acreage of these lands increases to a little over three thousand acres in the remaining planning periods.

Figure 6.7: Agricultural Lands Harvested for Fuelwood with Unrestricted Forest and Agricultural Lands (acres)



The acreage of agricultural lands supplying fuelwood increases when harvest of commercial forest lands is restricted. Figure 6.8 illustrates that the total agricultural acres harvested range between 11-36 thousand with higher acreage being harvested in the latter planning periods. The acreage harvested for Granite Falls stays relatively consistent at about 10-12 thousand for most planning periods. The main difference between this scenario and the unrestricted scenario is the increase in the use of agricultural lands at Alexandria. Although the harvested acreage increases in all periods, the most significant jump occurs after the fifth planning period when the acreage allocated to Alexandria surpasses Granite Falls. This fact indicates that the impact of restricted forest lands is more profound on Alexandria than Granite Falls. In the following section the results for northern hardwoods are presented.

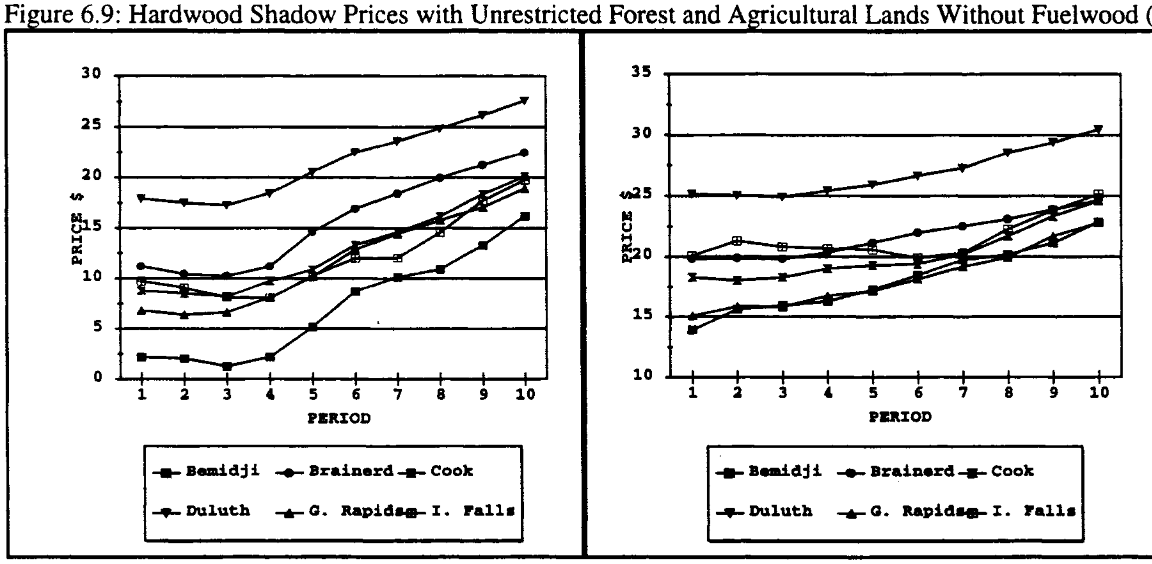
Figure 6.8: Agricultural Lands Harvested for Fuelwood with Restricted Forest and Agricultural Lands (acres)



6.6 Northern Hardwoods

The varying use of northern hardwoods across scenarios and across planning periods provides an example of the complexity associated with harvest scheduling and the interaction of different product types. Figure 6.9 (a) shows shadow prices for northern hardwoods when only unrestricted forest lands are available for harvest and no power plant demand target is imposed. Marginal costs are relatively low and stable during the initial 4-5 period, and then they begin to increase. Earlier we had established that aspen demand targets were not being met during these initial planning periods, in spite of high aspen shadow prices. Now consider Figure 6.9 (b) which represents hardwood shadow prices when both unrestricted forest and agricultural lands are available for harvest. Here, as noted in earlier section, aspen demands were met in all markets and planning periods. A comparison between Figure 6.9 (a) and (b) shows that the hardwood shadow prices increase by at least $5/cord in early planning period when agricultural lands are also available and aspen demands are met. This difference in shadow prices reflects the over harvest of hardwood stands which was necessary to get aspen within these stands to meet the aspen requirements. The result is that the marginal costs for hardwoods decrease, and the aspen shadow prices increase reflecting the small quantities acquired by the harvest of hard wood stands which would otherwise not be harvested.

Figure 6.9: Hardwood Shadow Prices with Unrestricted Forest and Agricultural Lands Without Fuelwood ($/cord)



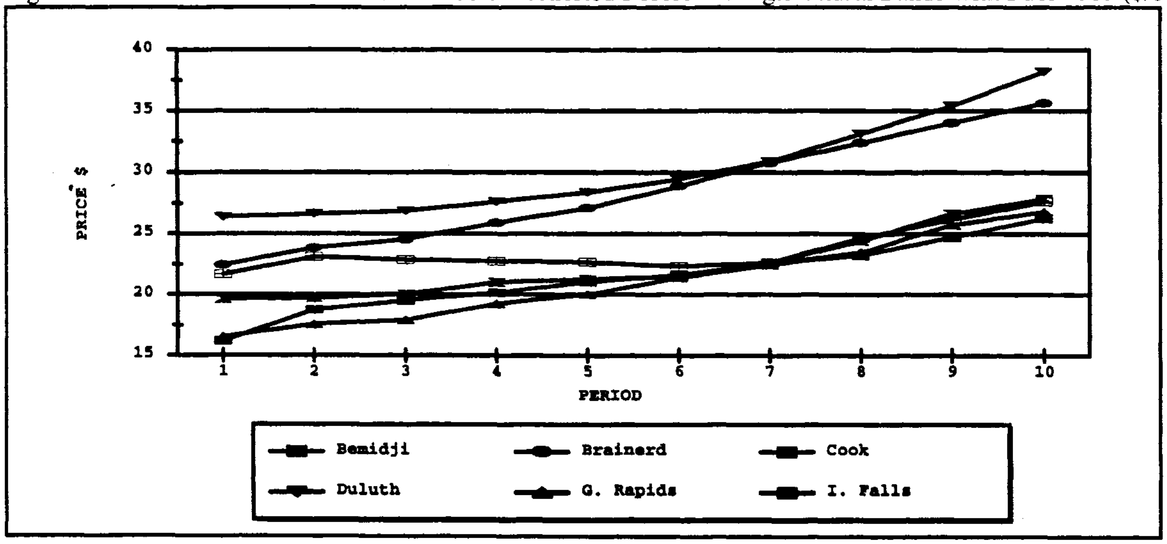
(a): Unrestricted forest lands are available for harvest.

(b): Unrestricted forest and ag. lands are available for harvest.

When agricultural lands are available for harvest, aspen demands are met by them and therefore, there is no need for over harvesting of hardwood stands. This increases the shadow prices for hardwoods and at the same time decreases the shadow prices for aspen.

The inclusion of fuelwood demand from the power plants also has a substantial impact on the marginal costs of hardwood products, as indicated in Figure 6.10. In the first planning period these prices are almost the same as observed in the case of no fuelwood requirements because there are no demands for fuelwood in this period. After the first planning period the shadow prices for all

Figure 6.10: Hardwood Shadow Prices with Unrestricted Forest and Agricultural Lands with Fuelwood ($/cord)



markets systematically increase, with relatively sharp increases associated with later planning periods. These price increases reflect the constraints in the hard wood supply over time because of hardwood and fuelwood requirements from the earlier periods. This increase in shadow prices is correlated with the increase in the fuelwood prices for both power plants locations as well. Exactly the same shadow price patterns are observed when restricted forest and agricultural lands with and without fuelwood requirements are considered.

6.7 All Other Timber Products

In addition to aspen, fuelwood, and northern hardwoods, demand for spruce, pine pulpwood, and pine bolts and sawlogs were also modeled in this study. Demand targets for these products in all markets and planning periods were successfully met. The shadow prices associated with the unrestricted scenarios were lower than those corresponding to the restricted forest land scenarios. The addition of agricultural lands to the production set did not have any significant impact on the marginal costs of these products, because these lands only produced hybrid poplar used as fuelwood or in place of aspen. The shadow prices for these products were slightly higher when fuelwood demands were also incorporated in the model. A complete summary of shadow prices, deviations from the demand goal, and the costs of meeting the demand goals for all timber and fuelwood products analyzed in this research is presented in Appendix F through Appendix M.

6.8 Comparison of Harvested Acres

The acreage of forest and agricultural lands harvested to meet all timber product requirements except fuelwood is presented in Table 6.5. There is no clear pattern between the acres harvested from restricted and unrestricted forest lands. When forest lands management is environmentally restricted, it is not necessarily the case that less acreage will be harvested in aggregate, because harvest can be shifted to areas which while more expensive are less restricted.

Table 6.5 : Comparison of Harvested Acres for All Scenarios Without Power Plants

	Forest Lands Unrestricted	**Forest Lands Restricted**	**Forests and Ag. Lands Unrestricted**			**Forest and Ag. Lands Restricted**		
Planning Period	**Forest Acres**	**Forest Acres**	**Forest Acres**	**Ag Acres**	**Total Acres**	**Forest Acres**	**Ag. Acres**	**Total Acres**
1	2131700	2139200	2058600	0	2058600	2063200	0	2063200
2	1912700	1896900	1630700	172355	1803055	1670200	204654	1874854
3	1763700	1811600	1582600	172355	1754955	1595800	204654	1800454
4	1811600	1829700	1590000	172355	1762355	1625700	204654	1830354
5	2058800	2032800	1701100	172355	1873455	1752800	196313	1949113
6	1985400	1994300	1547000	149725	1696725	1522100	167681	1689781
7	1826900	1843900	1431000	146348	1577348	1462100	164059	1626159
8	1806300	1822800	1435200	139158	1574358	1468700	156327	1625027
9	1825100	1694400	1432000	134919	1566919	1459500	150034	1609534
10	1689500	1756200	1364400	122433	1486833	1389700	142375	1532075

The inclusion of agricultural lands has a substantial impact on harvest of forest acreage. The range of forest lands involved in any given scenario and planning period is between 1.3 and 2.2 million acres. In comparison, the agricultural lands harvested are 140-200 thousand acres in each planning period. Recall that this acreage is less than half of the total acreage of agricultural lands analyzed in this study. The amount of forest land harvested is reduced by as much as 400 thousand acres in some planning periods. Relatively more agricultural lands are harvested with the restricted forest lands than with the unrestricted lands, some 20-30 thousand acres in each planning period. The inclusion of these lands is most significant in the early planning periods where the shortages in the aspen supply are more pronounced. The harvested acreage of agricultural and forest lands decreases in the subsequent planning periods as the age class imbalance improves.

Similar patterns in the acreage of agricultural and forest lands harvested exists when fuelwood demand from the power plants is added (Table 6.6). Comparison with Table 6.5 shows that the harvest of forest lands increases to about 1.7 and 2.3 million acres in any given period. The difference between the amount of forest lands harvested in the restricted and unrestricted cases is still very large and can be as high as 600 thousand acres in a few planning periods. The inclusion of power plants does not increase the acreage of agricultural lands harvested, however, in some planning periods it is actually reduced. This is because harvest of other cover types for fuelwood also results in small quantities of aspen which are allocated to the timber markets instead of power plants. The aspen generated from these cover types is cheaper than hybrid poplar produced on agricultural lands and therefore the model reduces the acreage of agricultural lands providing aspen.

The realization of Minnesota's timber and biomass demand targets modeled in this study require some sort of harvesting activity on about 1.5-2 million acres of forest lands in each planning period. Generally, higher acreages are harvested in the early planning periods and as the age class imbalance of forests improves the harvested acreage begins to decline. Imposing environmental restrictions on forest lands does not necessarily reduce the number of acres harvested but sometimes changes the location of the harvest. These changes result in higher shadow prices which reflect the cost of environmental mitigation.

Table 6.6: Comparison of Harvested Acres for All Scenarios with Power Plants

	Forest Lands Unrestricted	Forest Lands Restricted	Forests and Ag. Lands Unrestricted			Forest and Ag. Lands Restricted		
Planning Period	**Forest Acres**	**Forest Acres**	**Forest Acres**	**Ag. Acres**	**Total Acres**	**Forest Acres**	**Ag. Acres**	**Total Acres**
1	2186700	2186400	2050900	0	2050900	2067000	0	2067000
2	2106400	2171700	1852700	160593	2013293	1873300	203843	2077143
3	2037600	1984700	1752600	160593	1913193	1782900	203843	1986743
4	2087700	2015100	1769000	160593	1929593	1819600	203843	2023443
5	2268300	2304200	1850300	160593	2010893	1938600	202060	2140660
6	2330800	2318700	1717800	144175	1861975	1746100	173964	1920064
7	2183300	2100500	1656100	127592	1783692	1674800	166362	1841162
8	2149000	2162600	1735000	106455	1841455	1750200	155800	1906000
9	2151900	2266900	1723300	99066	1822366	1777600	135644	1913244
10	2004600	2061800	1696000	88773	1784773	1844600	123810	1968410

The location, cover type and ownership of all forest and agricultural lands harvested under any given scenario of this study are presented in Appendix F to M. All attributes of forest lands are presented on a county basis and for the agricultural lands on a township level.

Chapter 7: Summary and Conclusions

7.1 Policy Implications of Results

Modeling timber and fuelwood supply from traditional forest lands and agricultural lands managed under short-rotation production alternatives adds a new dimension to previous Minnesota forest planning efforts. The present study's use of location specific information and realistic estimates of production, harvesting, and transportation costs can provide decision makers with reliable estimates of marginal costs for delivered timber and biomass products.

Best management guidelines that can effectively deal with the complex issues such as wildlife, water, recreation, biodiversity, and timber production are rare. This research dealt with this issue by excluding certain forest lands considered environmentally sensitive from any harvesting activity and by restricting management options on many of the remaining forest lands. The comparison between the marginal costs of delivered timber products from restricted and unrestricted land base reflects the cost of imposing environmental restrictions. The study identified existing and future timber supply problems and made recommendations for their mitigation.

The results indicate that the industrial demand for all timber products analyzed in this study can be satisfied over the planning horizon, if some agricultural lands are devoted to poplar production. The addition is made necessary because of aspen, for which existing industrial requirements cannot be sustained over the planning horizon if only existing forest lands are used. These shortages are exceptionally high in the initial four to five decades largely because of age class imbalance in the aspen inventory. This situation is further exacerbated if the forest lands are required to be managed under more restrictive and environmentally beneficial prescriptions.

The shortages in industrial requirements of aspen products can be overcome in a number of ways. Forest industries can either import the balance of their aspen requirements from other states or use substitutes for aspen from sources within the state. Importing aspen can be an increasingly expensive operation because of transportation costs. It will also result in additional pressures on the forest resources of the exporting states. The use of aspen substitutes such as hybrid poplar from locations within Minnesota will require forest industries to invest in the modification or purchase of new compatible processing equipment. These investments might also be significant but will generally be required only once. Therefore, in the long run use of aspen substitutes available within the state might be less expensive than the import of aspen.

This research assumed that whenever necessary, the forest industry can use short rotation hybrid poplar produced on agricultural lands as a substitute for aspen. The results indicate that the inclusion of these lands allows the aspen demands at all markets to be satisfied over all planning periods. The combination of restricted forest and agricultural lands results in higher marginal costs than the combination of unrestricted forest and agricultural lands. The difference in these marginal costs shows the opportunity cost of environmental mitigation.

The present value of aspen shadow prices generated by the model are substantially higher than the actual market prices observed. In the linear programming framework used here, shadow prices are in fact marginal supply costs, so they should not be directly compared with actual market prices. In theory, these large differences between actual and shadow prices could reflect that timber products are being under priced.

The use of agricultural lands particularly in the initial planning periods has a significant impact on aspen prices and the acreage of forest lands harvested. Production of hybrid poplar results in large quantities of wood in relatively short time and thus significantly reduces the harvest of traditional forest lands. At most about two hundred thousand acres of these lands provide hybrid poplar to the timber markets in each planning period. It should be noted that not every township with agricultural acreage is allocated to timber production. The combination of land owner's opportunity cost, the transportation costs to timber demand markets, and the soil productivity influence the economics of timber production and determine the relative advantage of one township versus another.

Landowners with high productivity agricultural lands closer to the demand centers have a good opportunity to invest in the production of hybrid poplar. Anticipated shortages for aspen can mean significant monetary gains in the next decade. It is recommended that initially only small quantities of land, which are not in the traditional crop rotation should be utilized for this endeavor primarily to avoid risk and over production. Landowners located between major timber markets have an additional locational advantage. They will have the option to supply their product to multiple markets or a single market offering the highest prices.

This research also generated estimates of fuelwood costs for two power plants in Minnesota under several cost assumptions. First it was assumed that fuelwood will be supplied from agricultural lands only. The results showed that Alexandria will be the most cost effective location in terms of fuelwood supply. The best scenario estimated an average delivered fuelwood cost of $1.7/MBtu for Alexandria and $2/MBtu for Granite Falls.

Estimates of fuelwood costs were also computed under the assumption that forest lands will also be able to provide fuelwood. The role of agricultural lands significantly decreased in this case because of the apparent differences in the energy contents of hybrid poplar and other forest species such as northern hardwoods. The estimated marginal costs of fuelwood in the unrestricted scenarios were as low as $1.57/MBtu at Alexandria and 2.03/MBtu in Granite Falls in the initial planning period. These marginal costs rise in each subsequent planning period indicating that fuelwood supply from forest lands becomes constrained over the planning horizon. The role of agricultural lands as fuelwood supplier becomes relatively significant in these later planning periods, particularly for Alexandria. In the restricted scenarios, the marginal costs of delivered fuelwood increase by about \$0.07/MBtu for both power plant locations.

Most of the fuelwood cost estimates generated in this study are higher then the costs of coal which is traditionally used in Minnesota for electricity production. But if environmental externalities assooiated with coal fired power plants are an issue, then biomass subsidies might be considered to make coal and wood fired technologies compatible. Wood fired power plant technologies have significantly improved during the last decade. Conversion rates are comparable to coal, although production costs remain higher. Relatively small subsidies in terms of carbon credits might make the adoption of large scale electricity production from wood a reality.

Since it turns out that the power plants modeled in this study would most cost effectively acquire fuelwood from existing forest lands, substantial savings could be achieved if the plants are located in the northern part of the state where major concentrations of the forest lands exist, rather than the currently proposed southwestern locations. This will result in significantly reduced transportation costs and will help avoid unnecessary cross traffic flow patterns. The extent of the savings is yet to be determined by further research.

The results of this study also indicate that poplar produced on agricultural lands has a better chance of being used in the forest industry than in the power plants. This is because forest markets can pay more for poplar than the power plants. In comparison, the power plants can use northern hardwoods which are available at relatively lower costs and have a higher energy content.

7.2 Future Research

In future research, we intend to use a more comprehensive approach to incorporate environmental and ecological impacts of forest harvesting. In addition to the environmental mitigation strategies used in this study, a reservation value for each analysis area will also be incorporated. These reservation values will be generated from a matrix of cover type, age class, distance from water, and wildlife potential combinations for each analysis area. If the net present value of harvest is below this estimated reservation value, then that analysis area will not be harvested. This approach should provide more reliable estimates of the incorporating non-market commodities such as wildlife in the modeling process.

This study did not specifically deal with the issue of risks associated with hybrid poplar production. These risks can be significant in the establishment phase of poplar production and need to be addressed. We intend to develop a production function and a risk probability distribution model which would incorporate such risks and then determine the levels of investment necessary to reduce such risks. The incorporation of these risks will improve on the results of this research.

Currently, we are in the process of estimating the potential saving which can be realized by moving the location of the proposed power plants closer to the northern part of the state. The idea is that since the bulk of fuelwood is provided by the forests, substantial savings in terms of transportation costs can be achieved if the power plants are located closer to the forest lands. As stated above, this will also help in avoiding undue traffic on the Minnesota roads particularly, in the southern part of the state.

We are also developing a software, which will allow us to graphically demonstrate the wood flow patterns over roads in ton-miles corresponding to the cases considered in this study and the cases which we intend to study. Currently, we have this information in database format which is not easily interpreted. The development of this software will allow us to present information in a concise visual format which could be very useful to a wide variety of audiences.

REFERENCES

1. Jaakko Pöyry Consulting, Inc. 1992 a. *Maintaining productivity and the forest resource base: A technical paper for a generic environmental impact statement on timber harvesting and forest management in Minnesota.* Jaakko Pöyry Consulting, Inc., Tarrytown, NY. 305 p. + 15 appendices.

2. Berguson, W. 1994. Evaluation of land suitability and production economics of hybrid poplar. Natural Resources Research Institute. University of Minnesota, Duluth.

3. Taff, S.J. 1993. The CRP in the Upper Midwest: what should we do next. Minnesota Extension Service, University of Minnesota. 16 p.

4. MDNR. 1992. The Status of Short Rotation Intensive Culture in Minnesota. Department of Natural Resources, Division of Forestry. St. Paul MN.

5. Betters, D.A, L.L. Wright, and L. Couto. 1992. Short rotation woody crop plantations in Brazil and the United States. *Biomass and Bioenergy* 6:305-316.

6. Wright, L.L. 1994. Production Technology Status of Woody and Herbaceous Crops, *Biomass and Bioenergy* 6:191-210.

7. Wright, L.L., and J.W. Ranney. 1994. Short Rotation Woody Crops: Using Agroforestry Technology for Energy in the United States.

8. Wright, L.L., and A. Ehrenshaft. 1990. Short Rotation Woody Crop Program: annual progress report for 1989. ORNL-6625. Oak Ridge, TN: Oak Ridge National Laboratory. 113 p.

9. Wright, L.L., R.L. Graham, A.F. Turhollow, and B.C. English. 1992. *The potential impacts of short-rotation woody crops on carbon conservation.* In Sampson, R.N. and D. Hair (eds), *Forests and Global Change, Vol. 1: Opportunities for Increasing Forest Cover.* American Forestry Association, Washington, D.C.

10. Bassham, J.A. 1977. Increasing crop production through more controlled photosynthesis. *Science* 197:630-638.

11. Loomis, D.C. and W.A. Williams. 1963. Maximum crop productivity: an estimate. *Crop Science* 3:67-72.

12. Hughes, E. E. and G. A. Wiltsee. 1995. Comparative Evaluation of Fuel Costs from Energy Crops. *Proceedings of the Second Biomass Conference of the Americas*, Portland, OG, August 1995. National Renewable Energy Laboratory, Golden, CO.

13. Ostry, M.E., L.F. Wilson, H.S. McNabb, and L.M. Moore. 1988. *A guide to insect, disease, and animal pests of poplars*. Agric. Handb. 677. U.S. Department of Agriculture. 118 p.

14. Hansen, E.A., M.E. Ostry, W.D. Johnson, D.N. Tolsted, D.A. Netzer, W.E. Berguson, R.B. Hall.1994. *Field performance of Poplus in short-rotation intensive culture plantations in the north-central U.S.* Res. Pap. NC-320. St. Paul MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 13 p.

15. Ranney, J.W., L.L. Wright, and C.P. Mitchell. 1990. Carbon storage and recycling in short-rotation wood crops. *In Proceeding of the International Energy Agency Executive Committee (Forest Energy)*, December 1990, Stockholm Sweden.

16. Gebhart D.L., H.B. Johnson, H.S. Mayeaux, and H.W. Polley. 1995. The CRP increases soil organic carbon. *Journal of Soil and Water Conservation* (in press).

17. Perlack, R.D., J.W. Ranney, and L.L. Wright 1992. *Environmental emissions and socioeconomic considerations in the production, storage, and transportation of biomass energy feedstocks*. ORNL/TM-12030. Oak Ridge, TN 37831.

18. Ostlie, L.D. 1989. The whole tree burner: a new technology in power generation. *Biologue* 5(3):7-9.

19. EPRI. 1993. Strategic Analysis of Biomass and Waste Fuels for Electric Power Generation. EPRI Project3295-02. Palo Alto, CA.

20. Kapple, D.C. and H.M. Hoganson. 1995. *Close-to-market intensification of forest management*. Final report to Center for Transportation Studies Minneapolis, MN.. 139 p.

21. Ostlie, L. D. 1995. Whole Tee Energy™: A patented technology developed by Energy Performance Systems, Inc. Minneapolis, MN.

22. EPRI. 1994. *100 Mw_e Whole Tree Energy™ Siting and Feasibility Study*. EPRI Project RP3407-11. Palo Alto, CA.

23. Taff, S.J. 1993. *Expiring Minnesota CRP Contracts: 1996-98 state and county summaries*. Department of Applied Economics, University of Minnesota. 39 p.

24. Lazarus, W. F. 1995 *The 1994 Minnesota Rural Real Estate Market: The Farm Cash Rental Market*. Minnesota Agricultural Economist. Minnesota Extension Service, University of Minnesota. No. 679 Winter.

25. Hansen, J., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, and G. Russell. 1988. Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. *Journal of Geophysical Research* 93:9341-9364.

26. Jaakko Pöyry Consulting, Inc. 1992 b. *Harvesting systems in Minnesota: A background paper for a generic environmental impact statement on timber harvesting and forest management in Minnesota*. Jaakko Pöyry Consulting, Inc., Tarrytown, NY. 45 p.

27. Perlack, R. D. and L. L. Wright. 1995. Economic Status of Dedicated Biomass Feedstock Supply Systems, *Energy: The International Journal*, 4:279-284.

28. Walsh, M. 1994. *Costs of Producing Hybrid Poplar as a Dedicated Energy Crop*. Oak Ridge National Laboratory, Energy Division, Oak Ridge TN.

29. Shelton, J. 1976. *The Woodburners Encyclopedia: an information source of theory, practice and equipment relating to wood as energy*. Vermont Crossroads Press, Inc. Waitsfield, Vermont 05673.

30. Nichols, J. M. 1994. *An examination of the trade-offs between timber production and pine marten carrying capacity*. Ph.D. Dissertation, University of Minnesota, St. Paul. 128 p.

31. Davis, L. S. and K. N. Johnson. 1987. *Forest Management*. McGraw-Hill Publishing Company, New York. 790 p.

32. Hoganson, H. M. and D. W. Rose.1984. A simulation approach for optimal timber management scheduling. *Forest.Science*. 30(1):220-238.

33. Hoganson, H. M. and D. W. Rose. 1989. *DUALPLAN version 1.0: A Stand management scheduling system*. College of Natural Resources and Agricultural Experiment Station, Department of Forest Resources Staff Paper Series Report No. 73, University of Minnesota, St. Paul. 48 pp.

34. Hoganson, H. M. and D. C. Kapple. 1991. *A multi-market timber supply model*. University of Minnesota Department of Forest Resources Staff Series Paper No. 83.

35. McDill, M. and Rose, D.W. 1995: RxWRITE users guide. Unpublished Report. Department of Forest Resources, University of Minnesota. St. Paul Minnesota.

36. Belcher, D. W., M. R. Holdaway, and G.J. Brand. 1982. *A description of STEMS, the stand and tree evaluation and modeling system*. Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station.

37. Kapple, D. C. and H. M. Hoganson. 1991. *A geographic information system for modeling forest products transportation*. University of Minnesota Department of Forest Resources Staff Series Paper No. 82.

38. U. S. Geological Survey. 1990. *Digital Line Graphs from 1:2,000,000 scale maps*. National Mapping Program Technical Instruction Data Users Guide 3. U. S. Geological Survey. Reston, VA. 70 p.

39. Papadimitriou, C. H. and K. Steiglitz. 1982. *Combinatorial Optimization*. Prentice-Hall, Englewood Cliffs, NJ. 496 p.

40. Horowitz, E. and S. Sahni. 1976. *Fundamentals of Data Structure*. Computer Science Press, Inc., Potomac, MD. 564p.

41. Kapple, D. C. 1995. *Using forest inventory and analysis data to interpret spatial patterns in a forest management scheduling model.* Ph. D. Dissertation, University of Minnesota, St. Paul. 124 p.

42. Gunn, E. A. 1991. Some aspects of hierarchical production planning in forest management. *In Proceedings of the 1991 Symposium on Systems Analysis in Forest Resources*. pp 54-62. USDA Forest Service General Technical Report SE-74.

43. Johnson, K. N. and E. L. Scheurman. 1977. Techniques for prescribing optimal timber harvest and investment under different objectives-discussion and synthesis. *Forest Science, Mono. 18.*

44. Weintraub, A., and A. Cholaky, A. 1991: A hierarchical approach to forest planning. *Forest Science*, 2:439-460.

APPENDIX A

PRODUCT TYPE, PRODUCT SET, AND MARKET COMBINATIONS

Table A.1 Product Type and Product Sets by Markets

		MARKET AND PRODUCT SET								
	PRODUCT TYPE	None	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Fall	G. Falls	Alexandria
1	Production and Management Costs	1								
2	Harvest and Transport Costs	2								
3	Noncommercial Species	3								
4	Pine Pulpwood		12	25	25	13	25	14	4	5
5	Spruce Pulpwood		25	15	25	16	17	25	4	5
6	Aspen Pulpwood		6	7	8	9	10	11	4	5
7	Hardwood Pulpwood		18	19	20	21	22	23	4	5
8	Pine Bolts		24	24	24	24	24	24	4	5
9	Pine Sawlogs		24	24	24	24	24	24	4	5
10	Spruce Bolts		25	15	25	16	17	25	4	5
11	Aspen Sawlogs		6	7	8	9	10	11	4	5
12	Hardwood Sawlogs		18	19	20	21	22	23	4	5
13	Red Oak Sawlogs		18	19	20	21	22	23	4	5
14	Balsam Fir Pulpwood		25	15	25	16	17	25	4	5
15	Balsam Fir Bolts		25	15	25	16	17	25	4	5
16	Jack Pine Bolts		12	25	25	13	25	14	4	5
17	Balsam Poplar		6	7	8	9	10	11	4	5
18	Hybrid Poplar Fuelwood		25	25	25	25	25	25	4	5
19	Hybrid Poplar Pulpwood		6	7	8	9	10	11	25	25

Note: Set 25 is a dummy set.

APPENDIX B

FOREST INVENTORY ANALYSIS DATA STATISTICS

Table B.1: FIA Data by Ownership and Cover Type (acres)

	COVER TYPE								
OWNER	Pines	Balsam Fir	N. White Cedar	Tamarack	Spruce	N. Hardwoods	Aspen	Balsam Poplar	**TOTAL**
N. Forests	220100	185900	92200	29800	282000	345600	642100	23400	**1821100**
Misc. Public	38800	20000	71300	46500	65900	148200	222500	29800	**643000**
State	158000	167000	267500	334000	599400	435200	887200	127700	**2976000**
County	129200	181900	97700	127800	218100	615300	1034100	88500	**2492600**
Private	248800	182500	70700	170700	200700	1786500	2086200	206700	**4952800**
F. Industry	86400	71900	49000	9100	75500	138900	293400	25700	**749900**
TOTAL	**881300**	**809200**	**648400**	**717900**	**1441600**	**3469700**	**5165500**	**501800**	**13635400**

Table B.2: FIA Data by Treatment Class and Cover Type (acres)

	COVER TYPE								
TREATMENT	Pines	Balsam Fir	N. White Cedar	Tamarack	Spruce	N. Hardwoods	Aspen	Balsam Poplar	**TOTAL**
Normal	713600	632600	488800	536700	1092300	2779000	4341500	397500	**10982000**
Buffers	32300	55400	45400	36300	90000	201400	145900	29000	**635700**
Extended	71600	72900	65900	79800	181200	151800	308300	30700	**962200**
Old Growth	0	0	6700	0	4100	6300	4900	5500	**27500**
Reserved	63800	48300	41600	65100	74000	331200	364900	39100	**1028000**
TOTAL	**881300**	**809200**	**648400**	**717900**	**1441600**	**3469700**	**5165500**	**501800**	**13635400**

Table B.3: FIA Data by Treatment Class and Owmership (acres)

	OWNER						
TREATMENT	N. Forests	Misc. Public	State	County	Private	F. Industry	**TOTAL**
Normal	1315800	402600	2127200	2224300	4188400	723700	**10982000**
Buffers	112900	10200	99800	141800	263600	7400	**635700**
Extended	364900	0	597300	0	0	0	**962200**
Old Growth	27500	0	0	0	0	0	**27500**
Reserved	0	230200	151700	126500	500800	18800	**1028000**
TOTAL	**1821100**	**643000**	**2976000**	**2492600**	**4952800**	**749900**	**13635400**

Table B.4: FIA Data by Age Class and Cover Type (acres)

	COVER TYPE								
AGE CLASS	Pines	Balsam Fir	N. White Cedar	Tamarack	Spruce	N. Hardwoods	Aspen	Balsam Poplar	**TOTAL**
[0-30]	281900	233500	38600	215300	333100	595100	1907300	179400	**3784200**
[30-60]	348900	433600	75500	225000	520200	1407300	2472800	244000	**5727300**
[60-90]	193400	133600	196900	162700	410700	1195000	762700	76500	**3131500**
[90-120]	49500	5900	205300	82800	136700	235500	21700	1400	**738800**
[>120]	7600	2600	132100	32100	40900	36800	1000	500	**253600**
TOTAL	**881300**	**809200**	**648400**	**717900**	**1441600**	**3469700**	**5165500**	**501800**	**13635400**

Table B.5: FIA Data by County and Cover Type (acres)

	COVER TYPE								
COUNTY	Pines	Balsam Fir	Whcedar	Tamarack	Spruce	Hardwood	Aspen	Balsam Poplar	**TOTAL**
Aitkin	13400	19900	16500	80800	64000	261300	240000	15000	**710900**
Becker	22100	12400	0	20900	2000	120600	150900	3400	**332300**
Beltrami	59100	21000	61700	79800	54300	172700	321500	71700	**841800**
Benton	2700	0	0	0	0	26800	5200	0	**34700**
Carlton	7900	16900	4800	27600	24600	83200	159500	16000	**340500**
Cass	99700	23100	32300	36900	19900	233000	385900	10800	**841600**
Chisago	800	0	0	1700	0	36100	10000	0	**48600**
Clay	0	0	0	0	0	17500	5100	0	**22600**
Clearwater	15000	12400	6500	11600	5900	65100	150400	22500	**289400**
Cook	22100	93000	55600	3500	80300	123800	184200	2900	**565400**
Crow Wing	42800	3500	900	17200	8200	165100	149000	0	**386700**
Douglas	0	0	0	500	0	29100	1800	200	**31600**
Grant	1000	0	0	0	0	2700	1900	0	**5600**
Hubbard	87600	14100	900	11000	6900	79900	194000	5400	**399800**
Isanti	3900	0	0	2400	0	39700	6900	1200	**54100**
Itasca	95100	88200	65400	69400	124300	291100	528900	62000	**1324400**
Kanabec	2400	0	0	3800	0	81600	53300	1100	**142200**
Kittson	0	0	0	0	0	13800	50200	1100	**65100**
Koochiching	38900	111500	209000	95900	353700	160200	380600	74100	**1423900**
Lake	70800	121000	52000	5000	154400	239500	188500	18900	**850100**
Lake of the Woods	31000	16200	33400	56600	76800	26900	125000	32500	**398400**
Mahnomen	2100	900	0	1000	1100	50300	50400	8100	**113900**
Marshall	0	0	0	5200	2000	11900	92800	21400	**133300**
Mille Lacs	0	0	0	4400	1800	84000	48200	0	**138400**
Morrison	6200	0	0	4000	0	88100	66800	1300	**166400**
Norman	0	0	0	0	0	13500	12300	0	**25800**
Otter Tail	1300	0	0	9400	1100	137600	53300	5500	**208200**
Pennington	0	0	0	0	0	12700	16600	5500	**34800**
Pine	22500	8300	0	14100	24100	176900	239300	1200	**486400**
Polk	0	0	0	0	0	33500	23900	1100	**58500**
Red Lake	0	0	0	0	0	8600	17600	1100	**27300**
Roseau	24800	5500	5400	21600	13200	18400	95800	32500	**217200**
St. Louis	158900	240400	104000	128000	421800	466300	1095200	84200	**2698800**
Todd	1700	0	0	3300	0	67700	23900	1000	**97600**
Wadena	47500	900	0	2300	1000	29300	36800	1300	**119100**
TOTAL	**881300**	**809200**	**648400**	**717900**	**1441400**	**3468500**	**5165700**	**503000**	**13635400**

Table B.6: FIA Data by County and Ownership (acres)

	OWNERSHIP						
COUNTY	N. Forests	Misc. Public	State	County	Private	F. Industry	**TOTAL**
Aitkin	0	7900	255900	197800	238000	11300	**710900**
Becker	0	28500	20200	87600	191300	4700	**332300**
Beltrami	57800	203900	246100	140000	192000	2000	**841800**
Benton	0	0	1000	0	33700	0	**34700**
Carlton	0	10400	58900	58000	186200	27000	**340500**
Cass	241100	21400	104700	232900	209100	32400	**841600**
Chisago	0	0	5200	1300	42100	0	**48600**
Clay	0	0	0	0	22600	0	**22600**
Clearwater	0	59600	25800	66800	134300	2900	**289400**
Cook	362800	35000	75000	9200	57200	26200	**565400**
Crow Wing	0	0	20400	89600	260200	16500	**386700**
Douglas	0	0	1800	500	29300	0	**31600**
Grant	0	0	1000	0	4600	0	**5600**
Hubbard	0	900	52100	121200	204100	21500	**399800**
Isanti	0	0	2300	2400	49400	0	**54100**
Itasca	268300	2300	253800	255700	375300	169000	**1324400**
Kanabec	0	0	14900	7800	119500	0	**142200**
Kittson	0	0	18400	2300	44400	0	**65100**
Koochiching	0	64900	734400	278800	142700	203100	**1423900**
Lake	384600	3300	106700	143600	133600	78300	**850100**
Lake of the Woods	0	95700	230600	3100	66800	2200	**398400**
Mahnomen	0	27900	23600	5700	56700	0	**113900**
Marshall	0	8600	37400	0	87300	0	**133300**
Mille Lacs	0	9800	33800	0	94800	0	**138400**
Morrison	0	700	30400	0	135300	0	**166400**
Norman	0	0	1100	2400	22300	0	**25800**
Otter Tail	0	0	3300	1200	203700	0	**208200**
Pennington	0	900	1100	0	32800	0	**34800**
Pine	0	4500	111500	32300	335500	2600	**486400**
Polk	0	0	5600	2300	50600	0	**58500**
Red Lake	0	0	1100	0	26200	0	**27300**
Roseau	0	15600	123900	3400	74300	0	**217200**
St. Louis	506500	34300	356300	744800	929200	127700	**2698800**
Todd	0	6900	4300	1100	85300	0	**97600**
Wadena	0	0	13400	800	82400	22500	**119100**
TOTAL	**1821100**	**643000**	**2976000**	**2492600**	**4952800**	**749900**	**13635400**

Table B.7: FIA Data by County and Treatment (acres)

	TREATMENT					
COUNTY	Normal	Buffers	Extended	Old Growth	Reserve	**TOTAL**
Aitkin	565800	32900	55300	0	56900	**710900**
Becker	280700	14800	1000	0	35800	**332300**
Beltrami	651900	17900	63700	1100	107200	**841800**
Benton	25200	2700	1000	0	5800	**34700**
Carlton	282400	15800	11000	0	31300	**340500**
Cass	687200	26300	67600	7300	53200	**841600**
Chisago	41100	1700	0	0	5800	**48600**
Clay	14000	0	0	0	8600	**22600**
Clearwater	239800	8400	1400	0	39800	**289400**
Cook	433800	21500	72500	6300	31300	**565400**
Crow Wing	347400	1400	900	0	37000	**386700**
Douglas	21300	5700	0	0	4600	**31600**
Grant	4600	1000	0	0	0	**5600**
Hubbard	338900	11300	11700	0	37900	**399800**
Isanti	43300	8900	0	0	1900	**54100**
Itasca	1101300	44500	120600	3700	54300	**1324400**
Kanabec	125400	2400	4000	0	10400	**142200**
Kittson	56200	2200	3400	0	3300	**65100**
Koochiching	1162300	22100	153300	0	86200	**1423900**
Lake	649800	37600	123900	4700	34100	**850100**
Lake of the Woods	317400	1200	39500	0	40300	**398400**
Mahnomen	91900	1100	4300	0	16600	**113900**
Marshall	99000	8600	10600	0	15100	**133300**
Mille Lacs	109700	5900	9100	0	13700	**138400**
Morrison	125400	16900	5400	0	18700	**166400**
Norman	19000	4400	0	0	2400	**25800**
Otter Tail	169200	16100	0	0	22900	**208200**
Pennington	32500	1200	0	0	1100	**34800**
Pine	381400	37300	21600	0	46100	**486400**
Polk	49600	4400	0	0	4500	**58500**
Red Lake	23100	900	0	0	3300	**27300**
Roseau	170500	4900	21000	0	20800	**217200**
St. Louis	2136400	247300	156400	4400	154300	**2698800**
Todd	83500	3700	1000	0	9400	**97600**
Wadena	101000	2700	2000	0	13400	**119100**
TOTAL	**10982000**	**635700**	**962200**	**27500**	**1028000**	**13635400**

APPENDIX C

SILVICULTURAL OPTIONS FOR NATURAL AND REGENERATED STANDS

Silvicultural Options for Natural Stands

Jack Pine

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
- Maximum age 120 years
- Thinning only at age 30 years (Pulp)
- Thinning intensity 1:33 percent
- Maximum age for first thinning: 30 years
- Minimum interval between thinnings: 10 years
- Minimum interval between thinning and harvest: 20 years

Restricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
- No thinnings

Regeneration: Natural and conversion to Jack Pine

Red Pine

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
- Maximum age 120 years
- Thinning only at age 30 years (Pulp)
- Thinning intensity 1:33 percent
- Maximum age for first thinning: 30 years
- Minimum interval between thinnings: 10 years
- Minimum interval between thinning and harvest: 20 years

Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
- No thinnings

Regeneration: Natural and conversion to Red Pine

White Pine

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
- Maximum age 120 years
- No thinnings

Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
- No thinnings

Regeneration: Only natural regeneration

Black Spruce

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
- Maximum age 130 years
- No thinnings

Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
- No thinnings

Regeneration: Only natural regeneration

Balsam Fir

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 90 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

N. White Cedar

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 150 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 70 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

Tamarack

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 130 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

White Spruce

Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
Thinning only at age 30 years (Pulp)
Thinning intensity 1:33 percent
Maximum age for first thinning: 30 years
Minimum interval between thinnings: 20 years
Minimum interval between thinning and harvest: 10 years
Regeneration: Only natural regeneration

Oak-Hickory

Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 150 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

Elm-Ash-Maple
Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
    Maximum age 150 years
    No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
    No thinnings
Regeneration: Natural and conversion to Red Pine

Maple-Basswood
Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
    Maximum age 150 years
    No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
    No thinnings
Regeneration: Natural and conversion to Red Pine

Aspen
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
    Maximum age 90 years
    No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
    No thinnings
Regeneration: Natural and conversion to Red Pine

Paper Birch
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
    Maximum age 90 years
    No thinnings
Restricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
    No thinnings
Regeneration: Natural and conversion to Red Pine

Balsam Poplar
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
    Maximum age 90 years
    No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
    No thinnings
Regeneration: Only natural regeneration

Silvicultural Options for Regenerated Stands

Jack Pine
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 100 years
No thinnings
Regeneration: Natural and conversion to Jack Pine

Red Pine
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
Thinning only at age 30 years (Pulp)
Thinning intensity 1:33 percent
Maximum age for first thinning: 30 years
Minimum interval between thinnings: 10 years
Minimum interval between thinning and harvest: 20 years
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Regeneration: Natural and conversion to Red Pine

White Pine
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
Thinning only at age 30 years (Pulp)
Thinning intensity 1:33 percent
Maximum age for first thinning: 30 years
Minimum interval between thinnings: 20 years
Minimum interval between thinning and harvest: 20 years
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Regeneration: Only natural regeneration

Black Spruce
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Regeneration: Only natural regeneration

Balsam Fir
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 100 years
No thinnings
Regeneration: Only natural regeneration

N. White Cedar
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 70 years (Sawlogs and Pulpwood)
Maximum age 140 years
No thinnings
Regeneration: Only natural regeneration

Tamarack
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

White Spruce
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
Maximum age 120 years
No Thinnings
Regeneration: Natural and conversion to White Spruce

Oak-Hickory
Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural regeneration

Elm-Ash-Maple
Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 120 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
No thinnings
Regeneration: Only natural Regeneration

Maple-Basswood
Unrestricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 100 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 70 years (Sawlogs and Pulpwood)
Maximum age 140 years
No thinnings
Regeneration: Natural and conversion to Red Pine

Aspen
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 60 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 60 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Regeneration: Natural and conversion to Red Pine

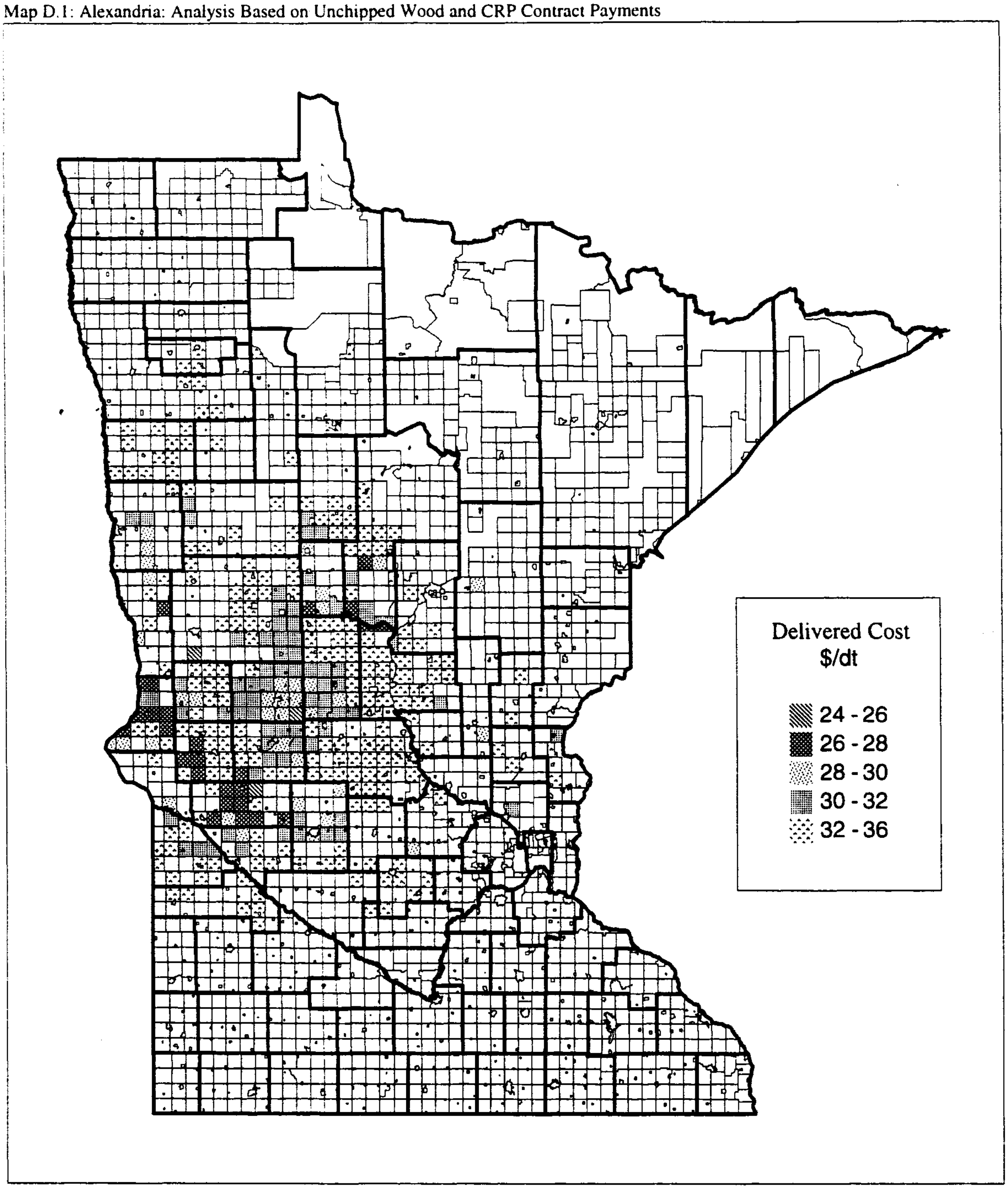
Paper Birch
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 70 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 50 years (Sawlogs and Pulpwood)
Maximum age 100 years
No thinnings
Regeneration: Only natural regeneration

Balsam Poplar
Unrestricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 60 years
No thinnings
Restricted Scenario: Clearcut-Minimum age 40 years (Sawlogs and Pulpwood)
Maximum age 80 years
No thinnings
Regeneration: Only natural regeneration

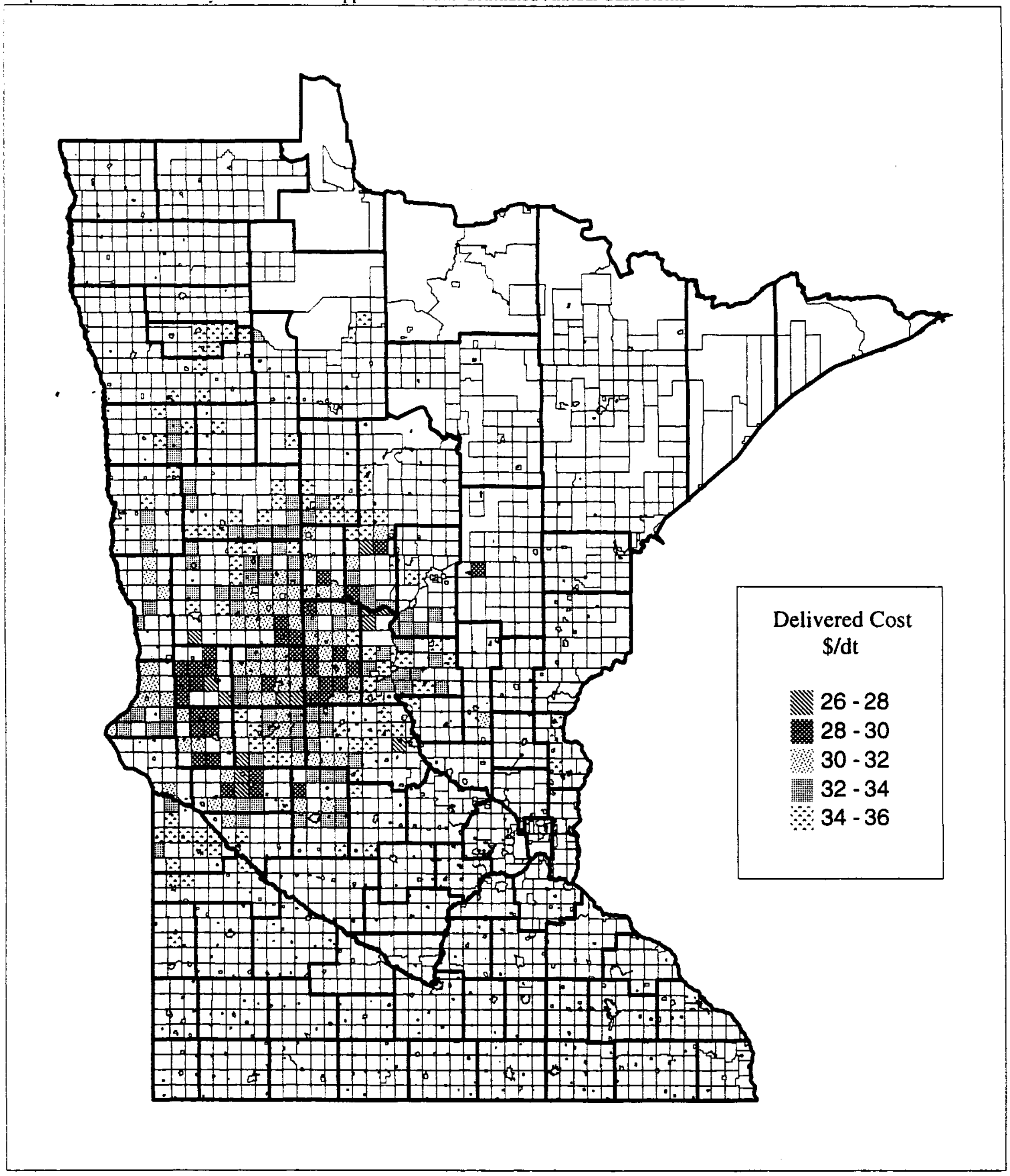
APPENDIX D

DELIVERED FUELWOOD COSTS BY TOWNSHIP FOR SINGLE POWER PLANT SCENARIOS USING ONLY AGRICULTURAL LANDS

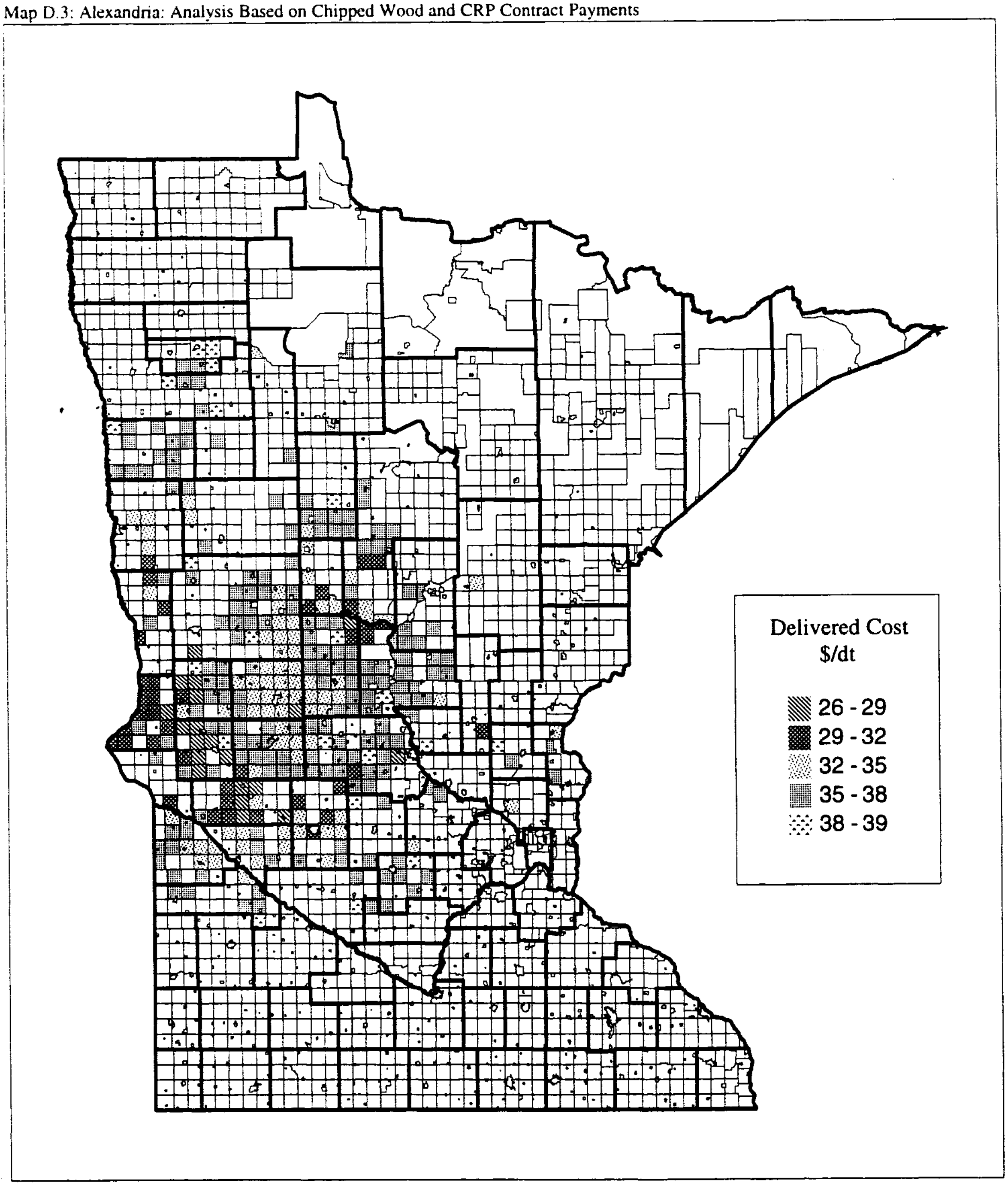
Map D.1: Alexandria: Analysis Based on Unchipped Wood and CRP Contract Payments



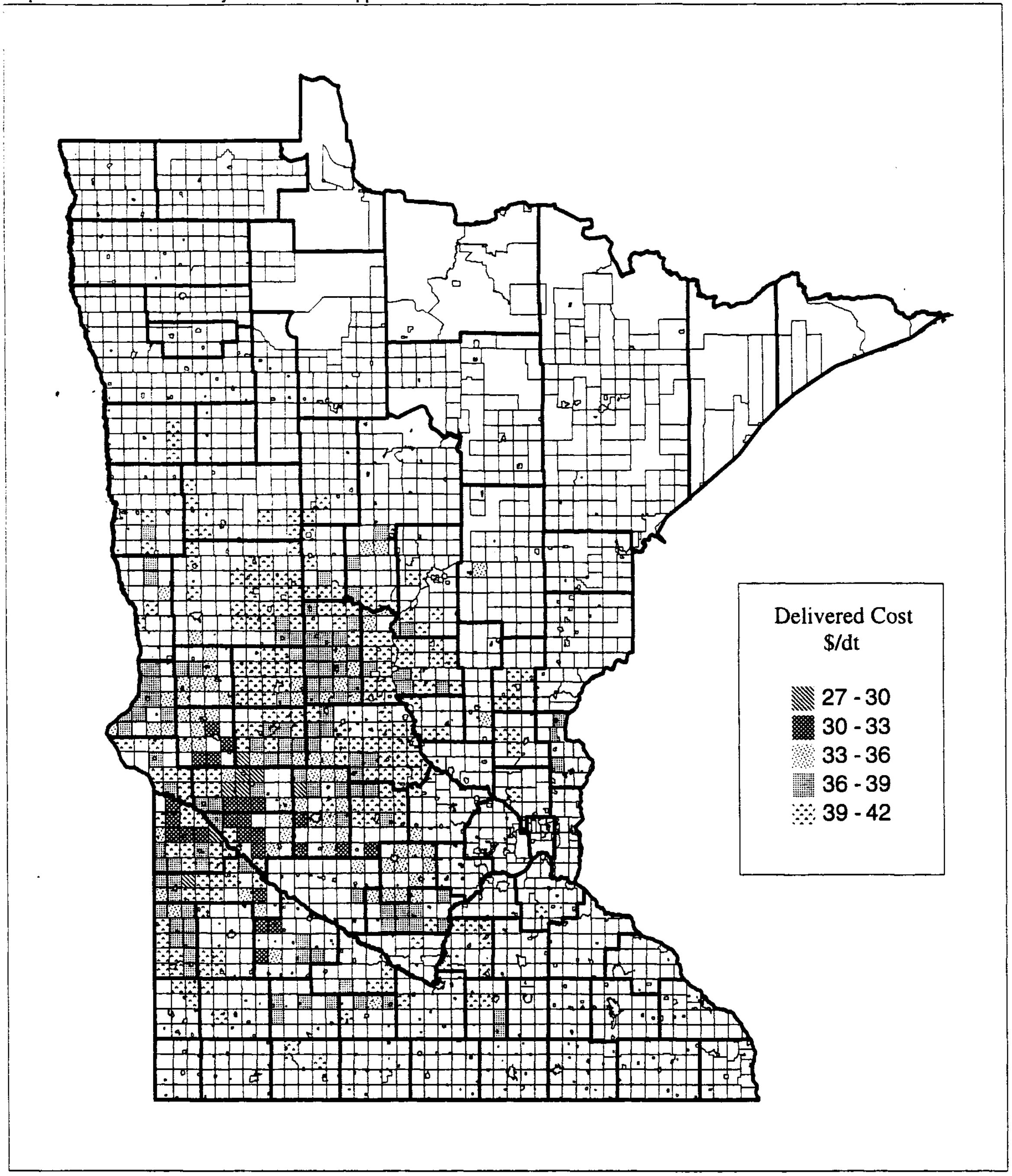
Map D.2: Alexandria: Analysis Based on Chipped Wood and Estimated Annual Cash Rents



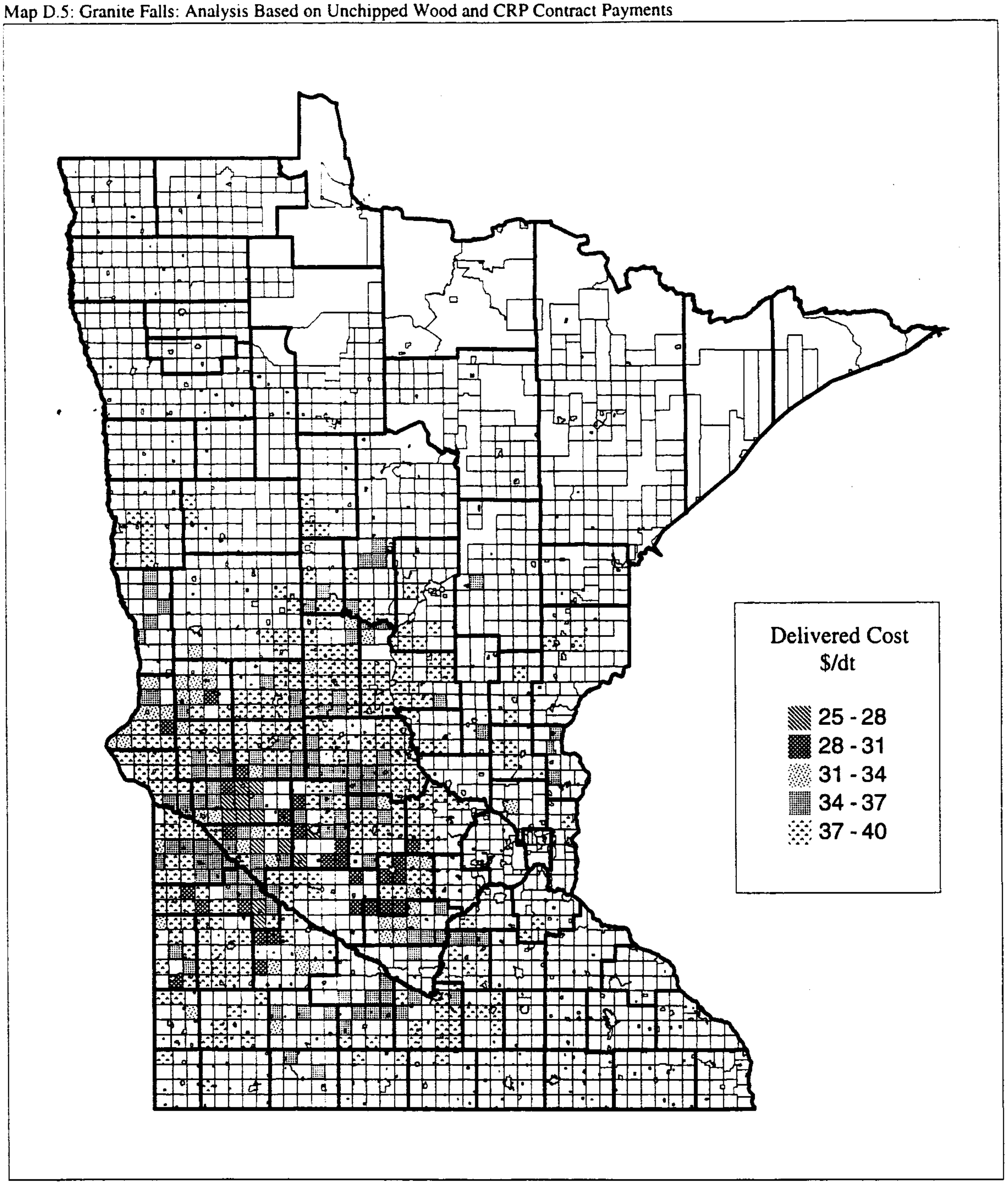
Map D.3: Alexandria: Analysis Based on Chipped Wood and CRP Contract Payments



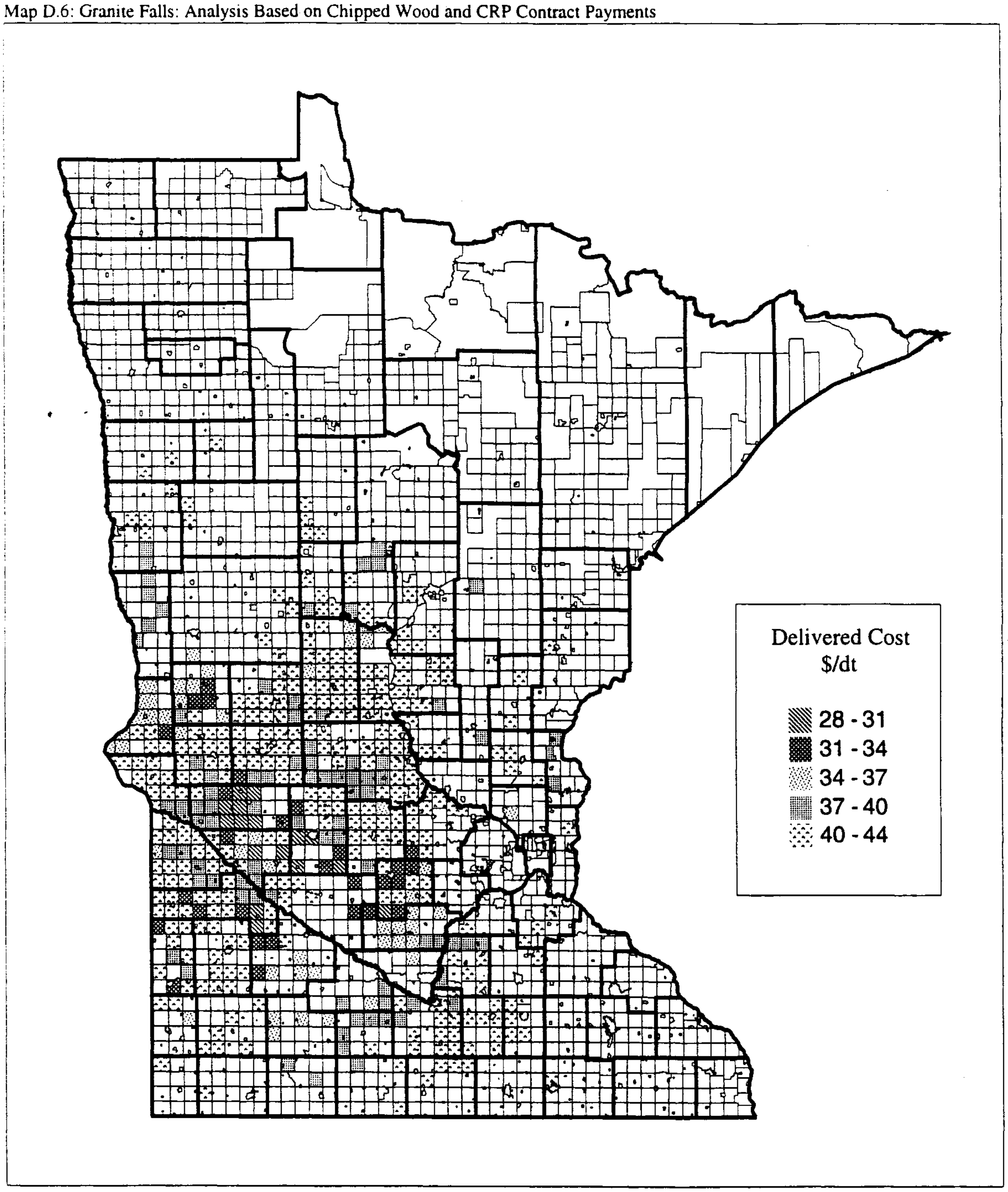
Map D.4: Granite Falls: Analysis Based on Chipped Wood and Estimated Annual Cash Rents



Map D.5: Granite Falls: Analysis Based on Unchipped Wood and CRP Contract Payments



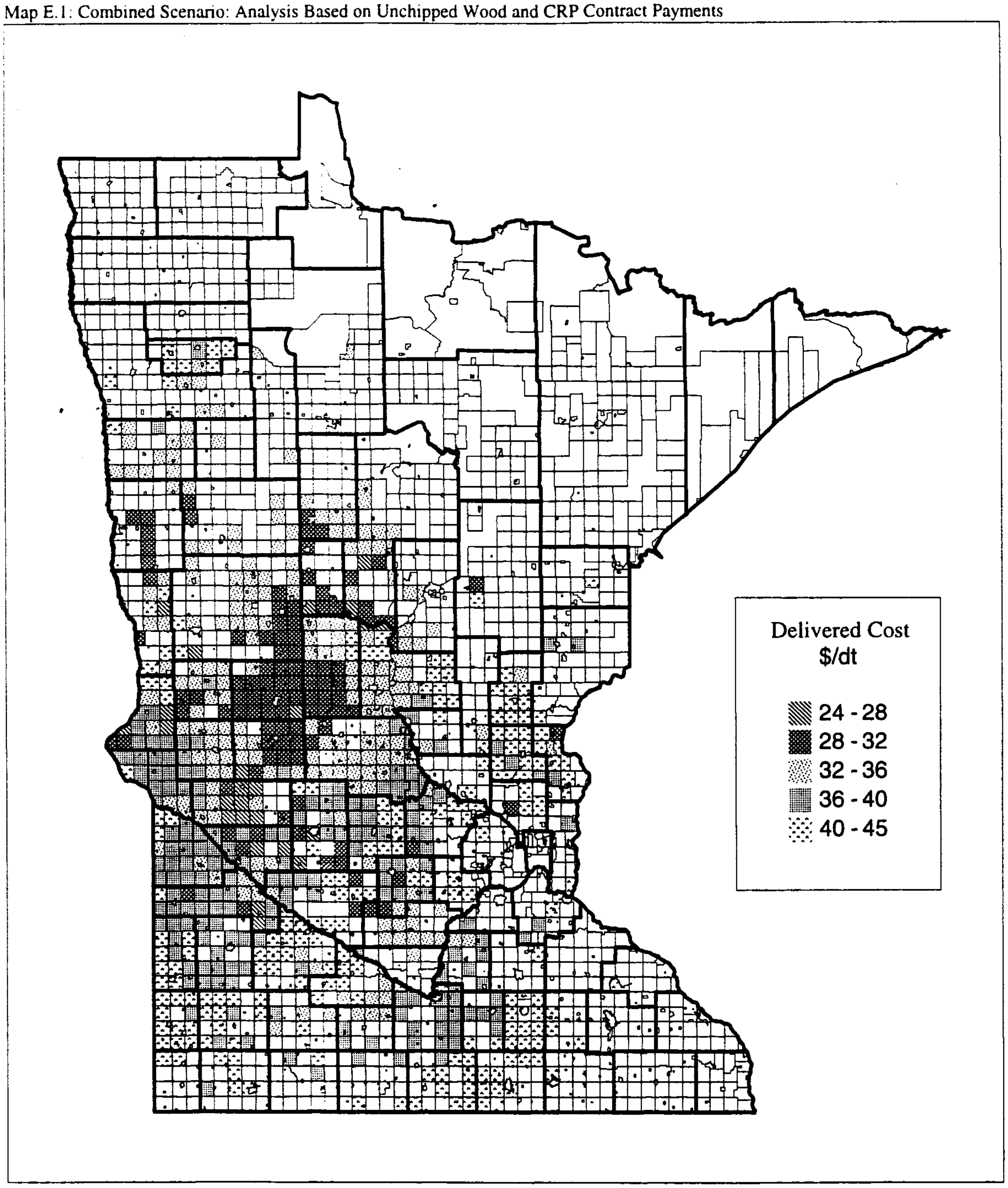
Map D.6: Granite Falls: Analysis Based on Chipped Wood and CRP Contract Payments



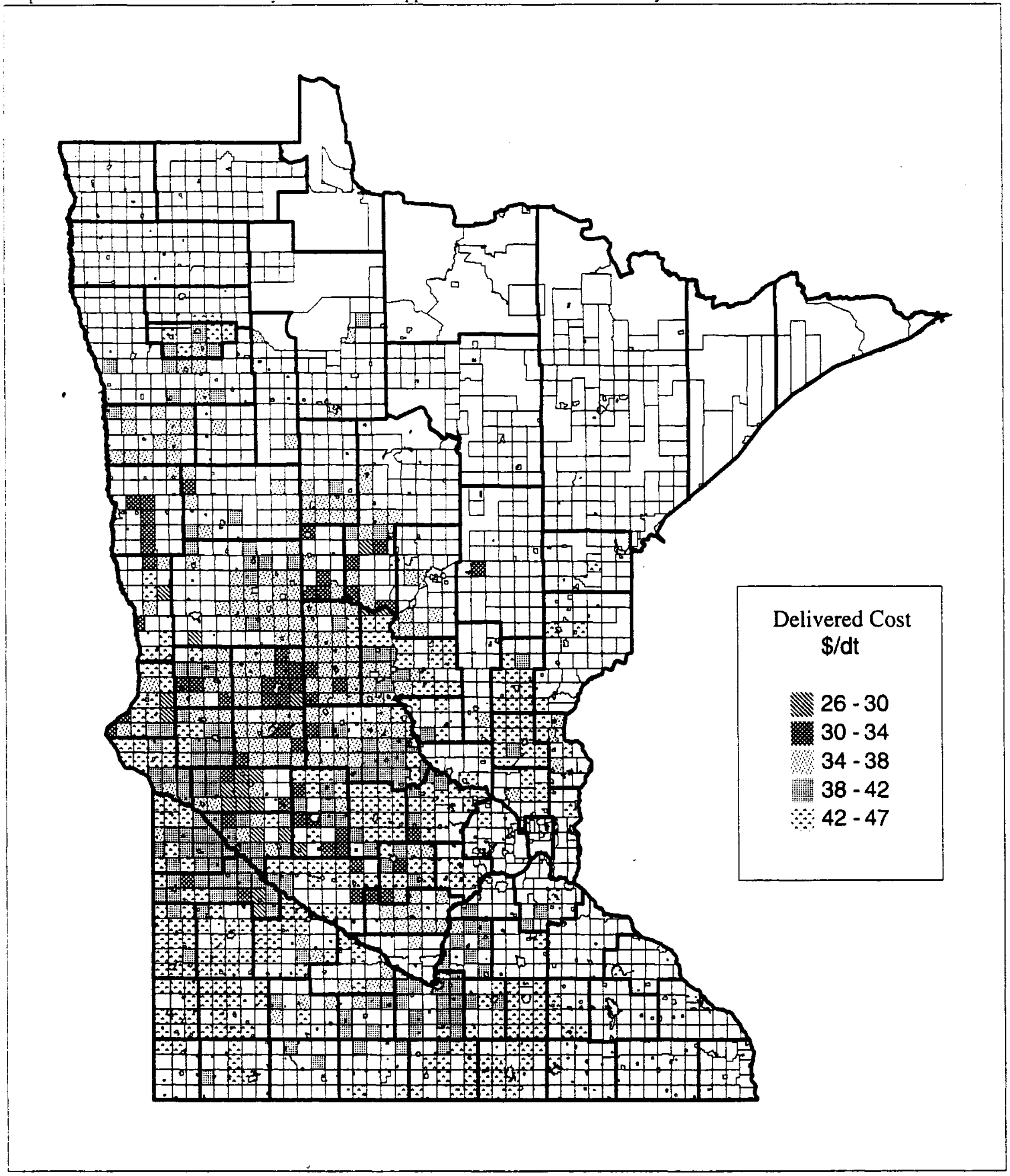
APPENDIX E

DELIVERED FUELWOOD COSTS BY TOWNSHIP FOR COMBINED POWER PLANT SCENARIOS USING ONLY AGRICULTURAL LANDS

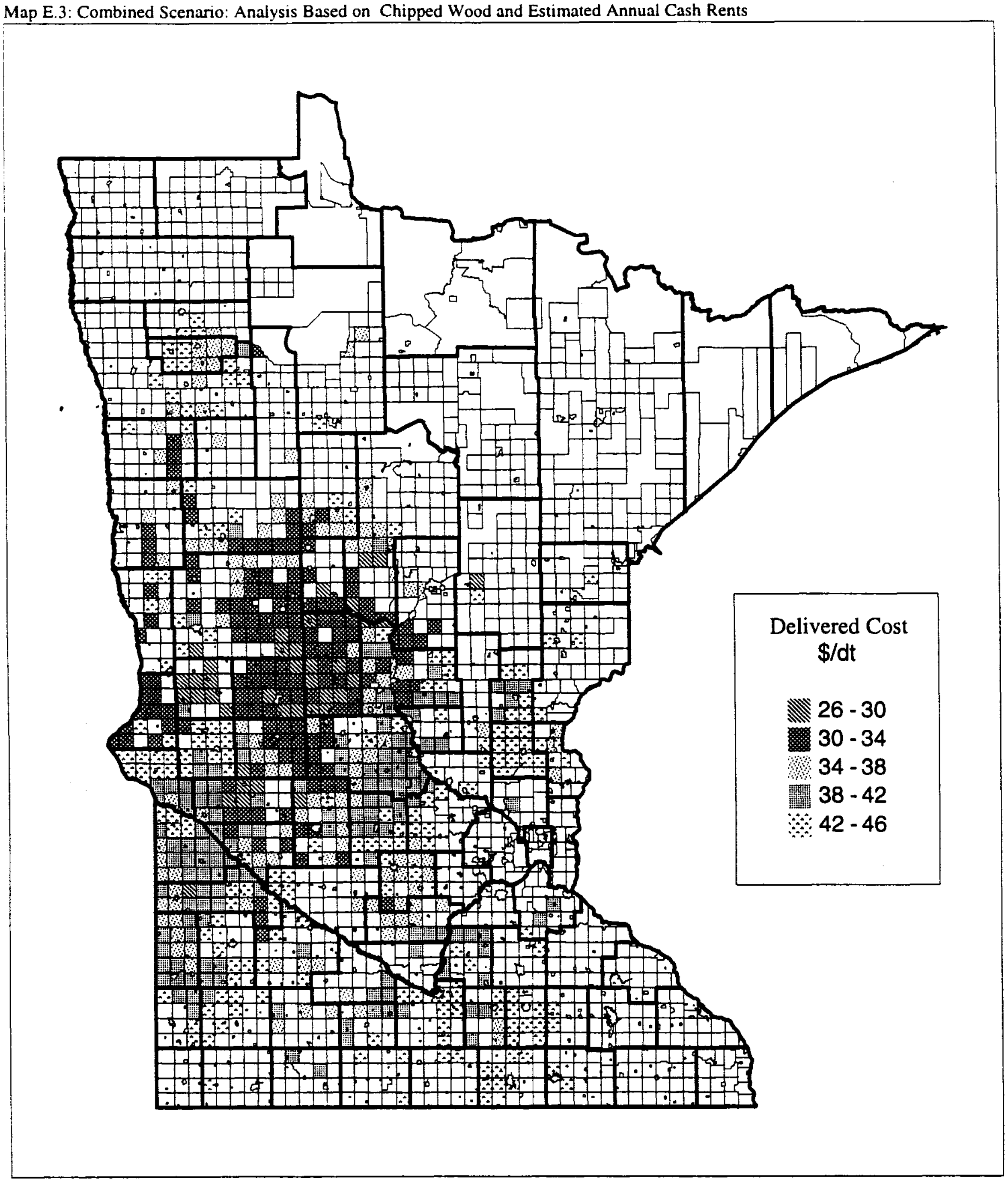
Map E.1: Combined Scenario: Analysis Based on Unchipped Wood and CRP Contract Payments



Map E.2: Combined Scenario: Analysis Based on Chipped Wood and CRP Contract Payments



Map E.3: Combined Scenario: Analysis Based on Chipped Wood and Estimated Annual Cash Rents



Appendix F

Scenario 1: Timber Product Demands with Unrestricted Forest Lands

Table F.1: Total Variable Costs ($) by Planning Period for Scenario 1

	VARIABLE COSTS		
PERIOD	Production and Management	Harvest and Transportation	TOTAL
1	23,953,680	1,042,454,000	**1,066,407,680**
2	25,988,510	998,583,600	**1,024,572,110**
3	43,643,960	976,723,700	**1,020,367,660**
4	62,433,830	934,524,000	**996,957,830**
5	76,143,250	1,009,524,000	**1,085,667,250**
6	79,462,660	1,000,076,000	**1,079,538,660**
7	83,418,230	1,000,426,000	**1,083,844,230**
8	85,378,200	1,033,214,000	**1,118,592,200**
9	87,173,460	1,029,715,000	**1,116,888,460**
10	89,898,980	1,021,753,000	**1,111,651,980**
TOTAL	657,494,760	10,046,993,300	10,704,488,060

Table F.2: Aspen Shadow Prices by Planning Period and Market for Scenario 1

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	51.80	53.43	50.75	42.14	54.99	53.64
2	61.32	63.38	60.93	45.28	64.28	64.64
3	70.00	72.13	70.02	47.72	72.94	73.57
4	77.75	80.67	77.53	49.78	80.50	81.08
5	79.38	77.89	75.62	48.72	76.16	79.12
6	73.79	72.71	70.44	45.66	71.32	74.01
7	70.29	69.99	68.13	44.21	68.66	71.25
8	66.53	67.26	65.14	42.87	65.22	68.70
9	62.35	63.30	61.18	41.84	61.45	64.59
10	61.86	60.02	59.54	40.88	59.76	63.06

Table F.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 1

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	2.17	11.19	8.79	17.90	6.81	9.73
2	2.04	10.45	8.51	17.49	6.41	9.08
3	1.23	10.26	8.22	17.24	6.65	8.14
4	2.17	11.16	9.73	18.41	8.11	8.04
5	5.17	14.59	10.87	20.51	10.17	10.24
6	8.73	16.89	13.27	22.48	12.85	12.00
7	10.15	18.43	14.59	23.61	14.42	12.03
8	10.90	19.93	16.14	24.82	15.76	14.53
9	13.26	21.20	18.37	26.16	17.06	17.73
10	16.19	22.44	20.06	27.60	18.91	19.72

Table F.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 1

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	29.37	43.02	37.84	51.53	49.33	43.37	9.73
2	29.62	43.09	38.51	53.72	51.42	45.06	9.08
3	30.84	44.44	40.18	54.77	53.30	46.44	8.14
4	31.69	45.18	42.16	57.01	56.43	49.40	8.04
5	24.43	34.45	28.47	59.06	61.23	53.56	10.24
6	20.40	31.18	26.10	62.94	67.24	58.09	12.00
7	2.19	14.98	7.07	67.51	71.37	63.51	12.03
8	-2.56	11.81	2.53	70.10	74.28	66.25	14.53
9	-0.90	11.82	3.49	71.07	75.71	68.25	17.73
10	-1.35	12.05	1.70	73.92	76.05	70.15	19.72

Table F.5: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 1

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	168400	158300	140600	120600	104300	145700	133700	148400	64900	126900	**1311800**
Balsam Fir	73600	90000	120800	118200	132000	104600	93000	88600	98900	105100	**1024800**
N. White Cedar	3800	7200	5600	4500	8800	5300	1200	1100	3700	6500	**47700**
Tamarack	26600	29300	40700	40700	39600	54300	72700	24000	42500	29300	**399700**
Spruce	282400	209800	157800	191300	228500	416800	252700	195300	56200	175500	**2166300**
N. Hardwoods	74600	114800	195400	218900	216600	235200	212200	205400	214300	221600	**1909000**
Aspen	1373900	1188500	1046400	1040000	1182500	942400	978100	1060900	1118000	971600	**10902300**
Balsam Poplar	135900	99000	104300	95500	120500	90000	100300	99100	95900	119700	**1060200**
TOTAL	**2139200**	**1896900**	**1811600**	**1829700**	**2032800**	**1994300**	**1843900**	**1822800**	**1694400**	**1756200**	**18821800**

Table F.6: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 1

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	304600	232400	277800	289000	252300	289000	236300	260800	210100	182400	**2534700**
Misc. Public	87300	68100	67100	55100	72000	87300	65200	69900	52800	72600	**697400**
State	374600	392200	362800	379200	351700	441900	420100	370000	322100	307700	**3722300**
County	512900	395600	307300	330800	456400	381500	355400	358400	349500	380100	**3827900**
Private	756100	718600	685700	645500	780700	693300	658300	638900	671000	705300	**6953400**
F. Industry	103700	90000	110900	130100	119700	101300	108600	124800	88900	108100	**1086100**
TOTAL	**2139200**	**1896900**	**1811600**	**1829700**	**2032800**	**1994300**	**1843900**	**1822800**	**1694400**	**1756200**	**18821800**

Table F.7: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 1

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1761200	1578900	1495500	1492200	1652500	1609100	1520100	1509600	1374900	1442500	**15436500**
Buffers	91100	62900	55700	83600	119000	79900	60000	86000	78300	76900	**793400**
Extended	143700	114200	133800	133500	118400	164000	132200	110800	129700	104100	**1284400**
Old Growth	7600	2800	1400	1400	6600	4900	0	4300	4000	2600	**35600**
Reserve	135600	138100	125200	119000	136300	136400	131600	112100	107500	130100	**1271900**
TOTAL	**2139200**	**1896900**	**1811600**	**1829700**	**2032800**	**1994300**	**1843900**	**1822800**	**1694400**	**1756200**	**18821800**

Table F.8: Acreage of Forestlands Harvested by Planning Period and County for Scenario 1

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	98600	105600	83300	75000	87200	92400	86000	92600	81900	88800	**891400**
Becker	42100	44300	27100	31600	32300	40700	33000	26000	32700	23000	**332800**
Beltrami	119900	121500	112400	109300	107400	110700	112800	91300	102700	90000	**1078000**
Benton	2700	0	900	5100	1000	3000	900	1700	6400	900	**22600**
Carlton	62700	55300	46600	52700	72200	63700	50900	68800	57100	77600	**607600**
Cass	200400	115900	97500	97300	156100	129200	93000	100000	117100	126200	**1232700**
Chisago	0	4700	2500	0	2000	3400	1600	2500	1200	3700	**21600**
Clay	0	0	1900	0	1200	0	0	1900	0	1200	**6200**
Clearwater	37200	50300	39500	40700	45100	38900	39500	46700	34000	39000	**410900**
Cook	19400	50500	100500	78500	30800	53800	61700	75100	41700	16000	**528000**
Crow Wing	73100	48800	54100	38000	82700	40800	56600	54200	54500	73500	**576300**
Douglas	900	900	0	2100	900	0	900	200	1500	0	**7400**
Grant	0	0	1900	1000	0	0	0	1900	0	0	**4800**
Hubbard	83600	54600	55700	74100	83000	50100	49300	46100	50400	80700	**627600**
Isanti	1300	2700	10400	6200	900	3100	1700	1600	5700	2200	**35800**
Itasca	231200	194600	183400	185800	211200	204900	194900	196400	194800	182500	**1979700**
Kanabec	18700	5100	22100	6900	13100	19500	22100	15600	11400	15000	**149500**
Kittson	0	10500	20800	13200	1200	6700	4700	16000	6600	3400	**83100**
Koochiching	191800	182700	157300	172700	199900	250800	181400	160100	124200	174800	**1795700**
Lake	116500	99700	114900	145300	116500	134700	96500	119700	100700	84800	**1129300**
Lake Woods	37400	33000	60600	48800	17500	48300	68400	59200	28900	23300	**425400**
Mahnomen	15700	12300	11200	10800	14200	12800	14000	12400	4600	14200	**122200**
Marshall	4400	17600	31700	38700	8600	14100	18500	33200	28500	8600	**203900**
Mille Lacs	5200	10900	24100	5600	8800	10000	18000	15900	10500	9000	**118000**
Morrison	31100	24400	19800	12700	30100	24400	19500	13200	16300	38600	**230100**
Norman	2400	2200	3600	0	2100	2300	3500	3600	0	3200	**22900**
Otter Tail	17000	13700	8900	17300	6100	25700	11500	17700	11500	5800	**135200**
Pennington	1100	4400	8600	6800	0	3300	5500	4200	6800	0	**40700**
Pine	109600	89300	44300	63300	97900	87000	82500	60000	97800	73500	**805200**
Polk	9800	6600	3300	3400	9000	8600	4400	3300	4500	6700	**59600**
Red Lake	3300	1100	7700	4400	1100	3300	3300	5300	3300	1100	**33900**
Roseau	10800	16600	57600	46400	6400	21900	23600	46900	30900	10800	**271900**
St. Louis	577900	495500	376000	410100	563600	473600	450600	409200	401500	456400	**4614400**
Todd	7500	6200	8700	5700	15300	4900	11000	6800	13000	8000	**87100**
Wadena	5900	15400	12700	20200	7400	7700	22100	13500	11700	13700	**130300**
TOTAL	**2139200**	**1896900**	**1811600**	**1829700**	**2032800**	**1994300**	**1843900**	**1822800**	**1694400**	**1756200**	**18821800**

Appendix G

Scenario 2: Timber Product Demands with Restricted Forest Lands

Table G.1: Total Variable Costs ($) by Planning Period for Scenario 2

	VARIABLE COSTS		
PERIOD	Production and Management	Harvest and Transportation	TOTAL
1	36,090,910	1,037,253,000	**1,073,343,910**
2	39,370,380	975,413,400	**1,014,783,780**
3	59,126,180	920,561,200	**979,687,380**
4	78,049,100	881,613,200	**959,662,300**
5	78,855,420	983,361,700	**1,062,217,120**
6	86,644,780	981,049,200	**1,067,693,980**
7	87,335,950	970,146,600	**1,057,482,550**
8	85,329,220	986,635,500	**1,071,964,720**
9	82,625,310	993,710,300	**1,076,335,610**
10	87,446,350	979,360,300	**1,066,806,650**
TOTAL	720,873,600	9,709,104,400	10,429,978,000

Table G.2: Aspen Shadow Prices by Planning Period and Market for Scenario 2

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	64.89	66.34	63.40	68.07	66.54	69.29
2	79.19	80.96	78.96	82.43	82.79	84.54
3	92.16	94.12	92.83	95.66	95.99	97.52
4	104.49	106.95	103.76	106.73	107.39	108.86
5	92.04	90.52	88.83	88.85	91.95	96.10
6	86.69	85.61	83.58	84.15	87.02	90.45
7	83.29	83.14	80.80	81.54	84.36	87.39
8	79.67	79.99	77.76	78.34	81.21	83.70
9	75.58	76.02	73.79	74.44	77.25	79.56
10	74.84	72.46	71.74	71.42	75.10	78.47

Table G.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 2

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	-2.01	6.95	3.85	13.71	2.31	5.31
2	-2.44	6.55	4.19	13.70	2.22	4.76
3	-2.15	6.65	5.03	14.08	3.44	4.22
4	-0.94	8.09	6.78	15.52	5.14	4.49
5	6.27	15.27	10.87	20.40	9.79	10.23
6	9.32	17.92	14.89	22.98	13.35	12.86
7	10.68	19.45	16.60	24.69	15.05	14.64
8	12.56	21.12	17.77	26.35	16.24	15.99
9	15.25	22.71	19.38	28.37	18.70	18.57
10	17.28	23.98	21.85	29.75	21.16	20.57

Table G.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 2

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	29.37	44.10	37.74	55.87	54.60	47.61	25.84
2	30.23	44.22	38.75	58.96	58.18	50.63	25.56
3	31.82	45.89	40.76	62.48	61.70	54.15	23.39
4	33.87	47.36	44.59	67.44	67.49	59.14	19.58
5	25.54	34.60	28.62	70.80	74.10	64.79	20.11
6	22.66	32.66	27.57	72.85	78.20	68.86	18.06
7	7.62	19.59	11.78	73.91	77.13	69.85	21.40
8	-0.49	12.04	3.91	73.37	77.56	69.86	26.71
9	0.49	12.36	3.26	73.32	76.98	69.53	33.52
10	0.09	11.72	3.53	75.57	78.05	71.83	40.51

Table G.5: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 2

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	158900	167700	152700	116000	115600	157400	135100	131400	95800	105400	**1336000**
Balsam Fir	85000	124200	127400	118000	141900	110600	119200	113100	103900	93700	**1137000**
N. White Cedar	5900	10700	7600	10700	8000	2600	3200	8900	5900	5000	**68500**
Tamarack	41100	21800	54400	43200	40200	58500	78500	36300	53200	47400	**474600**
Spruce	253100	201200	152000	210100	231600	350700	211300	160700	217500	130700	**2118900**
N. Hardwoods	101800	147300	226300	276300	231500	265400	251400	213400	239100	283900	**2236400**
Aspen	1346900	1147900	942900	951400	1165300	954300	945400	1037400	999300	933000	**10423800**
Balsam Poplar	139000	91900	100400	85900	124700	85900	82800	105100	110400	90400	**1016500**
TOTAL	**2131700**	**1912700**	**1763700**	**1811600**	**2058800**	**1985400**	**1826900**	**1806300**	**1825100**	**1689500**	**18811700**

Table G.6: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 2

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	327600	245400	255400	278500	273000	262700	256700	270700	265000	210200	**2645200**
Misc. Public	78300	54000	43400	36800	65100	68000	52100	34300	58500	41100	**531600**
State	342200	379100	372800	358700	372400	421400	373100	378500	344500	308500	**3651200**
County	533900	393700	332600	342500	480800	388800	367800	357900	386200	359500	**3943700**
Private	730900	744700	645500	655200	741700	734200	660500	630700	661800	670300	**6875500**
F. Industry	118800	95800	114000	139900	125800	110300	116700	134200	109100	99900	**1164500**
TOTAL	**2131700**	**1912700**	**1763700**	**1811600**	**2058800**	**1985400**	**1826900**	**1806300**	**1825100**	**1689500**	**18811700**

Table G.7: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 2

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1994900	1725400	1585200	1640100	1880700	1784200	1675200	1602800	1687400	1577100	**17153000**
Buffers	75600	93500	80100	95800	109400	103100	53400	59300	43500	25100	**738800**
Extended	61200	93800	98400	75700	68700	98100	98300	144200	94200	87300	**919900**
Old Growth	0	0	0	0	0	0	0	0	0	0	**0**
Reserve	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**2131700**	**1912700**	**1763700**	**1811600**	**2058800**	**1985400**	**1826900**	**1806300**	**1825100**	**1689500**	**18811700**

Table G.8: Acreage of Forestlands Harvested by Planning Period and County for Scenario 2

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	81200	107500	78100	84400	68400	86000	101700	101300	75000	91000	**874600**
Becker	59200	39500	34500	30000	52900	27600	42100	32700	30200	32400	**381100**
Beltrami	111900	110900	116800	89100	96100	108600	101100	89400	89700	90500	**1004100**
Benton	1900	0	900	3700	2400	3900	900	2300	6900	900	**23800**
Carlton	54100	45300	54600	38900	66600	63000	74100	47000	61100	39500	**544200**
Cass	197300	107100	98500	105700	157900	96200	97100	107300	136300	122400	**1225800**
Chisago	1700	3000	5800	0	3700	3400	0	8800	1700	4500	**32600**
Clay	0	1900	1000	1200	1500	1900	0	0	1200	0	**8700**
Clearwater	48300	48000	29800	44100	46200	37100	30200	32400	43000	27900	**387000**
Cook	45800	61000	83700	77500	48700	63800	68100	68400	66600	35000	**618600**
Crow Wing	64400	53200	52900	46700	79400	43100	57200	69100	52000	62400	**580400**
Douglas	900	900	1000	1100	900	1000	1700	0	1700	0	**9200**
Grant	0	0	1900	0	0	0	0	1900	0	0	**3800**
Hubbard	76600	64700	65400	66000	71200	58900	43700	41400	56200	79600	**623700**
Isanti	400	3300	3100	12300	3300	1400	4200	2800	1200	1400	**33400**
Itasca	229900	199900	171400	189500	186800	230200	185300	211600	201200	155800	**1961600**
Kanabec	19000	9000	16200	14700	10800	27600	20100	15600	15400	21000	**169400**
Kittson	1200	13000	19700	10500	3400	9400	14900	10500	9600	3400	**95600**
Koochiching	196600	182700	158500	205100	198700	217400	178200	156400	184800	165000	**1843400**
Lake	111300	88600	107900	142300	134700	103300	107100	108600	133700	109100	**1146600**
Lake Woods	35200	43700	50900	49700	42300	51700	44800	61800	26800	30800	**437700**
Mahnomen	17500	13000	9600	9600	14900	14900	7600	8800	13100	13700	**122700**
Marshall	6600	18700	28500	28300	9500	17200	26500	29300	7700	8800	**181100**
Mille Lacs	17700	7600	23500	7400	14500	12700	9700	17800	12700	14300	**137900**
Morrison	25700	32900	17100	9500	29500	28800	21200	12000	19100	31100	**226900**
Norman	3500	1100	3300	1800	2300	2400	5300	1200	900	3500	**25300**
Otter Tail	18400	13000	12600	10800	8900	24700	17000	10500	16700	9800	**142400**
Pennington	0	8900	7500	4600	1200	1100	8800	5100	3700	1100	**42000**
Pine	111600	68300	48200	69800	101300	82900	60100	69100	87500	80200	**779000**
Polk	8700	8800	3300	4600	6700	8600	3300	5300	2200	6700	**58200**
Red Lake	4400	4400	5500	2200	2200	6600	2200	3300	2200	3300	**36300**
Roseau	10400	23700	57000	38500	12100	30100	31000	36700	16700	13800	**270000**
St. Louis	553700	506700	376400	382900	553100	500300	437200	415700	421900	404700	**4552600**
Todd	6800	6000	8500	7400	10500	10300	11000	6900	10400	12300	**90100**
Wadena	9800	16400	10100	21700	16200	9300	13500	15300	16000	13600	**141900**
TOTAL	**2131700**	**1912700**	**1763700**	**1811600**	**2058800**	**1985400**	**1826900**	**1806300**	**1825100**	**1689500**	**18811700**

APPENDIX H

SCENARIO 3: TIMBER PRODUCT AND BIOMASS DEMANDS WITH UNRESTRICTED FOREST LANDS

Table H.1: Total Variable Costs ($) by Planning Period for Scenario 3

VARIABLE COSTS			
PERIOD	Production and Management	Harvest and Transportation	**TOTAL**
1	25,144,350	1,046,950,000	**1,072,094,350**
2	26,749,780	1,121,698,000	**1,148,447,780**
3	49,205,580	1,116,722,000	**1,165,927,580**
4	68,117,220	1,091,334,000	**1,159,451,220**
5	81,519,800	1,157,501,000	**1,239,020,800**
6	84,035,580	1,159,788,000	**1,243,823,580**
7	89,958,160	1,154,996,000	**1,244,954,160**
8	92,634,000	1,167,707,000	**1,260,341,000**
9	95,120,990	1,189,221,000	**1,284,341,990**
10	95,445,020	1,149,482,000	**1,244,927,020**
TOTAL	**707,930,480**	**11,355,399,000**	**12,063,329,480**

Table H.2: Aspen Shadow Prices by Planning Period and Market for Scenario 3

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	54.84	56.12	53.60	57.83	56.38	59.23
2	65.26	65.98	65.50	68.77	68.82	71.11
3	76.40	77.18	77.00	79.68	80.47	82.19
4	87.46	89.72	87.58	90.58	90.85	92.34
5	88.86	87.15	85.41	85.66	88.75	93.26
6	82.93	81.91	79.80	80.47	83.35	87.22
7	77.85	77.25	76.36	76.70	79.44	83.00
8	73.33	73.25	72.39	72.85	75.81	78.52
9	69.50	68.80	68.54	69.01	71.97	74.41
10	66.72	65.49	65.72	65.94	68.87	72.53

Table H.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 3

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	6.03	15.05	9.90	19.82	8.61	11.79
2	9.16	18.13	11.47	20.54	10.01	12.53
3	10.58	19.21	11.96	20.97	11.07	12.80
4	11.44	20.73	13.75	21.89	12.35	13.48
5	13.37	23.19	14.41	24.14	14.49	14.08
6	16.05	25.20	16.48	25.56	16.60	16.10
7	17.90	27.07	17.85	26.87	18.68	16.86
8	19.86	28.45	20.07	28.79	19.80	19.29
9	20.37	29.77	20.98	30.39	21.11	20.64
10	22.23	31.45	22.69	32.64	23.05	22.

Table H.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 3

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	28.26	42.33	37.03	49.55	47.45	41.27	11.79
2	28.41	42.42	37.60	51.22	49.48	42.86	12.53
3	29.35	43.20	38.93	51.91	51.26	43.76	12.80
4	30.20	43.65	40.44	53.58	54.16	46.77	13.48
5	22.54	31.51	24.88	56.49	58.82	51.26	14.08
6	23.09	32.89	26.71	59.67	64.83	55.58	16.10
7	19.41	26.33	18.68	64.84	70.01	60.90	16.86
8	17.18	23.68	15.74	67.50	72.95	64.07	19.29
9	18.30	23.49	15.46	67.40	74.49	65.59	20.64
10	20.16	23.63	15.45	69.36	75.64	68.63	22.00

Table H.5: Fuelwood Shadow Prices by Planning Period and Location for Scenario 3

	POWER PLANTS	
PERIOD	G. Falls	Alexandria
1	0.00	0.00
2	31.42	21.88
3	32.27	23.20
4	32.98	23.96
5	34.59	25.62
6	35.36	26.84
7	36.43	28.15
8	37.24	28.75
9	38.26	29.60
10	39.19	30.70

Table H.6: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 3

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	168900	148500	149500	124400	111800	173000	141700	146100	113200	96100	**1373200**
Balsam Fir	75900	95300	132600	118900	133100	111400	97900	116100	119900	109900	**1111000**
N. White Cedar	3800	8300	6900	4500	7800	4700	2900	1100	5700	7300	**53000**
Tamarack	28100	26300	34800	47700	39500	56600	109300	52100	79800	67800	**542000**
Spruce	300200	211800	139900	179300	224000	453300	269000	176500	161400	106900	**2222300**
N. Hardwoods	87000	276100	379200	392800	385200	378500	379200	365200	424700	494300	**3562200**
Aspen	1378900	1244800	1083300	1116200	1237800	1063900	1070700	1186400	1123400	1020800	**11526200**
Balsam Poplar	143900	95300	111400	103900	129100	89400	112600	105500	123800	101500	**1116400**
TOTAL	**2186700**	**2106400**	**2037600**	**2087700**	**2268300**	**2330800**	**2183300**	**2149000**	**2151900**	**2004600**	**21506300**

Table H.7: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 3

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	319400	228600	285600	309400	271200	305600	268000	275200	262600	238500	**2764100**
Misc. Public	92700	70900	83900	64800	88800	93400	80300	82800	93600	59700	**810900**
State	394300	401400	394800	396800	395300	477000	471500	428900	407200	323400	**4090600**
County	503800	461800	345600	356900	479300	453700	429600	402300	406700	422000	**4261700**
Private	764600	856300	820800	817300	910100	887600	807800	816400	889400	842600	**8412900**
F. Industry	111900	87400	106900	142500	123600	113500	126100	143400	92400	118400	**1166100**
TOTAL	**2186700**	**2106400**	**2037600**	**2087700**	**2268300**	**2330800**	**2183300**	**2149000**	**2151900**	**2004600**	**21506300**

Table H.8 Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 3

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1794100	1754300	1668500	1709800	1851600	1902400	1774600	1771200	1723600	1656900	**17607000**
Buffers	92800	68800	79500	90700	117200	97100	86600	91400	100700	97000	**921800**
Extended	148600	124400	138600	132600	131300	172700	157800	132500	152400	113700	**1404600**
Old Growth	7600	2800	1400	1400	6600	4900	1500	2800	4000	2600	**35600**
Reserve	143600	156100	149600	153200	161600	153700	162800	151100	171200	134400	**1537300**
TOTAL	**2186700**	**2106400**	**2037600**	**2087700**	**2268300**	**2330800**	**2183300**	**2149000**	**2151900**	**2004600**	**21506300**

Table H.9 Acreage of Forestlands Harvested by Planning Period and County for Scenario

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	106700	114200	93100	80100	100900	121900	105700	124900	107100	97700	**1052300**
Becker	33100	71700	54700	40100	52200	68300	59300	46000	35900	64400	**525700**
Beltrami	134300	105300	125900	122200	134000	120800	124800	105000	136900	87700	**1196900**
Benton	0	5700	2700	12500	5700	3600	2100	9000	6200	5900	**53400**
Carlton	64600	56400	51100	55800	77000	70500	66200	57000	84100	53600	**636300**
Cass	199200	126400	113600	129000	174100	133500	123300	151900	128600	152100	**1431700**
Chisago	0	6600	5800	5200	7200	9200	3700	3300	7900	6800	**55700**
Clay	1000	0	1900	2700	4000	3500	1900	1200	2200	0	**18400**
Clearwater	33700	75000	46900	47500	37800	63400	56600	35200	48600	56100	**500800**
Cook	20800	51900	103600	86200	37700	59500	77400	81900	36700	36600	**592300**
Crow Wing	74200	65900	71100	57200	86900	77300	62300	68000	70100	64500	**697500**
Douglas	0	15800	11200	1700	800	4200	4000	9800	9900	3800	**61200**
Grant	0	0	3400	1000	1200	0	1900	0	1200	1500	**10200**
Hubbard	72000	78500	63000	84300	76500	82900	44000	71700	66400	98400	**737700**
Isanti	400	13100	6000	6800	400	7500	12100	6900	12400	3900	**69500**
Itasca	240600	199000	190400	196600	216600	218700	212400	213900	223900	194600	**2106700**
Kanabec	14900	21200	27100	16200	19800	25300	28300	29000	23900	24400	**230100**
Kittson	1200	9300	22000	16400	2400	2400	11600	18100	12000	1200	**96600**
Koochiching	201100	178800	153500	190100	205100	257500	186400	179200	176900	166900	**1895500**
Lake	119100	107600	121300	147500	128600	156100	126200	121700	128700	111400	**1268200**
Lake Woods	41000	30900	58800	54400	18800	48900	67100	59300	32800	24800	**436800**
Mahnomen	15700	16000	12100	14400	25500	7800	20500	9200	21300	22600	**165100**
Marshall	7700	12100	36200	39600	11000	11900	25400	43000	18300	8800	**214000**
Mille Lacs	5200	22900	37700	14600	20000	22200	30500	19100	18700	27000	**217900**
Morrison	29400	39100	33100	20600	36600	26500	17400	22500	54600	44500	**324300**
Norman	3500	1100	4500	3300	4700	1200	4400	1200	5500	3600	**33000**
Otter Tail	15900	30800	25000	36000	46700	32600	40400	29300	35600	31200	**323500**
Pennington	1100	4400	8600	7900	1100	3300	7700	5100	4800	2200	**46200**
Pine	110300	90800	57800	69700	114200	85100	94800	90500	89700	95300	**898200**
Polk	8700	7700	5500	5700	11100	5300	4400	7500	5600	7800	**69300**
Red Lake	3300	3300	5500	6600	1100	7500	3300	5500	4400	2200	**42700**
Roseau	11900	19000	57500	48100	7600	23400	38200	35400	29000	11800	**281900**
St. Louis	600800	487400	397900	429100	569200	530600	478000	443200	489600	457500	**4883300**
Todd	7900	22500	11600	15300	18100	23300	11900	21200	10500	13000	**155300**
Wadena	7400	16000	17500	23300	13700	15100	29100	23300	11900	20800	**178100**
TOTAL	**2186700**	**2106400**	**2037600**	**2087700**	**2268300**	**2330800**	**2183300**	**2149000**	**2151900**	**2004600**	**21506300**

APPENDIX I

SCENARIO 4: TIMBER PRODUCT AND BIOMASS DEMANDS WITH RESTRICTED FOREST LANDS

Table I.1: Total Variable Costs ($) by Planning Period for Scenario 4

VARIABLE COSTS			
PERIOD	Production and Management	Harvest and Transportation	**TOTAL**
1	38,307,170	1,059,477,000	**1,097,784,170**
2	44,179,730	1,119,651,000	**1,163,830,730**
3	73,648,100	1,051,828,000	**1,125,476,100**
4	88,990,430	994,950,000	**1,083,940,430**
5	82,554,330	1,133,108,000	**1,215,662,330**
6	86,294,420	1,132,441,000	**1,218,735,420**
7	92,345,660	1,124,671,000	**1,217,016,660**
8	90,393,260	1,122,169,000	**1,212,562,260**
9	91,259,060	1,145,901,000	**1,237,160,060**
10	91,774,700	1,121,212,000	**1,212,986,700**
TOTAL	**779,746,860**	**11,005,408,000**	**11,785,154,860**

Table I.2: Aspen Shadow Prices by Planning Period and Market for Scenario 4

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	75.23	76.89	73.75	78.34	76.88	79.58
2	92.97	93.89	93.53	96.71	97.12	99.01
3	110.69	111.61	112.18	114.54	114.89	116.38
4	128.58	130.10	127.56	130.68	131.13	132.60
5	109.97	108.46	106.63	106.64	109.91	113.93
6	104.29	103.56	101.23	101.85	104.77	108.07
7	99.86	99.73	97.76	98.63	101.27	104.12
8	95.70	96.20	94.29	95.05	97.79	100.07
9	91.93	90.70	90.59	90.60	93.90	96.35
10	88.71	87.71	87.18	87.71	90.70	92.86

Table I.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 4

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	2.81	11.83	6.10	16.61	5.20	7.89
2	8.03	16.66	9.01	18.88	8.13	10.54
3	11.04	19.46	12.08	20.54	11.27	12.71
4	13.11	21.79	14.77	23.05	13.21	13.81
5	17.90	26.62	16.85	27.39	17.88	16.60
6	20.09	30.11	20.51	30.00	20.97	18.80
7	23.39	33.44	23.50	33.14	23.06	22.01
8	26.27	36.70	26.33	37.17	26.45	25.80
9	29.00	40.94	29.57	42.15	30.91	28.39
10	31.99	45.33	34.52	47.34	35.73	32.32

Table I.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 4

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	28.06	42.66	36.57	52.35	50.79	44.06	7.89
2	28.88	43.26	37.41	55.22	54.43	46.89	10.54
3	30.72	44.93	39.17	58.75	58.14	50.51	12.71
4	32.92	46.33	42.51	64.36	64.27	56.12	13.81
5	25.52	33.51	26.56	67.72	71.96	62.64	16.60
6	26.64	36.48	30.04	72.06	78.58	68.89	18.80
7	24.11	32.90	24.95	73.15	78.70	69.56	22.01
8	24.44	31.22	23.21	73.09	78.27	69.23	25.80
9	26.37	31.29	22.72	70.79	77.17	69.67	28.39
10	27.35	32.27	23.61	74.19	78.16	72.93	32.32

Table I.5: Fuelwood Shadow Prices by Planning Period and Location for Scenario 4

	POWER PLANTS	
PERIOD	G. Falls	Alexandria
1	0.00	0.00
2	31.05	21.01
3	33.00	23.55
4	34.71	25.32
5	37.75	28.68
6	39.42	30.62
7	42.08	33.25
8	44.88	35.81
9	48.34	38.55
10	50.61	40.18

Table I.6: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 4

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	158900	155600	157000	118300	128000	174100	128600	134800	140400	112000	**1407700**
Balsam Fir	83600	135600	133900	142000	142100	121600	128200	122500	141700	114600	**1265800**
N. White Cedar	12600	13300	7200	9700	15500	3800	8500	12600	4700	18500	**106400**
Tamarack	37600	24100	56800	43500	34700	77800	96800	62900	84300	67500	**586000**
Spruce	257900	199200	143300	203900	229100	374300	211600	157600	268800	178100	**2223800**
N. Hardwoods	118000	320600	460000	436500	378600	452200	428500	444100	463100	520100	**4021700**
Aspen	1372200	1220600	936700	969800	1251000	1016700	1009900	1118400	1049500	958400	**10903200**
Balsam Poplar	145600	102700	89800	91400	125200	98200	88400	109700	114400	92600	**1058000**
TOTAL	**2186400**	**2171700**	**1984700**	**2015100**	**2304200**	**2318700**	**2100500**	**2162600**	**2266900**	**2061800**	**21572600**

Table I.7: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 4

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	350200	246000	266400	299200	292300	278000	294700	334300	311600	247500	**2920200**
Misc. Public	81900	60500	59900	46100	72300	71400	58600	37300	89800	58100	**635900**
State	364200	395200	397300	377300	390100	469700	427400	444500	432500	392700	**4090900**
County	532000	474000	374400	376300	509600	464400	405800	452900	451500	409200	**4450100**
Private	734900	899000	766800	776300	890900	910300	802100	737700	850300	832900	**8201200**
F. Industry	123200	97000	119900	139900	149000	124900	111900	155900	131200	121400	**1274300**
TOTAL	**2186400**	**2171700**	**1984700**	**2015100**	**2304200**	**2318700**	**2100500**	**2162600**	**2266900**	**2061800**	**21572600**

Table I.8: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 4

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	2041200	1989200	1801200	1826300	2125600	2097500	1913000	1934800	2115100	1928600	**19772500**
Buffers	73600	89200	80200	107800	113000	109700	72100	67300	43600	33500	**790000**
Extended	71600	93300	103300	81000	65600	111500	115400	160500	108200	99700	**1010100**
Old Growth	0	0	0	0	0	0	0	0	0	0	**0**
Reserve	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**2186400**	**2171700**	**1984700**	**2015100**	**2304200**	**2318700**	**2100500**	**2162600**	**2266900**	**2061800**	**21572600**

Table I.9: Acreage of Forestlands Harvested by Planning Period and County for Scenario 4

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	89000	116900	96500	86700	89300	142800	112400	118700	91600	102500	**1046400**
Becker	50600	71900	39200	48700	55200	67200	60600	39100	68200	42700	**543400**
Beltrami	120800	118200	123800	101400	115600	118700	122500	104400	137400	114400	**1177200**
Benton	0	1700	2700	9300	4600	5300	3600	7200	1700	5000	**41100**
Carlton	55300	42500	61600	51300	75100	61600	74900	52100	73000	39200	**586600**
Cass	196100	127800	126200	131700	166300	107400	119100	162400	146000	152900	**1435900**
Chisago	1700	6600	8400	2600	8800	11000	5800	3000	6500	8600	**63000**
Clay	0	1900	2500	1200	1900	5400	0	1200	1000	3400	**18500**
Clearwater	44400	64900	36500	51400	44900	61300	34100	43400	53300	54800	**489000**
Cook	56100	63900	91800	93100	52000	72500	74600	95800	90400	60900	**751100**
Crow Wing	69700	63400	69000	61400	92500	52400	57400	71700	69200	68200	**674900**
Douglas	0	11800	7000	2200	800	2800	1000	8900	6700	3100	**44300**
Grant	0	0	1900	2500	0	1200	0	2900	0	1500	**10000**
Hubbard	73900	76700	72600	70200	71000	87600	47200	71000	65000	78700	**713900**
Isanti	400	3600	8400	13300	5300	6500	11000	5400	4800	12300	**71000**
Itasca	237900	212700	177700	193100	211000	241700	200300	245900	213800	209600	**2143700**
Kanabec	12900	21100	28600	20500	24200	24100	27000	19300	28900	19100	**225700**
Kittson	4800	11800	22000	9400	3400	13000	13700	13700	7600	3400	**102800**
Koochiching	202800	186600	168300	201800	217400	231500	192700	183300	207600	217400	**2009400**
Lake	129300	99500	111900	136000	159200	124700	115000	140100	151100	120900	**1287700**
Lake Woods	40100	41400	57800	48600	34600	61600	49900	65800	41300	41900	**483000**
Mahnomen	14700	18800	20400	10800	17900	8800	29900	15300	17500	25200	**179300**
Marshall	9900	17600	29600	31700	13000	13900	29600	32700	15400	14900	**208300**
Mille Lacs	8600	28400	32300	8800	21100	12400	34000	17900	23200	19500	**206200**
Morrison	23600	49600	22500	20200	31800	31600	22400	19200	37500	23700	**282100**
Norman	3500	2300	3300	3000	3500	2400	6500	4200	2300	3600	**34600**
Otter Tail	16000	22000	23900	35400	44900	34600	39500	23200	30300	32500	**302300**
Pennington	0	8900	9700	5700	2300	1100	8800	6200	4800	3700	**51200**
Pine	110700	74900	60400	65300	107100	94200	80500	76300	85300	92700	**847400**
Polk	7600	12100	6700	4600	7600	6600	8800	6500	6700	14300	**81500**
Red Lake	3300	5500	5500	2200	4200	6600	3300	6400	2200	8800	**48000**
Roseau	12500	27800	54800	40400	11300	37900	28100	42000	24400	26100	**305300**
St. Louis	570600	526700	372300	412200	562300	540500	460900	420100	511300	404200	**4781100**
Todd	6200	15500	14700	15500	20100	13600	11900	14800	13600	19000	**144900**
Wadena	13400	16700	14200	22900	24000	14200	13500	22500	27300	13100	**181800**
TOTAL	**2186400**	**2171700**	**1984700**	**2015100**	**2304200**	**2318700**	**2100500**	**2162600**	**2266900**	**2061800**	**21572600**

APPENDIX J

SCENARIO 5: TIMBER PRODUCT DEMANDS WITH UNRESTRICTED FOREST AND AGRICULTURAL LANDS

Table J.1: Total Variable Costs ($) by Planning Period for Scenario 5

	VARIABLE COSTS		
PERIOD	Production and Management	Harvest and Transportation	**TOTAL**
1	21,661,360	1,038,097,000	**1,059,758,360**
2	87,200,020	936,589,700	**1,023,789,720**
3	91,857,250	931,592,700	**1,023,449,950**
4	99,309,160	914,022,500	**1,013,331,660**
5	119,294,300	945,441,400	**1,064,735,700**
6	118,513,700	947,199,600	**1,065,713,300**
7	124,205,600	941,780,200	**1,065,985,800**
8	124,935,500	939,858,600	**1,064,794,100**
9	130,365,400	944,760,800	**1,075,126,200**
10	122,633,000	941,042,400	**1,063,675,400**
TOTAL	**1,039,975,290**	**9,480,384,900**	**10,520,360,190**

Table J.2: Aspen Shadow Prices by Planning Period and Market for Scenario 5

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	37.56	39.00	36.89	42.14	39.97	42.44
2	37.20	40.53	40.40	45.28	43.35	43.75
3	37.45	42.00	42.82	47.72	45.45	44.57
4	37.54	43.73	44.06	49.78	46.71	44.86
5	37.67	43.62	44.14	48.72	46.52	44.91
6	36.22	40.73	40.87	45.66	43.47	43.61
7	35.98	40.46	39.60	44.21	42.96	43.29
8	36.27	39.86	38.49	42.87	42.25	42.58
9	36.32	39.24	37.58	41.84	41.59	42.12
10	35.81	38.26	36.82	40.88	40.91	41.64

Table J.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 5

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	13.90	19.81	18.29	25.14	15.10	20.07
2	15.63	19.87	18.01	25.02	15.87	21.29
3	15.95	19.80	18.29	24.93	15.82	20.79
4	16.30	20.34	19.00	25.44	16.76	20.67
5	17.26	21.13	19.27	25.93	17.16	20.56
6	18.48	21.97	19.40	26.63	18.15	19.89
7	19.72	22.50	20.16	27.27	19.15	20.29
8	20.17	23.10	21.70	28.58	19.93	22.28
9	21.12	23.89	23.32	29.41	21.69	23.81
10	22.85	24.66	24.61	30.49	22.81	25.16

Table J.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 5

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	31.04	44.34	39.39	55.81	53.26	47.45	20.07
2	30.87	44.37	40.12	57.54	54.61	48.72	21.29
3	32.19	45.67	41.63	58.31	56.14	49.59	20.79
4	33.85	46.70	44.00	60.22	58.81	51.89	20.67
5	35.73	46.34	41.72	62.95	62.59	55.03	20.56
6	29.45	37.90	33.82	65.12	67.47	58.79	19.89
7	18.92	27.82	21.87	68.09	71.08	63.51	20.29
8	12.24	20.65	13.86	69.86	73.16	65.90	22.28
9	9.62	16.47	8.87	71.56	73.92	68.06	23.81
10	9.94	15.84	8.80	71.82	73.56	68.91	25.16

Table J.5: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 5

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	167200	150100	156400	119000	104600	82800	55100	143900	127200	112700	**1219000**
Balsam Fir	58800	115100	94100	109600	116700	105200	106900	80700	68300	66500	**921900**
N. White Cedar	0	1000	0	900	800	3400	4300	0	1500	800	**12700**
Tamarack	47800	35100	33300	33100	39200	51900	71100	15300	22500	15200	**364500**
Spruce	244900	199900	166600	193700	232700	176900	94500	261000	198100	151600	**1919900**
N. Hardwoods	117800	152100	183600	187800	230400	241600	200100	224300	224500	231600	**1993800**
Aspen	1320300	901600	877600	879900	912500	827800	829100	658900	726900	732000	**8666600**
Balsam Poplar	101800	75800	71000	66000	64200	57400	69900	51100	63000	54000	**674200**
TOTAL	**2058600**	**1630700**	**1582600**	**1590000**	**1701100**	**1547000**	**1431000**	**1435200**	**1432000**	**1364400**	**15772600**

Table J.6: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 5

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	276500	229100	246200	248500	216800	208700	177200	205300	178800	161000	**2148100**
Misc. Public	74600	34600	53100	44000	43400	37700	38100	44800	36100	35100	**441500**
State	359000	315000	308700	296700	334400	281500	288000	306100	236600	265000	**2991000**
County	506800	368300	303900	302700	326900	356200	316000	308700	314200	284200	**3387900**
Private	741100	599800	570600	590100	672600	562800	528000	485600	565000	536000	**5851600**
F. Industry	100600	83900	100100	108000	107000	100100	83700	84700	101300	83100	**952500**
TOTAL	**2058600**	**1630700**	**1582600**	**1590000**	**1701100**	**1547000**	**1431000**	**1435200**	**1432000**	**1364400**	**15772600**

Table J.7: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 5

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1688400	1359100	1323400	1317700	1389100	1244800	1178500	1167300	1197300	1134500	**13000100**
Buffers	90400	58800	44100	67700	97900	72700	49200	68000	58300	73900	**681000**
Extended	142500	97000	114800	107400	103400	118200	101600	112700	78100	76100	**1051800**
Old Growth	3900	3700	1400	1400	1400	2400	3700	1200	2900	1400	**23400**
Reserve	133400	112100	98900	95800	109300	108900	98000	86000	95400	78500	**1016300**
TOTAL	**2058600**	**1630700**	**1582600**	**1590000**	**1701100**	**1547000**	**1431000**	**1435200**	**1432000**	**1364400**	**15772600**

Table J.8: Acreage of Forestlands Harvested by Planning Period and County for Scenario 5

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	95200	105500	82900	68100	74500	83300	82400	81500	69900	63100	**806400**
Becker	31700	11900	26200	24300	17700	13000	17800	10000	11800	13800	**178200**
Beltrami	125800	72600	88200	76200	76200	82400	56700	65800	63000	62000	**768900**
Benton	1800	0	2800	3700	1400	1800	2200	1700	2800	1400	**19600**
Carlton	68300	67300	48900	56400	80900	52200	50600	56900	57500	71900	**610900**
Cass	186300	107800	87900	95600	103100	123700	93800	91100	86700	86200	**1062200**
Chisago	0	4700	1200	0	800	3000	3300	2500	0	2900	**18400**
Clearwater	41900	36200	26700	24500	37100	22800	25600	40400	27800	21200	**304200**
Cook	9500	24400	88400	77500	29500	23500	22700	20700	17100	8000	**321300**
Crow Wing	82100	54100	56800	40700	67900	60500	41700	45100	58000	53400	**560300**
Douglas	0	0	900	900	1000	0	0	600	0	0	**3400**
Grant	0	0	0	1000	0	0	0	0	0	0	**1000**
Hubbard	75900	47100	55900	60200	29200	71500	34100	36800	56900	37500	**505100**
Isanti	400	3600	9300	3500	1400	3800	1600	600	3200	1600	**29000**
Itasca	218200	186300	166600	167000	198900	145400	163900	162300	179200	163500	**1751300**
Kanabec	12200	5400	13200	13000	8600	10600	11200	21400	14300	15500	**125400**
Kittson	0	0	0	0	3600	1200	1200	1900	0	0	**7900**
Koochiching	180400	145300	147200	154100	149600	164900	154800	149600	142600	133500	**1522000**
Lake	120500	92300	111400	122700	132100	102000	70400	102900	100100	78200	**1032600**
Lake Woods	33500	23100	39100	40100	10800	38800	32600	26200	26400	15200	**285800**
Mahnomen	5500	5700	3100	8100	4800	3900	5100	4800	2100	5000	**48100**
Marshall	1100	0	4400	7700	17100	4100	7100	1100	1100	0	**43700**
Mille Lacs	5100	6300	20400	8800	10600	2900	9400	24600	13600	8400	**110100**
Morrison	40000	28600	15000	13100	19400	27000	23600	14300	11700	26300	**219000**
Norman	2300	0	0	0	0	0	0	0	0	0	**2300**
Otter Tail	11400	5300	10000	3900	6000	11400	6900	6700	3100	3500	**68200**
Pennington	0	2200	2200	1100	5700	0	0	0	1100	0	**12300**
Pine	103900	73100	60000	67500	92100	86500	82800	57000	73100	74700	**770700**
Polk	6600	0	2200	4500	1100	2200	2200	0	1100	4400	**24300**
Red Lake	1100	1100	2200	3300	3300	1100	2200	0	1100	2000	**17400**
Roseau	5600	8900	20900	25700	23500	9800	9300	7200	5000	4800	**120700**
St. Louis	580400	503400	364200	389700	467100	382900	396000	387500	374700	387600	**4233500**
Todd	7000	2500	8000	8600	8900	4800	7100	6800	13300	11700	**78700**
Wadena	4900	6000	16400	18500	17200	6000	12700	7200	13700	7100	**109700**
TOTAL	**2058600**	**1630700**	**1582600**	**1590000**	**1701100**	**1547000**	**1431000**	**1435200**	**1432000**	**1364400**	**15772600**

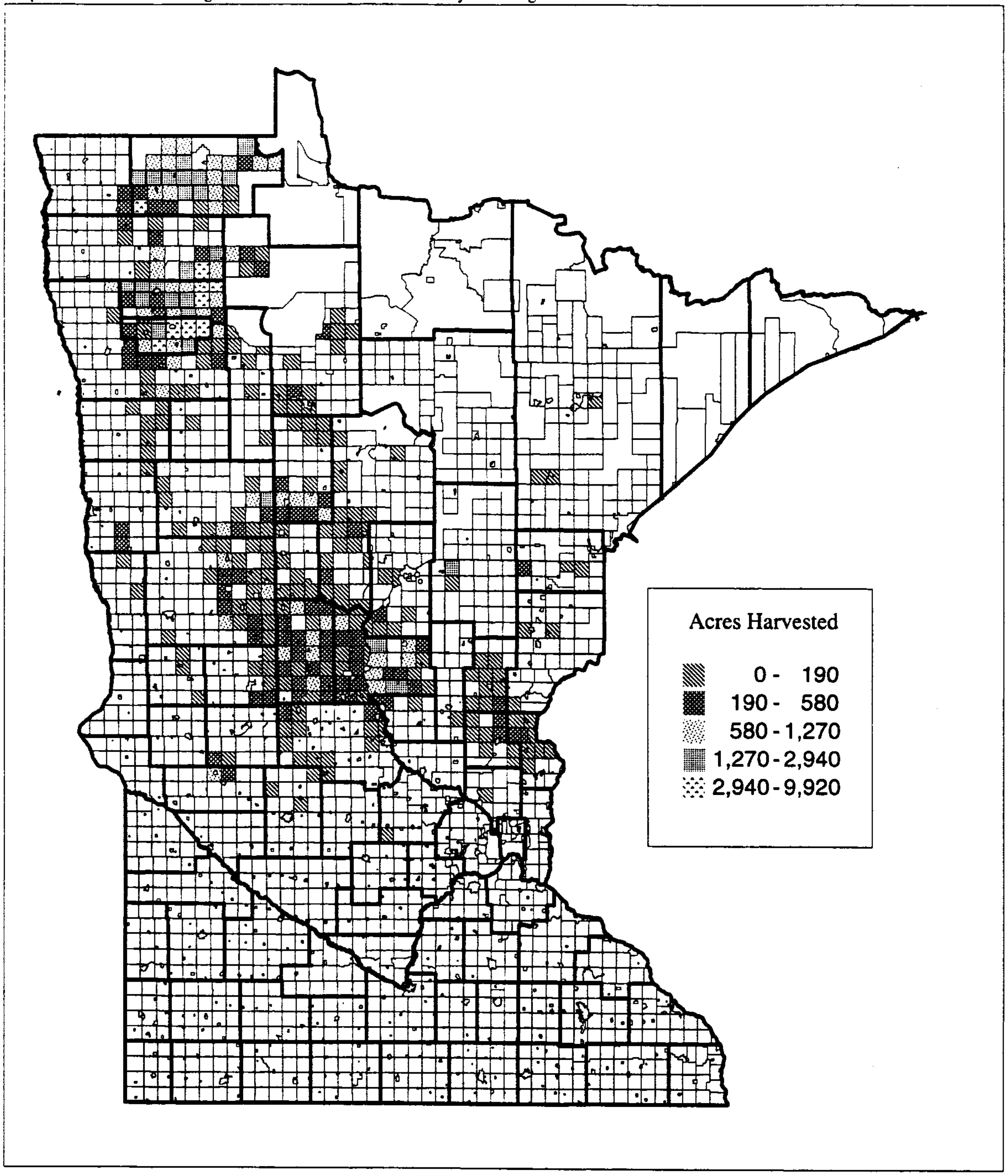
Table J.9: Acreage of Agricultural Lands Harvested by Planning Period and Market for Scenario 5

	PERIOD									
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	76142	74374	74311	74330	69011	69469	69777	69940	69027	**646381**
Brainerd	0	38731	38767	38811	38822	30873	30374	28859	27447	21762	**294446**
Cook	0	0	0	0	0	0	0	0	0	0	**0**
Duluth	0	3609	3620	3620	3609	2425	1818	944	739	585	**20969**
G. Rapids	0	8580	10450	10469	10450	8744	7110	5195	3724	3601	**68323**
I. Falls	0	45293	45144	45144	45144	38672	37577	34383	33069	27458	**351884**
TOTAL	**0**	**172355**	**172355**	**172355**	**172355**	**149725**	**146348**	**139158**	**134919**	**122433**	**1382003**

Table J.10: Acreage of Agricultural Lands Harvested by Planning Period and Land Capability Class for Scenario 5

	PERIOD										
LCS&SC	1	2	3	4	5	6	7	8	9	10	**TOTAL**
0E	0	62	62	62	62	62	62	62	62	62	**558**
0M	0	7918	7918	7918	7918	6418	6210	5748	5639	5441	**61128**
0S	0	2	2	2	2	0	0	0	0	0	**8**
0W	0	3627	3627	3627	3627	2317	2317	2317	2317	1905	**25681**
1	0	38	38	38	38	38	38	38	38	38	**342**
2C	0	60	60	60	60	0	0	0	0	0	**240**
2E	0	7391	7391	7391	7391	7139	7032	6368	5649	4825	**60577**
2M	0	29	29	29	29	0	0	0	0	0	**116**
2S	0	102	102	102	102	102	102	102	102	102	**918**
2W	0	59541	59541	59541	59541	50983	50845	48362	47813	42484	**478651**
3E	0	5895	5895	5895	5895	5085	4671	4205	3927	3215	**44683**
3M	0	102	102	102	102	42	42	42	42	42	**618**
3S	0	11468	11468	11468	11468	8414	7593	5614	4808	3388	**75689**
3W	0	46260	46260	46260	46260	42532	42274	41777	41587	40759	**393969**
4E	0	1405	1405	1405	1405	1302	1252	1237	1141	844	**11396**
4M	0	355	355	355	355	355	335	335	335	321	**3101**
4S	0	12977	12977	12977	12977	11484	10448	10039	9095	7260	**100234**
4W	0	13549	13549	13549	13549	12071	11847	11847	11499	11456	**112916**
6E	0	413	413	413	413	299	299	290	240	81	**2861**
6S	0	1048	1048	1048	1048	969	880	674	524	109	**7348**
6W	0	101	101	101	101	101	101	101	101	101	**909**
7E	0	12	12	12	12	12	0	0	0	0	**60**
TOTAL	**0**	**172355**	**172355**	**172355**	**172355**	**149725**	**146348**	**139158**	**134919**	**122433**	**1382003**

Map J.1: The Maximum Agricultural Lands Harvested in Any Planning Period for Scenario 5



APPENDIX K

SCENARIO 6: TIMBER PRODUCT DEMANDS WITH RESTRICTED FOREST AND AGRICULTURAL LANDS

Table K.1: Total Variable Costs ($) by Planning Period for Scenario 6

VARIABLE COSTS			
PERIOD	Production and Management	Harvest and Transportation	**TOTAL**
1	30,585,340	1,038,305,000	**1,068,890,340**
2	107,069,300	933,144,500	**1,040,213,800**
3	110,439,700	923,492,700	**1,033,932,400**
4	116,994,700	912,101,600	**1,029,096,300**
5	133,196,300	939,506,000	**1,072,702,300**
6	136,437,300	946,183,200	**1,082,620,500**
7	138,158,400	937,220,400	**1,075,378,800**
8	133,328,100	931,091,500	**1,064,419,600**
9	130,380,700	950,283,800	**1,080,664,500**
10	130,754,700	924,476,700	**1,055,231,400**
TOTAL	**1,167,344,540**	**9,435,805,400**	**10,603,149,940**

Table K.2: Aspen Shadow Prices by Planning Period and Market for Scenario 6

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	40.39	42.27	39.91	46.04	43.02	45.51
2	38.96	42.91	44.05	50.20	46.90	46.60
3	39.61	44.68	47.52	53.32	49.19	46.88
4	40.06	46.55	48.67	55.50	50.16	47.11
5	39.20	43.66	45.50	50.64	47.62	46.27
6	37.34	41.16	42.12	47.56	44.73	44.50
7	37.18	41.22	41.44	45.95	44.39	44.15
8	37.53	40.88	40.12	44.82	43.81	43.59
9	37.42	40.53	39.59	43.66	43.11	43.09
10	37.04	39.71	38.99	42.93	42.59	42.62

Table K.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 6

MARKET						
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	12.27	19.03	17.56	24.77	14.21	19.58
2	15.36	19.80	17.35	24.93	15.40	20.87
3	15.94	19.98	17.13	25.12	15.85	20.01
4	16.00	20.73	19.29	25.92	17.67	20.28
5	18.13	21.94	19.77	26.92	18.20	20.31
6	19.84	23.01	21.45	28.02	19.17	20.91
7	20.47	23.71	21.52	28.97	19.87	21.28
8	20.50	24.71	22.96	30.33	20.46	23.50
9	22.14	26.02	24.29	31.86	22.72	24.84
10	23.19	27.47	26.19	33.40	24.95	26.13

Table K.4: Pine. Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 6

	MARKET						
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	32.12	45.64	40.54	59.48	57.48	51.21	28.59
2	32.71	46.2	41.79	62.24	60.5	53.39	27.44
3	34.48	48.4	43.9	63.72	62.91	55.4	24.43
4	36.86	50.33	47.17	67.32	66.58	59	21.14
5	40.14	49.05	44.6	70.95	71.77	62.73	18.73
6	34.99	43.52	39.37	68.52	74.52	65.53	16.87
7	28.01	35.37	29.44	71.84	74.15	67.61	19.11
8	18.92	27.86	20.25	72.69	75.14	68.76	24.65
9	13.64	22.47	14.52	72.65	75.15	68.6	32.26
10	11.58	18.1	10.48	73.88	75.17	70.21	39.21

Table K.5: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 6

	PERIOD										
COVER TYPE	1	2	3	4	5	6	7	8	9	10	TOTAL
Pines	159800	162800	157400	116400	120600	82000	82600	116400	106500	118600	**1223100**
Balsam Fir	79500	132700	112100	113800	126200	97700	125600	96900	85800	72000	**1042300**
N. White Cedar	3400	5500	1100	5600	2700	2400	1100	5300	3400	1200	**31700**
Tamarack	49300	36400	51900	33500	35500	41400	68400	32500	33900	19000	**401800**
Spruce	214300	190300	156600	221100	229700	153800	92700	189200	180700	181100	**1809500**
N. Hardwoods	135500	187800	199400	218000	241800	254000	247400	227000	244800	256100	**2211800**
Aspen	1308700	886600	854300	841700	911000	841900	775000	747100	751900	668900	**8587100**
Balsam Poplar	112700	68100	63000	75600	85300	48900	69300	54300	52500	72800	**702500**
TOTAL	2063200	1670200	1595800	1625700	1752800	1522100	1462100	1468700	1459500	1389700	**16009800**

Table K.6 Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 6

	PERIOD										
OWNER	1	2	3	4	5	6	7	8	9	10	TOTAL
N. Forests	293200	231400	242200	259300	212600	215100	186800	235500	66400	189200	**2131700**
Misc. Public	66100	35500	35400	30100	33200	41700	30600	25200	156400	27800	**482000**
State	333300	302600	306900	334400	373600	264400	254500	295700	256900	275100	**2997400**
County	525500	387000	328600	293000	365700	350000	336000	314600	326500	294600	**3521500**
Private	733200	629200	576300	586600	634000	568500	572600	503700	525900	501200	**5831200**
F. Industry	111900	84500	106400	122300	133700	82400	81600	94000	127400	101800	**1046000**
TOTAL	**2063200**	**1670200**	**1595800**	**1625700**	**1752800**	**1522100**	**1462100**	**1468700**	**1459500**	**1389700**	**16009800**

Table K.7 Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 6

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	TOTAL
Normal	1932000	1507400	1427000	1475400	1582700	1370900	1305700	1275800	1342500	1274600	**14494000**
Buffers	60800	84100	83000	81100	95700	71800	62600	67400	44700	27100	**678300**
Extended	70400	78700	85800	69200	74400	79400	93800	125500	72300	88000	**837500**
Old Growth	0	0	0	0	0	0	0	0	0	0	**0**
Reserve	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**2063200**	**1670200**	**1595800**	**1625700**	**1752800**	**1522100**	**1462100**	**1468700**	**1459500**	**1389700**	**16009800**

Table K.8 Acreage of Forestlands Harvested by Planning Period and County for Scenario 6

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	TOTAL
Aitkin	75600	102500	82200	83000	63600	82700	90400	86100	68700	67700	**802500**
Becker	40400	13400	28300	24000	16000	14300	21000	18200	16300	13400	**205300**
Beltrami	126400	70200	99500	72000	82400	56300	60700	69100	65000	60500	**762100**
Benton	1800	0	1800	2300	3800	900	4800	1400	4500	6400	**27700**
Carlton	54600	52600	60700	41600	71700	51000	57200	48500	64000	49700	**551600**
Cass	188600	101300	92800	91400	102900	110600	92700	105200	87500	103500	**1076500**
Chisago	1700	3000	2500	0	3800	5500	1600	3800	0	2900	**24800**
Clearwater	49100	32900	24500	25900	36000	25600	35600	25700	21600	16900	**293800**
Cook	31200	42700	77500	68500	49400	33500	20700	42700	23200	24400	**413800**
Crow Wing	75600	58900	53100	43600	69500	47200	52900	42200	48200	60700	**551900**
Douglas	0	0	900	1900	3700	0	0	600	1900	0	**9000**
Hubbard	82200	49400	71400	52000	39800	59700	37200	49800	42500	39000	**523000**
Isanti	400	3300	1700	13700	2400	800	2400	600	2200	1400	**28900**
Itasca	229200	196300	161200	172000	176500	161900	186200	161500	203800	152600	**1801200**
Kanabec	15000	12800	14500	11300	9800	20400	17500	22100	18700	9000	**151100**
Kittson	0	2400	0	2400	1200	1200	1200	1900	0	0	**10300**
Koochiching	183400	156000	138100	174100	180000	148300	137100	137100	160000	134600	**1548700**
Lake	123500	93000	108400	124600	134500	98900	66700	110500	106500	91700	**1058300**
Lake Woods	43200	23600	35300	46300	25900	43500	42800	25600	14100	21400	**321700**
Mahnomen	6500	5700	4100	7800	4000	5400	2900	7000	900	3800	**48100**
Marshall	5500	1100	8800	8500	23800	2200	1100	2200	1100	0	**54300**
Mille Lacs	10400	4600	18200	15300	9300	7400	9900	22200	9700	8700	**115700**
Morrison	34600	32000	18300	8000	22700	24100	20400	17800	11000	18400	**207300**
Norman	1100	1200	0	0	0	0	0	0	0	0	**2300**
Otter Tail	10400	4400	6600	13000	6100	12500	12100	7700	4800	7900	**85500**
Pennington	0	4400	1100	9000	900	0	0	1100	0	0	**16500**
Pine	102200	73600	52200	64700	86000	84400	82200	51900	68800	73600	**739600**
Polk	6500	3300	2200	3300	1100	3100	1100	3300	5600	2200	**31700**
Red Lake	2200	1100	3300	5500	1100	1100	0	1100	2200	3300	**20900**
Roseau	6600	15200	22400	35600	19100	10700	8500	6300	3300	3000	**130700**
St. Louis	534900	504400	382400	373100	480300	391000	385800	376400	373600	389000	**4190900**
Todd	8000	3000	8000	7300	8200	5900	7300	8300	10800	12600	**79400**
Wadena	12400	1900	13800	24000	17300	12000	2100	10800	19000	11400	**124700**
TOTAL	**2063200**	**1670200**	**1595800**	**1625700**	**1752800**	**1522100**	**1462100**	**1468700**	**1459500**	**1389700**	**16009800**

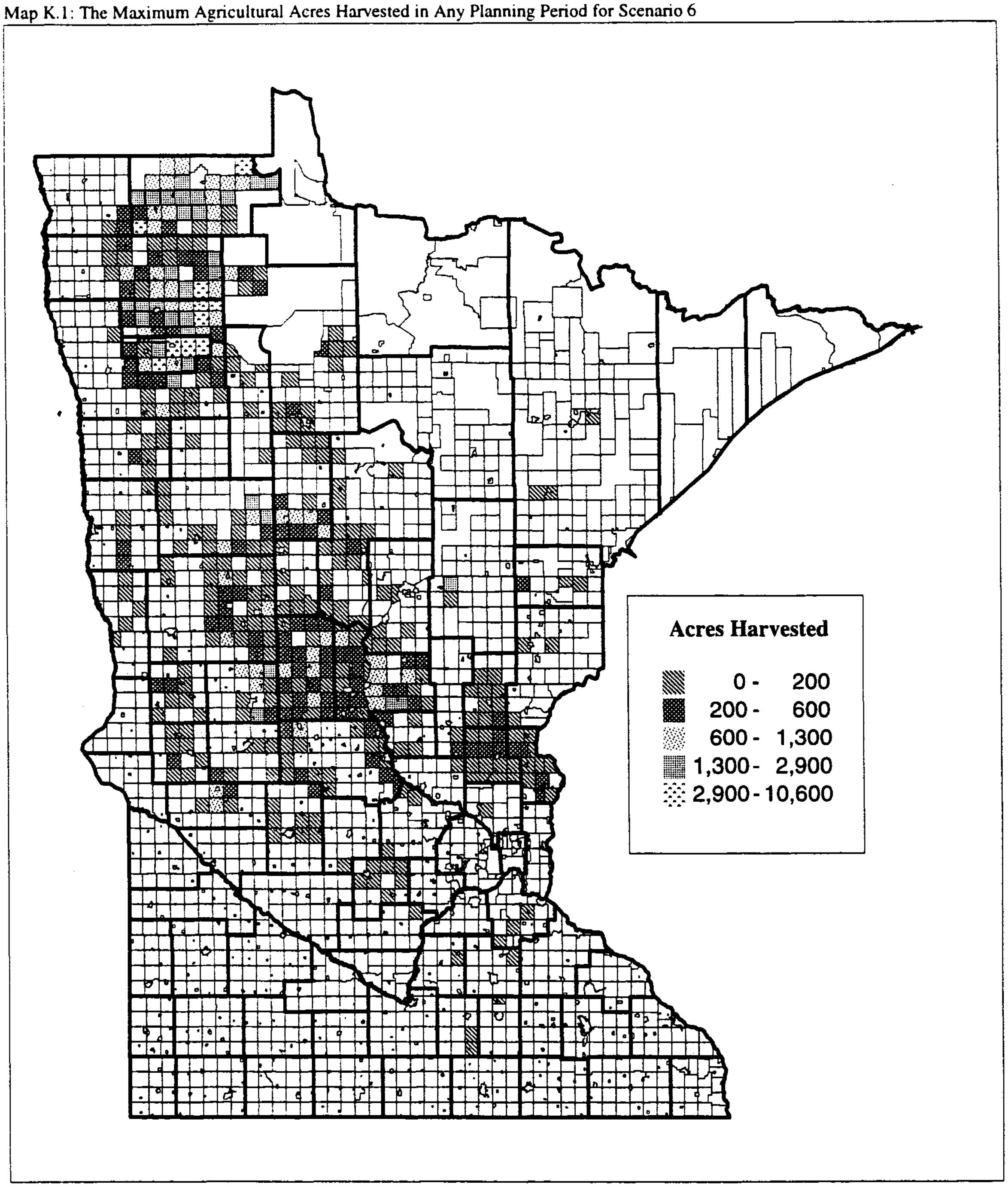
Table K.9 Acreage of Agricultural Lands Harvested by Planning Period and Market for Scenario 6

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	83082	82643	84569	83351	74298	74382	74467	75506	73263	**705561**
Brainerd	0	50307	50097	51649	45241	34147	34170	33547	30685	28438	**358281**
Cook	0	0	0	0	0	0	0	0	0	0	**0**
Duluth	0	6126	7799	7877	5443	3821	2622	1818	1302	944	**37752**
G. Rapids	0	12962	12473	11300	13715	9614	9518	8690	7069	5448	**90789**
I. Falls	0	52177	51642	49259	48563	45801	43367	37805	35472	34282	**398368**
TOTAL	**0**	**204654**	**204654**	**204654**	**196313**	**167681**	**164059**	**156327**	**150034**	**142375**	**1590751**

Table K.10: Acreage of Agricultural Lands Harvested by Planning Period and Land Capability Class for Scenario 6

	PERIOD										
LCSC	1	2	3	4	5	6	7	8	9	10	**TOTAL**
0E	0	290	290	290	165	62	62	62	62	62	**1345**
0M	0	9757	9757	9757	9385	7588	7206	6622	6366	6068	**72506**
0S	0	117	117	117	117	0	0	0	0	0	**468**
0W	0	6149	6149	6149	5353	3627	3627	3627	3627	2649	**40957**
1	0	38	38	38	38	38	38	38	38	38	**342**
2C	0	69	69	69	69	0	0	0	0	0	**276**
2E	0	8734	8734	8734	8105	7238	7205	7163	6954	6358	**69225**
2M	0	59	59	59	29	0	0	0	0	0	**206**
2S	0	550	550	550	167	102	102	102	102	102	**2327**
2W	0	64507	64507	64507	64209	58041	57768	53443	51543	50095	**528620**
3E	0	10946	10946	10946	8317	5779	5400	5219	4827	4205	**66585**
3M	0	247	247	247	247	42	42	42	42	42	**1198**
3S	0	15676	15676	15676	14921	10083	10083	9103	7953	5547	**104718**
3W	0	52785	52785	52785	51779	45502	44845	44093	42837	42697	**430108**
4E	0	1703	1703	1703	1513	1393	1302	1252	1252	1226	**13047**
4M	0	355	355	355	355	355	355	335	335	335	**3135**
4S	0	16278	16278	16278	15200	12655	12212	11727	10932	10039	**121599**
4W	0	14333	14333	14333	14283	13507	12283	12071	11884	11847	**118874**
6E	0	447	447	447	447	413	413	413	299	290	**3616**
6S	0	1501	1501	1501	1501	1143	1003	914	880	674	**10618**
6W	0	101	101	101	101	101	101	101	101	101	**909**
7E	0	12	12	12	12	12	12	0	0	0	**72**
TOTAL	**0**	**204654**	**204654**	**204654**	**196313**	**167681**	**164059**	**156327**	**150034**	**142375**	**1590751**

Map K.1: The Maximum Agricultural Acres Harvested in Any Planning Period for Scenario 6



APPENDIX L

SCENARIO 7: TIMBER PRODUCT AND BIOMASS DEMANDS WITH UNRESTRICTED FOREST AND AGRICULTURAL LANDS

Table L.1: Total Variable Costs ($) by Planning Period for Scenario 7

	VARIABLE COSTS		
PERIOD	Production and Management	Harvest and Transportation	TOTAL
1	21,031,250	1,034,532,000	**1,055,563,250**
2	83,793,690	1,055,027,000	**1,138,820,690**
3	87,964,750	1,050,655,000	**1,138,619,750**
4	92,663,540	1,034,646,000	**1,127,309,540**
5	115,349,400	1,063,473,000	**1,178,822,400**
6	116,432,300	1,053,749,000	**1,170,181,300**
7	119,706,300	1,069,242,000	**1,188,948,300**
8	120,035,900	1,090,327,000	**1,210,362,900**
9	121,693,600	1,095,647,000	**1,217,340,600**
10	120,456,900	1,109,572,000	**1,230,028,900**
TOTAL	999,127,630	10,656,870,000	11,655,997,630

Table L.2: Aspen Shadow Prices by Planning Period and Market for Scenario 7

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	37.21	38.66	36.21	41.35	39.29	41.83
2	36.34	38.69	39.44	44.06	42.24	43.28
3	36.65	40.32	41.69	46.22	44.06	43.97
4	36.71	42.15	42.84	47.99	45.29	44.33
5	37.10	42.77	43.03	47.47	45.33	44.58
6	35.64	39.41	39.45	43.97	42.07	42.98
7	35.29	37.93	37.78	41.85	40.98	42.46
8	34.98	36.64	36.39	39.95	39.82	41.53
9	34.78	35.68	35.48	38.74	39.04	41.02
10	34.68	34.67	35.00	37.73	38.29	40.54

Table L.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 7

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	16.19	22.45	19.65	26.38	16.54	21.68
2	18.79	23.83	19.71	26.63	17.58	23.11
3	19.50	24.52	20.06	26.86	17.90	22.86
4	20.19	25.89	21.04	27.63	19.27	22.75
5	21.08	27.10	21.28	28.39	20.06	22.69
6	21.67	28.89	21.56	29.48	21.43	22.34
7	22.57	30.75	22.60	30.86	22.48	22.65
8	23.26	32.39	24.44	33.13	23.50	24.67
9	24.72	34.00	26.65	35.39	25.72	26.18
10	26.29	35.61	27.86	38.19	26.83	27.66

Table L.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 7

MARKET							
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	31.04	44.26	39.26	55.49	52.97	47.13	21.68
2	30.79	44.33	39.95	56.79	54.20	48.15	23.11
3	31.87	45.35	41.25	57.16	55.66	48.84	22.86
4	33.45	46.34	43.36	59.14	58.19	50.89	22.75
5	35.12	45.99	41.58	61.61	61.60	54.02	22.69
6	32.48	42.92	38.54	64.07	66.51	57.67	22.34
7	28.40	36.78	30.84	65.92	70.28	62.03	22.65
8	26.84	33.52	26.40	66.99	72.11	64.56	24.67
9	26.64	30.47	23.32	66.47	72.81	66.09	26.18
10	26.24	28.24	21.57	67.23	72.89	67.18	27.66

Table L.5: Fuelwood Shadow Prices by Planning Period and Location for Scenario 7

POWER PLANTS		
PERIOD	G. Falls	Alexandria
1	0	0
2	35.0787	27.05132
3	35.73825	27.7783
4	36.41158	28.31625
5	37.23153	29.00142
6	38.19856	30.24554
7	39.30485	31.48357
8	40.62176	32.09346
9	41.44116	32.94445
10	42.00246	33.38364

Table L.6: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 7

PERIOD											
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	159000	154000	148800	123900	115400	86400	64000	148500	131300	107900	**1239200**
Balsam Fir	56400	122100	92700	113700	117500	101300	120300	80800	83100	83800	**971700**
N. White Cedar	0	1000	0	900	800	2500	4300	0	1500	2000	**13000**
Tamarack	48400	33000	30500	35900	38500	59500	83500	33400	50400	33600	**446700**
Spruce	247400	198900	159700	189200	219000	195000	93700	265100	191300	150900	**1910200**
N. Hardwoods	131500	319200	324000	336000	347300	371800	350900	416300	414700	451200	**3462900**
Aspen	1303000	951300	929900	899100	943700	842500	868400	737700	790100	810700	**9076400**
Balsam Poplar	105200	73200	67000	70300	68100	58800	71000	53200	60900	55900	**683600**
TOTAL	**2050900**	**1852700**	**1752600**	**1769000**	**1850300**	**1717800**	**1656100**	**1735000**	**1723300**	**1696000**	**17803700**

Table L.7: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 7

PERIOD											
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	277600	223800	252300	246100	227000	208700	188900	213700	183400	205500	**2227000**
Misc. Public	78200	34800	55600	51900	52500	41300	46600	58100	55600	50600	**525200**
State	360900	332100	297200	312900	355000	294300	307800	353500	281200	285300	**3180200**
County	508500	398400	339200	340900	335300	393100	354400	379300	369100	335800	**3754000**
Private	725400	780200	710800	702600	772200	683100	664800	639000	710500	729600	**7118200**
F. Industry	100300	83400	97500	114600	108300	97300	93600	91400	123500	89200	**999100**
TOTAL	**2050900**	**1852700**	**1752600**	**1769000**	**1850300**	**1717800**	**1656100**	**1735000**	**1723300**	**1696000**	**17803700**

Table L.8: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 7

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1677700	1549600	1460400	1447500	1503100	1402500	1350000	1419700	1439000	1402800	**14652300**
Buffers	88600	70000	60800	78400	108200	74900	65500	81700	69900	79300	**777300**
Extended	144900	96500	113400	110100	105100	125700	109300	116500	86400	89700	**1097600**
Old Growth	3900	3700	1400	1400	1400	2400	3700	1200	2900	1400	**23400**
Reserve	135800	132900	116600	131600	132500	112300	127600	115900	125100	122800	**1253100**
TOTAL	**2050900**	**1852700**	**1752600**	**1769000**	**1850300**	**1717800**	**1656100**	**1735000**	**1723300**	**1696000**	**17803700**

Table L.9: Acreage of Forestlands Harvested by Planning Period and County for Scenario 7

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	96500	104000	87400	91000	88900	93200	108900	111000	89700	86200	**956800**
Becker	26600	26400	62300	45400	31400	30600	45200	31600	35400	42400	**377300**
Beltrami	134800	68700	78700	81200	71800	95600	72200	74900	81200	68800	**827900**
Benton	0	6100	5400	10200	2400	4300	2400	5100	8900	8500	**53300**
Carlton	71200	71500	48600	55500	79400	56500	51000	58400	72900	65900	**630900**
Cass	183700	116700	107900	106400	124500	142900	108200	117600	113200	121500	**1242600**
Chisago	0	6600	9700	2600	4700	7100	2800	4700	4100	5000	**47300**
Clay	0	0	0	5800	7200	2500	0	0	1200	0	**16700**
Clearwater	37700	39400	36000	27200	39700	25900	31600	48100	30100	33900	**349600**
Cook	10900	19700	87600	75900	31300	22200	26300	22100	16400	20900	**333300**
Crow Wing	82200	69300	66100	52000	63600	71000	44100	63900	66000	83100	**661300**
Douglas	0	26300	3200	1100	0	0	3600	21300	4600	800	**60900**
Grant	0	0	1500	1000	1200	0	0	0	0	1500	**5200**
Hubbard	74500	58900	71600	63700	43200	72200	48700	73900	54000	53000	**613700**
Isanti	400	15000	5000	5500	3700	5600	8600	5700	4600	12700	**66800**
Itasca	218300	191100	168100	172300	208800	154900	168700	173700	194100	188200	**1838200**
Kanabec	8300	15600	26600	28800	11400	21600	26800	28000	19700	18800	**205600**
Kittson	0	0	0	0	3600	0	1200	0	0	0	**4800**
Koochiching	180500	153100	142100	151300	149000	171500	160000	161000	157300	129500	**1555300**
Lake	117200	97600	112300	125400	130700	110300	74900	117900	101800	87600	**1075700**
Lake Woods	32600	24000	33100	43500	11200	35800	28400	32000	30300	18500	**289400**
Mahnomen	6500	9400	4100	9300	8000	3300	12300	10000	19200	12700	**94800**
Marshall	1100	0	2200	4400	20400	4100	6200	900	1100	0	**40400**
Mille Lacs	3400	19700	33000	17900	28400	18900	13800	30600	17100	17300	**200100**
Morrison	35700	49300	24300	18000	29200	23600	25000	15400	39300	33800	**293600**
Norman	2300	0	0	0	1200	1200	3300	1200	1200	0	**10400**
Otter Tail	7000	38400	40600	33500	30500	20900	31200	19500	28500	43700	**293800**
Pennington	0	1100	3300	2200	4200	0	1500	0	1100	1100	**14500**
Pine	100900	75000	71900	67600	94100	85400	99400	74800	70200	82800	**822100**
Polk	6600	1100	2200	5600	1100	2200	2200	4200	3300	6600	**35100**
Red Lake	2200	0	2200	0	5500	2200	2200	2000	0	3300	**19600**
Roseau	5600	7800	17600	25300	24600	9500	7100	5000	6100	3300	**111900**
St. Louis	592100	498000	367300	402300	459400	398200	401000	399100	411000	414000	**4342400**
Todd	7300	25800	13100	12800	20200	12600	10700	11500	23600	12500	**150100**
Wadena	4800	17100	17600	24300	15800	12000	26600	9900	16100	18100	**162300**
TOTAL	**2050900**	**1852700**	**1752600**	**1769000**	**1850300**	**1717800**	**1656100**	**1735000**	**1723300**	**1696000**	**17803700**

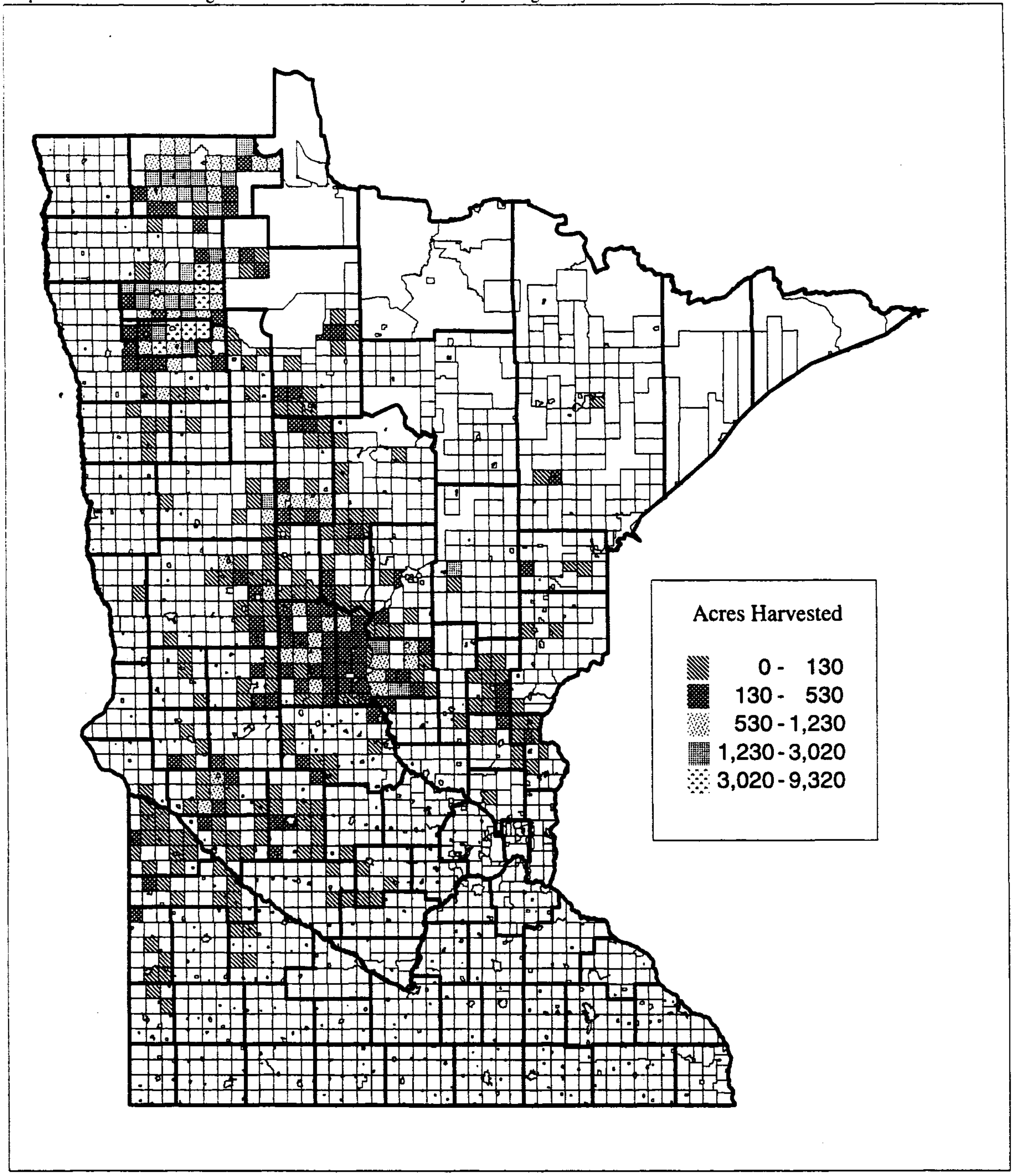
Table L.10: Acreage of Agricultural Lands Harvested by Planning Period and Market for Scenario 7

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	73360	72338	71639	71595	66886	60060	54333	54249	51119	**575579**
Brainerd	0	29534	29081	30143	30580	26331	18417	13441	11368	6578	**195473**
Cook	0	0	0	0	0	0	0	97	0	91	**188**
Duluth	0	2436	2436	2436	2425	1738	836	482	430	420	**13639**
G. Rapids	0	7764	9609	9622	9240	5236	2779	1967	2064	1752	**50033**
I. Falls	0	39045	39045	38896	38896	34873	34434	25006	19783	17641	**287619**
G. Falls	0	7856	7640	7640	7640	7936	7936	7936	7941	7941	**70466**
Alexandria	0	598	444	217	217	1175	3130	3193	3231	3231	**15436**
TOTAL	**0**	**160593**	**160593**	**160593**	**160593**	**144175**	**127592**	**106455**	**99066**	**88773**	**1208433**

Table L.11: Acreage of Agricultural Lands Harvested by Planning Period and Land Capability Class for Scenario 7

	PERIOD										
LCCSC	1	2	3	4	5	6	7	8	9	10	**TOTAL**
0E	0	62	62	62	62	62	62	62	62	0	**496**
0M	0	7055	7055	7055	7055	6272	5901	5170	4908	3958	**54429**
0S	0	0	0	0	0	0	0	0	0	0	**0**
0W	0	2609	2609	2609	2609	1965	1905	1905	1905	1905	**20021**
1	0	76	76	76	76	76	76	76	76	76	**684**
2C	0	0	0	0	0	0	0	0	0	0	**0**
2E	0	7082	7082	7082	7082	6255	4524	2837	2463	1692	**46099**
2M	0	0	0	0	0	0	0	0	0	0	**0**
2S	0	102	102	102	102	102	102	102	102	102	**918**
2W	0	56791	56791	56791	56791	51096	47985	38441	34294	30361	**429341**
3E	0	4946	4946	4946	4946	4236	3056	2013	1914	1141	**32144**
3M	0	42	42	42	42	42	42	42	42	42	**378**
3S	0	8354	8354	8354	8354	5262	4000	2970	2682	2049	**50379**
3W	0	47263	47263	47263	47263	44929	40631	35473	34503	33412	**378000**
4E	0	1302	1302	1302	1302	1035	840	545	370	270	**8268**
4M	0	355	355	355	355	335	335	335	298	298	**3021**
4S	0	11046	11046	11046	11046	9473	6640	5296	4319	2513	**72425**
4W	0	12127	12127	12127	12127	11891	10834	10551	10491	10327	**102602**
6E	0	299	299	299	299	279	94	94	94	94	**1851**
6S	0	969	969	969	969	764	464	442	442	442	**6430**
6W	0	101	101	101	101	101	101	101	101	91	**899**
7E	0	12	12	12	12	0	0	0	0	0	**48**
TOTAL	**0**	**160593**	**160593**	**160593**	**160593**	**144175**	**127592**	**106455**	**99066**	**88773**	**1208433**

Map L.1: The Maximum Agricultural Lands Harvested in Any Planning Period for Scenario 7



APPENDIX M
SCENARIO 8: TIMBER PRODUCT AND BIOMASS DEMANDS WITH RESTRICTED FOREST AND AGRICULTURAL LANDS

Table M.1: Total Variable Costs ($) by Planning Period for Scenario 8

	VARIABLE COSTS		
PERIOD	Production and Management	Harvest and Transportation	**TOTAL**
1	29,312,010	1,040,170,000	**1,069,482,010**
2	106,297,500	1,046,844,000	**1,153,141,500**
3	109,096,300	1,039,171,000	**1,148,267,300**
4	114,247,100	1,030,691,000	**1,144,938,100**
5	133,952,400	1,060,118,000	**1,194,070,400**
6	134,240,200	1,056,151,000	**1,190,391,200**
7	139,364,600	1,064,873,000	**1,204,237,600**
8	136,354,600	1,072,390,000	**1,208,744,600**
9	133,043,600	1,097,715,000	**1,230,758,600**
10	131,524,500	1,116,969,000	**1,248,493,500**
TOTAL	**1,167,432,810**	**10,625,092,000**	**11,792,524,810**

Table M.2: Aspen Shadow Prices by Planning Period and Market for Scenario 8

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	39.91	42.05	39.29	45.17	42.55	44.85
2	37.86	41.19	43.10	48.82	45.68	45.65
3	38.26	43.25	46.14	51.66	47.68	46.07
4	38.84	45.24	47.08	53.63	48.52	46.16
5	38.21	43.39	44.47	49.22	46.43	45.39
6	36.50	40.65	40.86	45.89	43.35	43.74
7	35.90	39.52	39.57	43.44	42.26	43.13
8	35.49	38.31	37.63	41.64	41.09	42.20
9	35.29	37.17	36.51	39.72	40.04	41.51
10	34.99	36.50	35.65	38.34	39.21	41.00

Table M.3: Northern Hardwoods Shadow Prices by Planning Period and Market for Scenario 8

	MARKET					
PERIOD	Bemidji	Brainerd	Cook	Duluth	G. Rapids	I. Falls
1	15.19	22.77	19.38	26.80	16.14	21.44
2	19.54	25.17	19.35	27.40	17.81	23.15
3	20.73	26.47	20.08	28.12	18.85	23.04
4	21.16	28.27	22.51	29.71	21.16	23.90
5	23.10	30.53	23.27	31.52	22.71	23.96
6	23.75	33.12	25.64	33.66	24.23	24.77
7	25.52	35.94	27.68	36.64	26.13	25.34
8	27.58	38.92	30.10	40.22	28.92	29.08
9	30.87	42.18	32.79	44.50	32.86	31.86
10	32.96	44.71	36.45	48.73	37.30	34.61

Table M.4: Pine, Spruce-fir and Pine Sawlog Shadow Prices by Planning Period and Market for Scenario 8

MARKET							
	Pine Pulpwood			Spruce-Fir			Pine Sawlogs
PERIOD	Bemidji	Duluth	I. Falls	Brainerd	Duluth	G. Rapids	Combined
1	32.21	45.66	40.64	59.07	57.09	50.74	21.44
2	32.78	46.29	41.92	61.51	60.01	53.00	23.15
3	34.44	48.40	44.00	63.06	62.32	54.84	23.04
4	36.36	49.82	46.09	66.47	65.79	58.24	23.90
5	39.36	49.06	44.68	69.91	70.92	61.92	23.96
6	36.62	45.41	41.02	69.26	74.61	65.30	24.77
7	34.02	41.39	35.05	70.70	74.19	66.64	25.34
8	31.55	37.65	30.24	68.82	74.34	66.93	29.08
9	30.17	35.05	27.06	68.87	74.05	67.04	31.86
10	27.55	31.72	22.97	69.68	73.98	68.79	34.61

Table M.5: Fuelwood Shadow Prices by Planning Period and Location for Scenario 8

POWER PLANTS		
PERIOD	G. Falls	Alexandria
1	0.00	0.00
2	36.30	28.33
3	37.30	29.51
4	38.64	30.54
5	40.43	32.14
6	41.95	33.99
7	44.11	35.42
8	46.41	36.92
9	47.71	37.73
10	48.56	38.17

Table M.6: Acreage of Forestlands Harvested by Planning Period and Cover Type for Scenario 8

PERIOD											
COVER TYPE	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Pines	156800	163100	150500	122000	122200	92200	81400	119900	105100	139200	**1252400**
Balsam Fir	80800	133900	107100	125900	124500	104700	129400	100500	107300	89300	**1103400**
N.White Cedar	1100	5800	1100	3300	2700	2400	2100	5900	3400	8700	**36500**
Tamarack	49300	32200	52300	38500	37500	57100	83900	51300	53900	52300	**508300**
Spruce	213900	186500	154500	217800	220800	176100	93800	194100	177500	185700	**1820700**
N. Hardwoods	150600	355300	360100	376300	390500	392300	391700	434400	437900	461100	**3750200**
Aspen	1296800	935000	896200	860300	961200	860700	828100	791800	827200	846600	**9103900**
Balsam Poplar	117700	61500	61100	75500	79200	60600	64400	52300	65300	61700	**699300**
TOTAL	**2067000**	**1873300**	**1782900**	**1819600**	**1938600**	**1746100**	**1674800**	**1750200**	**1777600**	**1844600**	**18274700**

Table M.7: Acreage of Forestlands Harvested by Planning Period and Ownership for Scenario 8

PERIOD											
OWNER	1	2	3	4	5	6	7	8	9	10	**TOTAL**
N. Forests	293700	239200	250900	270000	220000	232800	223500	269900	209200	219100	**2428300**
Misc. Public	67500	33400	45900	38300	33800	48400	44600	36000	32400	45900	**426200**
State	340600	306100	312900	343800	375600	311000	276100	348600	290300	346500	**3251500**
County	532600	419300	365700	332500	386900	394800	376800	347400	396400	385100	**3937500**
Private	718800	783900	705500	709700	784100	666500	661100	648900	709000	733500	**7121000**
F. Industry	113800	91400	102000	125300	138200	92600	92700	99400	140300	114500	**1110200**
TOTAL	**2067000**	**1873300**	**1782900**	**1819600**	**1938600**	**1746100**	**1674800**	**1750200**	**1777600**	**1844600**	**18274700**

Table M.8: Acreage of Forestlands Harvested by Planning Period and Treatment Class for Scenario 8

	PERIOD										
TREATMENT	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Normal	1935900	1696900	1613800	1662100	1761200	1572800	1494600	1520600	1659100	1730200	**16647200**
Buffers	60700	96500	87000	83300	101200	86200	78800	88600	42400	31000	**755700**
Extended	70400	79900	82100	74200	76200	87100	101400	141000	76100	83400	**871800**
Old Growth	0	0	0	0	0	0	0	0	0	0	**0**
Reserve	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**2067000**	**1873300**	**1782900**	**1819600**	**1938600**	**1746100**	**1674800**	**1750200**	**1777600**	**1844600**	**18274700**

Table M.9: Acreage of Forestlands Harvested by Planning Period and County for Scenario 8

	PERIOD										
COUNTY	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Aitkin	76000	108800	91900	101700	85200	106900	112900	114100	79100	89800	**966400**
Becker	35800	35400	65300	48300	32200	38100	44000	24500	46900	56900	**427400**
Beltrami	130900	72500	90400	91600	80800	64700	73600	83800	92600	80100	**861000**
Benton		3900	4600	6000	6300	1800	4600	4400	7200	3800	**42600**
Carlton	59900	55000	58500	43800	71800	59700	59000	43500	60900	68000	**580100**
Cass	189700	109500	122300	112700	121800	118300	118400	131200	112300	140200	**1276400**
Chisago	1700	5700	12300	4300	8400	8400	1200	7600	5300	7300	**62200**
Clay	0	1500	0	3200	3400	0	0	0	1500	3200	**12800**
Clearwater	48400	33100	34600	31500	42000	35000	38300	35800	35000	36500	**370200**
Cook	28900	45000	78700	71600	52600	42000	25800	55800	27900	30600	**458900**
Crow Wing	81400	63800	63500	47200	84200	54300	41200	55400	66400	79800	**637200**
Douglas	0	16900	7700	1400	0	1500	2600	14800	5800	1800	**52500**
Grant	0	0	1500	1000	1200	0	0	1000	1500	0	**6200**
Hubbard	82800	56000	86000	57300	67100	58900	43600	57000	55100	74300	**638100**
Isanti	400	6300	5400	14500	5000	9200	6300	3400	6200	12600	**69300**
Itasca	232600	196300	160800	177000	187300	187200	194600	179900	212800	206500	**1935000**
Kanabec	9800	20600	26800	19200	15400	26000	32000	15500	16800	17100	**199200**
Kittson	0	0	2400	1200	2400	1200	1200	1900	0	0	**10300**
Koochiching	188100	149900	138400	175400	175900	167100	132300	154500	175900	152500	**1610000**
Lake	124000	104800	107700	132200	133800	107500	84700	113700	129300	98200	**1135900**
Lake Woods	43200	22500	34300	42000	23100	48400	46000	20900	19000	25800	**325200**
Mahnomen	5500	7400	7200	13500	6100	11900	15400	13900	15200	10600	**106700**
Marshall	5500	1100	5500	9600	24100	2200	2200	1100	0	0	**51300**
Mille Lacs	5100	21300	28700	24300	19300	14000	15100	30000	22200	17100	**197100**
Morrison	31400	50300	25300	9200	20600	27700	25600	22600	28600	20500	**261800**
Norman	2300	0	0	2000	2100	1200	1200	4400	1200	0	**14400**
Otter Tail	2700	40800	24300	40700	27000	17200	30600	26100	32800	33600	**275800**
Pennington	0	3300	2200	7900	900	0	1100	1100	0	0	**16500**
Pine	100900	79700	55700	67900	96000	78000	87400	71700	85700	72700	**795700**
Polk	6500	4400	2200	4400	5500	3100	3300	7500	4400	6600	**47900**
Red Lake	3300	13100	2200	6600	2200	1100	1100	4400	1100	2200	**37300**
Roseau	8500	508600	21100	34000	18500	14500	9100	4600	5600	2300	**626800**
St. Louis	544700	0	387800	382000	480600	409600	401900	407700	391700	462400	**3868400**
Todd	6200	22400	17300	11200	13600	13100	9100	20600	14500	17700	**145700**
Wadena	10800	13400	10300	23200	22200	16300	9400	15800	17100	13900	**152400**
TOTAL	**2067000**	**1873300**	**1782900**	**1819600**	**1938600**	**1746100**	**1674800**	**1750200**	**1777600**	**1844600**	**18274700**

Table M.10: Acreage of Agricultural Lands Harvested by Planning Period and Market for Scenario 8

	PERIOD										
MARKET	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Bemidji	0	80185	79806	79242	79825	70487	68465	66062	60157	54381	**638610**
Brainerd	0	39631	41155	45086	39318	29595	23991	17727	13208	11527	**261238**
Cook	0	0	0	0	0	0	97	0	97	0	**194**
Duluth	0	5529	7204	7204	5242	2569	1411	686	430	430	**30705**
G. Rapids	0	12962	12366	11300	12218	7822	5428	4447	1967	2046	**70556**
I. Falls	0	50540	50005	50005	48469	39045	37577	33218	24958	19783	**353600**
G. Falls	0	11372	10688	10384	11640	11738	11947	12112	12369	15187	**107437**
Alexandria	0	3624	2619	622	5348	12708	17446	21548	22458	20456	**106829**
TOTAL	**0**	**203843**	**203843**	**203843**	**202060**	**173964**	**166362**	**155800**	**135644**	**123810**	**1569169**

Table M.11: Acreage of Agricultural Lands Harvested by Planning Period and Land Capability Class for Scenario 8

	PERIOD										
LCS&SC	1	2	3	4	5	6	7	8	9	10	**TOTAL**
0E	0	88	88	88	88	62	62	62	62	62	**662**
0M	0	10531	10531	10531	10531	8910	8452	8146	8060	7986	**83678**
0S	0	107	107	107	107	49	49	49	49	49	**673**
0W	0	4338	4338	4338	3963	2317	1965	1905	1905	1905	**26974**
1	0	76	76	76	76	76	76	76	76	76	**684**
2C	0	69	69	69	69	0	0	0	0	0	**276**
2E	0	8710	8710	8710	8634	8432	8106	7800	6986	6523	**72611**
2M	0	35	35	35	35	35	35	35	35	35	**315**
2S	0	102	102	102	102	102	102	102	102	102	**918**
2W	0	67055	67055	67055	67051	56619	55274	50945	41943	35295	**508292**
3E	0	10532	10532	10532	10506	9876	9524	8891	7707	7637	**85737**
3M	0	247	247	247	247	187	187	187	187	187	**1923**
3S	0	15245	15245	15245	14493	10231	8192	7896	7483	7402	**101432**
3W	0	53618	53618	53618	53547	49301	48098	46244	40897	36815	**435756**
4E	0	1547	1547	1547	1547	1431	1220	1090	939	887	**11755**
4M	0	355	355	355	355	355	335	335	335	335	**3115**
4S	0	14853	14853	14853	14395	12184	11294	9364	7067	6835	**105698**
4W	0	14297	14297	14297	14276	12127	11903	11485	10623	10491	**113796**
6E	0	447	447	447	447	374	374	356	356	356	**3604**
6S	0	1478	1478	1478	1478	1183	1013	731	731	731	**10301**
6W	0	101	101	101	101	101	101	101	101	101	**909**
7E	0	12	12	12	12	12	0	0	0	0	**60**
TOTAL	**0**	**203843**	**203843**	**203843**	**202060**	**173964**	**166362**	**155800**	**135644**	**123810**	**1569169**

Map M.1: The Maximum Agricultural Lands Harvested in Any Planning Period for Scenario 8