JAAKKO PÖYRY

JAAKKO PÖYRY CONSULTING, INC.

Maintaining Productivity and the Forest Resource Base

A Technical Paper for a Generic Environmental Impact Statement on Timber Harvesting and Forest Management in Minnesota

Prepared for:

Minnesota Environmental Quality Board
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This technical paper consists of the following three parts:

1) *Technical Report.* The technical report was prepared by Jaakko Pöyry Consulting, Inc. under contract with the Minnesota Environmental Quality Board to develop a Generic Environmental Impact Statement on timber harvesting. This technical report was approved by the EQB and is one of nine such reports prepared by the contractor as part of the GEIS study development process.

2) *External Reviewer Comments and Contractor Responses.* Prior to finalizing the technical report, the contractor commissioned an independent technical assessment of the report from qualified reviewers. Comments on the technical report provided by these reviewers, along with responses by the contractor to substantive comments, issues or questions raised are included immediately following the red divider.

3) *Advisory Committee Comments and Contractor Responses.* A ten member advisory committee was established by the Minnesota Environmental Quality Board to provide direction to and oversight of the GEIS study. Comments on the completed technical report provided by individuals on this committee, along with responses by the contractor to substantive comments, issues or questions raised are included immediately following the green divider.

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November 24, 1992

Dr. Michael Kilgore
GEIS Project Manager
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Dear Dr. Kilgore:

Pursuant to the State of Minnesota's GEIS contract (No. 30000-18408-01) with Jaakko Pöyry Consulting, Inc., as formally executed on May 15, 1991, and amended with Supplement No. 1 on July 10, 1991, and Supplement No. 2 on July 27, 1992, the sixth task included preparation of technical papers. One of these papers, Forest Productivity and the Forest Resource Base, is hereby submitted for review and approval.

The material contained in this document is presented in accordance with the terms outlined in Attachment A to the base contract, Section III, Subsection F.

We look forward to a favorable review and approval of this work product in due course.

Respectfully yours,

James A. McNutt

James A. McNutt
Executive Vice President
and GEIS Project Manager

cc: Art Veverka
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SUMMARY

This technical paper describes the analyses that were performed to address the question of the sustainability of various harvest levels over a 50-year planning horizon. The focus is on forest productivity and the resource base with special emphasis placed on timber supply. Environmental impacts of timber harvesting and forest management on soils, water quality, wildlife, recreation, etc. are addressed in other technical papers.

State-of-the-art planning models were used to develop schedules of forest management activities including harvesting, regeneration, and thinning for three different harvesting scenarios. The model scheduled these forest management activities by individual Forest Inventory and Analysis (FIA) plots over time. It was this schedule that formed the basis for detailed impact analyses of forest harvest activities on various timber and nontimber resources. To augment the understanding of the sustainability analysis, the structure and extent of the forest resource base was also examined. The results are presented here as a preface to the modelling and analysis effort.

Many factors influence how much wood is actually harvested from the forests of Minnesota at a certain point of time. The general level of harvesting is dictated by long-term economic conditions, legal restrictions, and biological and physical possibilities. Yearly fluctuations are more dependent on economic factors like stumpage prices, taxation burdens/incentives, and economics of other land uses.

The economic factors have a particular influence on nonindustrial private forest (NIPF) owners. In Minnesota, NIPF owners are a very important factor, as they hold 41 percent of the commercial forests and contribute approximately 37 percent of the annual harvest.

For the medium- and long-term it is important that the harvest level does not deviate too much from the *allowable cut,* this being the *harvest level* that the forests will be able to *sustain long-term* without jeopardizing the forest resource. The determination of the allowable cut is based on the size, composition and growth of the forest resource, and the principles for its management. Therefore, the allowable cut is a *dynamic concept* which evolves over time as the size, composition, growth, and management of the forest resource changes.

The Final Scoping Decision (FSD) specified study of three harvesting scenarios. The base scenario reflects current timber consumption levels by Minnesota's forest industry (4 million cords annually). The medium scenario reflects the demand of the forest industry after several of the plants now under construction or in the design or concept stage go on line (4.9 million

cords annually). The high scenario suggests an upper bound on biologically sustainable yields (7 million cords annually).

When the harvest levels under the three scenarios were met, they had distinct implications for the cost of producing timber, on the impacts associated with these harvest levels, and the future sustainability of these harvest levels past the 50-year planning horizon.

Harvesting at almost any level brings both human-induced and natural changes that impact the characteristics and condition of the forest, often for decades. The nature and severity of the impacts is documented here in terms of gross physical characteristics such as forest stand age class and species structure, spatial patterns and timber yields. Regarding specific impacts, two sets of model runs were developed. The first was unconstrained in the sense that all timberland in Minnesota (14,773,000 acres) was assumed available for harvest. The remaining two classes of forest land that were not available for harvest were reserved forest (1,113,100 acres) and unproductive forest (828,300 acres). This first set of runs illustrated the potential forest growth and yield under existing levels of management. The second set of runs was constrained to approximate actual timberland availability (for harvesting) by ownership, anticipated changes in forest area, various existing and prospective policies and procedures of the major forest land managers and mitigation strategies developed in the course of the study. As examples, existing and prospective policies included allowance for old growth and implementation of best management practices (BMPs). Mitigation strategies included extended buffers for wildlife that restricted clearcutting in certain riparian areas. The results of the two sets of runs were then used to assess the severity of impacts and to develop recommendations for preferred mitigation strategies.

First Model Runs and Analysis

Results for the first model runs indicated that the overall study approach was feasible and produced realistic depictions of possible scenarios. The scenarios were developed using the FIA data and a combination of modelling tools. Specific results were:

1. Based on assumptions including minimal constraints on harvesting practices, all three levels of harvesting are feasible over the planning period and beyond. However, this conclusion does not incorporate all of the biological/ecological concerns dealt with in the second runs, or management intensification that could increase yields.

2. Achieving these harvest levels clearly impacts a large number of acres across all ecoregions. The area of timberland projected to be harvested one or more times during the 50-year study period varies from approximately 8.8 million acres in the base scenario, 10.2

million for the medium, and 12.9 million in the high scenario. Adding the reserved and unproductive acreage to the timberland never cut also suggests considerable acreage is not disturbed by harvesting over the 50-year study period, notably 7.9, 6.5 and 3.8 million acres for the base, medium and high scenarios, respectively.

3. The greatest harvesting pressure will occur in the early part of the next century. The number of stands harvested will diminish towards the end of the planning period, reflecting assumed current management and harvesting of regenerated stands with improved stocking.

4. Stumpage prices for products are dependent on location and harvest levels.

5. The aspen covertype will experience the heaviest level of cutting and is projected to account for between 40 percent (high scenario) and 60 percent (base scenario) of the total area harvested.

6. The average age of aspen stands harvested in the northern region of the state drops significantly during the study period for all three scenarios as the minimum rotation age (40 years) is gradually implemented.

7. Harvesting modelled in the southern region of the state for the high scenario would affect most (all but 11,000 acres) of the oak-hickory stands on timberland in that region. The base scenario envisions 217,000 acres left uncut. The high demand scenario would likely not be sustainable in these covertypes in this region in the long-term.

8. A high proportion of the modelled increases in demand are projected to come from private property, particularly the medium and high scenarios in the northern region of the state.

9. The spruce and balsam fir covertypes would be subjected to much higher levels of harvesting under the high scenario compared to the base scenario.

10. The high demand scenario harvest levels for some of the covertypes, e.g., black spruce, jack pine, balsam fir, tamarack, and the northern hardwoods, led to age-class distributions indicating these high harvesting levels could not be sustained in the long-term, based on current levels of management.

11. Analysis of harvest volumes by owner and period for the three scenarios indicate that private ownerships will have to play an

increasing role in supplying timber for harvest. The role of these ownerships will increase as the level of demand increases. These ownerships would also have the greatest opportunity to intensify management to mitigate timber supply shortfalls elsewhere.

12. The aspen covertype plays an important role in all demand scenarios. Other covertypes such as the northern hardwoods and other softwoods also play an increasing role in the medium and high scenarios. Proportionally greater increases in the harvest from covertypes other than aspen will be needed to meet the higher demand scenarios. Development of facilities which can process species that are currently unmerchantable will increase the level of utilization in mixed species stands. This will also augment supplies of aspen and other species by making logging of mixed species stands commercially viable.

13. Overall, tree species composition on timberlands is moderately affected by these harvesting scenarios. This assumes most of the impact is due to changing age class distributions and not a reduction or elimination of covertypes. Individual covertypes can vary considerably in age related species composition, but the overall impact is reduced because of the high proportion of mixed species stands, i.e., most stands contain a number of tree species.

14. Covertype change trends are still strongly affected by the species and age class structure resulting from the logging and land clearing of the late 1800s and the early part of this century. In general, harvesting favors retention of pioneer species while long rotations favor more tolerant species. The long-term trends seem to show a decline in aspen acreage and an increase in maple-basswood. Lowland conifers in general appear to maintain their acreage. Perhaps most significant is that management or lack of it will largely determine future covertype acreage and age class structure of the forest. Many other characteristics or benefits of forests will then follow from that.

15. Reserved and unproductive forest, though not subjected to harvesting, also changed substantially through stand aging processes. In particular, these areas will be subject to successional processes that will likely diminish the extent of pine and other early successional stage covertypes.

16. External to the actual modelling process, a review of trends led to estimates that forest and timberland area will likely shrink in the north and expand in central and southern Minnesota over the period 1990-2040. However, constraints on harvesting (described in the second runs) will likely further reduce the availability of timberland

in the north and reduce the impact of any expanded forest area in the south.

Second Model Runs and Analysis

Analysis of the results of the first runs led to modelling refinements and the incorporation of ownership constraints and possible mitigations. Consequently, the second runs represent a more detailed and realistic look at the specified harvest levels and how they might be achieved, given various mitigations.

Among the existing and prospective agency policies and procedures and mitigations, accepted and/or modified by the Advisory Committee, those that were amenable to implementation in the second runs were:

- extended rotation forests (ERF), i.e., lengthened (usually by 50 percent) minimum rotation ages for approximately 20 percent of the timberland on state and USDA Forest Service ownerships;
- greater use of uneven-aged management (approximated by thinning practices);
- designation and reservation of old growth and acreage that might replace that;
- BMPs, i.e., thinning or ERF within 100 feet of water; and
- wildlife buffers (thinning only within 200 feet of water) on the national forests and in the southeastern part of the state.

In addition, estimates of the actual availability of timberlands for harvest or management, developed separately by ownership, were used to set aside a portion of the timberland as *not available* for various economic, environmental and social concerns. Table I.1 summarizes this acreage.

Table I.1. Approximate second run acreage availability by use and treatment category for timberland, statewide, 1990.

Use and treatment category	Acres	Percent
1. Normal harvest	11,289,200	76.4
2. BMP and wildlife buffers	742,900	5.0
3. Extended rotation forest	899,400	6.1
4. Old growth and replacement	57,500	0.4
5. Not available	1,784,400	12.1
Total 1 to 3 (available)	12,931,500	87.5
Total 4 to 5 (not available)	1,841,900	12.5
Total	14,773,400	100

Other model changes for the second runs included refinement of the silvicultural decision trees used in the first runs to lengthen minimum rotation ages from 40 to 50 or more years. The exceptions were for aspen and balsam poplar, where minimum rotation ages were retained at 40 years. Thinning options were also refined, notably to reflect desired practice within buffers and for approximating and encouraging uneven-aged management.

Forest and timberland area change from 1990 to 2040 was also implemented gradually throughout the 50-year period using estimates of annual change rates. Changes in forest area were assumed to occur on nonindustrial private lands in the northern part of the state with equal percentage changes applied across all forest types. For the southern part of the state, changes were assumed to occur equally across all ownerships. The area change translated into a 873,125 acre decrease in timberland in the two northern FIA units and a 979,174 acre increase in the southern two FIA units by the year 2040. While the net change is small, these changes clearly impact results by FIA unit and ecoregion and need to be considered in the interpretion of harvest scenario results.

Covertype areas were further subjected to change occurring at the time of harvest and later via stand dynamics or succession. Change occurring at harvest was developed from (1) decision trees for planting and (2) covertype change determined from natural regeneration patterns. Subsequent to harvest, the individual tree based growth model projections were evaluated by a covertype determination algorithm at the end of each ten-year projection period. This evaluation allowed for estimating covertype change due to stand dynamics and successional processes. This was a major difference in procedure from the first model runs where essentially all cover types that were naturally regenerated were assumed to remain in that covertype.

Since the first runs, the USDA Forest Service FIA project has developed factors to adjust the tree growth and mortality in the growth model used. These factors were implemented in the second runs to improve predictions. In most cases the adjustment factors served to reduce estimates of forest growth.

Harvests from national forests were also constrained to the allowable sale quantities in their respective forest plans with the exception of the high scenario.

Timber product values and consumption by various markets were also updated as new information became available.

The various model changes do confound comparisons with the first runs as differences are due both to the addition of mitigative constraints and model changes in the revised runs.

Impacts of Constraints and Mitigations on Results
With all the ownership constraints, mitigative measures and model changes incorporated in the second runs, the base scenario was at first found to be infeasible as the aspen consumption level could not be met when using even unrealistically high aspen shadow prices. Shadow prices are equivalent to the marginal costs of producing an addition unit of the associated product. Major reasons for the infeasibility were (1) the substantial shift of acres into categories considered unavailable for harvest or requiring long rotation lengths, (2) reduced forest growth estimates, and (3) reductions of timberland area in the north. Further review also suggested that contributing factors were (1) the short planning period and (2) the existing age-class imbalance of the forest.

Adjustments to achieve feasibility involved lengthening the planning horizon to sixty years, but that in itself did not overcome the infeasibility problems. In order to finally overcome this problem it was necessary to lower the aspen harvest target levels. This meant that some of the aspen demand would need to shift to other species in future periods of the planning horizon. It is likely that decreasing aspen supplies along with associated increases in prices relative to other species will stimulate a substantial shift in demand to those other species. Predicting the extent of the shift, however, is fraught with uncertainty. To move forward, it was assumed that the shift in the projected aspen consumption would be to hardwoods, as the latter exhibited the lowest marginal costs of production for the first model runs. For the medium scenario, it was found that harvest levels could be achieved if 10 percent of the aspen harvest level was shifted to northern hardwoods by the year 2000 with an additional shift in year 2010 for a total shift of 25 percent. For the base scenario, the same 25 percent shift was assumed even though it was clear that feasible schedules could be developed with somewhat smaller shifts. Final marginal cost estimates for the base and medium scenarios served to guide the development of targets for the high scenario. Given these assumptions, specific second run findings were:

1. Under the *base scenario* the rising and higher marginal costs for aspen confirm concerns for the future supply of aspen. Marginal costs for the pine group under the base scenario actually drop substantially over the planning horizon. This drop is likely due to past red pine reforestation efforts, as many plantations will reach harvestable age in later periods of the planning horizon. However, the short planning horizon as compared to typical rotation lengths for red and white pine does not fully address pine reforestation needs to meet potential harvest level targets for periods beyond 2040. Marginal costs for northern hardwoods remain low over time, as compared to all other species groups.

2. Under the *medium scenario*, marginal cost estimates again suggest that aspen is the species in shortest relative supply. Marginal costs rise to over $80 per cord delivered for aspen while those for northern hardwoods remain relatively low. Marginal costs for spruce-fir under the medium scenario rise steadily and approach $80 per cord by the end of the planning horizon. As with the base scenario, marginal costs for pine decline.

3. For the *high scenario*, marginal cost estimates increase substantially for all species. The marginal cost of producing hardwoods also rises substantially above the marginal cost of other species by the end of the planning horizon. This suggests that in achieving a seven million cord harvest level, the harvest for northern hardwoods was set too high. The high marginal costs for all species by the end of the planning horizon also suggests that these harvest levels could not be maintained over a longer time horizon. Maintaining them would require either reducing the constraints and mitigations imposed or implementing intensive forest management options not considered in these runs on a large-scale.

4. Marginal cost estimates for pine changed relatively little between the base and medium scenario. Substantially higher costs for the highest scenario reflected the much higher harvest targets for pine under that scenario. Marginal costs for spruce-fir changed substantially between the base and medium scenario, suggesting that a large spruce-fir harvest level increase would have a large impact on the future production cost and price for spruce-fir.

5. Constraints to implement the allowable sale quantities for each national forest carried a marginal cost estimate that measures the cost savings that could be achieved if an additional cord could be harvested from national forest timberland. Marginal cost estimates were not developed for the high scenario, as constraints defining allowable sale quantities were not imposed with that scenario. Considering the potential of national forest timberlands, it is apparent that both national forests could produce substantially more timber than is reflected in their allowable sale quantities. Model runs for the high scenario suggested that harvest level targets could not be met without additional harvesting on the national forests.

6. The southern region of the state showed marginal costs for red oak are higher and tend to rise fast over time for scenarios with higher red oak harvest levels. A relatively constant and low marginal cost for the "other wood" group for all three scenarios suggests that the harvest level targets for this group could have been raised more for the high scenario. However, this region contains a relatively small

component of the statewide timber supply and could not support a large increase.

7. The breakdown of harvest volumes by product category showed some changes in utilization. Under the base scenario, only aspen shows a large reduction in the quantity of sawlogs produced over time, dropping from over 1 million cords per year in period 1 to approximately 475,000 cords in period 4. This reduction is due to a change in age class and associated size of available timber as the scenario progresses. Similar drops occurred for the medium and high scenarios. However, even with the drop, production of aspen sawlog size material is still substantially above the estimate of 210,000 cords for current annual consumption of aspen sawlogs by sawmills. Under all three scenarios, pine sawlog production is above current pine sawlog consumption by sawmills. The highest scenario assumed more than a doubling of the pine sawlog consumption level over the medium scenario, as this product group appeared to have the potential for a large increase.

8. Results for the southern region of the state suggest a broad mix of species will continue to be harvested with an increase in the production of aspen and maple-basswood over time.

9. Changes in results for the second runs are not surprising. The forest area in the southern part of the state expanded and that in the north declined. Both of these changes were substantial. Additionally, several constraints reduced the proportion of forest area available for harvest overall, especially on public lands. The growth model adjustment further reduced estimated yields and the ERF options slowed realization of some of those yields. Prices thus rose, making management investments more attractive and probably increasing the harvest on private lands. Likewise, areas with harvesting constraints tend to reduce the long-term sustained yield. In terms of the resource, there is a slight buildup in the acreage of older age classes and associated values. In total, these changes will likely reduce the timber yield unless counteracted by investments in management that do not conflict with mitigations for other purposes. In reviewing the results, it is important to remember that these results are not a plan, but a refinement of the first run assessments.

10. Harvest acreages for the second runs are summarized in table I.2. The acres cut category includes those acres clearcut once, acres clearcut twice, acres thinned but never clearcut, and acres thinned and clearcut. Compared to the first model runs, the second runs reduced the overall acreage subject to harvesting over the 50-year planning horizon by harvesting some acres more frequently. This

reduction in acreage subject to harvesting uses a result of increased management constraints.

Table I.2. Original acres cut one or more times and never cut in the second runs, 1990–2040.

Forest land use and harvest status	Second model runs Total (acres)
Total forest land acres	16,714,800
Reserved/unproductive	1,941,400
Timberland	14,773,400
Base Scenario	
Acres never cut	7,600,000
Acres cut	7,173,400
Medium Scenario	
Acres never cut	6,156,400
Acres cut	8,617,000
High Scenario	
Acres never cut	4,308,200
Acres cut	10,465,200

11. Revised long-term sustained yield analyses were performed in much the same manner as the earlier long-term sustained yield analyses. However, the revised analyses are based on the updated growth model and take into account ownership constraints, mitigative strategies and the results of the revised timber harvest scheduling runs. The ending inventory from the scheduling model was also analyzed. Marginal costs were used as timber prices to determine the management alternative for each FIA inventory plot that maximizes the soil expectation value of the plot. Using that alternative, average annual yields were determined for each plot and then summed over all plots representing timberland potentially available for harvest. Results varied substantially depending on whether the marginal costs of the base, medium or highest harvest level scenario were used in selecting the optimal management alternative. The biggest difference between scenarios was the area considered profitable for timber production. The resulting profitable acreage was 7.4, 9.7 and 12.5 million acres for the base, medium, and high scenarios, respectively.

12. With the above approach to analyze long-term sustainable yield, the acres harvested within the aspen forest type changed relatively little between scenarios, but the optimal rotation age for most aspen acres is sensitive to the prices assumed.

13. The lack of acreage in the red pine plantation category is a concern. Even under the highest scenario, shadow prices were not high enough to suggest shifting acres into this forest type. However, results would have been different if a longer planning horizon had been used, giving more consideration to longer-term harvest level objectives. In terms of a sustained yield, shifting acres into the red pine plantation category would increase the sustainable yield as average annual growth rates for red pine are very high compared to most other species.

14. The *base scenario* analysis led to an estimate that a timberland area of approximately 7.4 million acres could sustain close to a 4 million cord annual harvest level. This would leave over 7 million potentially harvestable acres unharvested over the long-term. This explains why the forest industry sees development opportunities in Minnesota. The analysis further suggests that annual harvest levels higher than 4 million cords could be sustained in the long-term once the forest is regulated, i.e., when the age class structure is balanced. This also suggests that large areas of timberland could potentially be shifted towards other management objectives without severely impacting timber production at the 4 million cord level in the long-term.

15. The *medium scenario* analysis indicates that long-term sustained yield levels could be maintained at the 4.9 million cord annual harvest level by utilizing less that 10 million acres of timberland. With the potential to shift additional acreage to plantations or more intensive management options, results strongly suggest that a five million cord level could be maintained in the long-term once a regulated condition is achieved.

16. The *high scenario* analysis utilized most of the timberland acreage assumed to be available and yet fell over 1.5 million cords short of the assumed 7 million cord annual harvest level. This suggests that the high level could not be maintained in the long-term without a substantial increase in management intensification and/or reducing the loss of timberland acreage to other land uses. As one moves from the medium to the high scenario, the sustainable harvest level increases 680,000 cords but requires adding 2.7 million acres to the harvested land base. This is an average increase of only 0.25 cords per acre compared to an average annual harvest level of 0.53 cords per acre, based on the land base assumed for the base scenario. Clearly those additional acres are less productive sites. This highlights the need to recognize differences in site quality in decisions affecting timber production.

17. Overall, as in the first runs, tree species composition on timberlands was only moderately affected by these harvesting scenarios. Ownership constraints and mitigations also served to reduce the number of species that showed large declines in tree numbers.

18. Covertype change trends remain strongly affected by the species and age class structure resulting from the logging and land clearing of the past. In general, the higher harvesting scenarios favored an increase in aspen, but that covertype acreage on timberland still increased only slightly (14, 18 and 22 percent under the base, medium and high scenarios, respectively, over the 50-year planning horizon). Long-term trends also seem to show a significant decline in jack pine and black spruce covertype acreage. However, those changes are suspected to be due partly to stand dynamics, natural succession and the imprecision of covertype determination. For such mixed species stands, even small changes can lead to a new covertype designation—yet overall species composition is affected very little. Conversely, red and white pine covertype acreage increased. However, those changes are suspected to be due mostly to succession and/or covertype determination procedures as opposed to harvesting and management.

19. Reserved forest, though not subjected to harvesting, also changed through stand aging processes and successional processes.

20. Preferred mitigations to maintain the forest resource base include incentives for afforestation, reforestation and policy instruments that would reduce the loss of forest land, notably timberland, to other land uses. Preferred mitigations to improve the productivity of forest lands are management investments, including but not limited to species-site matching; regeneration to full stocking levels, and capturing mortality through shorter rotations and thinnings. Such investments can enhance timber supply and reduce conflict with other forest uses by improving per acre productivity, thereby reducing the acreage that might need to be harvested to meet any particular level of demand.

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1 INTRODUCTION

1.1 Objectives

In response to two issues identified in the *Workplan for a Generic Environmental Impact Statement; Timber Harvesting and Management in Minnesota* (Jaakko Pöyry Consulting, Inc. 1991), this paper focuses on the assessment of the current resource base and the productive potential of Minnesota's forests. It specifically addresses the following questions regarding the status of timber harvesting and the forest resource in Minnesota.

Maintaining Productivity of Forests for Timber Production. *Making sure that forests are able to sustain (over long periods of time) the production of ample supplies of timber in an environmentally sensitive manner is of major importance to society. Considering previously specified timber harvesting levels and looking at timber harvesting and management activities statewide:*

1. *Based on most recent statewide forest inventory information, what allowable timber harvest rates are sustainable for major Minnesota forest types? What rates are possible for sustaining economic activity based on pulp, fuelwood and quality sawtimber products? What methods are used (or could be used) to estimate allowable harvest rates (considering structural and taxonomic diversity, specific geographic areas, and various landowner classes)?*

2. *What is the relationship between current and future estimates of sustainable timber supplies and the demands expected for the supply of such timber? Are there seasonal differences in timber demand and supply?*

3. *Are there classes of landowners, geographic regions or forest types where timber harvest rates may be expected to exceed allowable timber harvest rates or biological growth? If needed, what strategies can be implemented to assure the perpetuation of a renewable forest resource? What are the impacts of these strategies and what forest conditions will result from their implementation.*

Forest Resource Base. *Forests are dynamic ecosystems which change naturally and in response to human intervention (e.g., timber harvesting). Understanding the nature and extent of such change is important to the making of wise management and land use decisions. Considering previously specified timber harvesting levels and looking at timber harvesting and management activities statewide:*

1. *To what extent have changes occurred in the size and composition of Minnesota's forest land base (using reliable statewide information)? What were the major factors contributing to this change?*

2. *To what extent do timber harvesting and management activities impact the abundance, composition, spatial distribution, age class structure, genetic variability and tree species mixture (for example, in creating forest monocultures) of Minnesota's forests (based on reliable information)? To what extent are changes in these characteristics specifically attributable to timber harvesting and management of certain forest landowner categories?*

1.2 Issue Description

The major issues to be addressed by this study are detailed in the series of questions raised in section 1.1. The issues deal with five areas: timber supply, sustainability of supply, factors affecting supply, and strategies to ensure adequate timber supplies and changes in the forest land base.

In responding to the issues and questions, this technical paper draws heavily on the initial harvesting scenarios document (Jaakko Pöyry Consulting, Inc. 1991c). That document described the modelling process used to generate the three harvesting scenarios specified in the FSD (MEQB 1990). The modelling was a major part of work undertaken by this study group. The model output was used to partially or fully address the following questions:

1. What allowable timber harvest rates are sustainable for major Minnesota forest types (assuming certain rotation lengths, management intensities, utilization standards, and technologies and how do sustainable harvest levels change with different assumptions about these factors)?
2. What harvest rates are possible for sustaining economic activity based on pulp, fuelwood and quality sawtimber products?
3. What is the relationship between current and future estimates of sustainable timber supplies and the demands expected for the supply of such timber?
4. Are there classes of landowners, geographic regions or forest types where timber harvest rates may be expected to exceed allowable timber harvest rates or biological growth?
5. What strategies can be implemented to assure the perpetuation of a renewable forest resource?
6. What are the impacts of these strategies and what forest conditions will result from their implementation.
7. To what extent do timber harvesting and forest management activities impact the abundance, composition, spatial distribution, age class structure, genetic variability and tree species mixture (for example, in

creating forest monocultures) of Minnesota's forests (based on reliable information)? To what extent are changes in these characteristics specifically attributable to timber harvesting and forest management of certain forest landowner categories?

Additional FSD questions were addressed based on the literature, forest inventory data analysis and other sources. Questions addressed in this way were:

1. What methods are used (or could be used) to estimate allowable harvest rates?
2. Are there seasonal differences in timber demand and supply?
3. To what extent have changes occurred in the size and composition of Minnesota's forest land base?
4. What were the major factors contributing to this change?

The model, data input and assumptions are described in sections 3 and 4 of this report.

The scenarios or harvest levels should not be read as targets or recommendations from the Environmental Quality Board (EQB) or the GEIS Study Group. They have been used solely for the assessment purposes described above. The choice of scenarios has been developed as a tool to provide a form of sensitivity analysis for all of the impact assessments. The three levels of harvest specified in the FSD cover a wide range of possible harvesting levels and therefore provide information on the range of impacts. The base scenario depicts the current (and therefore likely minimum) level of harvest; the medium scenario suggests possible expansions and the high scenario suggests an upper bound on long-term biologically sustainable yields.

2
DESCRIPTION OF MINNESOTA'S FOREST RESOURCES

2.1
Historic Overview of Minnesota's Forests

Portions of this section were drawn from background papers on Public Forestry Organizations and Policy (Jaakko Pöyry Consulting, Inc. 1992b) and Biodiversity (Jaakko Pöyry Consulting, Inc. 1992d).

Land ownership patterns, forest types and many other forest characteristics which exist in Minnesota today were strongly influenced by history. In the early 1800s, Minnesota's forest acreage was extensive (31.5 million acres) and dominated by conifers. Because of the forest's fire history, probably not more than one-third of the presettlement forest was old growth when logging first started in the state (Cunningham and Moser 1938). White pine attracted the most attention and was essentially all logged between 1880 and 1910. The annual timber cut peaked about 1900 (Cunningham et al. 1958) at a volume in excess of 7 million cords. Thereafter logging declined and then moved to other species, particularly other conifers and the larger hardwood trees. The harvest reached a low point of 1.3 million cords in the mid-1930s. However, adding in the fuelwood harvest suggests the overall low point was 2 to 3 million cords. The harvest was then roughly stable until the 1960s. Since then the trend has been gradually upwards. The combination of heavy slash accumulations following logging, minimal fire protection, and land clearing efforts resulted in catastrophic fires which destroyed property and human lives. Soil productivity was also affected by the destruction of the forest floor (humus and leaf litter).

Speculators became interested in these low productivity, cleared lands, and they began selling them as farmland to Easterners and immigrants looking to settle west. As a result, most of Minnesota fell into private ownership at this time (included in this category are Native American owned lands, which have been reclassified in recent years to Other Private from Other Federal). Settlement resulted in large transfers of formerly public domain lands and Native American lands to other private owners. Federal policy was to transfer as much of the public domain lands into private hands as quickly as possible. This began to change with the establishment of the national forests early in the century. By that time, however, vast acreages of the most productive land had passed into private ownership.

Of the federal acreage that remained, acreage in what is now the Boundary Waters Canoe Area Wilderness (BWCAW) was retained, as well as acreage within the Chippewa National Forest specifically reserved by treaty. The Chippewa National Forest was first established as a forest reserve in 1902. The Superior National Forest, including the BWCAW, was designated as such in 1909. The remaining federal land was transferred to the fledgling state conservation agency via various land grants. Since the late 1920s, the USDA Forest Service has continued to purchase land, primarily to increase national forest acreage within the established forest boundaries but not for the sole purpose of growing timber. For further details on these developments, see the background paper on Public Forestry Organizations and Policy (Jaakko Pöyry Consulting, Inc. 1992b).

In the 1930s and 1940s, large-scale tax forfeiture occurred and public agencies acquired privately owned lands that had been unable to support viable agriculture. The fact that they had been considered to be viable agricultural lands at one time distinguishes them, from a productivity standpoint, from the federal lands, as the majority of these never supported agriculture. Again, private owners generally retained the most productive agricultural land (and timberland) concentrated in south, central and northwestern Minnesota.

At the time, state and county agencies did not have the personnel, money or expertise to properly manage the tax forfeited lands which came under their jurisdiction. Consequently, many of these acres gradually converted back to forest naturally. This new forest was largely hardwood and had a large component of aspen, a pioneer species.

Historical analysis of quantitative data is normally quite difficult due to differences in how data are defined and collected, both between different organizations and over time within the same organizations. Qualitative data is even more difficult to work with. The most comprehensive information on general characteristics of Minnesota forest resources is the forest survey conducted by the USDA Forest Service. The first forest survey of Minnesota was carried out in 1934–36. Field work for the fifth survey was completed in 1990. A detailed historic view is possible after the first survey and the regrowth of Minnesota's forests from 1936 to the present time can also be chronicled.

Cheng and Ek (1992) have described the decline and regrowth of Minnesota's forests in terms of land use changes. Beginning with an estimated 31.5 million acres of forest in the last century, the total forest area declined rapidly with logging and land clearing for cropland and more recently with urbanization. That decline occurred largely from 1880 to the 1960s, with most of the loss occurring in the first half of the period. Since the late 1970s forest area has increased slightly, but with a continued small decline in the north.

The character of the forests has also changed, especially in terms of species composition. According to Cunningham and Moser (1938), the original forests contained an estimated 5.8 million acres of pine (jack, red and white) or 18 percent of the forest area. By 1936 such pine occupied only 8 percent of the area. Today pine comprises 6 percent of the area. At the same time the aspen and other hardwood types have grown in terms of percentage of forest area and commercial importance.

Most hardwood stands originated in the 1920s or later with the initiation of organized fire control. Many conifer stands originated from earlier logging of softwoods. The age class distribution of conifers is less concentrated than hardwoods because of earlier cutting and steadier markets in the early part of this century. Additionally, many acres have been cut several times, first for pine sawlogs, then for spruce or hardwoods and, more recently, for aspen pulpwood. In some cases these cuts were selective. Due to its origin, today's forest is largely even-aged in character and still growing in terms of average stand age and tree size. This regrowth has exceeded removals because market demand for the species such as aspen that dominate this new forest has developed slowly. For some species, timber demand has only begun to approach the rate of regrowth in the last decade.

This rapid regrowth and change in forest character has had enormous implications for wildlife, which in turn have influenced the species composition of the forest. The forest has also become very important to water quality, aesthetic and recreational interests.

Subsequent sections of this report will examine the character of the forest in more detail. Those analyses will describe a forest that is very dynamic and likely to change with or without harvest and management.

2.2 Definition of Forest in Minnesota

Description and analysis of forest characteristics depends on definitions. In most cases these definitions are those developed from forest surveys. In Minnesota, the most comprehensive information on general characteristics of forest resources is the statewide forest survey conducted by the USDA Forest Service through its Forest Inventory and Analysis (FIA) project based at the agency's North Central Forest Experiment Station in St. Paul. This unit has been responsible for statewide forest surveys since the first survey was conducted in 1934-36. Subsequent surveys or major updates were developed in 1953, 1962, 1977 and 1990. The MNDNR Division of Forestry assisted with the 1977 and 1990 surveys to increase their intensity. Hereafter the term FIA is used to reference reports and data from those surveys. This paper also draws heavily from the definitions and procedure established by FIA efforts.

When a new survey is completed, the FIA project adjusts the data of the previous survey to make the two comparable, but surveys done prior to that are often not adjusted.

In reviewing this report, readers are strongly cautioned that comparisons between surveys must be done carefully—changes in procedures and definitions may give the appearance of change when, in fact, no change has occurred. This is a hazard particularly in the inspection of fine detail.

Forest land in Minnesota is a combination of land and land use types with trees. These are easily distinguished visually, but are complicated in terms of potential use and associated implications. Table 2.1 summarizes estimates of forest land by land use category for 1990 and three earlier dates. The 1990, 1977, 1962, 1953 and 1936 data are specific statewide forest survey dates. However, the 1953 data is best described as an update using a variety of sources. This table allows some general observations to be made concerning the developing character and use of Minnesota's forest resource over 1953–90. Caution should be used in interpretation, however, as the definition of unproductive forest land, and hence timberland acreage, differed between 1953 and 1962 and again between 1977 and 1990.

Table 2.1. Forest land area in Minnesota by major land class for 1953–90 (thousand acres).

Year	All Forest Land[a]	Timberland[b]	Reserved Forest Land[c]	Unproductive or Other
1990	16,715[d]	14,773	1,113	828
1977	16,709	13,695	1,179	1,835
1962	18,445	15,412	470	2,563
1953	19,344	18,098	428	818

Source: Data by year obtained from: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1977=Jakes 1977; 1962=Jakes 1977, Stone 1966, Stone and Vasilevski 1963 (for units); 1953=USDA Lake States Forest Experiment Station 1953; 1936=Cunningham and Moser 1938. Data for 1962 and earlier omit reservation of Voyageurs National Park and the BWCAW.

[a] Forest land is defined as "Land at least 16.7 percent stocked by forest trees of any size, or formerly having such tree cover, and not currently developed for nonforest use" (Kingsley 1991).
[b] Timberland is defined as "Forest land that is producing or capable of producing crops in excess of 20 cubic feet per acre per year of industrial wood crops under natural conditions, that is not withdrawn from timber utilization, and that is not associated with urban or rural development. Currently inaccessible and inoperable areas are included" (Kingsley 1991).
[c] Reserved forest land is defined as "Forest land withdrawn from timber utilization through statute, administrative regulation, designation or exclusive use for Christmas tree production, as indicated by annual shearing" (Kingsley 1991).
[d] Increases in all categories from 1977 to 1990 are more the result of a survey method correction than an actual gain.

2.2.1 Land Use

The acreages in table 2.1 are the result of an aggregation of lands defined in the FIA survey by the variable *ground land use.* Table values have also been adjusted to common definitions. A list of ground land uses and codes is given in appendix 7. For the purposes of this study, *timberland or commercial forest* was based on the FIA ground land use variable and consists of plots coded as timberland, pastured timberland and plantations. These categories and plots were the only ones used to model future timber supplies. However, other categories described below were examined to assess overall forest conditions. *Reserved forest* land consists of reserved unproductive forest land (reserved woodland) and reserved timberland. Thus reserved forest land consists of both unproductive and productive forest land, both of which are withdrawn from timber utilization. *Other forest* land consists of unproductive forest land that is not reserved (woodland). *Nonforest with trees* consists of a variety of land uses with trees. The full complex of categories considered in the study is shown in table 2.2. Notable in that table is that approximately ten percent of the land uses with tree cover fall into the other forest or nonforest with trees categories, meaning that it is neither commercial nor reserved forest land. The table also illustrates the difficulty of defining forest land on an operational basis in forest survey.

Table 2.2. Summary of 1990 FIA *test data* plots by ground land use.[a]

Ground Land Use[b]	Number of Plots	Thousand Acres	Percent of Total Acres
Timberland or Commercial Forest			
Timberland	11,554	14,077.3	
Pastured timberland	300	372.8	
Plantation	264	323.3	
Subtotal	12,118	14,773.4	83.6
Reserved Forest			
Reserved woodland[c]	24	30.6	
Reserved timberland	650	1,082.5	
Subtotal	674	1,113.1	6.3
Other Forest			
Woodland[c]	744	828.3	
Subtotal	744	828.3	4.7
Nonforest with Trees			
Christmas tree plantation	3	3.2	
Cropland with trees	16	18.9	
Pasture with trees	75	88.5	
Wooded strip	75	101.0	
Idle farmland with trees	26	32.9	
Marsh with tree	186	219.2	
Narrow windbreaks	28	44.9	
Wide windbreaks	15	20.5	
Windbreaks	26	40.5	
Wooded pasture	79	101.1	
Cropland without trees	1	.6	
Urban forest reserved	58	65.4	
Urban with trees	172	216.9	
Subtotal	760	953.6	5.4
TOTAL	**14,296**	**17,668.4**	**100.0**

[a] This includes only those plots with an area expansion factor. With the exception of reserved plots, those included here had ground plot tree records. Reserved plot data was developed from FIA plot observations based on aerial photo interpretation. Some analyses may include slightly more or fewer plots where records varied in their completeness for certain variables.
[b] See appendix 7 for definitions.
[c] Woodland is unproductive forest land.

Unless otherwise indicated, the data used in this report are preliminary 1990 FIA survey data provided by the USDA Forest Service, North Central Forest Experiment Station. These preliminary data, hereafter referred to as *test data*, have not been subject to the full extent of editing conducted by the USDA Forest Service in the usual longer FIA analysis process and, therefore, may show minor differences from USDA reports expected at a later date.

2.2.2 Forest Types

Minnesota forests are largely concentrated among fourteen forest covertypes common to the Great Lakes region. These types and their extent in Minnesota are described in table 2.3. Definitions of these types are provided in appendix 7. The criterion for allocating an FIA plot to a particular covertype is based on the plurality of stocking. In the case of the FIA data,

Table 2.3. Forest type acreage for FIA timberland, reserved and unproductive plots, statewide (thousand acres).

Forest Type	FIA Covertype Code	1977	1990			
		Timberland	Timberland	Reserved	Unproductive	Total
Jack pine	1	504.4	447.5	131.5	0	579.0
Red pine	2	246.9	301.6	80.4	0	382.0
White pine	3	65.6	63.2	3.8	1.3	68.3
Black spruce	12	1,041.8	1,322.1	126.6	533.7	1,982.4
Balsam fir	13	859.1	734.3	93.1	12.5	839.9
Northern white cedar	14	498.6	680.5	25.1	38.3	743.9
Tamarack	15	465.4	705.1	8.9	110.7	824.7
White spruce	16	79.2	93.8	39.9	0	133.7
Oak-Hickory	50	893.9	1,190.4	9.5	13.4	1,213.3
Elm-Ash-Soft maple	70	738.1	1,291.5	42.8	33.1	1,367.4
Maple-Basswood	80	1,283.9	1,396.7	17.0	0	1,413.7
Aspen	91	5,302.3	5,115.4	422.1	30.3	5,567.8
Paper birch	92	997.6	834.7	94.9	2.1	931.7
Balsam poplar	94	548.9	427.7	7.1	8.4	443.2
Other	0	0	0	10.4	1.0	0
Nonstocked	99	169.4	169.9	0	43.5	222.8
Total		13,695.1	14,773.4	1,113.1	828.3	16,714.8

Source: Timberland acreage by forest type for 1977 was drawn from Jakes (1977). Timberland figures for 1990 were developed from survey unit reports by Kingsley (1991), Murray (1991), Leatherberry (1991) and Roussopoulous (1992). Reserved and unproductive acreages were developed from FIA test data.

the type determination is based on a stocking algorithm that considers the live trees on all ten points comprising the field plot (see definition of stocking in appendix 7). While the types have simple and short names, most stands have a considerable mixture of species. Most FIA plots contain three to six species. This species diversity within type is illustrated in other publications such as empirical yield tables by covertype (Hahn and Raile 1982). The maple-basswood covertype name suggests a mixture of species, but even the aspen covertype carries up to 50 percent or more of its composition in other species in many stands (see Hahn and Raile 1982, tables 44–50). In fact, stands comprised of just one species are rare in any type in Minnesota. This mixing of species also diminishes the precision of forest type identification. Thus type acreages need to be interpreted with caution. Subsequent sections of this report discuss the determination of forest type and species composition within types (see sections 4 and 5 and appendix 7).

2.3 Characterization of Existing Forest

Forests can be described quantitatively in a number of ways including characterizations of forest area; their location within ecoregions; ownership; stand size and age class structure; stocking; and in terms of timber inventory, removals, growth and mortality. In addition to existing conditions and recent trends, it is also valuable to describe the history and long-term trends of forest development and use. These views are presented in the following sections.

2.3.1 Distribution and Patterns

Area

Minnesota's forest area can be described in several ways. The usual reporting has been by the FIA survey units described in figure 2.1. The 1990 and earlier statewide surveys (1936, 1953, 1962 and 1977) are reported on in a number of publications (e.g., Cunningham and Moser 1938, Cunningham et al. 1958, Stone 1966, Jakes 1977, Jakes and Raile 1979, Kingsley 1991, Leatherberry 1991, Murray 1991, Roussopoulous 1992, Stone 1966).

The area by FIA units is summarized in table 2.4 for 1936–90 survey dates. The table shows the changes over time by land class and by survey unit. Additional breakdowns by counties are given in cited reports. Note that most of the current reserved acreage is accounted for by the BWCAW. Also, about 64 percent of the current unproductive forest area is in the lowland black spruce forest type.

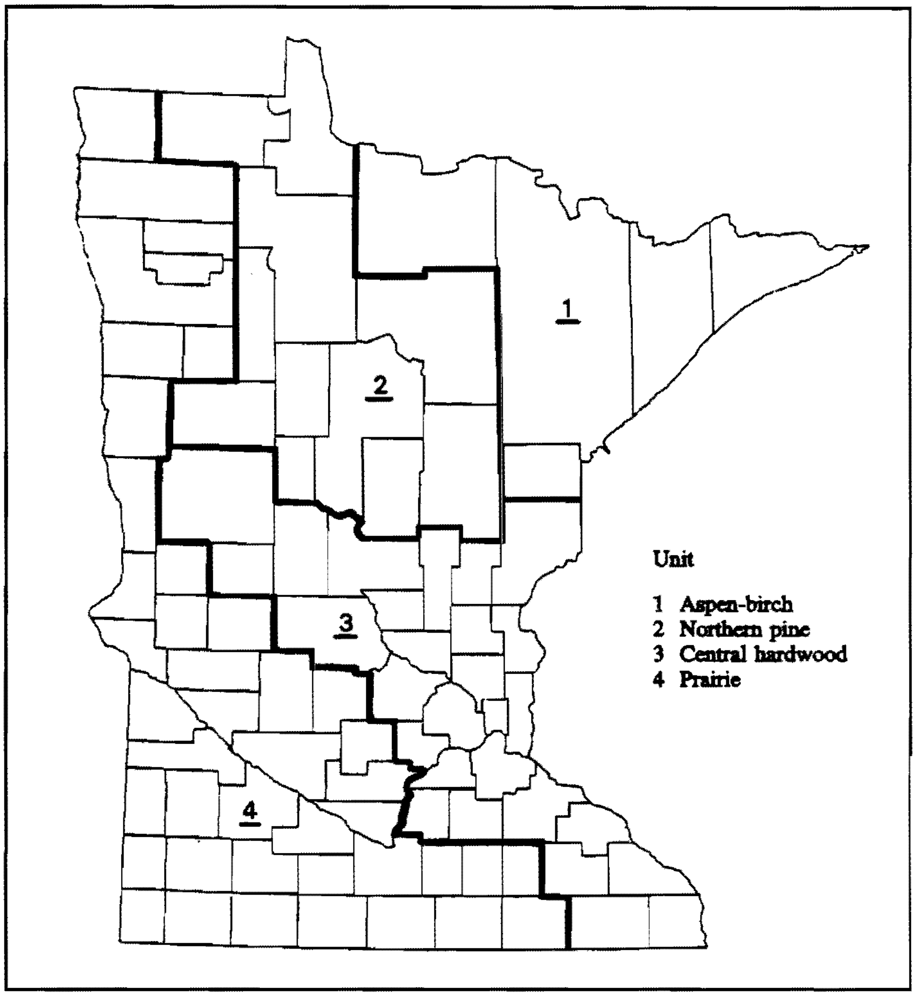


Figure 2.1 Location of FIA survey units.

Ecoregions

The FSD called for a study that would enable the EQB to assess the cumulative impacts of harvesting and related forest management issues at a statewide level, over time, for the specified range of harvesting levels. In order to achieve the stated objectives, the study had to be conducted at a scale of resolution that provides this broad perspective, while still including sufficient detail to substantiate the analysis and to enable development of appropriate strategies to avoid and/or ameliorate identified impacts.

To facilitate this, the state was subdivided into geographic regions with similar physical and biophysical characteristics (ecoregions). The ecoregions used in this study were derived from those defined by the Upper Great Lakes Biodiversity Committee (UGLBC). This is an interdisciplinary group

Table 2.4. Forest area and percent of gross area by FIA survey unit and land class for 1936–90 (thousands of acres).

Year[a]	All Forest Land	Timberland (%)[b]	Reserved	Unproductive and other	All Land
All Units					
1990	16,714.8	14,773.4 (29.0)	1,113.1	828.3	50,882.6
1977	16,709.2	13,695.1 (26.9)	1,178.6	1,834.5	
1962	18,445.0	15,411.8 (30.2)	470.1	2,563.1	
1953	19,343.7	18,097.6 (35.6)	428.0	818.1	
1936	19,615.4	18,215.0 (35.8)	400.0	1,000.0	
Aspen-Birch Unit					
1990	7,362.0	5,878.7 (67.7)	1,003.3	480.0	8,679.3
1977	7,471.8	5,451.4	1,050.6	964.8	
1962	7,770.3	6,244.0	400.9	1,125.4	
1953	7,893.6	6,986.6	907.0		
Northern Pine Unit					
1990	6,336.4	5,975.5 (53.8)	34.2	325.4	11,110.5
1977	6,512.2	5,758.4	46.9	706.9	
1962	7,004.2	6,025.0	29.1	950.1	
1953	7,684.5	7,427.7	256.8		
Central Hardwoods Unit					
1990	2,357.2	2,275.4 (19.0)	68.0	13.8	11,950.7
1977	2,143.7	1,951.1	72.4	120.2	
1962	2,748.2	2,360.3	36.6	351.3	
1953	2,750.1	2,692.6	57.5		
Prairie Unit					
1990	660.4	643.8 (3.4)	7.6	9.1	19,142.1
1977	581.5	534.2	8.7	38.6	
1962	922.3	782.5	3.5	136.3	
1953	1,015.5	990.7	24.8		

[a] Timberland as a percent of 1990 land area.
[b] Data by year obtained from: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1977=Jakes 1977; 1962=Jakes 1977, Stone 1966, Stone and Vasilevski 1963 (for units); 1953=USDA Lake States Forest Experiment Station 1953; 1936=Cunningham and Moser 1938. Data for 1962 and earlier omit reservation of Voyageurs National Park and the BWCAW.

including scientists representing the natural resources agencies and conservation organizations in the Great Lakes area. The UGLBC map for Minnesota shows 16 major ecoregions differentiated by: (1) the range limits of plants (Ownbey and Morley 1991, Johns 1983), (2) physiography (Wright

1972), especially where physiography controlled the prairie/forest border (Grimm 1984, McAndrews 1966), (3) surficial geology (Hobbs and Goebel 1982), (4) soils (Cummings and Grigal 1987, Minnesota Soil Atlas (1971-81), and (5) modern natural vegetation (Minnesota County Biological Survey 1987-present). These ecoregions are similar to the landscape regions proposed by Kratz and Jensen (1983), who synthesized much of the same information that was available prior to 1983.

For the purpose of data summary and reporting, the UGLBC ecoregion map is unnecessarily fine, because many of the units are distinguished by plant communities or the range of species that are components of prairies, prairie/forest mosaic communities, or wetlands. Units so-defined were combined for this study when the forest communities were similar. This combination of regions resulted in a map of seven ecoregions (figure 2.2) that will be used in this study. However, in some aspects of analysis, uplands and lowlands of each ecoregion, often defined largely by covertype, are considered and reported on separately.

The actual GEIS map units and UGLBC equivalents are:

GEIS Unit	UGLBC (from reference in preparation)
1. Glacial Lake Plains	III.11
2. Border Lakes	III.10
3. Lake Superior Highlands	III.9
4. Central Pine-Hardwood Forests	III.13, III.14, III.12, III.8, III-IV.4
5. Western Prairie/Forest Transition Zone	III-IV.2, III-IV.3
6. Eastern Prairie/Forest Transition Zone	IV.1, I.9
7. Western Prairies	III-IV.1, IV.4, IV.2, IV.3

In some cases, the western prairies ecoregion was broken further into a south, southwest and northern component as appropriate (ecoregions 7, 8 and 9, respectively). Some of the analysis undertaken as part of the study was performed using smaller units than the above ecoregion subdivisions. Results from analyses undertaken at these levels of detail are aggregated and reported at the ecoregion scale.

Note that the reporting of environmental, economic, social and other impacts in other technical papers was sometimes best handled using other types of regional subdivisions. Choice of the subdivisions to use for additional reporting was governed by the form of data available and concern for interpretation with respect to past reporting on Minnesota's forest conditions.

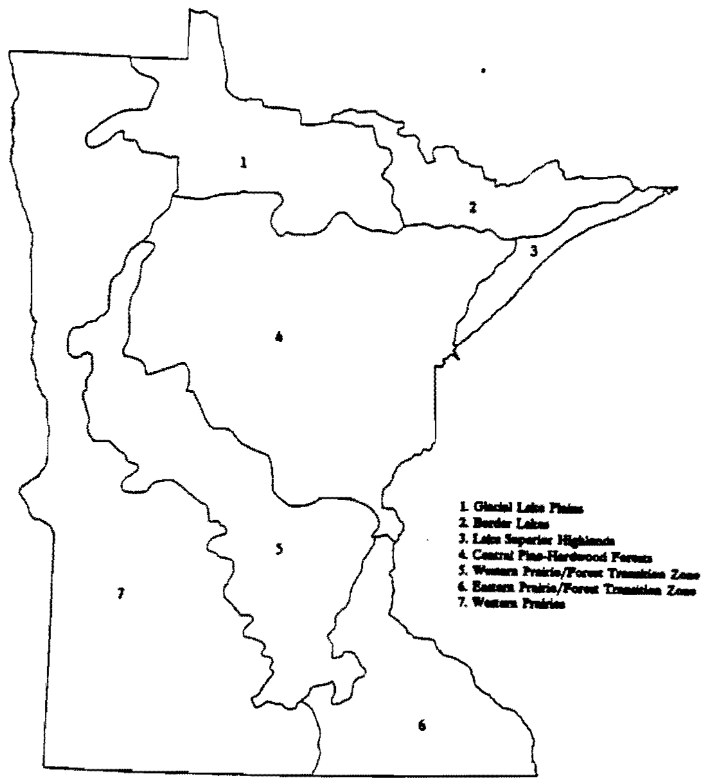


Figure 2.2. Location of ecoregions used in GEIS.

A tabulation by ecoregion shown in table 2.5 shows that over half the timberland occurs in ecoregion 4 (Central Pine-Hardwood Forests) and 85 percent of the reserved acreage is in ecoregion 2 (Border Lakes). Table 2.6 further indicates that timberland in the county and other private ownership categories is concentrated in ecoregion 4 while the other ownership categories exhibit a more geographically diffuse pattern.

2.3.2 Ownership

The ownership pattern of timberland in Minnesota has changed slightly since 1953 (table 2.7). Much of the change is the result of decreases in the amount of timberland due to reservation (BWCAW and Voyageurs National Park), and reclassification of land from timberland to unproductive and then back to timberland status.

Table 2.5. Forest land area in Minnesota by major land class and ecoregion, 1990 (thousand acres).

Ecoregion	All Forest Land	Timberland	Reserved	Unproductive
1	3,372.0	2,862.4	21.1	488.5
2	2,023.7	1,049.8	941.9	32.0
3	908.0	871.7	30.6	5.7
4	8,172.9	7,813.1	84.5	275.3
5	934.7	910.3	15.4	9.0
6	637.2	619.9	14.0	3.3
7	666.3	646.2	5.6	14.5
Total	16,714.8	14,773.4	1,113.1	828.3

Table 2.6. Timberland by ownership class and ecoregion 1990 (thousand acres).

Ecoregion	Total	National Forest	State	County	Other Public	Industry	Other Private
1	2,862	125	1,414	347	63	273	640
2	1,050	590	151	119	4	49	137
3	872	289	114	182	2	61	224
4	7,813	817	1,204	1,819	63	367	3,543
5	910	0	51	22	32	0	805
6	620	0	67	6	20	1	526
7	647	0	77	11	14	0	545
Total	14,774	1,821	3,078	2,506	198	751	6,420

Table 2.7. Timberland area in Minnesota by ownership class 1953-90 (thousand acres).

Year	All Classes	National Forest	State	County	Other Public	Forest Industry	Other Private
1990	14,774	1,821	3,078	2,506	198	751	6,420
1977	13,695	1,715	2,651	2,342	155	772	6,060
1962	15,412	2,142	2,639	2,732	126	716	7,057
1953	18,098	2,195	3,484	3,619	143	509	8,148

Source: Data by year obtained from: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1977=Jakes 1977; 1962=Jakes 1977, Stone 1966; 1953=Cunningham et al. 1958.

Reclassification of timberland into the reserved land use category accounts for most of the reduction in timberland for federal ownership. The decrease on other lands is more difficult to explain. Past large-scale shifts in timberland acreage have been closely linked to demand for agricultural land. Timberlands have been cleared and used for cropland during periods of higher commodity prices. Also, other private includes Native American lands with a substantial portion of unproductive forests, including some that may have been subject to reclassification.

Use of these marginal agriculture lands for cropping has caused concern among federal and state agencies with responsibilities in this area. Federal and state programs have been developed in the past decade to convert these acreages back to tree or shrub cover, much of which would eventually result in its reclassification to timberland. However, these are fairly new programs while the conversion of woodlots to cropland has been consistent for many years. Thus, such changes will take time to show up in the FIA data.

Urban expansion is also a significant factor in timberland loss on private ownerships, at least around the Twin Cities and in the St. Cloud/Rochester corridor—an area where a high percentage (higher than the state average) of forest land is likely to be classified as timberland due to the generally more productive soils.

While timberland is concentrated in the northeast portion of Minnesota, timberland in the various ownership categories by survey unit (table 2.8) shows even more distinct patterns.

Table 2.8. Area of timberland by ownership class and forest survey unit 1990 (thousand acres).

Survey Unit	National Forest	State	County	Other Public	Industry	Other Private	Total
Aspen-birch	1,254	1,331	1,234	46	462	1,552	5,879
Northern pine	567	1,371	1,205	83	285	2,465	5,976
Central hardwood	0	298	60	55	4	1,858	2,275
Prairie	0	78	7	14	0	545	644
Total	1,821	3,078	2,506	198	751	6,420	14,774

Source: Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopolous 1992.

The only significant timberland owners outside the aspen-birch and northern pine FIA units are other public and private owners. Thirty-five percent of other public timberland is in the central hardwood and prairie units, and 37 percent of private timberland holdings are in these same two units. The remainder of private holdings are concentrated in the northern pine unit—38 percent of the total. These ownership patterns could have significant impacts on the stumpage prices and delivered wood costs to various mills, depending on whether the various ownerships respond differently to higher levels of timber demand. Additionally, they have important implications for the management of forests for nontimber values.

Studies to determine the cause of timberland area change suggest the cases vary in a complex manner over time and by region of the state (Plantinga et al. 1989). National forest timberlands are the most concentrated, with 69 percent of all USDA Forest Service lands occurring in the aspen/birch FIA unit and the remainder in the northern pine unit. Industry lands are only slightly less concentrated—61 percent occur in the aspen/birch unit and 38 percent in the northern pine unit. Approximately 97 percent of county timberland is evenly split between the aspen/birch and northern pine units. Approximately 88 percent of state lands are in these two units.

2.3.3 Stand Size Class and Age Class

The stands comprising Minnesota's timberland are aging and more of the acreage is stocked than in the past. These trends are reflected in comparisons of stand size class data over time. The data in table 2.9 show a shift of acres from the seedling and sapling category to poletimber and sawtimber classes. Sawtimber as a class rose from 12.2 percent of timberland in 1953 to 33.1 percent in 1990.

Table 2.9. Timberland area in Minnesota by stand-size class, 1953-80 (thousand acres).

Year	All Size Classes	Sawtimber	Poletimber	Saplings & Seedlings	Nonstocked and Other
1990	14,774	4,895	5,261	4,449	169
1977	13,695	3,135	6,956	3,435	169
1962	15,412	2,387	7,520	4,294	1,211
1953	18,098	2,017	5,281	6,317	4,483

Source: Data by year obtained from: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1977=Jakes 1977; 1962=Jakes 1977, Stone 1966; 1953 = Cunningham et al. 1958; 1936=Cunningham and Moser 1938. The increased acreage of timberland 1977-90 is more the result of a survey unit method correction than an actual gain.

There is a simple explanation for this trend. Forests have become established on many formerly cutover lands and, once established, timber volume growth has exceeded removals (harvesting) and mortality. Therefore, much timberland acreage has grown into the older, larger size classes. For many covertypes the forests are much older, on average, than they were in 1953.

Even though harvesting has converted older stands to young ones over that period, covertypes with little harvesting now have extensive acres of maturing stands.

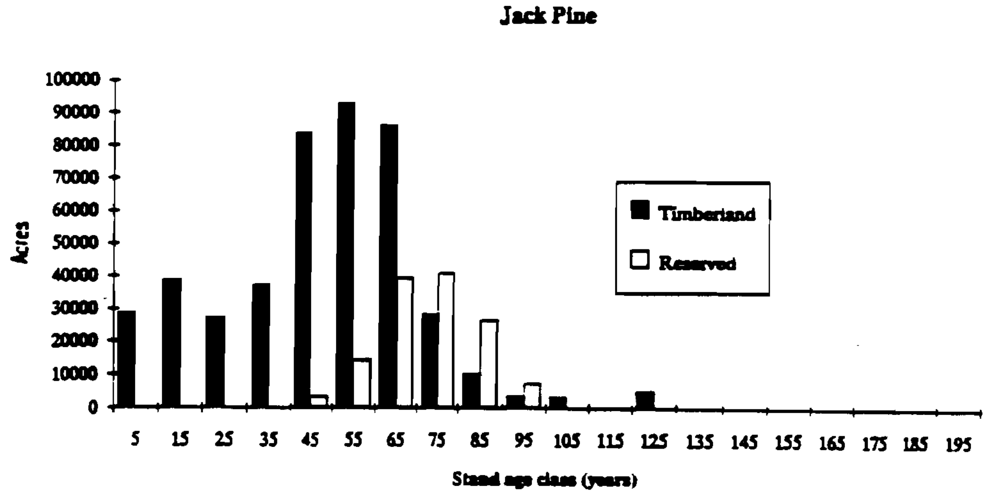
The result of regrowth plus harvesting over this period is reflected in the age class distributions for timberlands. A tabulation of such age class distributions for all covertypes is given in appendix 8. For reasons discussed in the next paragraph, only gross changes to age class distributions can be interpreted.

The stand age variable is difficult to accurately measure in the field for a variety of reasons: (1) difficulty in reading rings from increment cores for many species (particularly aspen), (2) variability in sample tree ages, (3) possible unintentional bias or error in choosing trees representative of stand age, (4) variability in years to reach Dbh (the usual point of measurement), (5) some stands may vary widely in age to the point of being uneven-aged, and (6) reserve stand ages were estimated from aerial photo interpretation. A stand may encompass trees with ages ranging over twenty years and still be considered even-aged.

The following describes the age class distributions for each covertype. Figures 2.3 and 2.4 present this information graphically for several covertypes to illustrate the trends discussed in the text. As described in section 3, age class distributions are important to developing and maintaining a given forest structure and composition. When a forest has an equal number of acres in each age class, the age class distribution is considered *balanced*. Balanced age class distributions in turn assist in developing an even flow of timber yield and other forest values. Where age class distributions are unbalanced, management typically employs strategies that will replace existing stands upon harvest or natural mortality to achieve a more balanced age class structure.

Jack Pine

Jack pine is typically a short-lived pioneer species, which can develop following fires to occupy extensive areas. It is considered shade intolerant. It is usually succeeded by more tolerant species on all but the dry sandy sites, where it may form an edaphic climax. It was a major pulpwood species until the 1960s, when the utilization of aspen developed and replaced it in many markets. Reduced harvesting of jack pine in the last two decades has allowed the development of an extended age class distribution with a large acreage of mature stands and a small acreage in young stands (see figure 2.3).



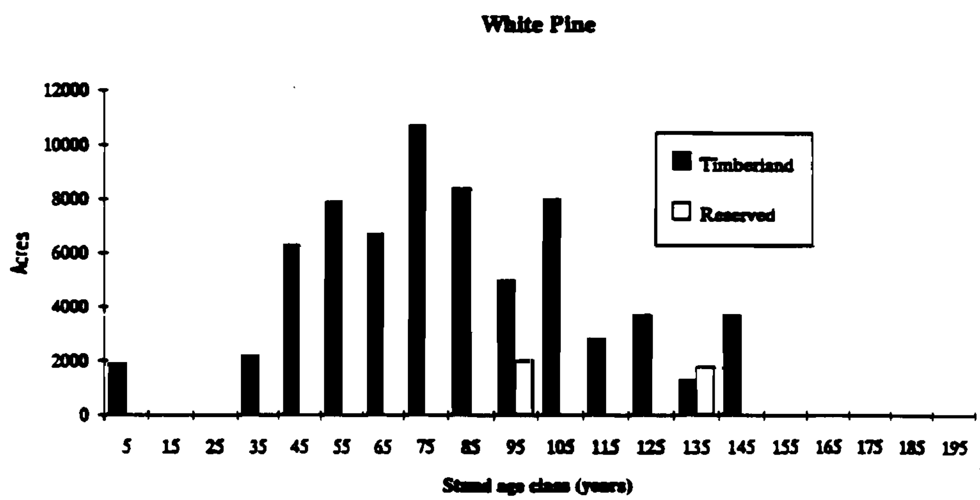


Figure 2.3. Age class distribution of jack pine and white pine forest types for FIA timberland and reserved forest, 1990.

Red Pine

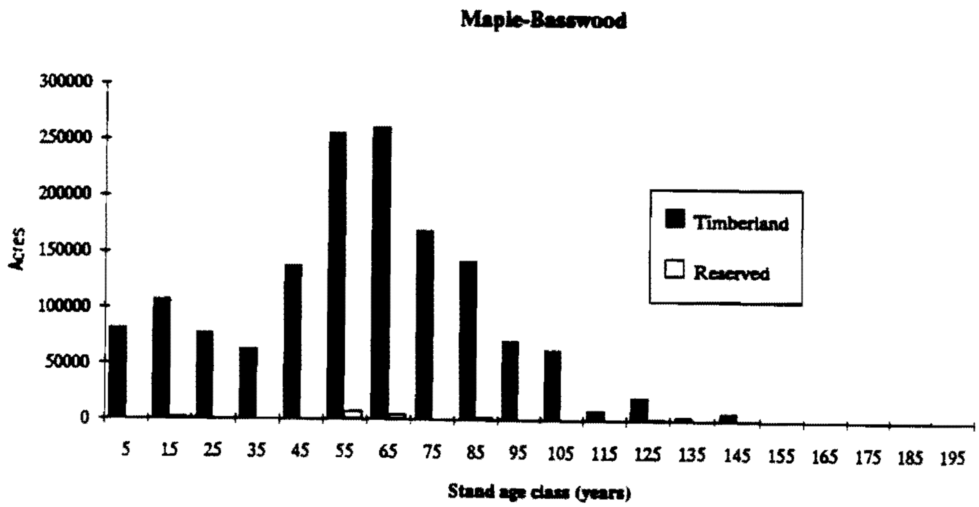
Red pine acreage is reduced compared to presettlement times, but planting for many decades shows up in recent inventories. Stands in Minnesota are typically young and the area planted still small. However, red pine is an important source of timber because of its rapid growth, ease of stand establishment and relative freedom from insect and disease problems. Red pine grows best on well-drained sandy to loamy soils, but it can grow and is planted on a much wider range of sites.

White Pine
White pine was *the* major timber species of the 19th century. However, logging followed by extensive land clearing, fires and blister rust disease greatly diminished its numbers and preclude broad-scale reestablishment. White pine is one of the largest trees found in northern forests and is important aesthetically. It may be found singly or in groups in many forest conditions, but large stands are no longer common. The actual covertype shows a wide range of age classes in the timberland category, but few stands in the youngest age classes. Young or replacement stands in reserved areas are virtually nonexistent (see figure 2.3). This suggest the need for active management to perpetuate this species.

Black Spruce
The black spruce type occupies about ten percent of the state's forest area. It has been an important pulpwood species for many decades. Most older black spruce forests owe their origin to wildfire and so tend to be even-aged. However, as older trees die, younger trees may fill in and stands can become uneven-aged. The age class distribution indicates a wide range of ages with most stands being in the 45- to 75-year range. The fact that substantial acreage exists in the younger age classes on timberland suggests that past management has been at least moderately successful in achieving regeneration following harvesting. A high proportion of the acreage is in older stands, which suggests a large number of stands are either difficult to access or harvest. Harvest levels for black spruce have been well below the sustainable level. Also, approximately half of the formerly unproductive acreage of this covertype appears to have been reclassified in 1990 to timberland.

Maple-basswood
The maple-basswood forest type acreage on timberlands is dominated by stands from 50 to 70 years of age (see figure 2.4). This is typical of stands that developed in the early part of this century after logging and following the decline of agriculture. Like several other hardwood forest types, low demand has led to an unbalanced age class distribution with few younger stands present. The reserved forest acreage in this type is small and concentrated in the middle to older age classes in the central and southern portions of the state. The species comprising the covertype are generally shallow rooted, long-lived and respond to release or disturbance to advanced ages. Two site quality situations are recognized: (1) stands largely composed of sugar maple on well-drained sites, and (2) less well-drained or excessively drained sites with significant amounts of red maple and other hardwood species. Stands in the first category have the potential to grow

sawtimber. Stands in the second category are typical of sites where tree form is poor and sawtimber quality is low. With time these stands can become uneven-aged. This covertype has a rich overall tree species composition compared to most pioneer covertypes.



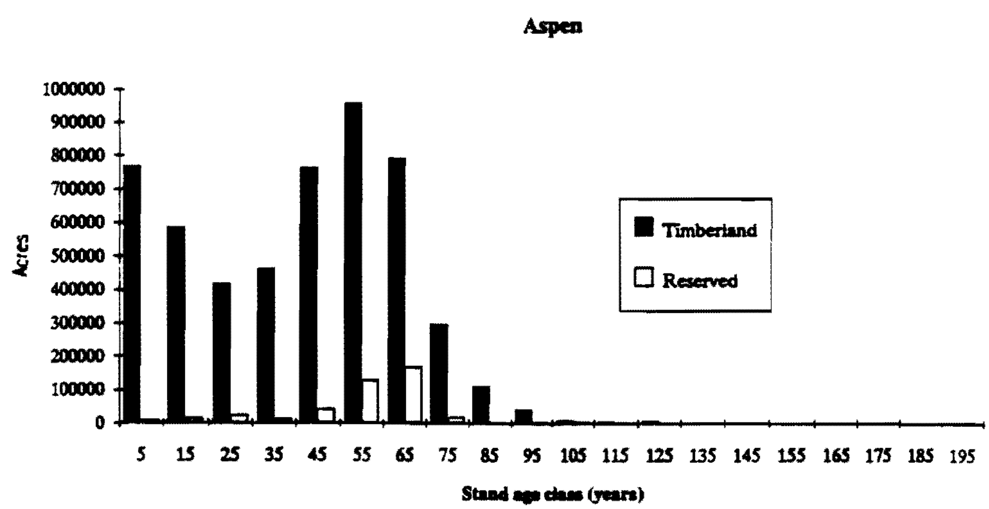


Figure 2.4. Age class distributions for FIA maple-basswood and aspen forest covertypes for timberland and reserved forest, 1990.

Aspen

Aspen is a fast growing but short-lived tree species that typically reaches maximum timber volume production in the 25- to 50-year age range. Beyond that, growth diminishes and mortality and decay losses can reduce stand yields. However, in the northern part of the state, stands are capable of growing to more than 100 years of age. Individual trees may far exceed that. Like other types, most of the present stands originated in the first half of this century. Some observers have referred to this as a *wall of wood* moving to older age classes. However, harvesting over the last 20 years has led to a more balanced distribution of acres by age class, i.e., harvesting of older stands followed by prolific natural regeneration by suckering has led to development of substantial acreage of younger or replacement stand acreage. As shown by figure 2.4, there is a shortage of acreage in 25- and 35-year-old age classes, raising concerns about the adequacy of aspen timber supply in the period 2010–20. In managed stands, rotation ages are typically shorter than 50 or 60 years. The acreage of older stands suggests that these stands have not been utilized for one or more of the following reasons: lack of demand; inaccessibility or unavailability due to insufficient stumpage prices or constraints placed by owners. Silviculturally, this is also a concern because older stands on many sites do not sprout and regenerate well. Thus how these stands are managed and harvested over the next several decades will have a large impact on the continuity of timber supplies for major industries. The age class distribution of aspen is also considered important for wildlife, particularly game species that are favored by early successional stages of vegetation. The current large acreage of this type insures that it will be a major factor in both timber and nontimber management efforts for many decades.

Balsam Fir

Balsam fir is a short-lived species, very tolerant of overstory competition and a common understory tree. In this covertype, white spruce, birch and aspen are common associated species. At times the type has been called spruce-fir. Like many other types, most stands originated in the first half of this century and the majority of trees and acreage are in the pole size class. Lack of markets has contributed to the buildup of stands in the older age classes. Stands in reserved areas are also aging and will likely become an uneven-aged spruce-fir forest unless disturbed by fire or the spruce budworm.

Northern White Cedar

The acreage of northern white cedar has increased steadily since the 1930s. However, there has been comparatively little harvesting in this covertype. This is reflected in the large proportion of stands found in the older age classes. Stands in reserved areas are generally the older age classes. High quality cedar is in demand and there is some harvesting of this species, but most of it appears to come from cedar found in other covertypes. This type may be increasing with natural succession and by the removal of other species, leaving a residual that is then dominated by cedar. The actual harvest of the cedar covertype is small because many mature stands do not have enough high quality timber to support a commercial harvest (Johnston 1977b).

Tamarack
This type has an approximately balanced stand age class distribution to age 95, then less acreage in older stands. In the 1990 survey, approximately one-third of the acreage formerly classified as unproductive was reclassified as timberland.

White Spruce
This species occurs as scattered individuals within natural stands of other types, usually on better soils. Large stands are uncommon. Much of the current type acres on timberlands are actually plantations established steadily over the last 50 years. Consequently, the stand age class distribution is well-balanced up to age 60. However, planting and regeneration efforts seem to have diminished in recent years, largely because of increased utilization of aspen.

Oak-hickory
Oaks grow in association with many other species. Based on interpretation of the age class distributions, most oak stands in Minnesota became established after 1900. This was partly due to fire control following settlement and also due to the decline in agriculture, particularly livestock grazing. The fact that the majority of the acreage is in mature or older age classes has contributed to the high rate of harvest in this type. The current young stand age class acreage is clearly insufficient to replace the current acreage of older stands. The distribution of reserved acreage suggests a similar problem. The mature stands left uncut will likely be lost through succession to another forest type. In the case of harvesting, regeneration problems may also lead to other species assuming dominance.

Elm-ash-soft maple
This covertype shows a considerable acreage gain since the 1977 survey. This is a type that often follows willows and cottonwoods. The timberland acreage gain is probably due to young stand development and the successional movement of stands from other classifications to this type category. In addition, much of what was formerly classified as unproductive was apparently reclassified as timberland in 1990.

Paper Birch
Paper birch is a pioneer species. Many stands were established in the early part of this century after fire. Historically, demand for this species has been low, compared to other species. Thus the timberland age class distribution

shows a high proportion of acreage in mature age classes. The age class distribution for paper birch on reserved forest land shows a similar pattern.

Balsam Poplar
This species occurs commonly in mixture with birch, spruce, aspen, elm and ash. On timberland, the stand age class distribution is fairly well-balanced from young to mature age classes.

2.3.4 Stand Size

The stand size in acres reflects natural forces affecting regeneration such as fire history. Other activities such as past harvesting, regeneration and management are also reflected in stand size. Table 2.10 summarizes stand size as reported in the FIA database. Actual values represent a combination field and aerial photo based estimate. Though these methods do not provide a precise measurement, the estimates do permit some examination of trends as might be developed in detailed stand mapping efforts. The table suggests stand size varies by covertype and ecoregion, with the more heavily forested regions having the largest average stand size. Overall stand sizes appear small, less than 20 acres for most forest type and ecoregion combinations.

Table 2.10. FIA average stand size in acres by covertype and ecoregion for timberland (acres).*

Forest Type	Ecoregion						
	1	2	3	4	5	6	7
Jack pine	12.4	9.3	22.6	10.4	1.0	4.0	10.0
Red pine	11.1	14.3	27.0	9.5	6.0		
White pine	12.8	9.6	27.5	7.6	10.9		10.0
Black spruce	20.5	10.0	10.6	10.6	6.0		
Balsam fir	10.2	12.6	10.8	8.4			160.0
Northern white cedar	19.4	15.4	17.8	12.3			11.7
Tamarack	22.0	10.0	29.9	10.3	9.5		45.6
White spruce	12.9	9.0	7.5	12.0	5		
Oak-Hickory	14.8	78.5		9.6	8.6	11.6	7.4
Elm-ash-soft maple	12.0	4.7	13.5	8.3	5.2	7.3	4.6
Maple-Basswood	26.1	13.7	50.9	10.2	6.9	7.2	6.0
Aspen	14.4	13.9	25.2	11.3	7.3	3.9	6.8
Paper birch	13.9	18.2	20.3	11.2	19.1	7.8	2.0
Balsam poplar	8.62	5.8	12.9	10.1	9.1		8.6

* Since stands (but not plots) were selected with probability proportional to size, table values were developed by dividing total acreage within a cell by the total number of stands the sampled stands represented. This is equivalent to a probability weighted average, i.e., an unbiased estimate of average acreage.

This pattern has important implications for both timber and nontimber variables. Note that stand size corresponds roughly to the average logging site area or treatment unit size used in Minnesota, as identified in the Harvesting Systems background paper (Jaakko Pöyry Consulting, Inc. 1992e). However, the average logging site area was 32 acres, suggesting that many such sites include several nearby stands or that larger stands have been favored for harvesting. It is important to note that substantially more than half of the acreage and volume harvested comes from stands of larger than average size.

2.3.5 Stocking

The stocking variable in the FIA data has a precise but abstract definition. FIA definitions given in appendix 7 list definitions corresponding to five stocking classes. Acreage of these classes is summarized in table 2.11 by FIA unit for 1990. Examination of the table suggests that 60 percent of the forest is at less than full stocking in terms of growing stock trees.

Table 2.11. Area of timberland by FIA unit and stocking class of growing stock trees in 1990.*

FIA Unit	All classes	Nonstocked	Poorly stocked	Moderately stocked	Fully stocked	Overstocked	Percent Fully stocked or overstocked
Aspen-birch	5,878.7	94.3	945.1	1,939.5	1,824.8	1,075.0	49.3
Northern pine	5,975.5	103.3	1,143.3	2,288.9	1,681.4	758.6	40.8
Central hardwoods	2,275.4	51.9	706.5	1,092.1	355.4	69.5	18.7
Prairie	643.8	21.1	187.3	287.6	103.5	44.3	23.0
All units	14,773.4	270.6	2,982.2	5,608.1	3,965.1	1,947.4	40.0
Percent of acres	100	1.8	20.2	38.0	26.8	13.2	

* This table is based on stocking percent of growing stock trees rather than all live trees. To use definitions of stocking for this table, replace the term *all live* by *growing stock.*

A more commonly used measure of site occupancy is stand density expressed as basal area per acre. Table 2.12 describes this measure by covertype for a range of stand age classes. To the extent that these values are below those considered optimal for growth, they suggest increasing stand density as a means to improve productivity. As a guide for interpretation, values less than 90 at ages greater than 40 suggest understocking.

Specific stocking levels depend on desired end products and rotation ages and can vary depending on owner objectives. In this technical paper, *understocking* implies less than full utilization of the growing space for timber production objectives. Preferred stocking levels could differ in stands managed for recreation or wildlife objectives.

Table 2.12. Average stand basal area by covertype and stand age class for timberland, 1990.*

Forest Type	Stand Age Class 5	15	25	35	45	55	65	75	85+
	square feet per acre								
1 Jack pine	13.2	25.0	63.8	99.5	95.0	93.8	99.5	101.6	95.9
2 Red pine	9.2	41.7	99.5	97.2	117.8	133.3	114.4	117.4	117.0
3 White pine	58.0	–	–	81.9	125.3	139.8	92.1	83.6	112.1
12 Black spruce	10.9	28.8	36.5	55.8	60.8	72.9	78.0	76.1	80.5
13 Balsam fir	22.4	49.4	60.3	71.0	90.4	91.9	100.0	91.5	101.3
14 Northern white cedar	10.4	34.0	44.5	77.9	114.6	104.5	102.9	124.7	122.2
15 Tamarack	7.3	20.3	38.8	44.0	47.5	58.7	71.7	65.7	67.6
16 White spruce	4.0	17.6	45.9	77.5	88.7	101.2	108.6	51.2	83.0
50 Oak-hickory	25.7	37.6	56.6	66.1	85.0	97.9	94.9	97.7	100.1
70 Elm-ash-soft maple	30.4	28.7	43.1	61.8	69.0	79.6	86.9	84.2	97.4
80 Maple-basswood	27.7	44.2	61.8	61.7	89.1	105.6	105.2	105.6	105.6
91 Aspen	21.7	44.8	62.1	80.4	90.9	98.2	100.0	102.3	111.0
92 Paper birch	27.5	31.3	34.1	72.6	88.4	97.4	94.3	102.0	94.7
94 Balsam poplar	22.4	33.6	46.7	54.3	70.6	94.3	87.7	99.4	95.2

* Shaded cells suggest understocking.

2.3.6 Volumes and Production

The standing volume of timber growing on Minnesota timberland has increased significantly over the last four decades (table 2.13). The increase has occurred in both softwoods and hardwoods but is of greater magnitude in hardwoods. The increase is a function of the regrowth of the forest to larger average tree size classes, and that is also reflected in the sawtimber volumes shown in the table.

Incomplete historic data indicate that the increase in growing stock volume has occurred in all ownership categories but has been most dramatic on private lands and public lands *not* included in the national forest system. Sawtimber volume increases do not show this pattern as clearly.

Pulpwood and Sawlog Production in Minnesota

Production of pulpwood and sawlogs from Minnesota's forests have increased dramatically since 1955 and 1960 (tables 2.14 and 2.15). By species, the largest percentage increases occurred in the production of aspen pulpwood (sixfold), other hardwoods pulpwood (tenfold) and oak sawlogs (threefold). More of this wood was used by Minnesota industries in 1987 compared to 1955 or 1960 (i.e., less is being exported to industries outside the state) with the exception of oak, particularly red oak.

Table 2.13. Growing stock volume and sawtimber volume on timberlands in Minnesota by softwoods and hardwoods (million cubic feet).

Year	Growing stock (million cubic feet)			Sawtimber (million board feet)		
	All Species	Hardwood	Softwood	All Species	Hardwood	Softwood
1990	15,091	10,460	4,631	34,657	22,489	12,168
1977	11,455	7,978	3,477	24,608	16,077	8,531
1962	9,444	6,060	3,384	14,875	8,742	6,133
1953	7,235	4,406	2,829	12,538	7,499	5,039
1936	6,903	3,652	3,251	12,455	5,867	6,588

Source: Data by year obtained from: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1977=Jakes 1977; 1962=Jakes 1977, Stone 1966; 1953=Cunningham et al. 1958; 1936=Cunningham and Moser 1938. The 1936 results utilize different standards than later surveys.

Inspection of tables 2.14 and 2.15 also indicates a significant shift in industry demand from reliance on softwoods to heavy use of hardwoods, particularly aspen over the period 1955-90.

Table 2.14. Pulpwood production from roundwood and net imports/exports in Minnesota by species group (thousand standard cords, unpeeled).

Year	Total		Pine		Other Softwoods		Aspen		Other Hardwoods	
	prod. vol.[a]	im./ex. vol.[b]	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.
1990	2,278	not av.	138	not av.	386	not av.	1,658	not av.	96	not av.
1987	1,964	44	111	4	221	30	1,578	0	54	10
1985	1,790	96	137	2	242	52	1,361	41	50	1
1980	1,236	248	150	44	324	102	699	86	63	16
1975	1,251	157	199	30	379	68	616	56	57	3
1965	1,013	109	181	(24)	323	125	468	6	41	2
1955	886	163	218	41	393	152	266	(32)	9	2

Source: USDA Forest Service 1991a.

[a] Production volume.
[b] Net import or export volume. Imports are in parentheses ( ).

Table 2.15. Sawlog production and net imports/exports in Minnesota by species group (thousand board feet).

Year	Total		Pine		Other Softwoods		Red & White Oak		Aspen		Other Hardwoods	
	prod. vol.[a]	im./ex. vol.[b]	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.	prod. vol.	im./ex. vol.
1988	307,155	1,147	97,909	(11,056)	14,169	2,177	57,255	7,820	82,496	(34)	55,326	2,240
1985	243,910	(503)	70,740	(4,796)	6,812	(29)	51,334	4,346	65,559	(224)	49,465	200
1980	230,740	4,407	65,639	580	13,165	0	25,766	1,406	80,789	(113)	45,381	2,534
1975	156,123	3,273	51,010	1,332	9,913	273	18,542	1,156	49,501	103	27,157	409
1960	168,110	6,767	65,236	5,042	10,890	542	19,180	596	37,587	1	35,217	586

Source: USDA Forest Service 1991a.

[a] Production volume.
[b] Net import or export volume. Imports are in parentheses ( ).

2.3.7 Growing Stock Volume Dynamics

The status of Minnesota's forest with regard to the growing of timber can be characterized using growing stock volume dynamics obtained from the FIA survey. Growing stock volume considers only those trees that satisfy typical size and quality standards for merchantability and then only the utilizable portion of those trees. The volume dynamics (rate of resource change) is often more informative than current status. The rate of resource change has three components: *net growth, mortality,* and *removals*. Net annual growth of growing stock is defined as the annual change in volume of sound wood in live sawtimber and poletimber trees and the total volume of trees entering these classes as ingrowth, less volume losses resulting from natural causes. Analysis of current status and change in that status across different species groups, areas of the state, and ownership categories can be useful as a way to identify management concerns and opportunities. The relevant data for species groups is presented in tables 2.16, 2.17, 2.18 and 2.19. Aside from oak and aspen, hardwoods have been divided into two categories; hard and soft hardwoods. The hard category includes sugar maple, ash, elm and associates; the soft category includes basswood, birch, soft maple, etc. The components described in the tables below were constructed from data provided by Kingsley (1991), Murray (1991), Leatherberry (1991), and Roussopoulous (1992).

Table 2.16 indicates that in 1990 Minnesota's timberlands supported over 15 billion cubic feet of growing stock volume. Softwood species constituted 30 percent of the total and hardwood species made up the remaining 70 percent.

Over 30 percent of the total volume was in aspen species.[1] The two FIA units in northern Minnesota contribute 95 percent of the state's softwood volume and nearly 75 percent of the hardwood volume. Nearly 90 percent of the aspen resource is in these FIA units. The central hardwood FIA unit contributes a large hardwood component, approximately 20 percent of the state's total hardwood volume, which includes approximately 50 percent of the state's oak volume. While aspen is approximately half of the hardwood species volume in Minnesota, nonpine softwood species, primarily spruce and fir, constitute nearly 70 percent of the softwood total. Assuming the timberland acreage in table 2.1, the average volume per acre is 1,021 cubic feet per acre.

Table 2.16. Net volume of growing stock trees on timberlands by species group and FIA unit, 1990 (million cubic feet).

	FIA Unit				
Species group	Aspen-birch	Northern Pine	Central Hardwood	Prairie	All Units
Jack, red, white pine	475	835	81	2	1,393
Other softwood	2,044	1,109	76	9	3,238
Total softwoods	2,519	1,944	157	11	4,631
Oaks	22	532	801	145	1,499
Other hard hardwoods	402	696	415	111	1,624
Aspen	1,790	2,285	455	152	4,681
Other soft hardwoods	875	1,130	503	148	2,655
Total hardwoods	3,089	4,642	2,174	555	10,460
All species groups	5,608	6,586	2,331	566	15,091

Average net periodic annual growth of Minnesota's timberlands (as determined from the period 1977-90) averaged 2.4 percent of 1990 growing stock volume (table 2.17). That is approximately 25 cubic feet or 0.31 cords per acre. This annual growth is highly dependent on site and stand conditions including age class structure. This annual growth calculation is also somewhat lower than current annual growth, an alternative growth definition used by FIA and others for many forest management purposes. Averaged across all FIA units, aspen and pine species exhibit higher growth rates than the other species (2.8 and 3.1 percent, respectively). The table also shows that growth rates in the northern portion of the state tend to be higher than those in the south.

[1] Here aspen species includes quaking aspen, bigtooth aspen, and balsam poplar. For wood processing purposes the three are readily substitutable.

Growth rates depend on many other factors, of course, such as age structure and stocking levels.

Table 2.17. Average net annual volume growth of growing stock trees on timberland by species group and FIA unit, 1977–90 (million cubic feet) and percent () for all species groups.

Species group	FIA Unit				
	Aspen-birch	Northern Pine	Central Hardwood	Prairie	All Units
Jack, red, white pine	12.9	26.9	3.5	0.1	43.4
Other softwood	42.8	23.5	2.0	0.4	68.8
Total softwoods	55.8	50.5	5.5	0.5	112.2
Oaks	0.7	14.7	15.5	2.3	33.2
Other hard hardwoods	9.3	13.9	5.3	0.9	29.4
Aspen	49.2	64.0	14.3	4.9	132.4
Other soft hardwoods	17.3	26.7	12.8	3.1	59.9
Total hardwoods	76.4	119.3	47.9	11.3	254.9
All species groups	132.1 (2.4)	169.8 (2.6)	53.4 (2.3)	11.8 (2.1)	367.1 (2.4)

Annual mortality of growing stock over the last 12 years averaged nearly 1.5 percent of 1990 growing stock volume (table 2.18). While this may seem low, it should be recognized that this is more than 50 percent of net growth. In the hardwoods group, loss of elm to Dutch elm disease has exacerbated mortality figures to a small degree, but the loss due to mortality is high. As a percent of growing stock volume, annual mortality is fairly balanced with respect to location in the state and species group.

Annual removals from growing stock over the last 12 years averaged about 207 million cubic feet (table 2.19) (roughly 2.6 million cords). Removals include products harvested, logging residue, etc. (see appendix 7 for a detailed definition). For softwoods, removals averaged around 50 percent of net periodic annual growth while for hardwoods the comparable figure was 60 percent. Aspen species have undergone the highest utilization rates, and approximately 70 percent of net periodic annual growth is harvested. Small differences exist between FIA units when removals are expressed as a fraction of growth. The other soft hardwoods group, as well as softwoods in general, seem to be underutilized from a production standpoint.

Comparison of the estimates of volumes removed versus volume lost to mortality shows that for most hardwoods and softwoods more growing stock volume is lost to mortality than is harvested. The exceptions are the oak and aspen species groups.

Table 2.18. Average annual mortality of growing stock trees on timberland by species group and FIA unit, 1977-90 (million cubic feet) and percent () for all species groups.

Species group	FIA Unit				
	Aspen-birch	Northern Pine	Central Hardwood	Prairie	All Units
Jack, red, white pine	4.1	6.9	0.6	0.0	11.6
Other softwood	35.5	18.4	1.0	0.0	55.0
Total softwoods	39.6	25.3	1.6	0.1	66.5
Oaks	0.0	2.5	5.4	0.4	8.4
Other hard hardwoods	4.5	11.6	12.0	3.7	31.8
Aspen	28.5	43.1	9.4	3.6	84.6
Other soft hardwoods	10.1	11.2	5.7	1.2	28.3
Total hardwoods	43.2	68.5	32.4	9.0	153.1
All species groups	82.8 (1.5)	93.8 (1.4)	34.0 (1.5)	9.1 (1.6)	219.6 (1.5)

Table 2.19. Average removals of growing stock trees on timberland by species group and FIA unit, 1977-90 (million cubic feet) and percent () for all species groups.

Species group	FIA Unit				
	Aspen-birch	Northern Pine	Central Hardwood	Prairie	All Units
Jack, red, white pine	8.9	11.8	0.4	0.0	21.1
Other softwood	22.7	9.4	0.1	0.0	32.3
Total softwoods	31.7	21.2	0.5	0.0	53.3
Oaks	0.1	4.5	11.1	1.8	17.5
Other hard hardwoods	3.5	4.2	7.1	1.6	16.4
Aspen	35.6	48.2	6.9	2.8	93.5
Other soft hardwoods	11.9	9.8	4.3	0.9	26.9
Total hardwoods	51.1	66.7	29.3	7.2	154.2
All species groups	82.8 (1.5)	87.9 (1.3)	29.8 (1.3)	7.2 (1.3)	207.6 (1.4)

Table 2.20 describes growing stock volume by land ownership class. For the state as a whole, national forest, state and counties each account for approximately 15 to 20 percent of total volume. NIPF ownership is 40+ percent statewide of growing stock volume, and ranged from 24 to nearly 90 percent by survey (FIA) unit.

Table 2.20. Net volume of live and growing stock trees on timberland by ownership class and FIA unit, 1990 (million cubic feet).

FIA unit	Ownership Class						
	National Forest	State	County	Other Public	Forest Industry	Other Private	Total
Aspen-birch	1,358	1,115	1,224	161	415	1,336	5,609
Northern pine	743	1,229	1,422	518	248	2,426	6,586
Central hardwood		316	70	88	6	1,851	2,331
Prairie		47	8	10		501	566
All units	2,101	2,707	2,724	777	669	6,114	15,092

Net periodic annual growth estimates nearly mirror those of growing stock volume when broken down by ownership, i.e., percent growth figures are nearly constant across ownerships (table 2.21a). The one notable exception is forest industry lands, which appear to support slightly higher growth rates under current management.

Table 2.21. Average net annual growth and removals on timberland by ownership class and FIA unit, 1977-90 (million cubic feet).

a) growth

FIA unit	National Forest	State	County	Other Public	Forest Industry	Other Private	Total
Aspen-birch	30.9	24.4	28.9	3.1	10.6	34.1	132.0
Northern pine	19.1	29.9	35.1	11.6	8.1	66.1	169.9
Central hardwood		7.7	1.4	1.8	0.1	42.5	53.5
Prairie		1.5	0.3	0.2		9.8	11.8
All units	50	63.5	64.7	16.7	18.8	152.5	367.2

b) removals

FIA unit	National Forest	State	County	Other Public	Forest Industry	Other Private	Total
Aspen-birch	21.1	17.8	15.9	1.3	11.9	14.7	82.7
Northern pine	16.1	12.3	20.2	3.4	6.5	29.4	87.9
Central hardwood		2.2	0.6	0.1		26.9	29.8
Prairie		0.2	0.1		0.1	6.8	7.2
All units	37.2	32.5	36.8	4.8	18.5	77.8	207.6

Removals are broken down by ownership in table 2.21b. National forest, state and county lands each contribute 16 to 18 percent of utilized wood. Forest industry lands contribute a greater share of removals than their volume status or growth rate would suggest, though removals do not exceed growth. Perhaps more significant is that other private owners as a whole have (over the last 12 years) contributed *their share* of removals both in terms of volume and growth rate of their timberlands. This indicates that even if attitudinal differences and philosophies toward harvesting exist between the different classes of owners, such differences have not been strongly reflected in removal levels for the different land ownership classes.

2.3.8
Changes Since the 1977 Inventory and Trends

Previous sections have documented the most important changes since the 1977 inventory. These are (1) a slight increase in total forest acreage, (2) an increase in the overall timberland acreage (largely due to the reclassification of formerly unproductive forest land to timberland), (3) aging of the forest, and (4) an increase in timber size and standing volume coincident with that aging. Growth continues to exceed removals for most species groups and covertypes, but the gap is narrowing. Species groups where removals exceed growth are jack pine and elm. The elm situation is the result of losses due to Dutch elm disease.

Table 2.22 contrasts net volume growth and removals for surveys back to 1936. Despite an increase in absolute growth and the increase in mortality relative to growth, the decline of growth percent in recent years is indicative of a maturing forest. Most covertypes show unbalanced age class distributions, which means timber yields and resource characteristics will continue to change for some time. Harvesting and/or other management provides some options to direct the changes in terms of species age class structure or covertype composition of the forest.

Finally, when interpreting growing stock tables, it is important to note that this classification includes only about 87 percent of the live trees in the inventory (see table 2.23). This percentage varies by survey unit and is generally lower for hardwoods than conifers and the southern survey units. Compared with the 1977 survey, the 1990 survey shows more timber in large size classes and correspondingly higher average tree quality (a higher percent of growing stock) in the north. The southern units appear to show a higher percentage of dead trees, perhaps due to insect and disease problems of elm, oak, etc., and the 1987 drought.

Whether or not harvest and management are expanded and intensified, the forest continues to be subject to disturbances that change its character. Using the FIA stand history data, table 2.24 provides an estimate of those changes as observed from the 1990 inventory.

Table 2.22. Comparison of average net annual volume growth, mortality and removals from 1936, 1953, 1962, 1977 and 1990 from original survey reports (million cubic feet) for growing stock.[a]

	Year	All		Hardwoods		Softwoods	
			Percent[b]		Percent		Percent
Net growth	1990	367.1	2.4	254.9	2.4	112.2	2.4
	1977	348.9	3.0	229.1	2.9	119.8	3.4
	1962	364.2	3.7	257.4	4.2	106.8	3.0
	1953	384.6	5.3	267.0	6.1	117.6	4.2
	1936	373.1	5.4	229.1	6.3	144.0	4.4
Mortality	1990	219.6	1.4	153.1	1.5	66.5	1.5
	1977	141.5	1.2	107.8	1.4	33.7	1.0
	1962	111.0	1.1	55.6	0.9	56.4	1.6
	1953	173.0	2.4	105.0	2.4	68.0	2.4
	1936	95.4	1.4	57.2	1.6	38.2	1.2
Removals	1990	207.6	1.4	154.2	1.5	53.4	1.2
	1977	193.6	1.7	124.8	1.6	68.8	2.0
	1962	125.6	1.3	63.1	1.0	62.5	1.7
	1953	154.2	2.1	76.2	1.7	78.0	2.8
	1936	161.3	2.3	82.9	2.3	78.4	2.4

Source: 1990 = Kingsley (1991), Murray (1991), Leatherberry (1991), Roussopoulous 1992; 1977 = Jakes (1977); 1962 = Stone (1966); 1953 = Cunningham et al. (1958); 1938 = Cunningham and Moser (merchantable trees).

[a] Estimates vary by procedure and assumptions for each survey area thus these values are only approximately comparable. See appendix 7 for definitions of key terms.
[b] Percent of survey report growing stocking volume.

These table values are imprecise and many incorrectly state disturbance of various kinds, partly because many of the undisturbed plots and some other categories of plots were not visited on the ground. Disturbance can also vary by covertype and type of ownership. Nevertheless, the table values are still helpful in understanding change by creating a rough picture of changes occurring in the forest over the last decade. If stand history codes 0 and 9 (no disturbance and natural regeneration of nonforest land) are combined it is apparent that approximately 79 percent of the timberland was undisturbed in the last ten years. Of the 21 percent (2.1 percent per year) that was changed or disturbed, more than half of that change can be attributed directly to human activity. The 2.1 percent per year implies an overall 47-year cycle

Table 2.23. Timber classes by FIA unit in percent of volume* (thousand cubic feet).

Class of Timber	FIA Unit Aspen-birch	Northern pine	Central hardwoods	Prairie	All units
1990					
Growing stock trees	92.2	89.7	77.0	69.5	87.4
Cull trees	6.8	9.2	20.3	25.7	11.1
Salvable dead trees	1.0	1.1	2.7	4.8	1.5
1977					
Growing stock trees	91.5	86.5	86.9	84.5	88.4
Cull trees	7.9	12.3	12.4	15.4	10.7
Salvable dead trees	0.6	1.1	0.7	0.1	0.8

Source: 1991 = Kingsley (1991), Leatherberry (1991), Murray (1991), Roussopoulous (1992). 1977 = Spencer and Ostrum (1979), Jakes and Raile (1980), Vasilevski and Hackett (1980), Hahn and Smith (1980).

* Percent of all live and dead tree salvable volume.

Table 2.24. Stand history code summary by land use as estimated from ground visits and aerial photo interpretation of FIA plots (percent of acres impacted over last 10 years)[a].

Code / Disturbance	Percent of Acres Impacted by Land Use: Timberland	Reserved Forest	Unproductive Forest
0 No disturbance	78.81	99.13	96.93
1 Grazing	2.22	0.08	0.49
2 Timber stand improvement	0.31	0.00	0.07
3 Commercial clearcut	5.25	0.00	0.00
4 Partial harvest cut[b]	3.24	0.00	0.12
5 Natural disturbance (fire, insects, disease, wind)	8.21	0.62	2.22
6 Disturbance by human activities (other than harvest)	0.52	0.17	0.17
7 Planting of forest land	0.76	0.00	0.00
8 Planting of nonforest land	0.13	0.00	0.00
9 Natural regeneration of nonforest land	0.55	0.00	0.00
Total	100.00	100.00	100.00

[a]FIA procedures instruct field crews to identify only those disturbances that have occurred in the last 1 to 5, 6 to 10, 11 to 15 and 16 to 20 years. Since many disturbances are more difficult to determine with time, this study emphasizes those occurring in the last 10 years, i.e., those considered to be most accurately assessed. Additionally, to be counted, a disturbance must be evident on five or more of the ten sample points comprising a plot.
[b]Less than 50 percent of the merchantable stems have been removed.

of disturbance of change for timberland, i.e., some type of stand disturbance like those in table 2.24 occur, on average, every 47 years. Alternatively, this implies that an average of 314,328 acres are disturbed annually. For comparative purposes, the area reported as harvested annually in the Silvicultural Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992c) was 199,828 acres over the period 1990–91. Using codes 2, 3 and 4 as evidence of harvesting over the last ten years indicates that, on average, 0.88 percent of the timberland or 130,000 acres were harvested each year for the last decade. Further, harvesting at this level would imply a 114 year cycle of disturbance due to harvesting. Given that this latter acreage figure is an average over a ten-year period, and is therefore expected to be lower than the 1990–91 harvest acreage, the estimates of overall disturbance rates are credible.

3
ALLOWABLE CUT AND SUSTAINED YIELD CONCEPTS

3.1
Concepts in Planning Allowable Cuts and in Estimating Sustained Yield

3.1.1
Definition of Allowable Cut and Sustained Yield

"The organization and control of growing stock for a sustained yield of forest products from a specific forest area has traditionally been called forest regulation" (Meyer, Recknagel, Stevenson and Bartoo 1962). Forest regulation lies at the heart of forest management. It involves the use of the tools of management such as site, stocking, structure, growth and yield. It also involves the size and timing of timber cuts.

Forest regulation utilizes the concept of sustained yield. The Society of American Foresters has defined sustained yield management as

> "Management of a forest property for continuous production with the aim of achieving, at the earliest practicable time, an approximate balance between net growth and harvest, either by annual or somewhat longer periods."

Today the concept of sustained yield is not only concerned with the continuity of growth and yield, but also the continuity of goods and services from the forest. Managing a forest for sustained yield requires maintenance of the productive capacity of the forest.

The focus of this discussion is on timber only. The importance of nontimber aspects of Minnesota's forests are introduced later when operational constraints and mitigation strategies to reduce negative environmental impacts of timber harvesting are formally considered. Also, detailed aspects of nontimber concerns are the focus of other technical papers.

Even flow is frequently misinterpreted as being synonymous with sustained yield. Even flow regulation requires that management plans establish a periodic allowable cutting rate, with the objective of providing an even flow of timber in order to encourage the stabilization of communities and opportunities for employment. Thus, even flow cannot be practiced separately from sustained yield. However, sustained yield can be practiced separately from even flow.

Both sustained yield and even flow policies employ the concept of a fully *regulated forest*, i.e., a forest that has an equal number of acres in each age class and no age class older than the desirable rotation age (see also definition in appendix 1). When forest inventories are unbalanced and sustained yield is an objective, a key question deals with the time period over which unbalanced timber inventories should be converted to sustained yield, i.e., how fast full regulation is to be achieved. Economic and environmental considerations play an important role in this decision. Imposing an even-flow constraint on harvest volumes during the conversion period often implies making substantial economic and/or environmental sacrifices.

This question cannot be answered without looking at the various implications for different conversion speeds. If surplus volumes exist, one strategy might be to liquidate the surplus as quickly as possible, providing that market prices are good and the total surplus could be sold without depressing prices. Cash earned from selling the surplus timber could be invested to earn interest. This strategy may be the best from a purely financial point of view. On the other hand, when prices are assumed to grow rapidly, it probably would pay to convert surplus volume more slowly.

Sustained yield is a rough guide to potential harvest from a forest property after it has been fully regulated. The target forest and its associated sustained yield will depend on a number of factors including: selected rotation age, management intensity, utilization standards, and technical changes. These factors in part reflect market conditions and the owner's personal objectives. Since these factors change over time, the target forest as well as the associated sustained yield will change. A fully regulated forest remains an ideal that is seldom achieved by a single enterprise, much less across an entire state.

3.1.2 Major Forest Regulation Techniques

Determination of an allowable cut is one of the most important decisions a forest manager makes. The rate of harvesting has far-reaching consequences for the total forest enterprise. The allowable cut is typically calculated for a specific period, utilizing the most current inventory information, and is revised periodically. Allowable cut is composed of both intermediate (thinning) and final (clearfelling) harvests.

Major considerations concerning the allowable cut are

- total volume that should be cut;
- cutting sequence of stands;
- species, size, and quality; and
- spatial arrangement of cuts.

There are many different approaches to the determination of the cut. All are based on the common regulatory principle that, if the actual volume of the forest is equal to the desired size class distribution, then the actual yield on a sustained yield basis may be equivalent to the actual growth (Recknagel, Stevenson, and Bartoo 1962). If the actual volume is below the desired level, the cut is kept below growth to provide for the accumulation of additional growing stock. The reverse is true when the reserve is larger than desired.

The following are general approaches to allowable cut determination:

1. area control;
2. volume control;,
3. combined area and volume control; and
4. modern operations research techniques, including linear programming and heuristic simulation.

Area Control

The principle of area control is very simple. This method determines the allowable cut in terms of volume, on the basis of acres assigned for cutting. Specifically, the area cut per year equals the total acres divided by rotation. Since volume must occupy area and area available directly determines volume, calculating allowable cut in this manner is quite logical.

Volume Control

In volume control, the allowable cut is determined by the conditions of the existing growing stock and often the growth of the growing stock. There are over 200 different volume control models worldwide, which serve a common purpose: to bring an unbalanced, unregulated forest into a regulated condition. The allowable cut is based primarily on estimates of the current growing stock volumes and growth, compared to the same quantities on a fully regulated forest. The principle behind this is to harvest what the forest can grow on a sustained yield basis once the forest is regulated; but in the meantime to harvest above or below the growth, depending on whether there is a surplus of growing stock volume over desirable growing stock volumes. In the case of a surplus, the annual harvest is some measure of the growth plus some part of the volume surplus liquidated over some time period. In the case of a growing stock deficit, harvest is less than growth in order to build up growing stock volumes.

Combined Area Plus Volume Control
Some methods exist that combine the advantages of area control and volume control. The Tabular Check method is an example of such a method. It determines via an iterative process an allowable volume cut that harvests the existing inventory exactly once each rotation.

Modern Methods
Timber regulation problems are solved more and more by using linear programming and heuristic simulation. An example of the first is Timber RAM (Resources Allocation Model) developed by the USDA Forest Service (Navon 1971). Other examples are the Allowable Cut Evaluation System (ACES) developed by Rose (1991) and DUALPLAN (Hoganson and Rose 1984).

Simulation models have been used extensively in forest management to estimate maximum harvest levels that can be maintained over time. All these models are concerned with determining how much timber can be harvested and tend to ignore the problem of scheduling specific stands for treatment; they either assume a simple scheduling rule or require one as a model input. The key to models is the way they rank stands or stand treatments. Devising a method of prioritizing alternatives is the major difficulty in developing a simulation model for timber management scheduling. The prioritizing method must be responsive to the changing conditions of the forest over time. It must be sensitive to the relative levels of timber demand and supply and how these relative levels change over time. Specifically, it must be capable of determining when management needs to gear up and invest heavily in regeneration activities, and when management can cut back and rely on existing inventories. To be responsive in this sense, it seems that some sort of adjusting mechanism or tuning process is essential for prioritizing alternatives within the simulation process.

Simulation models used for determining allowable cut levels mimic management by actually harvesting and growing stands over time. Each period they rank stands and harvest until the current estimate of the allowable/desirable cut is reached. This approach has several inherent problems. First, forests contain multiple products. There is not one simple harvest level to achieve each period. Harvesting an individual stand usually produces timber for several products. Meeting cut levels for all products simultaneously can be difficult. Another problem with the fixed-time step method is in recognizing the many options available for individual stands, as well as the long-term impact of those actions. The situation is not always so simple as deciding whether or not to harvest. Thinning as well as clearcuts are possible. Furthermore, full tree chipping, traditional roundwood operations, and chip and sort systems are all considered clearcuts, yet each yields significantly different products and total volumes.

Different owners utilize different levels of sophistication in the calculation of allowable cuts. The MNDNR, counties and BLM basically utilize an area control method. The national forests by law are utilizing a sophisticated linear programming model called FORPLAN. Industry is still using simple area or volume control techniques, but is shifting more and more to optimization methods such as linear programming. NIPF owners generally do not calculate allowable cuts in a very scientific manner.

3.1.3
What's Behind an Allowable Cut Estimate?—Applicability to Statewide Planning

People unfamiliar with forestry often view the term *allowable cut* as a single, hard and fast number that describes the limit on the volume of timber that can be harvested without causing detriment to the forest. Few people realize that there is no generally accepted definition of an allowable cut let alone a generally accepted method of estimating it. As identified in the previous section, assumptions concerning *future* forest management can have a dramatic impact on *today's* allowable cut estimates.

The basic objective behind most allowable cut estimates is to select a harvest level that will help move the forest toward an ideal state, a forest that will produce a continuous flow of forest products over time, with harvests each year offset by forest growth. This concept dates back to the beginning of professional forest management. Hundeshagen's method for estimating the allowable cut, a simple formula method, was developed in 1821 and is still used by some land managers today.

In theory, the concept of an allowable cut is simple and appealing. In practice, many complicating factors make allowable cut estimates, especially those based on simple formulas, a very general management guide at best. To understand some of those factors let's consider some simple questions that have enormous implications on the allowable cut.

What is the ideal future forest management state? Many factors complicate the answer to this question. As discussed in section 3.1.4 (factor 18), the level of forest management intensity can influence the quantity and quality of the forest products. When estimating an allowable cut does one assume a maximum investment of $2 per cord to produce timber or an investment of $50 per cord? In most cases, greater investments will lead to greater production and thus greater allowable cuts. Most public agencies have been conservative in these types of assumptions, probably making their allowable cut estimates well below that which could be achieved if funding opportunities were not limited. The *ideal* state becomes more of a *desired* state that can be maintained under a limited budget.

Forests produce a variety of timber products as well as nontimber products such as recreation and wildlife. Should an allowable cut be calculated for each product? That would seem to be appropriate; however, the production level for one product influences the production potential of other products because they all share the same land base. What is the best mix of products? Should it be assumed that today's mix is the best mix? Maybe the answer is to simply produce an equal *allowable value* of products over time. But would predominantly red pine sawtimber in one period and red pine pulpwood in the next period be acceptable? By ignoring product value differences, the focus is on the quantity harvested and not the quality left for future periods.

What is the cost of achieving the ideal state? Allowable cuts that move a forest to the ideal state can limit potential returns from the forest during the conversion period. Lost revenues can be large. Some argue that a better policy might be to give more attention to capturing returns during the conversion period, redirecting them back into a forest management program. In effect, the additional revenues would be used to help overcome the budget constraints that limit the definition of the ideal state.

How is changing technology accounted for? Nine factors that could increase the allowable cut are described in section 3.1.4. Of these, two (13 and 20) reflect the potential for technology to increase yields. Research will likely influence both the cost of production and the value of forest resources. For example, aspen was once a weed tree in Minnesota, and now more aspen is cut than any other species. The introduction of genetically improved species could increase allowable cut levels tremendously in the future. Price differentials in the market are also likely to lead to incentives to develop new uses for underutilized but abundant species. It is grossly simplified to assume that current values and production requirements are precise estimates of future conditions. Utilization of other marginally commercial species will likely increase. Increasing income and populations could lead to increases in demands.

How should an allowable cut be implemented? Assuming an allowable cut estimate for a property is accepted, how should it be implemented? Certainly private landowners have their own objectives and time preferences as to when and if to harvest. If private lands produce an uneven flow of forest products, should public forests be managed to help counterbalance that flow? Minnesota has large publicly-owned forests controlled by federal, state and county government. Should these agencies coordinate their management or should each estimate their own allowable cut independent of allowable cuts on other lands?

Allowable cut estimates have been of less significance in the past because harvest levels have been below levels that can be maintained, even with relatively little forest management. Today, allowable cut estimates are becoming more of a focal point with very little understanding of how they are estimated. Perhaps it is time to shift focus toward the opportunities and tradeoffs of alternative management strategies, thereby influencing the allowable cut. New methods for analyzing alternatives, coupled with computer technology, allow resource analysts to learn more about potential management alternatives. Translating this information to people concerned about the forest is important. It cannot be accomplished simply by reporting a single estimate of the allowable cut.

3.1.4 Factors Influencing Allowable Cuts

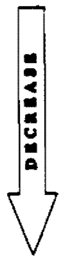
Many factors influencing the level of the allowable cut are illustrated by figure 3.1 and table 3.1. Most mitigative actions for increasing timber supply can be found among the factors listed in that figure. A conscious decision to emphasize other amenities would require additional considerations.

Factors Decreasing the Allowable Cut

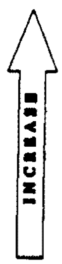
1 Land clearing
The forest resource is reduced by transferring forest land to other land uses such as agriculture, urban developments, mining, etc. Based on FIA estimates (table 2.4), in the period 1962 to 1977, changes in land use reduced the area of Minnesota forest land by nearly 10 percent while during the period 1977-90 the net total area of Minnesota forest land did not change.

2 Fire
Forest fires have historically been a serious threat to the U.S. forests. Minnesota does not normally face a major threat from fires, although fires in the past have reduced the forest asset.

3 Pests and diseases
Average annual mortality of growing stock trees on timberland averaged nearly 440,000 cords annually during the period 1977-90 (table 2.18). This is roughly 10 percent of the current annual harvest level. The most common cause of mortality was disease. In the past, insect attacks have caused serious damage. Older, slower growing trees are especially susceptible to insect and disease attacks.



1. Land clearing (loss of forests to agricultural and urban uses)
2. Fire
3. Pests and diseases
4. Nutrient losses
5. Soil erosion
6. Soil compaction
7. Inadequate or overstocked regeneration
8. Reservation of productive areas (conservation, wilderness, recreation)
9. Lack of management/investment
10. Inefficient harvesting (low utilization of resources)
11. Suboptimal rotation age or cutting cycle (too long or too short)
12. Low wood and timber values (decrease investment in forestry)



13. Improved utilization (product development, harvesting techniques)
14. Increased productive area (motivate owners, afforestation)
15. Improved regeneration and stocking
16. Control of fire, pests and diseases
17. Improved access and road systems
18. Intensified forest management (thinning, fertilization, etc.)
19. High wood and timber values (increase investment in forestry)
20. Increasing proportion of fast growing species (site matching, plantations)
21. Conversion of overmature stands

Figure 3.1. Factors influencing allowable cut of timber.

Table 3.1. Comparison of actual versus estimated potential average net annual volume growth per acre by ownership (cords per acre per year).

Ownership	Cords per Acre			
	Actual 1970-90[a]	Estimated Potential[b]	Potential Increase	Percent Increase
National forest	.35	.69	.34	98
State	.26	.68	.42	160
County	.33	.79	.46	142
Forest industry	.32	.77	.45	142
Other private	.30	.73[c]	.43	143

[a] Computed by dividing table 2.21(a) by table 2.6 values.
[b] Source: MNDNR Division of Forestry and 1977 USDA Forest Service FIA.
[c] Weighted by acreage of *farmer* and *other private* categories.

4 Nutrient losses
A nutrient loss can occur under certain conditions; for instance, if certain species are used over generations on vulnerable soils. If no ameliorative measures are applied, this could lead to a reduction in the productive capacity of the site.

5 Soil erosion
Due to its relatively mild topography, soil erosion is not a major problem in Minnesota, but local damage can occur as a result of careless road building or logging. Loss of soil can lead to a reduction in site productivity as well as other water quality impacts.

6 Soil compaction
Use of heavy machinery with high ground pressure tires can lead to serious compaction of certain forest soils, particularly when soils are wet. This hinders the trees from making full use of the site, which leads to reduced growth and in extreme conditions, death of the retained trees. The majority of the soils in Minnesota do not seem vulnerable to soil compaction, but this will be further verified.

7 Inadequate or overstocked regeneration
Most of the forests in Minnesota are regenerated naturally through seeding from retained trees or by shoots from the stumps and roots of harvested trees. If not properly tended, such regeneration becomes too dense under favorable conditions, and in other parts fails to create a satisfactory cover. Both tendencies lead to reduced growth. Where trees are too dense they take longer to develop commercial dimensions. Where there is scattered regeneration, the trees do not utilize the full productive potential of the site.

8 Reservation of productive areas
There is a growing concern worldwide to reserve forest areas for conservation and recreation purposes. On the U.S. west coast this has led to drastic reductions of 20 to 40 percent in the allowable cut. According to the 1990 FIA survey estimates (table 2.5) 6.66 percent of all forest land is reserved in Minnesota.

9 Lack of management/investment
To some degree, management decisions for all landowners are related to economic factors. Investments in reforestation are difficult for some owners to justify, based on current timber prices. Many nonindustrial landowners are also reluctant to invest because of the long production period involved. With many areas relying on natural regeneration, full growth potential will not be realized.

10 Inefficient harvesting
Present stem harvesting systems tend to leave substantial quantities of wood in the forest. Alternative harvesting systems could recover this component of wood, especially in thinnings where all trees are small. It also applies to the small trees in a clearcut. The terrain in Minnesota is suitable for mechanized short wood systems, which could further reduce the logging losses. Total removal of biomass, on the other hand, could lead to productivity declines due to excessive nutrient removal.

11 Suboptimal rotation age
The mean annual volume increment, i.e., the average rate at which trees grow, varies over age; there is a sharp increase during the young ages, a maximum, and then a gradual reduction. The maximum volume production from a site with even-aged trees of a particular species is obtained when the trees are harvested at the time the mean annual increment has reached its maximum. Recreation and wildlife considerations sometimes lead forest managers to extend the rotations. This factor will be considered in the scheduling model. If the final cut of the stand is done before or after the time of maximum annual increment, the total production over a rotation is potentially reduced, thereby reducing the allowable cut. The sustained yield analysis described in section 5.11 revealed that for Minnesota species the impact of rotation age changes on sustainable yields is quite small for the long-term, but rotation lengths can influence the potential harvest level over the transition period to a regulated forest.

12 Low wood and timber values
Low prices for timber products tend to decrease investments in all aspects of forest management. Owners may also manage for other benefits (nontimber) for which relative value increases may be higher.

Factors Increasing the Allowable Cut

13 Improved utilization
Better utilization of the forest resource can be achieved mainly through two actions:

- Technological development of processes that can economically utilize all species and sizes of wood. For example, paper birch is often left in the forest after harvest.
- Development of harvesting and transport systems that more efficiently handle small-sized wood (see point 10 above).

14 Increased productive area
The productive forest area can be increased by:

- Shifts into forestry from other land uses, such as less productive agricultural land. Some fiscal incentives would probably be needed to get farmers interested, as the value of wood at present makes it difficult for them to justify such long-term investments.
- Educating and activating some NIPF owners, who otherwise would leave their forests unmanaged. This could be done by forming Forest Owners Associations (FOA) which could strengthen the owners' economies of scale and bargaining position and lead to a more rational utilization of the forest resource. An FOA could achieve the following:

  - common marketing of the forest produce,
  - service to the owners for managing their forests according to economic criteria, and
  - contracting service at competitive costs for harvesting the forests.

  The initial financing of the FOA would have to come from the owners, but in the long-term the FOA could be self-supporting by selling its services to the owners. In a situation with oversupply of some species, the FOA could also take on a role as wood processor by investing in appropriate industry and thereby creating new markets for surplus wood.

15 Improved regeneration and stocking
By utilizing more planting as a regeneration technique the new forest is given a quicker start. Genetically improved material can be used which will further improve productivity. Weed control can significantly improve establishment success and can improve early growth rates leading to higher average annual yields.

Similar benefits can be achieved by tending natural regeneration with precommercial thinnings where defective trees are removed, creating a spacing that will increase growth on the remaining trees. Prices currently do not generally support precommercial thinnings.

16 Control of fire, pests and diseases
The allowable cut can be increased if these destructive agents are controlled. The pests and diseases can be controlled by:

- Keeping the forests vigorous and healthy through intensive forest management, with thinnings carried out so they do not damage remaining trees. The thinnings should always remove weak and damaged trees which are a potential harbor for fungus and/or insect attacks.
- Avoiding storage of harvested wood with bark in the forest during the period when potentially damaging insects are multiplying.
- Regenerating fungus infected stands with species that are less vulnerable to the specific fungus.

- Avoiding creating wounds on the tree stems by pruning, etc., which can be an entry point for insects or fungi of the type that causes oak wilt.

17 Improved access and road systems
Some productive forests are still economically out of reach because of lack of proper roads. In many cases, prices may not support roading investments and the negative impacts of road building also need to be considered.

18 Intensified forest management
More intensive management of forests can increase the yield from the forest estate and, therefore, the allowable cut. In the end it will be economic, environmental, and political considerations which decide how intensively particular forests should be managed. Examples of yield increasing activities are:

- Regular thinnings.
- Fertilization. Trials have shown a growth increase of 30 percent during an 11-year period after fertilizing aspen stands with nitrate. In well-situated, high value stands fertilizing can be very profitable.

Intensive forest management is sometimes detrimental to other forest values such as biodiversity and a rich wildlife.

19 Increase wood and timber values
The price paid for standing aspen pulpwood in Minnesota (stumpage) is less than one-tenth of what is paid in, for example, Scandinavia. This is likely to be the result of a long tradition of abundant forest resources. Given the current timber price conditions in Minnesota it is difficult to justify regeneration investments based on standard return on investment criteria. Without a substantial increase of stumpage values, the forests of Minnesota are unlikely to develop to their full productive potential.

Increased stumpage values would provide important incentives and resources needed to achieve more intensified management.

20 Increasing proportion of fast growing species
By gradually replacing unproductive forests with high yielding species adapted to the local conditions and soils, the overall production of the forests can be increased substantially. An intensive genetic improvement program and species/provenance-to-site-matching are crucial to such development.

21 Conversion of overmature stands
The conversion of slow growing, overmature stands to young, faster growing stands increases potential future harvest levels. The harvest also utilizes standing timber before mortality and/or decay render the wood unmerchantable.

3.2 Forest Resources Planning Technologies

3.2.1. Characteristics of Forest Resources Planning

A number of characteristics, especially long time horizons and associated uncertainty, make land and resource planning a difficult and challenging undertaking. Land use alternatives involve biological processes and require long planning horizons. New and complex questions have been raised by the phenomena of acid rain and global warming. The potential impacts on the productivity of land resources and their ability to provide desired goods and services need to be understood. Complex global interrelationships and changing technologies are making many aspects of the future unpredictable, especially in relation to the time frame involved with growing timber. Notwithstanding these complexities and difficulties, forest management decisions still must be made today. Decisions made today can strongly affect future options for management. Thus, information is needed for all planning periods and more importantly, information from the various stages needs to be linked for effective decisionmaking. This complexity requires the utilization of sophisticated models, designed to answer specific questions. The costs of poor decisions to society can be substantial, and these costs justify research efforts to improve planning models.

There is no one model that can deal with all aspects of forest planning, and for everu model selected for use there are equally good alternatives. Models are simply abstractions of reality. However, models can have an enormous value as learning tools. For forest management, their use dates back to the simple forest regulation models of the 1800s developed in Europe. Basically, these early models described the ideal forest and the process of converting the forest to the ideal state. Many of the concepts of these models are still the backbone of some forestry programs in this country. However, questions have arisen as to whether the ideal future state for the forest and associated costs of achieving it can be identified. Economic efficiency has become a major concern. Fortunately, with the advent of the computer and constantly improving computer technologies, more complex models can be applied to help guide decisionmaking.

The term *harvest scheduling model* is the most common term used to describe the computer models used to aid forest management decisionmaking. This expression is very misleading because these models are not used just for scheduling harvests. Besides being used to help develop a management schedule for a specific forest, *scheduling models* can help analyze forestry opportunities in a number of additional ways. They can help to:

1. predict future timber availability for alternative industrial expansion opportunities at specific plant locations;
2. predict the impact of alternative industrial expansion opportunities on the timber procurement costs for existing forest industries;
3. determine the impact of alternative forest management budget levels;
4. evaluate management policies such as even flow or designated wilderness or recreation areas;
5. evaluate the potential forestwide or regionwide impact of new or more intensive forest management practices such as improved genetic stock, short-rotation intensive culture, or thinning or fertilization options; and
6. evaluate the potential impact of new forest harvesting systems or changes in timber utilization standards.

3.2.2 Important Aspects of Forestry Problems

The most difficult process of modelling a problem is the process of *structuring the problem* or describing its key factors in a mathematical form. For most forestry problems it is difficult to determine how much emphasis should be given to these various factors, which are often interrelated. Potentially important interrelated factors that occur in most forest wood supply or yield problems include:

1. multiple forest products;
2. differences in stand characteristics;
3. future production opportunities including nontimber opportunities;
4. alternative management intensities;
5. multiple harvest systems;
6. multiple ownerships with differing objectives;
7. changing land base;
8. growth and yield uncertainties;
9. stand accessibility;
10. multiple products in each stand;
11. multiple markets;
12. long production periods;
13. spatial interactions;
14. limited resources for management;
15. forest policy guidelines or directives;
16. sequential decisions;
17. alternative timber uses;
18. distance to market;
19. uncertain timber demands; and
20. imports of timber supplies from other regions.

It should be clear from this list that it is impossible to develop a model that can accurately describe and account for all factors. Many involve uncertainty and for others data may be limiting. Therefore, models focus more on practical aspects and make assumptions to account for others. In all cases, models are abstractions of reality. Hence all forest regulation models are extremely simplified when compared to reality.

3.2.3 Major Modelling Difficulties

Difficulties are associated with each step of the modelling process, from data collection and model formulation through to application and interpretation of results.

Data collection
Most models are extremely data intensive. Data is required for all the important aspects of the problem. This usually includes information on the existing forest inventory; growth and yield projections including estimates for natural regeneration; and harvest, transport, roadbuilding and regeneration costs.

Model formulation
The three most challenging aspects of modelling forestry problems deal with: (1) the spatial elements of the problem, (2) uncertainty as it relates to the basic data and the sequential nature of decisions, and (3) the large size of the problem. Spatial elements of the problem are difficult for two reasons. First, because of the potential interactions between stands, alternatives for neighboring stands need to be considered simultaneously. This does not necessarily increase the size of problem, but it adds considerable complexity. Second, the locations of stands relative to specific markets for products harvested can add another, very large dimension to the problem and make the number of potential management options for some stands enormously large.

Considering that most data used in the modelling process has an element of uncertainty, it is not surprising that uncertainty is a problem. For many aspects of uncertainty, very little information is available for developing confidence intervals on estimates or probability estimates for possible outcomes. The need to recognize uncertainty is well documented in the literature, but few methods are available for addressing it explicitly. Uncertain futures and the need to keep options open are well recognized, but uncertainty is difficult to model because of its many aspects (Hoganson and Rose 1987). Other considerations include attitude towards risk and the utility of the potential outcomes. For example, are landowners interested in maximizing expected return, or is the landowner more concerned about the consequences of a worst case outcome? In general, problems are generally large even when the future is assumed to be known. Current modelling methods can recognize some simplified aspects of uncertainty, but even that usually requires a significant increase in both model size and complexity.

Model size is also a problem. Model formulations must often be simplified to keep formulations of practical size. A common problem is to develop a method for classifying the stands and aggregating the data to meet model size limitations. Balancing the emphasis given to each aspect of the problem is difficult with few guidelines available. Generally, the classification scheme can limit the usefulness of the model. Unfortunately, the classification scheme used must be identified at the beginning of the modelling process, when it is often unclear what questions are most important. Later, after more is learned about the problem, one can always go back and make changes, but changes can be costly because of the work required in data collection and synthesis.

Application and interpretation of results
In terms of application and interpretation of results, it is important that users understand the model being used, especially the critical assumptions or weaknesses of the model. Unless users fully understand the model, it is unlikely that they will understand how much they should rely on the model or even how they can best utilize it.

3.2.4
Strategies for Simplifying Problems

Models must be simple enough to be useful, yet no one model can be developed to answer all questions. The scope of modelling efforts can range enormously. One might want to *minimize* costs for a single mill or *predict* future timber supplies for an entire region. In each case, the overall objective, scope of analysis and time frame are likely to be significantly different. However, it is likely that many different models can share information and model components. Models can also be linked so that results of one model can serve as input to another model. As an example, the estimated prices describing regional concerns from a regional model could be very useful as price inputs to help recognize regional concerns in more site specific models. There is a danger of oversimplifying in an attempt to break down the problem and solve it in parts. For example, it is difficult to separate harvest decisions from regeneration decisions, so separate models for harvest decisions and regeneration decisions are unlikely to work well. When breaking problems down into subproblems, it is important that the linkages and associated assumptions are clear and their implications understood.

Another key aspect in model development and use is the understanding of exactly how the model will be used to help make decisions. For example, it is important to recognize which decisions will need to be made before more information becomes available. In general, it is desirable to give more emphasis in the model to the immediate future with the idea that more analyses can be performed later for decisions that are not needed immediately. Also, it is important to recognize that multiple model runs are almost always needed to test model assumptions. To test some new assumptions considerable savings might be possible by starting the solution algorithm from an intermediate or even final solution for a prior set of assumptions. In some cases it might be possible to automate the process of performing a sensitivity analysis concerning assumptions. The final solution often contains an enormous amount of useful information besides an *optimal* solution or schedule. This is especially true with linear programming models, which are probably the most widely used models in forestry.

3.2.5
Desirable Characteristics of Planning Models

Discussions concerning land and resource planning technologies must consider the appropriateness of specific tools, and also assess which type of question(s) can best be addressed with which kind of model. Data requirements, model integration, and output interpretation are other important aspects. Development of flexible, easily used tools is essential.

Improving computer technologies have enabled the development of more complex models that help guide decision making by synthesizing greater amounts of information into a form that is easier to interpret. Expert systems could be extremely useful in the modelling process. By incorporating an understanding of the problem into the modelling process, the problem size can be reduced because it will never need to be specified or enumerated completely. This has already been applied by Hoganson and Rose (1984) to some extent in both their solution process and in their methods for valuing ending inventory. Database and GIS, linked with planning models, should also enhance planned abilities to work with large amounts of data and to recognize spatial problems (Rose et al. 1988). Land use planning is constrained by the availability of data and new data collection efforts are required. Satellite imagery is certain to play a major role in the near future in the inventory process and will help overcome many of the data problems related to land use.

As described previously, the most difficult process of modelling a problem is the process of structuring the problem, or describing the key aspects of the problem in a mathematical form. A number of general rules can be stated concerning the adequacy of a selected model to answer specific questions:

1. The more complex the question, the more complex the model required;
2. The more complex a model, the more information required to run it. The trade-off between cost of information and collection and improvement in decision making ability needs to be examined;
3. The simpler a model, the more assumptions needed concerning external factors that are outside the control of the model; and

4. The simpler the model, the less can be predicted or estimated about the outside world.

Two key, yet somewhat contradictory, characteristics describe a good planning model:

1. The model must be complex enough to give a good description of the real world. Unless the problem described by the model is a good description of the real problem, solutions or insights gained from the model are not likely to apply to the real world.

2. The model must be simple enough to be useful. In other words, it must be simple enough so that users can understand the critical assumptions, understand how the model works, and collect the necessary input data. It must not be so time consuming or costly to run that users cannot test the potential impact of the various assumptions.

3.2.6 Linear Programming (LP) Models

Land and resource planners today have access to vastly better tools than were available only a few decades ago. Simplistic formula methods for calculation of allowable timber cuts have been replaced with mathematical programming and simulation procedures. Has land use planning become better with the increased sophistication of planning technologies? The answer to this depends on how available models are being applied in specific cases.

In selecting a general model form, models have the general characteristics (strengths and weaknesses) of the form selected. For forestwide or scheduling problems the two most common forms are linear programming (LP) models and simulation models. LP models are desirable because they can find optimal solutions for the problem as formulated, but model size is a problem for many forestry applications. Simulation models are better suited for recognizing more complex relationships, but simulation models do not solve problems, they only mimic the situation. Recently Hoganson and Rose (1984) developed a modelling approach that uses some of the general characteristics of both model forms. Essentially the method breaks down the model into smaller problems and uses simple search techniques and a economic interpretation of the problem to search for the key variables of the problem. Using this approach a large model does not necessarily imply a complex model because the large problem is broken into parts, each of manageable size. A general description and example of this relatively new and specialized modelling method is given by Johnson and Davis (1987).

All LP approaches to management scheduling can be classified into two categories: Model I and Model II (Johnson and Scheurman 1977). The basic difference between these two models is their definition of an activity or a decision variable. In Model I the identity of the management unit is preserved throughout the entire planning period, but in Model II this identity is only maintained from the regeneration time to the first harvest. All areas harvested at the same time are combined to form a new management unit. Although the number of decision variables in Model II is smaller, more constraints are required. Several excellent historical accounts of the development of planning models in the USDA Forest Service exist (Iverson and Alston 1986, Jones 1986, Iverson 1986). A number of papers dealing with the development and implementation of FORPLAN in the USDA Forest Service can be found in Hoekstra et al. (1986).

FORPLAN (Johnson, Jones, and Kent 1980) has surfaced as one of the most sophisticated and widely used tools for forest planning since the first LP applications in forestry appeared. FORPLAN, Version 1 and forerunners of this model such as the Timber RAM, a Model I structure developed by Navon (1971), and MUSYC (Multiple Use Sustained Yield Resource Scheduling Calculation), a Model II formulation developed by Johnson and Jones (1979), emphasized a single resource or timber.

Stochastic LP was introduced to provide solutions to formulations that are best described by random variations of key variables such as insect and disease incidence. This technique has undergone rapid development over the last two decades, but its major drawback is its major assumption of the normal distribution of model parameters which does not always hold, especially in resource allocation problems (Sengupta 1972). Stochastic LP formulations also increase model size, which is already a major concern for deterministic applications.

Goal programming was invented for multi-objective problems when LP, a single-objective model, with other objectives included as constraints, did not generate feasible solutions. This infeasibility of LP is related to the unidimensionality of the objective function which needs to be optimized (maximized or minimized) within all given constraints that are to be satisfied. One way to cope with this problem is to combine all goals into one by converting their values into one criterion, namely utility. In practice, this is not an easy matter, and there is no effective methodology for developing such a utility function.

3.2.7 Major Limitations of LP Models

Many questions have been raised as to the adequacy of LP models as long-range planning tools (Chappelle et al. 1975). FORPLAN has been the subject of several critical evaluations (Walker 1982; Apple 1982; Rose 1984; Hoekstra et al. 1987; Bailey 1986; Kent and Davis 1988). At the same time, many plans of individual national forests have come under intense attack by public and private agencies and individuals, and are being challenged in the courts.

The limitations of the modern LP approach to planning are not so much inherent in LP itself, but in the technical limitations imposed on planners by even the largest computers and the exponential increase in solution costs of increasingly large LP problems. A high level of aggregation of stand data is required, therefore, in most LP formulations for land use planning. For public land management agencies the complexity of the planning process has been increased with the multiple use considerations required by law. This has also increased the degree of uncertainty and the need for more complex sensitivity analyses. Uncertainty also calls for increased flexibility in management plans. Optimal solutions derived for such highly aggregated models are very sensitive to changes in assumptions. Thus, optimal solutions implemented in the short-run could easily turn out to be nonoptimal. Unfortunately actions are often also irreversible. It is difficult or impossible to derive operational plans from aggregated models that can be easily and effectively implemented by the forest practitioner. The high costs of generating optimal LP solutions have also stood in the way of using sensitivity analysis to deal with questions of uncertainty.

3.2.8 Heuristic Simulation Models

Simulation models have recently received more emphasis because new heuristic simulation approaches that have overcome some of the problems of LP based models are now available. Bullard and Klemperer (1984) make the case for the use of heuristics or inexact solution techniques in forestry. Hof and Pickens (1986) describe an approach to utilizing local planning analyses as inputs in developing large-scale resource management plans. Their approach did not appear to closely emulate a global optimization in terms of local output solution values or budget allocations across local planning units, but represents an example of research needed to overcome the problems associated with solving large LP models.

Simulation models are better suited than LP models for recognizing more complex relationships. Simulation models, however, do not solve problems, they only mimic the situation. Developing a method of prioritizing alternatives is the major difficulty in developing a simulation model for land management scheduling. Good heuristic rules have not been identified for the forest management problem. The prioritizing method must be responsive to the changing conditions of the forest. It must be sensitive to the relative levels of timber demand and supply and the way these relative levels change. Among the better known simulation models is TREES (Timber Resources Economic Estimation System) by Tedder et al. (1980a).

As previously mentioned, Hoganson and Rose (1984) developed a modelling approach that uses some of the general characteristics of both simulation and linear programming. It overcomes several of the major problems associated with the use of LP, such as the need for data aggregation and associated problems of model sensitivity and the difficulty in linking strategic with tactical and operational planning. Essentially the method breaks down a Model I or II formulation of the management scheduling problem into smaller problems, and uses simple search techniques and an economic interpretation of the problem to search for the key variables of the problem. Using this approach a large model is broken into parts, each of manageable size. With this approach a large number of stand types can be recognized, and recognition can be given to the significant differences between stands.

The key to the acceptance of this new approach lies in the supporting theory for the prioritizing method used to rank stand treatments. It takes advantage of the special characteristics of management scheduling problems. The approach is based on the economic interpretation of the key dual variables of an LP formulation of the problem. Solutions can be derived for highly disaggregated model formulations. The much smaller degree of sensitivity of optimal action plans to changes in assumptions is an additional advantage of the disaggregated model. The approach makes it possible to combine individual compartment planning with forestwide strategic planning and to develop optimal solutions at the same time. These solutions can be generated at extremely low costs and have been derived for real cases, including several thousand individual stands (Hoganson and Rose 1984). Plans incorporate relevant knowledge about the inventory, the larger economic environment, and the uncertainty in which management decisions are being made.

This approach has been adapted for use in this project. The following section describes the DUALPLAN/DTRAN models and their application to the task of generating the three harvesting scenarios as part of the GEIS study process.

4
METHODOLOGY AND DATA USED

4.1
Work Scope

The work of this study group was of fundamental importance to the GEIS.

Specific questions were to be addressed:

1. What allowable timber harvest rates are sustainable for major Minnesota forest types?
2. What harvest rates are possible for sustaining economic activity based on pulp, fuelwood and quality sawtimber products?
3. What is the relationship between current and future estimates of sustainable timber supplies and the demands expected for the supply of such timber?
4. Are there classes of landowners, geographic regions or forest types where timber harvest rates may be expected to exceed allowable timber harvest rates or biological growth?
5. If needed, what strategies can be implemented to assure the perpetuation of a renewable forest resource?
6. What are the impacts of these strategies and what forest conditions will result from their implementation?
7. To what extent do timber harvesting and management activities impact the abundance, composition, spatial distribution, age class structure, genetic variability and tree species mixture (for example, in creating forest monocultures) of Minnesota's forests (based on reliable information)? To what extent are changes in these characteristics specifically attributable to timber harvesting and management of certain forest landowner categories?
8. What methods are used (or could be used) to estimate allowable harvest rates?
9. Are there seasonal differences in timber demand and supply?
10. To what extent have changes occurred in the size and composition of Minnesota's forest land base?
11. What were the major factors contributing to this change?

Most of these issues were directly addressed through existing data, the planning model that was utilized in this study or the interpretation of model outputs. Some issues were addressed outside the study group. The seasonality of supply and demand is addressed in the Harvesting Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992e).

The study group made use of the latest (1990) FIA inventory data to analyze the current resource status. Based on this evaluation, it developed a schedule of harvest and forest management activities that could potentially meet prespecified production requirements. The productive potential and therefore the long-term sustainable yield potential of Minnesota forests were examined for different time periods under different levels of investments in forestry practices, and for different ownerships and regions. This part of the study was started after the study group had developed a clear understanding of the existing resource base, as well as an understanding of how this has been shaped by past actions. The results served as the basis for estimating the potential of the forest resource to produce various levels of timber outputs and the associated costs of producing these outputs. The scheduled activities by time period and by location provided the basis for doing an impact analysis including environmental and economic impacts and the assessment of impacts on other resource uses.

Forest management schedules were developed using the DTRAN scheduling model (Hoganson and Kapple 1991). Separate model formulations were constructed to examine each of three scenarios describing future harvest levels. Initial model applications focused on timber production with summaries of results in management schedules used by other study groups to help develop potential mitigative strategies. Mitigative strategies as suggested by existing and developing agency policies and practices were then incorporated into a second set of model applications for each of the three harvest level scenarios.

The marginal cost of producing the targeted timber output levels for each scenario is an important result from the scheduling model. These cost estimates reflect the changing conditions over time as a result of the assumed harvest levels. Separate marginal cost estimates were developed for each of four product groups in each of six market centers in northern Minnesota. Differences in marginal cost estimates between the different model runs reflect the potential impact of harvest levels and mitigative measures on the cost of timber production. Differences in marginal cost estimates between forest product groups reflect relative supply differences between the groups.

Another important aspect was the evaluation of potential impacts on the forest management scenarios brought about by increased uses of recycled fiber in Minnesota. Input from the background paper on recycled fiber was used to assist in this exercise.

To utilize the proposed methods, access to three basic sources of information was required: (1) the 1990 FIA forest survey data, (2) growth and yield models, and (3) data on management costs. While shortcomings in all three data sources could be listed, these shortcomings did not invalidate the results of the modelling efforts. Nevertheless caution needs to be exercised when interpreting outputs. The modelling efforts provide guidance to ways information could be improved in the future and where the highest priorities are for undertaking additional data collection.

4.2 Information and Data

The following data were used for this element of the study:

1. The current level of harvesting in Minnesota by product and ownership category.
   Source: MNDNR Division of Forestry

2. The location and productive capacity of existing and projected wood-based industries drawing on Minnesota's forest resources.
   Source: MNDNR Division of Forestry; forest industry associations; Jaakko Pöyry data bank.

3. A digitized data base of all major highways in Minnesota.

4. FIA statewide forest inventory data collected in 1977 and 1990 by the USDA Forest Service North Central Forest Experiment Station (NCFES) in cooperation with the MNDNR Division of Forestry.
   Sources: USDA Forest Service NCFES

5. FIA statewide forest inventories for 1936, 1953 and 1962.
   Source: Literature

6. Stand and tree evaluation and modeling system (STEMS) growth and yield routine for Minnesota covertypes (Belcher 1982). The study used the GROW routine (Brand 1981) which contains the same growth and mortality prediction equations as the STEMS and TWIGS models (Brand et al. 1988). GROW was used because it is the simplest implementation of the prediction equations among these three model forms. The study group then added appropriate interfaces to the FIA data and other model software components. The GROW version used contained the latest (spring 1991) updated coefficients.
   Sources: USDA Forest Service NCFES

7. Data on costs of timber harvesting and forest management activities.
   Sources: Background papers on harvesting systems and silvicultural systems; MNDNR Division of Forestry; USDA Forest Service NCFES; Jaakko Pöyry data bank; University of Minnesota; industry sources.

8. Silvicultural management options:
   Sources: Silviculture and harvesting background papers; MNDNR Division of Forestry; USDA Forest Service NCFES; Jaakko Pöyry data bank; University of Minnesota; industry sources.

9. Data on history of Minnesota's forests.
   Sources: Previous FIA inventories; the Marschner map of original vegetation; literature.

10. Data on spatial patterns of forest vegetation.
    Sources: New photography and maps of a sample of 30 FIA plot locations together with a ground check of those maps; four townships in northern Minnesota with fully digitized cover and transportation network.

4.2.1 Description of FIA Data

The FIA data formed the basis for all simulations. A complete description of procedures used in collecting these data can be found in three documents: *North Central Regional Forest Inventory and Analysis Field Instructions* (USDA Forest Service 1989), *Aerial Photo Sampling Instructions for the Fifth Forest Resources Inventory of Minnesota* (USDA Forest Service 1989b), and the *North Central FIA Database Codebook* (USDA Forest Service 1989c). Prerelease data for each of the four survey units formed the basis for this analysis. For those unfamiliar with forest surveys, the FIA survey is based on a large sample overall that is selected by probability sampling procedures to be representative of forest conditions across the state.

Survey Design and Implications

The 1990 Minnesota survey used a two-phase sample design augmented by use of a growth model. This sampling scheme and associated estimators are similar to sampling with partial replacement (SPR) in that a set of randomly located plots is available for remeasurement and a random set of new plots is established and measured. A significant feature of the Minnesota design is stratification for disturbance on the old (1977) sample and use of the growth model to improve regression estimates made on old undisturbed forest plots (figure 4.1). Detailed descriptions of the sampling and estimation procedures are presented by Hansen (1990). The growth model used in the inventory was STEMS.

The major steps in the survey design:

Aerial photography (phase 1)

In this phase two sets of random points were located on current aerial photography. The first is a set of new photo plots and the second is a set of relocated old ground plot locations from the 1977 inventory. For the Aspen-birch and Northern Pine units, photos were 1:58,000 scale color infrared National High Altitude Photo program (NHAP) prints. Photos used for the Central Hardwood and Prairie units were 1:40,000 scale black and white prints. In addition, 35mm true color prints at a scale of 1:15,840 were taken of all of the 1977 ground plot locations. These 35mm prints were used in addition to the NHAP prints to help detect disturbances in the 1977 ground plot locations.

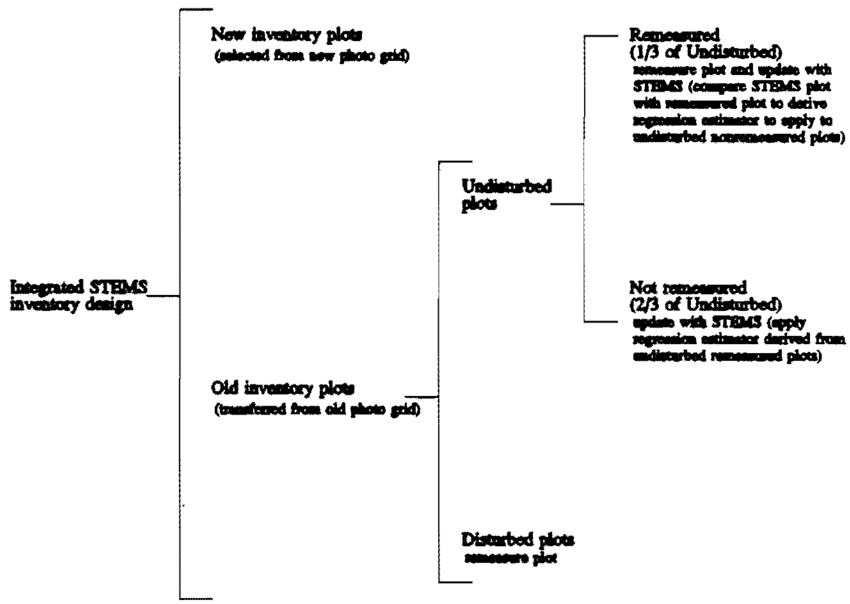


Figure 4.1. Overview of the Minnesota sample design.

The locations of the plots used in the 1977 inventory were transferred to these new photographs. The photographs were then assembled into township mosaics, and a systematic grid of 121 one-acre photo plots was overlaid on each township mosaic. Each of these photo plots was examined by aerial photo-interpreters and classified stereoscopically for land use. In total, 247,735 photo plots were examined in this way. If trees were present, forest type and stand size density class were recorded. All of the 1977 ground plot locations were also examined for disturbance (logging, fire, catastrophic mortality, etc.) with the aid of the 35mm photography. Subsequently, all the old *disturbed* sample locations, a one-third sample of the old *undisturbed* sample locations, and a sample of the new photo plots were sent to field survey crews to verify the photo classification and to take further measurements. This verification sample consisted of 43,959 plots. Classifications were categorized as:

- timberland;
- reserved forest land;
- other forest land;
- questionable;
- nonforest with trees;
- nonforest without trees; and
- water.

Plot measurements (phase 2)
On plots classified as timberland, wooded pasture, or windbreak (at least 120 feet wide), a ground plot was established, remeasured, or estimated by STEMS model update of the 1977 plot records. This sample consisted of 12,118 plots of which 9,156 were measured in the field and 2,962 were updated to 1990 by the STEMS model. Old plots that could not be relocated were replaced with a new plot at the approximate location of the old one. Each ground plot consists of a 10-point cluster covering approximately 1 acre. Note that in establishing plots, points fall according to a regular grid, except that points may be shifted by a set of rules should some fall in a ground land use other than that recorded for the plot as a whole. At each point, trees 5.0 inches or more in dbh were sampled on a variable-radius plot, and trees less than 5.0 inches dbh were sampled on a 1/300-acre fixed-radius plot. Trees had to be equal to or greater than 1.0 inches dbh to be included in the sample. The variable radius plot procedure essentially tallies trees on plots concentric with the sample point, and the plot size varies with tree size. The measurement procedure for the new and old sample locations was as follows:

New inventory plots. A random sample of the new photo plots was selected for field measurement. Ground plots were established, and measures of current classification such as land use, forest type, and ownership as well as size and condition of all trees on the plot were recorded. These locations were monumented for future remeasurement.

Old inventory plots. These plots were established, monumented, and measured as part of the 1977 field inventory. The procedures for these old plot locations were different from those for the new plots. Old plots were classed as ***undisturbed*** or ***disturbed*** in the aerial photo phase of the sampling process. Disturbance refers to any change on a plot that can be detected on aerial photos and that the STEMS growth model cannot predict, such as catastrophic mortality, cutting, seedling stand development, and land use change. All disturbed plots and a one-third sample of the undisturbed plots were remeasured to obtain estimates of current condition and changes since the last inventory. All trees measured on these plots in 1977 were remeasured or otherwise accounted for, and all new trees were observed and measured.

All sample plots that were forested at the time of the 1977 inventory and undisturbed until this inventory were projected to 1990 using the STEMS model. Subsequently, these projected plots were treated as ground plots, even though they were never visited. Note that the STEMS model *grows* the individual trees comprising the plot, thus projections do not lose species detail due to aggregation as in some models. Plots typically contain 30 to 50 tree records (i.e., species, diameter, etc., for each tree). The comparison of the projected and observed values on the one-third sample of the undisturbed forest plots that were remeasured provided local calibration data. This was used to adjust the projected values of the undisturbed plots that were not remeasured. The adjustment procedure is a modification of that described by Smith (1983).

The old sample plots that were not forested in 1977 and that were undisturbed until the current inventory (no evidence of conversion to another land use) were also subsampled (field checked) at the one-third rate. Any changes to forest use detected on these plots were used to adjust the two-thirds sample of those plots that were not field checked.

The procedure for computing statistics from this sampling design was more complicated than the simple two-phase estimation procedure used in the past. The procedure yields two independent samples, one coming from the new photo points and the other from the old photo points that are remeasured or modeled. The following steps describe the computations by type of plot:

- *Area estimates.* Area estimates were made using two-phase estimation methods; a preliminary estimate of area by land use is made from the aerial photographs (phase 1) and corrected by the ground observations (phase 2). A complete description of this estimation method is presented by Loetsch and Haller (1964).

- *Volume estimates.* Estimates of volume per acre were made from the trees measured or estimated (with STEMS) on the 10-point plots. Estimates of volume per acre were multiplied by the area estimates to obtain estimates of total volume. Net cubic foot volumes (gross volume minus defect) were based on a modification of the method presented by Hahn (1984) for use in the Lake States. This modification consisted of using the merchantable height equation contained in Hahn's report in conjunction with Stone's tree volume equation to estimate gross volume. This estimate was then corrected by species for variation in bark and cull volume to yield an estimate of net volume. Cull (defect) equations developed and used for this process are shown in appendix 3. Projected net volumes were for all trees; no distinction was made between growing stock and cull trees as such tree classes were considered difficult or impossible to predict with accuracy in 50-year projections.

Scribner log rule conversion factors were derived from full tree measurements taken throughout the Lake States (Michigan, Wisconsin, and Minnesota) and an equation developed by Wiant and Castenaeda (1977). The factors (multipliers) used by FIA and in this study to convert board foot international volumes to the Scribner rule are shown in the following tabulation:

DBH (inches)	Scribner rule conversion factor	
	Softwoods	Hardwoods
9.0-10.9	0.7830	--
11.0-12.9	0.8287	0.8317
13.0-14.9	0.8577	0.8611
15.0-16.9	0.8784	0.8827
17.0-18.9	0.8945	0.8999
19.0-20.9	0.9079	0.9132
21.0-22.9	0.9168	0.9239
23.0-24.9	0.9240	0.9325
25.0-26.9	0.9299	0.9396
27.0-28.9	0.9321	0.9454
29.0+	0.9357	0.9544

- *Growth and mortality estimates.* For remeasured plots, estimates of growth and mortality per acre come from the remeasured diameters of trees and from observation of trees that died between inventories. As reported by the FIA unit, growth is the average net annual growth between the two inventories in question and is computed from data on remeasurement plots and STEMS updated plots, using methods presented by VanDeusen et al. (1986). Mortality is also average net annual for the remeasurement period. On new plots, where trees were not remeasured, estimates of growth and mortality were obtained by using the survey unit adjusted STEMS to project the growth and mortality of trees for one year. Catastrophic mortality is ignored, leading to underestimates of mortality.

- *Average annual removals estimates.* Average annual growing-stock and sawtimber removals (1977 to 1989) were estimated only from the remeasured plots.

Generation of Reserved Forest Data

FIA procedures for measuring forested plots which fall in reserved land areas (e.g., BWCAW) do not include a field visit. Only aerial photo interpretation and map data were available for these plots. Therefore these plots do not possess a tree list, rendering them unsuitable for growth projections using

STEMS. To address this problem and to facilitate the prediction of future stand conditions in these reserved areas, tree lists were imputed from neighboring stands. The imputation used a stepwise process, beginning with very restrictive matching criteria. The first step assigned each reserved plot a tree list from a randomly selected timberland plot in the same county of the same 10-year age class, size class, and site index value. Where matches were not found, the matching criteria were relaxed until a match was found for every reserved plot.

4.2.2 Model and Data Shortcomings

The modelling tools utilized in this study are among the most sophisticated ever used in such a study. While it was possible to develop forest management schedules in great detail, the models and data used here do have limitations. These limitations do not invalidate the key findings of the study, but they need to be taken into account before making specific recommendations. Any result should be seen in the context of the whole, i.e., individual results should not be taken out of context and be interpreted as general truth. The major limitations are as follows:

- The model is deterministic and therefore does not account for uncertainty surrounding most factors.
- There is no complete inventory of all forest lands in Minnesota. Forest lands are represented via the FIA sample plots, and these can vary from their map locations by as much as several hundred meters. Immediate spatial detail associated with each sample plot is assumed to be the plot or stand it characterizes. The area of like conditions each plot represents is approximately 1,235 acres located in that FIA unit. Additionally, the FIA plots may fall across covertype boundaries (the straddler plot problem, i.e., plots straddle more than one stand condition). Hansen[1] has examined this for the Minnesota FIA data and found that approximately 20 percent of the plots straddle different stand conditions (two or more of the ten points comprising the plot appear to lie in another forest condition). The extent of this problem depends on the size and shape of stand and plot size. Since the FIA plots cover approximately one acre, it is possible to estimate the percentage of plots that straddle stand boundaries. The probability of such straddle plots, for regular shape stands averaging 20, 40 or 80 acres in size, can approach 0.40, 0.29, and 0.21, respectively (Ek and Burk 1991). However, the problem can be more severe for long, narrow forest types. It is expected that the USDA Forest Service will be quantifying the extent of this

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[1] Personal communication, M. H. Hansen, USDA Forest Service, NCFES FIA, March 1992.

problem, but results may not be ready for some time. The consequence is that some mixed stand conditions in the data may be an artifact of the plot size and survey design. Thus covertype species and other composition descriptors may appear more mixed than visits to individual mapped stands would suggest. This does not affect estimates of timber volumes in 1990 or overall species composition, but it does suggest caution when interpreting estimates of specific forest type area and type composition. In relation to timber supply analysis there could also be some concern, as timber supply models assume the basic analysis unit is homogenous. The models cannot recognize any potential gains that might be possible if, in fact, the sample points represent multiple stands, and gains could be realized by managing each stand differently.

- The model develops optimal forest harvesting and management plans across all ownerships. That optimality is defined as minimizing delivered wood cost, subject to constraints on specific timber production targets for individual markets and time periods. Standing timber was also valued, which prevented liquidation of the inventory. However, this assumes that such plans can be coordinated among the various ownership groups and that incentives are built into markets and institutions to induce owners to behave this way.
- There are a number of limitations in the FIA database with respect to the precision and accuracy of stand age and other variables.
- FIA plots and other sources offer only limited information for the development of ingrowth and forest regeneration models and for quantifying the transition of stands from one covertype to another (see section 4.5).

4.3 Organization of Work by Tasks

The following tasks were carried out to achieve the objectives of this study group:

Task 1

An analysis and summary was prepared of the 1990 statewide forest survey information across all owners, covertypes, and ecoregion. The USDA Forest Service's FIA data was downloaded to a database for easy retrieval of information for developing summary tables and preparing inputs into a forest management change and scheduling model. The study group utilized a relational database program. This was integrated with software to retrieve user-defined information and to provide input into a prescription writer program. The study group developed the appropriate summary table categories. These data were also made available to other study groups.

Task 2
Available growth and yield and regeneration models were analyzed to determine the most appropriate growth model for forest management scheduling. The USDA Forest Service individual tree growth model STEMS (in the form of the GROW routine) was chosen as the best growth and yield model.

Task 3
The silvicultural systems and harvesting systems background papers and consultation with forestry agencies provided technical and economic information on the cost of forest management activities including site preparation, planting, thinning, forest protection, administration, harvest, and road construction.

Task 4
Using the above data and analysis, descriptions of technically feasible management alternatives and associated silvicultural systems were developed for all covertypes in Minnesota. These alternatives included management regimes currently in use.

Task 5
A forest management scheduling model was formulated. It involved setting up the input files for the scheduling model DTRAN. These input files consisted of the management alternatives developed under task 4, the associated economic cash flow files, and the road networks linking the forest with timber processing facilities in the state. The economic cash flows associated with each prescription were developed by the RXWRITE computer program.

Task 6
The three harvesting levels outlined in the FSD were used to define objectives for the initial DTRAN runs. The wood harvested under these scenarios was allocated by major product to primary industry locations. For the medium harvest level scenario, additional wood demands were imposed on the defined industry centers based on identified industry development proposals. For the high scenario, additional wood demands were imposed on existing market centers without any knowledge of likely expansion.

Task 7
Outputs from the DTRAN runs carried out under task 7 were interpreted to provide inputs into the impact analysis process from other study groups and to answer questions about the sustainability of the forest resource base under the various demand scenarios. This involved a description of the costs of producing timber by production period and location (including ecoregion), and a summary of the key activities by geographic location.

Task 8
Several outputs from task 7 were summarized in tabular form, i.e., acres by activity and planning period for each county or ecoregion. In addition, customized plot data were made available as database files to individual study groups, in the context of the impact assessment matrices. Visual depictions of the spatial and temporal distribution of the harvest were prepared. The output data were distributed to the other study groups for assessment of perceived impacts of forest management actions on key resources such as water, wildlife, fisheries, recreation opportunities, soils, and biodiversity.

Task 9
New scenarios were formulated to run the forest change and scheduling model after incorporation of ownership constraints and selected mitigating strategies. The second model runs introduced ownership constraints that limited availability of certain categories of timberlands. These constraints reflect current and prospective management procedures and policies applied by the major forest land managers. Examples of availability constraints include riparian lands and old growth forests. Other constraints include management on longer rotations for a proportion of stands in some covertypes. In addition to existing constraints, the mitigation strategies developed in the course of the GEIS study were included. An example of these mitigations is a restriction on harvesting within 200 feet of streams in the southeastern part of the state. The second runs also applied the USDA Forest Service allowable harvest limits for yields from their timberlands.

Task 10
The scheduling models were run using the new scenarios. The outputs of the model in terms of production potential, production costs, and inventory changes over time reflect the costs of the mitigation strategies developed as part of this study.

Task 11
The results from the modified forest management scheduling were analyzed and summarized. The results were presented to the other study groups for a second round of analysis.

Task 12
A summary of key results and recommendations was developed.

Task 13
A summary of the changes in the size and composition of Minnesota's forestry land base will be prepared.

Task 14
The current technical paper resulting from this additional work addressing the questions raised about the forest resource base and about maintaining the productivity of forests for timber production was updated.

4.4 Harvesting Scenarios

The primary outputs in this work product were the development of initial harvesting and forest management scenarios. The three scenarios were developed to meet the specific requirements set out in the FSD. These initial scenarios were the primary means of generating information required to conduct the first stage of the impact assessment process. How they were used to aid this process is discussed below.

All three statewide timber demand levels were specified in the FSD. The first two levels of harvesting are based on current or projected demands for a range of timber products to be supplied at specific locations. The third and highest level was developed after examining results for the medium scenario to estimate in general terms what types of demand (species and market location) would be most likely to develop if the harvest level were to rise to the highest level. Of course, this was very subjective as it was done prior to the analysis completed.

In addition to harvesting, the management activities associated with meeting these timber supply demands are also identified in the scenarios. Management activities modelled are those required to regenerate or replant harvested areas and to thin older stands. These assumptions and activities are not intended to describe either low or high levels of management inputs. Rather the modelling was geared to utilize activities and inputs typical of recent years. The scenarios also provide depictions of key activities of interest to the GEIS—they do not include site specific or technique detail. They suggest the relative area of harvesting needed to meet the three specified levels of harvesting over time. They also cover the broad changes to key attributes of the forest, such as age class distribution, proportion harvested, covertype changes, and other indicators of change. The three scenarios provide this information at a level of detail that is suitable for analysis at a statewide or ecoregion level.

The study groups used the model output as the primary input to the impact matrices that were described in the workplan. Impacts were assessed for significance based on criteria to be developed between the Study Group, Advisory Committee and EQB. Based on these assessments of significance, mitigation alternatives have been developed. Mitigation strategies were developed by the Study Group with input from the EQB and Advisory Committee.

Once developed, the mitigation strategies were simulated by either constraining activities or by altering management inputs. Constraints included restricting the model from scheduling harvesting or other activities in particular categories of stands. This was done by a variety of methods, including total exclusion of harvesting from specific areas and different assumptions of land availability from particular ownerships.

Output from the second series of model runs was analyzed to determine the effects of possible mitigation strategies on the wood supply situation and, hence, the ability of the forests to supply the nominated volumes of wood.

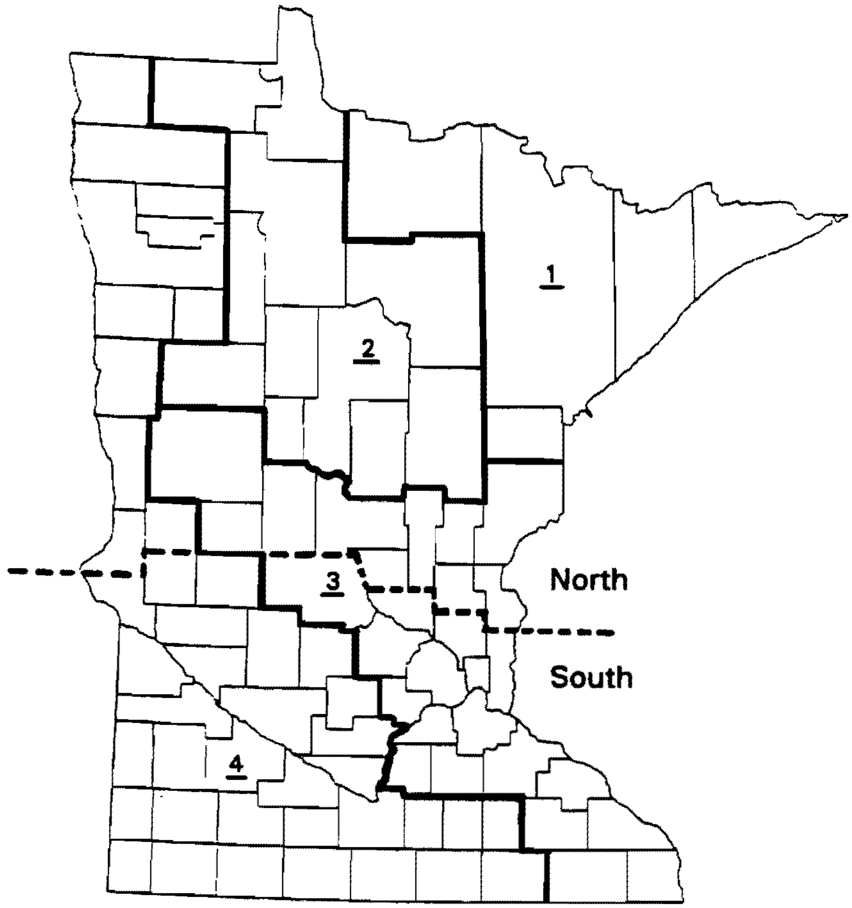
Clearly, the ability to model the distribution of harvesting activities needed to meet the three levels of demand was of fundamental importance to the impact assessment process. In addition, comparison of the output from these unconstrained model runs with the output for the second runs indicated the likely changes in forest conditions resulting from adoption of the potential mitigation strategies. This sensitivity analysis will help decisionmakers to develop the insight needed for balanced and workable policies.

4.4.1 Subdivision of the State

The harvesting scenarios have been prepared to reflect the three levels of harvesting specified in the FSD. For ease of processing, the state has been divided into two regions reflecting basic patterns in forest covertypes and the markets for the range of timber products. The subdivision was developed by assessing the percentage of northern hardwoods covertype in the total forest area of the counties in the FIA regions 3 and 4. The major species in this covertype include oaks, maples, elms, and ash. Those counties with more than 85 percent northern hardwoods were included in the southern region. The northern region includes the bulk of the aspen resource while the southern region is predominantly oak. Based on application of this criterion, 37 counties were included in the northern region and 44 in the southern region. These primary subdivisions are shown in figure 4.2.

4.4.2 Basis for Demand

Statewide demand for timber is the summation of demands for wood products by individual industries at specific locations. The three scenarios, *base*—4 million cords/year, *medium*—4.9 million cords/year, and *high*—7 million cords/year, have been driven by specified levels of demand contained in the FSD (as updated to account for recent industry developments). The first 10 years of each scenario reflects a gradual increase in industrial capacity as new plants now under construction come online.



Unit Number	
1	Aspen birch
2	Northern pine
3	Central hardwood
4	Prairie

Figure 4.2. Northern and southern regions and FIA survey units.

The actual volumes of wood and assumptions relating to processing plants used to create the base demand and medium demand scenarios are detailed in section 4.6.1.

In contrast, no details were provided in the FSD as to the species used or plant locations to be modelled to make up the additional volume in the high demand scenario. This level was described in the FSD as the "estimated maximum annual volume of timber available for harvest statewide for all tree species in the year 2000." Therefore, this third level of demand, assumed to be reached by the year 2000, is a *level of production* for which *demand* was *created*. The study examined output from the first two runs and identified volumes of wood that were surplus to existing or projected demands. Based on these analyses, new centers of demand were created to utilize these surpluses up to the specified 7 million cord level. The additional wood needed for the higher demand scenarios was assumed to come primarily from the northern region. The list of possible projects in the FSD, together with results of initial investigations by the study group, indicate that there is little prospect of significant additional industrial development in the southern region. In addition, there are no obvious sources of wood, surplus to existing needs, that would be sufficient to sustain large new industrial developments. It is possible to increase the volumes of northern hardwood species harvested for fuelwood and to supply additional sawlogs. These categories of demand were assumed to be the only possible additional sources of demand for the higher demand scenarios.

The scenarios have focused on developments that utilize wood fiber, or pulp grade timber, rather than solid wood (i.e., sawlogs). This reflects the direction set out by the FSD in defining possible developments as part of the medium harvesting scenario. It also reflects the fact that there has been no evidence of proposed or likely investment in new plants in the sawmilling industry that would be capable of significantly affecting the demand levels being modelled. This is not to say that sawmills will not continue to be an important part of the state's forest industry, it is simply that the pulp and paper and board based industries are those most likely to develop in the state if present trends continue. The scenarios assume additional demand will exist for sawlogs. These modest increases are included in the medium and high scenarios.

4.5 Modelling the Harvesting Scenarios

Timber supply is a complex concept without a simple definition. An economist would define it as "the quantity of timber available to the market at various price levels during a specified period of time." From this definition, it is clear that the physical inventory of the forest must be known. In addition, the price for the timber delivered to the various markets and how these prices compare with those the market is willing to pay must also be taken into account.

The problem in applying the simple economic definition of timber supply is that many complicating factors enter the picture. Timber production is unique when compared to other production processes. Extremely long production periods are needed, and the tree itself is both the product and the factory. Timber stands differ significantly in terms of growth rates, volume and type of products produced, size, ownership, and access. The following are examples of some of the factors that must be considered when developing timber supply scenarios.

Multiple Products
Forests produce many outputs across a range of nontimber and timber products. Some of these nontimber uses preclude harvesting. When harvested, many forest types (especially mixed species types) yield more than one timber product. The decisions on the proportions of each product produced can be dependent on market demand, sorting costs, and price competition between industries. Consequently timber may not always go to the market corresponding to its highest or best use.

Transport Costs
Transport costs are a major component of delivered wood cost and will influence the ability to supply products from one stand (location) to different markets. Access limitations can also influence whether a stand is available for harvest or the season it is available.

Management Flexibility
Forest owners can vary management of their forests to take advantage of existing or future markets. They can hold back timber by not harvesting when markets are down. If prices are expected to rise they can manage their forests more intensively, thereby increasing yields and/or bringing production forward.

Changes to the Forest Over Time
The size and volume of trees that comprise the stands analyzed in the study will change over the long planning period being used. In addition, depictions of the changes that occur following harvesting must also be created. Different management choices will create different future forests.

Such factors combine to create many options for the management of each stand. Computer models have become increasingly important tools used in forest planning. Their use enables planners to quickly evaluate many options against specified criteria, and to translate the preferred options into realistic timber supply scenarios.

This study has prompted adaptation and development of models that are capable of generating realistic harvesting scenarios by incorporating the following:

- knowledge of the volume (by size and species), location, and ownership of wood potentially available;
- knowledge of existing, planned or potential wood based industries and their locations;

- knowledge of current costs associated with timber harvesting, transport and forest management activities;
- an understanding of the regional transport network to link the wood supplies with the processing facilities;
- an understanding of the way different forests are managed and the implications these management regimes have for the yield of timber in the short and longer term;
- an understanding of the criteria used by industries in making purchases of timber;
- the ability to simulate tree growth and forest development to reflect regeneration after harvest and growth that would occur during the planning period; and
- the ability to alter utilization levels on a per tree or per acre basis.

Two models were utilized to simulate statewide timber harvesting scenarios. The models used are DTRAN, a forest management scheduling model that *optimizes* harvesting and management activities where the objective is to minimize the total cost of production; and RXWRITE, a set of programs used to develop options for the prescriptions for harvesting and management activities for each area of forest or stand. The options are selected for each stand by the DTRAN management scheduling model as it seeks to achieve specified harvest levels for each product group and market center. DTRAN is a more advanced version of the DUALPLAN model discussed in the Feasibility Assessment document.

Other models are linked with DTRAN and RXWRITE as necessary to modify and interpret inputs and outputs. The tree growth model, GROW, developed by the USDA Forest Service, is used to estimate growth of trees and stands for use by the RXWRITE model. The GROW routine was used in lieu of the larger STEMS software package developed by the USDA Forest Service. GROW is the simplest implementation of the models in STEMS. A basic geographic information system (GISTRAN) has been incorporated into the DTRAN model. GISTRAN generates transport information that is subsequently used to allow graphic depiction of outputs from the model.

Figure 4.3 provides an overview of the information flow between key elements of the modelling process. The following sections briefly describe the models and set out the categories of assumptions used to define the scenarios. More detailed technical descriptions of the modelling tools and how they work are being written and will be published as *Users Manuals* by the Department of Forest Resources, University of Minnesota.

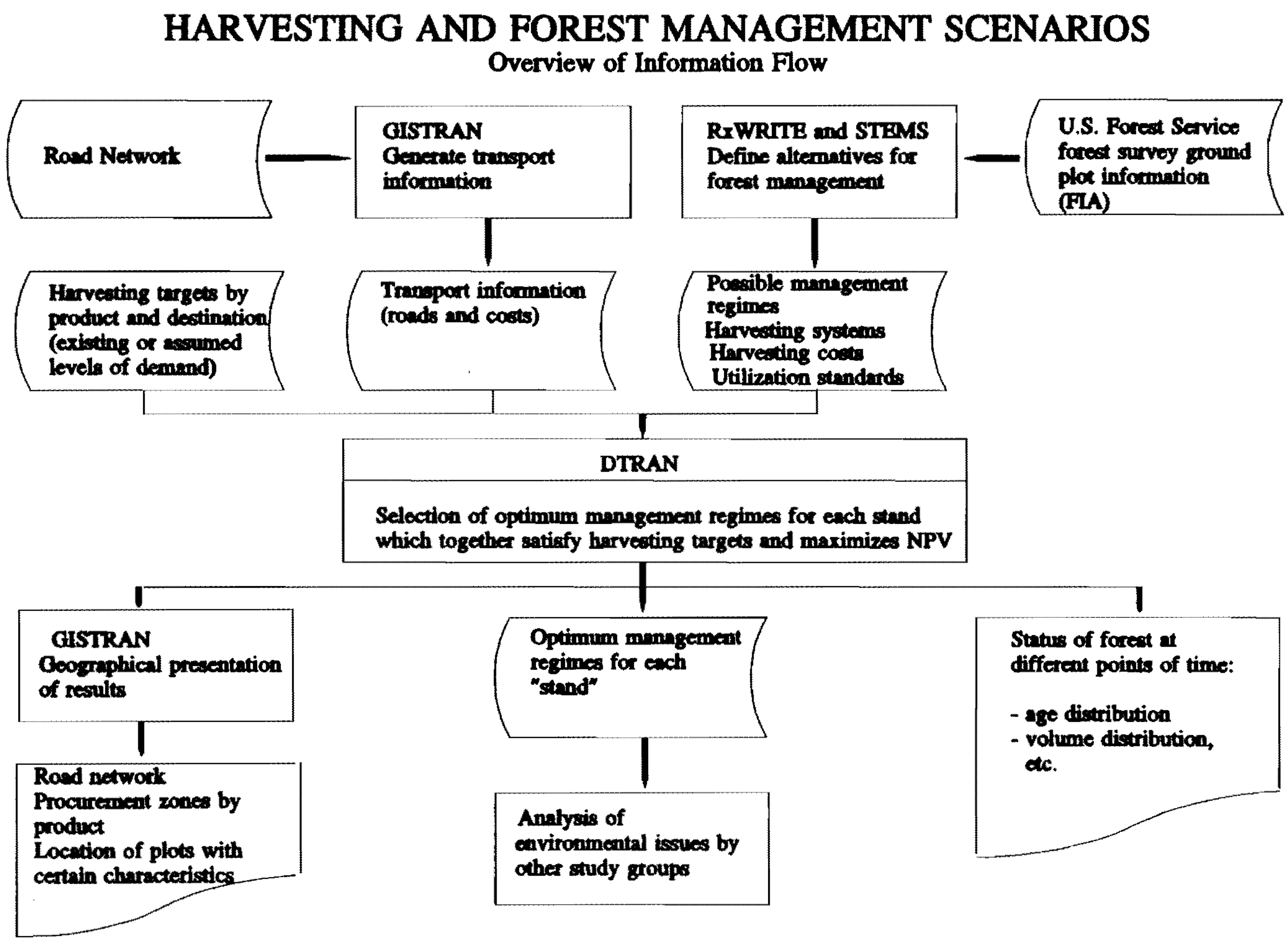


Figure 4.3. Overview of information flow.

4.5.1
RXWRITE Prescription Writer for Harvesting and Forest Management Activities

Base Data
The *preliminary* 1990 FIA test data set was used to describe the state's forests at the start of the modelling process. This data set provides a consistent description of the forest cover throughout the state. The FIA data contain a wealth of information. A subset of this data was used for this part of the study. Attributes used by the models include:

- plot identification number;
- FIA unit number;
- county;
- ownership;
- covertype;
- stand size (acres);
- age;
- site index;
- tree list (species and diameter);
- distance from nearest road; and
- UTM coordinates (approximate).

The unique stand identification number allows the other data attributes for each plot to be linked back to the plot to enable subsequent analysis as part of the impact assessment process. In all, some 14,296 plots were used in the modelling process. These plots are approximately an acre in size and large by forest inventory standards. The locations of these plots is depicted by figure 4.4. Additional maps are included in appendix 11. The FIA data provide a unique expansion factor that applies to each tree and plot. The expansion factor is used to multiply plot attributes to obtain stand attributes such as total volume and the larger area that is represented by the plot data. These stands are the basic units that are manipulated by the models to generate the harvesting scenarios. A typical plot expansion factor would be 1,500, i.e., a plot represents some 1,500 similar acres. A more complete description of these data is provided in appendix 7.

The modelling process treats the stands represented by these plots as single *analysis units*. Activities, including harvesting, were assumed to occur uniformly across the stand. This approach would be imprecise if few plots were used. However, the large plot data set and statewide perspective used by this study smooth the results sufficiently to provide a strong statistical basis for the assumptions implicit in this methodology.

Management Prescriptions
Many choices are available to the forest manager when contemplating the management options for a wood production forest. When can it be cut? Can

it be thinned? What products will be produced? How should the stand be regenerated? These decisions can be based on a series of rules such as minimum rotation ages, product specifications, stand and tree growth data, etc. These rules can be defined and then used to assist with the task of making decisions for the many stands that are being modelled. The rules are applied to stands based on stand conditions (as defined by the FIA data), specifications for products potentially yielded and other factors, many of which would be used by forest managers making real decisions about stand management.

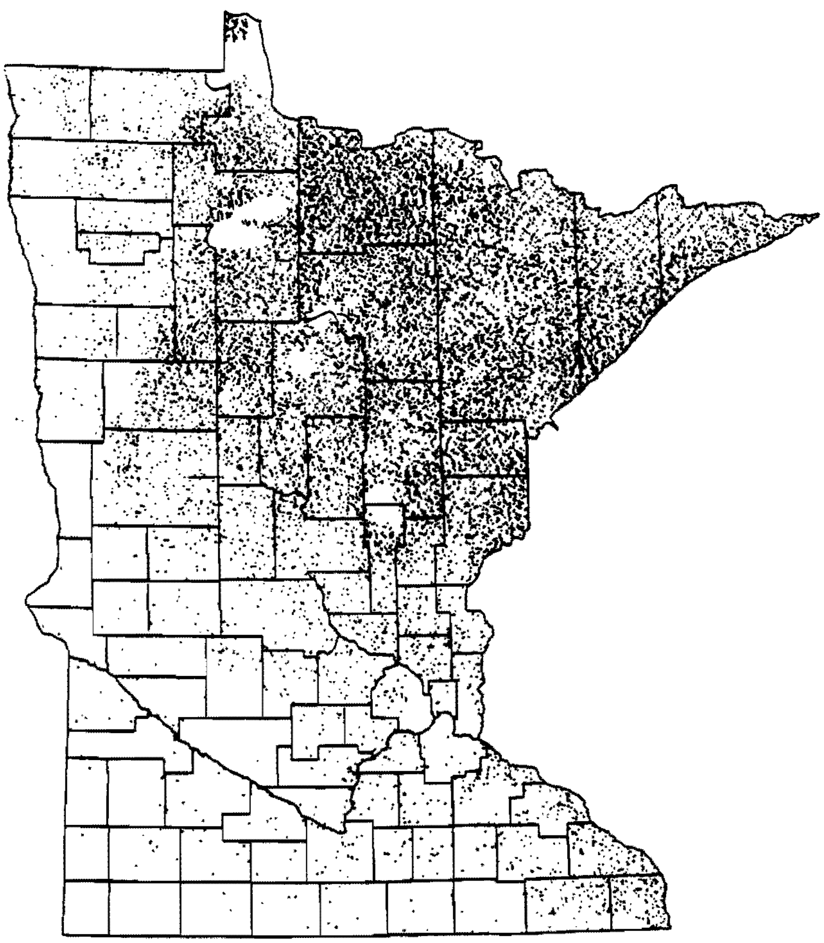


Figure 4.4. FIA plot locations to be used in GEIS.

The range of management options can be further expanded to include those aimed at achieving objectives other than timber production. The options considered in this first series of runs have been confined to those directed at producing timber. Later runs will incorporate modifications to reflect other management objectives.

The RXWRITE program used the stand data to generate alternative management prescriptions for each stand over user specified planning periods, and implicitly for an infinite planning horizon beyond the planning horizon (50 years for the study). Widespread previous experience suggests that 10-year planning periods allow a sufficient level of resolution over time without overwhelming computing facilities with the detail needed to run the models with a shorter interval. Management prescriptions (harvesting and silvicultural) were assumed to be implemented at the start of each planning period. Those simulated included thinning, clearcutting, site preparation, natural and artificial regeneration, and site conversion.

The number of alternative prescriptions for each stand varied according to its covertype and age. Stands from each covertype were aggregated into 10-year age classes. A separate set of prescriptions was prepared for each covertype/age class combination. In all, 233 covertype/age combinations were identified for the northern region; and 235 combinations were identified for the southern region.

The number of prescriptions written varied with the starting age of the stand and the silvicultural prescriptions that could be applied. Younger stands had more prescriptions written, as there were more decision points for management than for older stands. As an example, young jack pine starting at age zero had 17 potential prescriptions written. Old jack pine at a starting age of 120 years had only four potential prescriptions.

The silvicultural options varied significantly between covertypes. Aspen managed as even-aged stands had a maximum of six alternative prescriptions. In contrast, maple-basswood covertypes in the southern region had up to 87 alternatives, reflecting that this covertype is typically managed as uneven-age stands. The sequence of options available for each stand over time is called a stand *decision tree.* An example for one of the pine covertypes is provided as figure 4.5. Options for harvesting are constrained by minimum and maximum rotation ages for each covertype. Rotation ages were estimated as the minimum and maximum ages that products suitable for industry could be produced. In the northern region, thinning options were only generated for the red pine, jack pine and white pine covertypes. In the southern region some stands, red oak in particular, were assumed to be available for thinning at almost any age (see 4.6.5).

The various silvicultural and harvesting options are defined in appendix 1. In practice the choice and combination of prescriptions can constitute the range from poor to good management from the standpoint of timber supply.

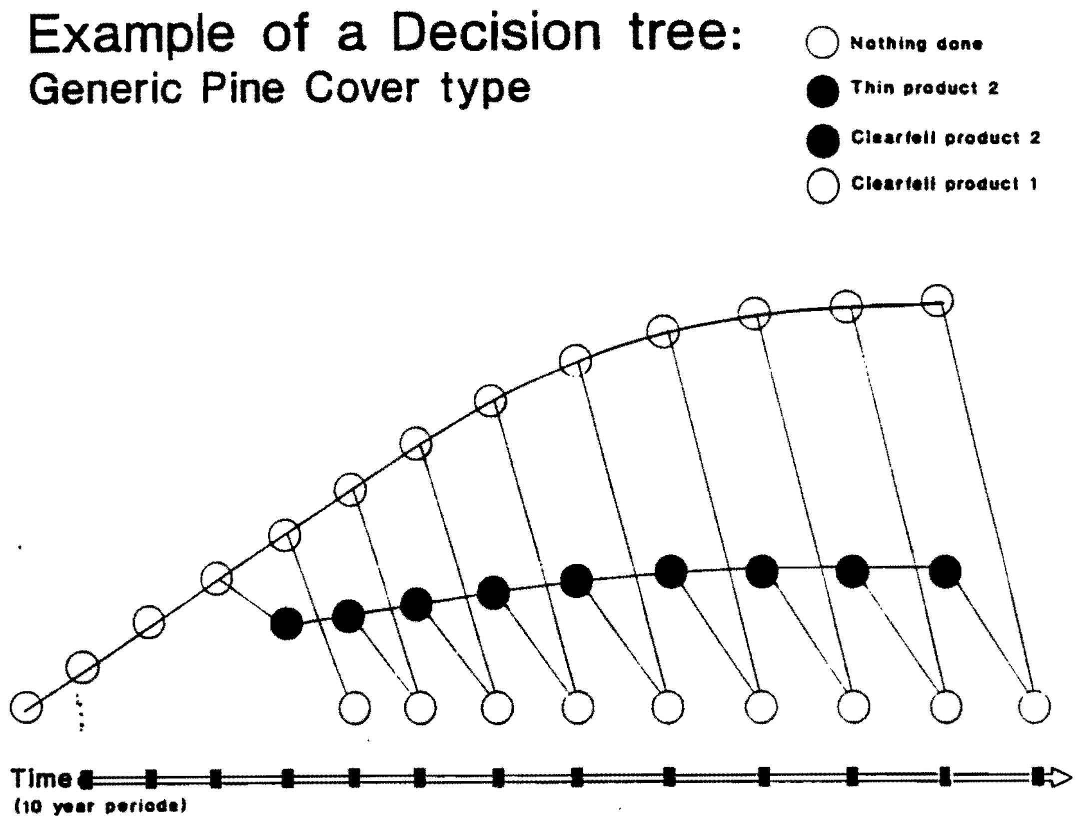


Figure 4.5. Example of a decision tree.

Regeneration Stands
RXWRITE uses a list of standard regeneration stands that are applied following clearcutting. The regeneration stands vary according to:

- original covertype;
- site index; and
- type of regeneration, either natural or planted.

The species composition and number of trees in these assumed regeneration stands change as these variables change. The relationship between these variables and the resulting regeneration stands were derived from averages of FIA sample plots. The model recognizes 26 different regeneration stands (see 4.6.5). The costs to regenerate or plant stands are identified (see appendix 2) and are included as a factor in the model.

Where stands are thinned or selectively cut, the model grows the remaining trees in the tree list. No new trees are added to the list as this would complicate the model, and any new trees added to the lists would be unlikely to contribute to output of wood products within a fifty year planning horizon. However, younger regrowth will be assumed when stand conditions are assessed for other purposes, such as wildlife values.

Product Yield
The model projects the growth of trees within the stand by applying the GROW model to the FIA plot tree data. This generates data for each tree at any point during the planning period. When a harvest is simulated for a stand, the volume for each tree is calculated by using these data and applying a set of *volume equations*. These equations provide a gross tree volume, which is adjusted to reflect that a proportion of trees within any stand are unsuitable for harvesting, or that they are only partially useable because of their shape, damage or decay. Net volumes that recognize these losses are obtained by subtracting or *culling* a percentage of the total volume. The cull percent varies by species and by product class (sawlog/pulplog) and is calculated using cull prediction models that are described in appendix 3.

In addition to cull losses, the volume yielded from a stand is also reduced because a proportion of each tree will not meet minimum industry specifications. Minimum specifications vary by product classes and by species within product classes. The primary specifications used in the model relate to diameter. The minimum breast height and top diameters for the pulplogs and sawlogs for each species group are set out in appendix 4. This appendix also includes tables which set out the potential gains to be achieved by increasing the amount of each tree utilized by reducing the minimum top diameter specifications.

For each stand, the individual tree volumes are allocated to a species group and product class. Species group and product class volumes are then allocated by the DTRAN model.

Logging Cost
Logging costs vary from stand to stand. Generally, logging costs diminish as stand size increases, access improves (i.e., offroad transport distance reduces), and trees become larger. Use of clearfelling techniques also result in lower costs. The model uses an assumed base logging cost of $22 per cord, which is then varied to reflect stand conditions. Factors included in the cost model were clearcut or thinning, average tree size, average offroad skidding distance, volume removed per acre, and total logging volume. These factors combine to generate a range of logging costs that vary as stand characteristics change. The harvesting cost model used is set out in appendix 5. Assuming a base cost of $22 per cord, the model generated the following

range of costs when applied to the extremes in the range of conditions likely to be present in Minnesota:

- thinning (cost per cord) between $16 and $29; and
- clearcutting between $11 and $22.

Each stand was assessed using this model and the logging costs of harvested wood at the landing were calculated for use in the DTRAN model.

4.5.2 DTRAN Forest Management Scheduling Model

DTRAN is used to model the capacity of a defined area of forest to supply multiple product flows to different market locations over time. It was developed to examine regional or statewide supply issues.

An easy way to understand the DTRAN model is to think of the following scenario: imagine a crystal ball which would predict all prices of goods and services, timber and nontimber. Under this scenario, forestry planning becomes a relatively easy exercise. First, all technically feasible management alternatives for each stand could be listed. Then these alternatives could be evaluated stand by stand, using common cash flow or investment principles. The alternative that generates the highest discounted net revenue could then be selected. Under the assumption of known prices or values, this could be done for each stand independently without worrying about the interactions between stands.

The optimal alternative for each stand would generate an associated flow of products, goods, and services over time. These flows could then be added to obtain the optimal total production of goods and services at given prices. These total flows might not, however, be the ones that society really wants. If, for example, the total output of recreation days is too low, it follows that too small a price or value for that product was used. By adjusting prices up or down in an iterative fashion, the model finds a set of prices that will produce the right amount of the products specified as demands in the model.

These iteratively derived shadow prices are the same as the marginal cost of producing one unit of the product demanded. The marginal cost, by definition, is the additional cost that society or a producer would have to pay to obtain one additional unit of the product. As an example, one could visualize this process using the production of an additional cord of aspen pulpwood. The marginal cost to get the additional cord of pulpwood would reflect the fact that it may be necessary to look for a timber stand that is less desirable to harvest than the last one chosen, either because it is farther away from the market that wants the additional cord or because it has characteristics that would tend to increase the per unit harvest cost, such as low volume per acre and poor quality.

The model generates optimal solutions with the ability to recognize multiple market locations but without the need to specify explicitly each potential shipping option for each harvest option. Problems with alternative market destinations for multiple products are difficult to address using conventional timber harvest scheduling models based on LP. DTRAN utilizes a basic understanding of the problem, breaking the problem down into parts in its mathematical solution process to reach an optimal solution. This solution is optimal in the sense that product to market allocations are at the lowest cost for a fixed level of supply. In brief, the model attempts to approximate competitive processes and a rational marketplace. Final results include a set of marginal costs or shadow prices that can be used in an economic analysis of individual projects to recognize forestwide objectives or concerns.

Understanding the Modelling Approach

As noted above, DTRAN uses an optimization approach that estimates the minimum cost of meeting production level targets for the forest. The sum of these targets provide the statewide harvesting levels. These targets could include nontimber as well as timber targets, but only timber targets were recognized explicitly in these first runs, in accordance with the FSD requirements. As discussed previously, results should not be viewed as predictions of what will or should happen. Rather, results are an indicator of how and at what cost production levels might best be achieved, given the broad range of management alternatives available and the types of costs recognized.

The intent of the model is to examine a range of potential targets (objectives) through multiple model runs. In the first set of runs, the objectives were to examine whether the three levels of harvesting could be achieved and what forest management activities would be required to meet these targets. Subsequent runs will reflect the mitigation strategies developed from the study process and approved by the EQB (see also figure 4.3).

The model uses specific management schedules for each scenario examined. Selected schedules can be examined in detail to identify potential impacts on specific forest types in specific forest locations. Both time and spatial elements are critical aspects within the model as production targets can be defined in both time and space.

Compared to other optimization approaches for forest planning, the strength of this modelling approach is its ability to recognize an enormous amount of detail. The model breaks the forestwide modelling problem down into separate modelling problems for each stand, or in this case, each FIA ground plot. As discussed above, a number of potential management prescriptions with estimated product yields were developed for each stand. Where stands are clearcut, a regenerated stand is simulated. Use of tree based data for each stand, coupled with a very large number of stands, provides the level of detail needed to generate realistic scenarios.

The marginal costs of production associated with each forestwide target level are the keys for linking the analysis of individual stands with the objective of meeting forestwide target levels of production over time. As discussed previously, the marginal cost of production is the cost of producing the last and most expensive unit of production needed to achieve a specified level of production. In the context of a forestry problem, the marginal units are most likely those located farther from the mill or in stands with a higher logging cost, as described in section 4.5.1. These marginal costs of production for each product can be used in a basic economic analysis to value forest management alternatives. If the marginal costs are estimated correctly, the best alternative for each stand is the alternative that has the largest present net value based on these marginal costs. The interest rate used to discount future cashflows to enable comparison with present values is discussed further in section 4.6.8.

It should be stressed that the marginal costs generated by the model are relative costs only. They do not reflect prices that would necessarily be paid for a particular product at a particular location. However, differences between costs for the same product at different locations and the trends in cost movements for markets over time are important and reflect relative cost advantages and changes in market conditions.

The overriding objective of the DTRAN model solution approach is to determine the value of these marginal costs. The model does this by simply starting with an initial set of marginal cost estimates, determining the implied optimal schedules for those costs (prices), and then examining the flows from each stand (see below). The statewide picture is built up by adding flows from all stands. Intermediate results are used to refine the initial marginal cost estimates. This process is repeated until the simulated *product* flows are close to the specified product flows for the given scenario. In effect, the model seeks to minimize the total discounted cost of management over an infinite planning horizon.

Forest Flows, Markets and Targets
Any resource flows—inputs or outputs—are referred to as forest flows. For example, aspen pulpwood, red pine sawlogs or red oak sawlogs are all treated as distinct resource flows. The model recognizes 11 categories of output flows of wood products. These flows are measured as volumes of wood. Dollar costs were the only measured input flows considered in this analysis and included harvest costs, planting costs, site conversion costs, and transportation costs for some products. Therefore, a combined total of 12

resource flows (1 input and 11 outputs) were used by the model. Six potential *market centers* were recognized in the northern study region. These market centers were developed to simplify the task of allocating products to all the mill sites shown on table 4.10. A regional center was chosen and all demand within the region was assumed to be delivered to that center. This significantly reduces the complexity of the model process. The six market centers for the model are shown in figure 4.6.

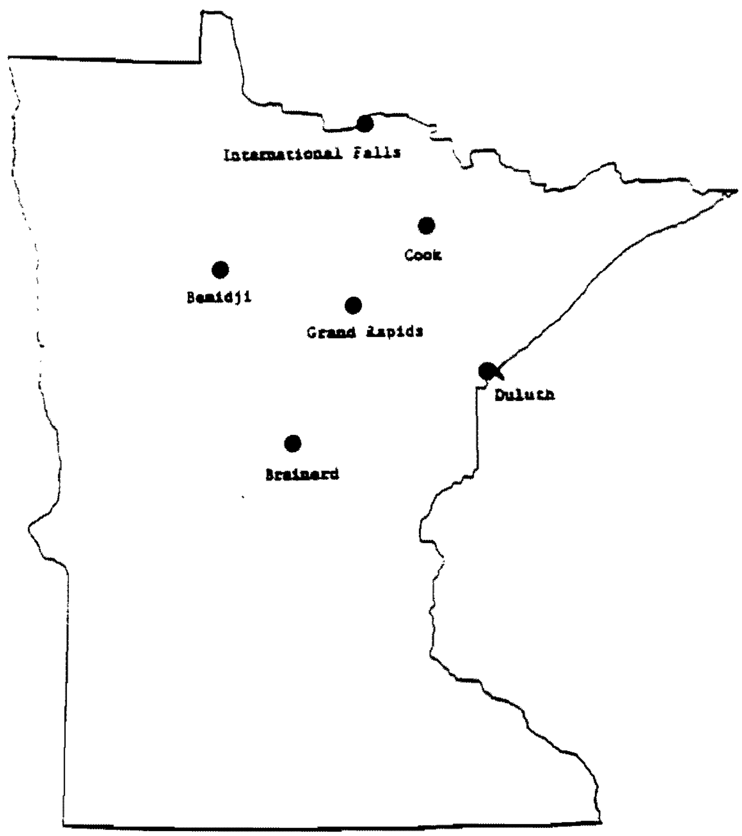


Figure 4.6. Aggregated market locations assumed for the analysis.

Therefore, based on the above, there are 12x6 or 72 possible combinations of resource flows (the products and costs) by market center. The model was simplified by aggregating the 72 possible combinations of products by market centers into 28 sets of broader product categories for the six market centers, plus several categories of sawlogs that were assumed to flow to regions rather than locations. These sets were used for the purposes of defining target levels and examining model results. Of the 28 sets, 26 are shown as highlighted boxes in the tables which define the demand levels by period in tables 4.11, 4.12 and 4.13 in section 4.6.1. Some of these sets recognized specific market combinations while others considered all market locations as a whole. Combinations such as *aspen total-Bemidji; aspen total-Cook* are examples of the former; and *red and white pine sawlogs total* is an example of the latter. Within each aggregated group, products were assumed to be of the same relative value. Two additional sets, noncommercial species and costs, make up the 28 sets.

Five 10-year planning periods were considered. The level of demand at each market center could be set for each planning period to reflect assumed or predicted changes in demand for timber as new industries become established in a market area. These changes in the target figures for each demand center are ultimately reflected in the statewide demand figures.

No market centers were simulated for the southern region. This is because the model cannot handle a large number of small production facilities, and because demand from such a facility is small in relation to the harvest levels from even a single stand. Demand locations were assumed to be dispersed throughout the region, and estimated marginal costs reflect the value of products loaded on a truck at the stand.

4.5.3 GISTRAN Transport Information

GISTRAN is a basic GIS that generates transportation related information used by DTRAN and portrays model results graphically in terms of wood procurement zones for each market. The model incorporates spatial information that describes both the existing transport network and the FIA plot locations. It is able to compute shortest route information which is used by DTRAN in the market allocation process.

4.5.4 Growth and Change Model

The choice of models in any projection require criteria, but there are no universally accepted standards as needs can vary greatly by objectives and circumstances. As a guide, the National Council for the Paper Industry for Air and Stream Improvement (NCASI 1990) consulted various modelers and developed a statement with respect to criteria for forest growth modelling. The scientists consulted were Daniel B. Botkin, Thomas E. Burk, Thomas Dell and Alan R. Ek. NCASI's synthesis of the input from these scientists was:

A. Recommended Set of Minimum Standards/Criteria

(1) The purpose for which the model was developed should be explicit. Generally, models may be used as an integral part of basic research, or for the purpose of guiding research, or for the purpose of guiding the development of policy (e.g., 6). ... if a model developed for one purpose is used for another purpose the results may be misleading.

(2) The objectives of the model—e.g., process simulation or empirical description of stand dynamics—should be stated explicitly. ... explicit objectives are essential to assessing whether or not the model addresses the critical questions in an acceptable way.

(3) The variables of interest should be specified. One needs to be able to determine at the outset whether the variables of interest are incorporated in the model and whether the output (projections) for these variables meet performance criteria.

(4) The method of model construction should be specified. This is applicable in a single equation model or one of many interrelated equations.

(a) The conceptual basis of the model should be clearly stated. Decisions on level of detail, model fitting methods, and selection criteria for significance of coefficients should be described.

(b) The equation forms should be specified. For example, some models may consist of equations that are abstract representations of the underlying biology. Others may be linear additive models of a statistical nature.

(c) The sample survey or experimental design that was used to develop the coefficients and parameter values in the model should be described. Lacking this, the source of the coefficients and parameter values should be given. The person making the assessment needs to know whether all regions of the "design space" of interest have been included in the data.

(d) The calibration methods used should be described. Questions about operation of parts or subroutines of the model, about the model as a whole, and, where appropriate, the amount of explained variation, R^2*, should be answered in an unambiguous way.*

(5) Model performance should be described in terms of generality, realism, precision and sensitivity.

(a) Generality: to what forest situations and what growth deterring or stimulating conditions is the model applicable? Is the model applicable to a wide range of conditions, or only a narrow set of conditions?

(b) Realism: for the forest conditions modeled, does the output show results that are compatible with the real world? Are the projected patterns of change over time like those known to occur in the real world? Are diameter distributions as would be expected? Is volume production comparable to the real world? The question set would be circumscribed by the purpose and objectives of the model.

(c) Precision: for the conditions predicted, does the model meet the a priori standards for accuracy and precision? Are the standards met throughout the range of conditions that are contained in the statement of purpose and objectives?

(d) Sensitivity: is the model so constructed that the overall performance is not sensitive to unrealistically small differences in the size of the coefficients? If the value of a coefficient is changed slightly, is chaos ... generated?

B. A Point of Decision

The foregoing are a recommended set of minimum criteria/standards. If these standards/criteria are not met, the user of the model should be sensitive to possible limitations or defects in the model. Early in the age of computers an acronym became well known: GIGO, which stood for Garbage In, Garbage Out. To this day, that assessment must still be made. ... there is a myth extant today that models are better than data.

C. Additional Attributes

Modelers are by nature imaginative people. Many "bells and whistles" may be added to a basic model. A list of desirables would be long and author specific. The point must be made, however, that the added niceties are only as good as the quality of the basic model to which they are added.

The NCASI goes on to suggest that this is the essence of the subject, but that particular situations may call for more explicit criteria.

In most cases, models will not pass all criteria. There are, however, degrees of acceptance, largely based on the available alternatives and the ability to interpret the results of the analysis given the limitations of the models. The following model descriptions may be direct or may employ appropriate references. These references are important because the major models used here have some history in science, applications and testing. There is also a significant body of literature on model evaluation and behavior (Gertner 1987, 1990). No new models have been developed for this study nor could they have been, given the study time available. Refinements or localization to existing models were needed in some cases in order to adapt to the FIA data and study situations.

STEMS Model for Overstory Growth

Regeneration Model

The regeneration model employed is one based on empirical tabular analysis of the 1990 FIA data. This analysis was used to develop surveywide average tree lists for young stands of each covertype. Following harvest, existing FIA plot tree lists are replaced by a tree list corresponding to the surveywide average tree list for young stands of the replacement covertype.

For model development, FIA data were first screened to meet certain criteria. Specifically, all plots were considered which were (1) between 10 and 20 years old in 1990, (2) ground-visited (sample kind 5 or 9), (3) classified as commercial forest (ground land use 20, 21, or 22), and (4) classified as a seedling/sapling stand (stand size class 3). There were three exceptions to these rules. The first was that the upper age limit was raised where insufficient data were available. The second was a further partitioning into site quality classes, and the third was further partitioning into data for planted versus natural stands. As an example, there were three regeneration tree lists for the aspen covertype—corresponding to high, medium, and low site index values. As implied above, once the data were sufficiently screened, an average tree list was generated from each unique set of data (one or more sets for each forest type). Due to the infeasibility of including all possible trees (a tree being a unique species, Dbh and crown ratio condition, and the associated expansion factor), trees were aggregated by Dbh and crown ratio classes. Five Dbh classes (1 to 2.9 in., 3 to 4.9 in., 5 to 6.9 in., 7 to 10.9 in., and 11 in. and greater) and three crown ratio classes (0 to 29 percent, 30 to 59 percent, and 60 percent and greater) were defined. In addition, only the six most prevalent species were identified. All remaining species were classified as either other softwood or other hardwood. These regeneration stand tree lists are described in appendix 2.

The GROW model (i.e., STEMS) does not have a regeneration component, yet this was clearly desired for estimating future forest conditions in this study. Given the paucity of organized data on regeneration in response to harvesting, the known difficulty in developing such a model for numerous species, and the lack of developed and tested models, the approach described by Ek et al. (1980) was selected. The approach involves substituting the average plot tree list from regenerated stands in the stand age range of 10 to 20 years. In a few cases, this range was relaxed to include slightly older stands to achieve an adequate sample. This approach provides a statistically unbiased estimate of average regenerated stand conditions by covertype. The actual choice of replacement covertype is treated in the next section. For implementation, the regeneration tree list is substituted for the previous stand 15 years following harvest.

The approach is simple but suffers, as do all regeneration models, from a lack of a large number of detailed observations. More observations would allow breaking lists down further by site, stand and treatment conditions. In particular, species composition can vary widely among sites and stands. In this case, tabulation of tree lists by site quality seemed to pick up some species composition patterns, particularly for aspen. However, further breakdowns were not informative—the data is simply very noisy. It would be helpful to have more precise models and information, but research and modelling of regeneration by Belli and Ek (1988) suggest that is still very distant.

Covertype Change Assumptions

Initial model runs were conducted with the assumption that a stand which is harvested will always return to the same forest type, unless site conversion was specified. To check this assumption, the FIA data were used to examine commercial forest stands which had been harvested between 1977 and 1990. A cross tabulation of the results showing 1977 forest type versus 1990 forest type was developed. Two such cross tabulations are provided in tables 4.1 and 4.2. Table 4.1 is all available data meeting the above mentioned criteria.

Table 4.2 is the subset of those plots which in 1977 had 10 percent or more of their stocking in terms of basal area in quaking aspen. The cells in the interior of the table show the percent of each forest type in 1977 (columns) that converted to each forest type by 1990 (rows). The right hand column indicates covertypes gaining acreage (more than 100 percent) and those losing acreage (less than 100 percent) as a result of all covertype changes over the period 1977–90. For example, table 4.1 indicates that 23 percent of the harvested jack pine stands became aspen stands over this period. Also, the total number of aspen stands increased by 12 percent.

There is a well-known correlation between the amount of aspen in a stand and the characteristics of future stands following a clearcut harvest, and the two tables support this idea. Additional tables with more and less aspen percent were also developed, but they were not very informative as sample size diminished rapidly with finer selection criteria. Unfortunately, no clear and easily implementable covertype conversion rule is evident. These tables will be used to help refine the final model runs. Specifically, the tables will be used to define a natural conversion rule, if feasible, which will be implemented in the final runs.

Table 4.1. continued.

B. Number of plots

Forest Type—1990		Forest Type—1977														
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Total
Jack pine	1	18	0	0	0	0	0	0	0	0	0	0	1	0	0	19
Red pine	2	3	10	1	0	0	0	0	0	1	0	0	0	2	0	17
White pine	3	0	1	3	0	0	0	0	0	0	0	0	1	1	0	6
Black spruce	12	0	0	0	30	1	0	2	1	0	0	0	0	0	0	34
Balsam fir	13	1	0	0	2	17	3	0	0	0	0	0	6	3	1	33
N. white cedar	14	0	0	0	1	5	18	0	0	0	1	0	0	0	0	25
Tamarack	15	0	0	0	5	1	3	21	0	0	0	0	0	1	0	31
White spruce	16	0	0	0	0	2	0	0	2	0	0	0	1	0	0	5
Oak-hickory	50	3	0	0	0	0	0	0	0	10	0	1	2	3	0	19
Elm-ash-soft maple	70	0	0	0	2	1	0	0	0	0	23	10	12	6	3	57
Maple-basswood	80	0	0	0	0	0	0	0	0	2	0	25	9	2	0	38
Aspen	91	8	3	3	8	17	2	0	3	0	1	8	373	26	13	465
Paper birch	92	1	0	0	2	5	3	1	1	0	1	0	4	27	0	45
Balsam poplar	94	0	0	0	0	1	1	0	0	0	2	1	5	0	20	30
Total		34	14	7	50	50	30	24	7	13	28	45	414	71	37	824

Table 4.1. continued.

B. Number of plots

Forest Type—1990		Forest Type—1977														
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Total
Jack pine	1	18	0	0	0	0	0	0	0	0	0	0	1	0	0	19
Red pine	2	3	10	1	0	0	0	0	0	1	0	0	0	2	0	17
White pine	3	0	1	3	0	0	0	0	0	0	0	0	1	1	0	6
Black spruce	12	0	0	0	30	1	0	2	1	0	0	0	0	0	0	34
Balsam fir	13	1	0	0	2	17	3	0	0	0	0	0	6	3	1	33
N. white cedar	14	0	0	0	1	5	18	0	0	0	1	0	0	0	0	25
Tamarack	15	0	0	0	5	1	3	21	0	0	0	0	0	1	0	31
White spruce	16	0	0	0	0	2	0	0	2	0	0	0	1	0	0	5
Oak-hickory	50	3	0	0	0	0	0	0	0	10	0	1	2	3	0	19
Elm-ash-soft maple	70	0	0	0	2	1	0	0	0	0	23	10	12	6	3	57
Maple-basswood	80	0	0	0	0	0	0	0	0	2	0	25	9	2	0	38
Aspen	91	8	3	3	8	17	2	0	3	0	1	8	373	26	13	465
Paper birch	92	1	0	0	2	5	3	1	1	0	1	0	4	27	0	45
Balsam poplar	94	0	0	0	0	1	1	0	0	0	2	1	5	0	20	30
Total		34	14	7	50	50	30	24	7	13	28	45	414	71	37	824

Table 4.2. Type change matrix for harvested plots, 1977–90, for all FIA covertypes—ten percent or more aspen by basal area. The plots used in creating the following matrix met the following conditions:

1. remeasured, ground visited plots (sample kinds 2 or 6)
2. commercial forest (ground land use at each cycle less than 30)
3. disturbed by harvesting (disturbance code equal to 4)
4. naturally regenerated (stand origin less than 2)
5. stand age in 1977 was greater than 30 (indicates that it was merchantable)

A. Percent of 1977 forest type plots.

Forest Type—1990		Forest Type—1977														
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Percent of 1977 Total
Jack pine	1	44.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	55.55
Red pine	2	0.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.12	0.00	75.00
White pine	3	0.00	12.50	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	2.56	0.00	100.30
Black spruce	12	0.00	0.00	0.00	70.00	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.00
Balsam fir	13	11.11	0.00	0.00	0.00	19.04	20.00	0.00	0.00	0.00	0.00	0.00	1.44	2.56	5.00	66.67
N. white cedar	14	0.00	0.00	0.00	0.00	4.76	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00
Tamarack	15	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
White spruce	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.33	0.00	0.00	0.00	0.24	0.00	0.00	66.67
Oak-hickory	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.0	0.00	0.00	0.48	2.56	0.00	175.00
Elm-ash-soft maple	70	0.00	0.00	0.00	0.00	4.76	0.00	0.00	0.00	0.00	60.00	30.76	2.88	2.56	0.00	420.00
Maple-basswood	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.07	2.16	0.00	0.00	92.31
Aspen	91	44.44	37.50	75.00	30.00	61.88	40.00	0.00	66.66	0.00	20.00	46.14	89.28	53.76	45.00	106.55
Paper birch	92	0.00	0.00	0.00	0.00	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.72	30.72	0.00	41.03
Balsam poplar	94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	1.20	0.00	50.00	80.00
Total		99.99	100.00	100.00	100.00	99.96	100.00	100.00	99.99	100.00	100.00	99.87	98.88	99.84	100.00	

Table 4.2. (continued)

B. Number of plots

Forest Type—1990		Forest Type—1977														
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Total
Jack pine	1	4	0	0	0	0	0	0	0	0	0	0	1	0	0	5
Red pine	2	0	4	0	0	0	0	0	0	0	0	0	0	2	0	6
White pine	3	0	1	1	0	0	0	0	0	0	0	0	1	1	0	4
Black spruce	12	0	0	0	7	1	0	0	0	0	0	0	0	0	0	8
Balsam fir	13	1	0	0	0	4	1	0	0	0	0	0	6	1	1	14
N. white cedar	14	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3
Tamarack	15	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
White spruce	16	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2
Oak-hickory	50	0	0	0	0	0	0	0	0	4	0	0	2	1	0	7
Elm-ash-soft maple	70	0	0	0	0	1	0	0	0	0	3	4	12	1	0	21
Maple-basswood	80	0	0	0	0	0	0	0	0	0	0	3	9	0	0	12
Aspen	91	4	3	3	3	13	2	0	2	0	1	6	372	21	9	439
Paper birch	92	0	0	0	0	1	0	0	0	0	0	0	3	12	0	16
Balsam poplar	94	0	0	0	0	0	0	0	0	0	1	0	5	0	10	16
Total		9	8	4	10	21	5	1	3	4	5	13	412	39	20	554

Ingrowth

Ingrowth is defined as the number or volume of trees that periodically grow into the smallest measured size class of a stand. However, the growth model used for the project does not include an ingrowth module. That limitation may result in conservative estimates of future numbers of trees and/or volumes, particularly where thinning uneven-aged management options are implemented. As very little of this management occurred in the initial runs, the impact is probably small. This will have a conservative effect on the estimated forest conditions from the final runs. The subject of ingrowth models was thoroughly reviewed and researched extensively by Shifley (1990). Examining six forest types in the north central U.S., Shifley found that, on average, 65 percent of the ingrowth trees are of the same species as one of the trees present in the overstory of the parent stand. Shifley proceeded to develop ingrowth models with significant fit statistics, but low overall precision. Other efforts, such as gap models described by Shugart et al. (1984), Pastor and Post (1985) and variations, have postulated ingrowth in the form of regeneration dynamics, but these have not been rigorously tested on large data sets in this region and are probably too general for the short-term objectives of this study. Ek and Monserud (1974, 1981) developed a model with detailed regeneration and understory dynamics, but that has not been extended and calibrated for Minnesota species and forest conditions. Several of these models also require more input data than is present in FIA plot records.

Given the lack of an ingrowth model, another approach is to include as many trees as possible in projections right at the start. This step is taken here by inclusion of all trees ≥1.0 inch dbh in the FIA plot records. That this is adequate for projections up to 50 years is questionable, but projection results to 17 years on the Cloquet Forestry Center by Moeur and Ek (1981) tended to overpredict number of trees, average diameter, basal area and biomass. Those results were based on the MFPS model which, like the GROW routine, utilized the tree growth and mortality components of the STEMS model and trials on 63, 35 and 36 remeasured plots from the jack pine, red pine and aspen covertypes. Part of the results were attributable to the absence of trees less than 5 inches dbh in the data, which diminished apparent tree competition and also led to underestimates of mortality.

Randall et al. (1988) investigated this type of application further and found that projections of FIA plots to 50 years leaving out trees from below 5 inches dbh tended to underestimate 50-year results as compared to projections made with all trees ≥1 inch dbh (see table 4.3). These results lack a comparison to actual plot values, but they are indicative of the importance and effectiveness of including small trees as done here.

Table 4.3. STEMS model projections: summary of the relative difference (%) from control for number of trees, basal area, pulpwood volume, and sawtimber volume per acre when trees less than 5 inches Dbh are omitted from projections for red pine, maple-basswood, and aspen covertypes at projection years 0, 20 and 50 (from Randall et al. 1988).

Type and censorship treatment	Number of trees			Basal area			Pulpwood volume			Sawtimber volume		
Year:	0	20	50	0	20	50	0	20	50	0	20	50
Red pine (softwoods only) (<5")	-45.1	-33.9	-24.6	-5.6	-6.8	-4.9	-1.7	-4.5	-2.9	-1.8	-1.6	-1.0
Maple-basswood (hardwoods only) (<5")	-71.4	-66.1	-60.8	-19.1	-20.2	-15.9	-1.3	-10.3	-8.9	-1.2	3.0	11.1
Aspen (hardwoods only) (<5")	-61.1	-53.3	-51.4	-15.2	-10.0	-4.7	-1.2	-.9	1.4	-1.2	10.5	16.1

Conclusions are that lack of an ingrowth model will tend to underestimate numbers of trees and, to a lesser extent, volumes. However, the underestimate of numbers of trees will, in turn, reduce competition in the model and therefore favor compensation by lowered mortality and attainment of larger individual tree sizes. For undisturbed stands, underestimation of future species composition would also be expected, since projections would not have an ingrowth component for any species. Where stands are harvested, species composition would be *updated* by the regeneration tree lists. This lack of an ingrowth model is unfortunate, and suggests an area for further research. Interpretation of results here, however, will be aided by long-term historical data on forest development.

STEMS Model Testing

The STEMS growth model was developed in the 1970s by the USDA Forest Service to enable earlier inventories to be updated and to project future resource volumes based on detailed knowledge of existing resources. The version used here was the published STEMS85 version (Holdaway and Brand 1986) with various coefficients updated to spring 1991 and implemented by the GROW routine. The STEMS model is one of many individual tree based forest growth models developed since the early 1960s (see reviews by Dudek and Ek 1980, Shugart 1984). The model form is essentially a simplification and approximation of biological theories of how trees and forests grow. Model parameters are largely estimated directly from field data using statistical procedures. The STEMS model projects growth of individual trees in plots. It includes consideration of both tree growth and mortality on the plot. STEMS, like many growth models, may overestimate actual growth and, therefore, future yields. There are two reasons for this. First, the model does not predict or account for the impact of catastrophic events (fire, windstorms, poor management, etc.) except where such plot data were included in the data used to construct the model. Second, the model is developed in part using data collected from selected field sites that may be growing better than the average for those conditions. For example, parts of the model were developed using *research* and other *remeasured* plot data. Such data generally represents selected conditions, i.e., at the very least they were plots that were undisturbed for the remeasurement period. In the study group's expert judgement, STEMS is likely to overestimate growth on the average across all FIA plots. Regarding species and locality specific errors, regression based models like STEMS generally overestimate the lowest values and underestimate the highest values. That, plus the apparent underrepresentation of Minnesota stands in the construction of STEMS, probably lessens its sensitivity to conditions here. The model, by nature of its construction, is also somewhat insensitive to site quality influences. Reports such as those of Holdaway and Brand (1983, 1986), Buchman (1983), Buchman et al. (1983), Moeur and Ek (1981), and Walters and Ek (1992) are helpful in indicating the range and direction of error, but because results are very locality and species specific, it is difficult to generalize. Additionally, weather changes from one growth period to the next can easily obscure model errors. The Study Group has attempted to refine STEMS error estimates and interpretations as opportunities develop in the course of the study. These findings were considered again in the course of interpreting the final model outputs.

The tests by Holdaway and Brand (1986) summarized in tables 4.4 and 4.5 are helpful, but not definitive. They show differences between average actual and predicted number of trees and basal area values by species. Re-analysis by Brand and Holdaway (1989) shows that errors in components of change (growth, mortality, etc.), are percentagewise larger than when comparing end of period values. Basal area errors are emphasized because they are highly correlated with volume and biomass errors, but they are easier to compute. However, many of these analyses lack a ready means of comparing or assessing performance in terms that help in interpreting and/or adjusting model output.

Walters and Ek (1992) present a comparison of the growth implementation package (GIP), an empirical yield model and the GROW model for selected FIA plots in Minnesota (see table 4.6). These were plots that were classified as undisturbed between 1977 and 1990. Results indicate both over- and underpredictions for basal area. However, projections in this study need to be developed for both undisturbed and disturbed plots. Table 2.24 in section 2.3.8 shows harvesting as affecting 8.5 percent of the plots over a ten year period and natural disturbance (fire, insects, disease, wind, etc.) affecting another 8.2 percent. Consequently, an analysis was developed to describe prediction capability statewide over both undisturbed (by cutting or natural factors) and a larger set of plots incorporating both undisturbed and disturbed conditions.

Table 4.4. Mean number of trees errors (trees/acre) by Lake States species in 10 years using the STEMS85 model (the number of plots appears in parentheses). Positive values are overpredictions from Holdaway and Brand (1986).

Forest type	All		Cloquet Forestry Center, MN		Chequamegon National Forest, WI		Nicolet National Forest, WI		Hiawatha National Forest, MI		Manistee National Forest, MI	
Jack pine	7	(127)	-4	(79)	16	(7)	42	(6)	42	(20)	-2	(15)
Red pine	4	(85)	-1	(49)	22	(6)	-6	(4)	-11	(11)	26	(15)
White pine	-1	(13)	19	(6)	-6	(2)	-41	(2)	-12	(3)	–	
White spruce	-13	(10)	5	(4)	–		-27	(4)	-45	(1)	–	
Balsam fir	30	(51)	13	(23)	32	(14)	7	(8)	124	(6)	–	
Black spruce	-16	(40)	-19	(29)	-25	(2)	27	(3)	-22	(6)	–	
Tamarack	-11	(23)	-3	(19)	-46	(4)	-54	(2)	–		–	
N. white-cedar	-10	(47)	11	(14)	-4	(2)	-25	(9)	-36	(14)	68	(2)
Lowland hardwoods	35	(30)	13	(3)	80	(5)	48	(2)	-43	(1)	29	(19)
N. hardwoods	13	(135)	–		31	(40)	10	(49)	-16	(28)	27	(18)
White oak	21	(15)	–		–		–		–		21	(15)
N. red oak	7	(15)	–		5	(4)	-109	(1)	-62	(2)	40	(8)
Oak-hickory	-9	(35)	–		-82	(1)	–		–		-7	(34)
Aspen	5	(121)	11	(30)	14	(23)	-2	(42)	1	(14)	3	(12)
Paper birch	5	(58)	3	(36)	16	(8)	-10	(9)	45	(4)	-3	(1)
All	6	(822)	0	(292)	21	(123)	1	(145)	1	(114)	12	(148)

Table 4.5. Mean basal area errors (sq.ft./acre) by Lake States species in 10 years using the STEMS85 model (the number of plots appears in parentheses). Positive values are overpredictions from Holdaway and Brand (1986).

Forest type	All		Cloquet Forestry Center, MN		Chequamegon National Forest, WI		Nicolet National Forest, WI		Hiawatha National Forest, MI		Manistee National Forest, MI	
Jack pine	-2.5	(127)	-5.9	(79)	1.5	(7)	2.6	(6)	4.0	(20)	2.1	(15)
Red pine	-2.5	(85)	-3.6	(49)	2.8	(6)	-4.7	(4)	-9.1	(11)	4.2	(15)
White pine	-2.4	(13)	3.9	(6)	-2.7	(2)	-14.3	(2)	-6.6	(3)	–	
White spruce	-3.1	(10)	5.9	(4)	-2.4	(1)	3.6	(4)	-4.4	(1)	–	
Balsam fir	5.3	(51)	5.9	(23)	1.1	(14)	2.9	(8)	16.6	(6)	–	
Black spruce	-4.3	(40)	-6.4	(29)	-2.5	(2)	11.3	(3)	-2.9	(6)	–	
Tamarack	.0	(23)	1.7	(19)	-6.6	(2)	-10.2	(2)	–		–	
N. white-cedar	-.7	(47)	1.7	(14)	.6	(8)	-4.0	(9)	-4.8	(14)	19.9	(20)
Lowland hardwoods	16.4	(30)	4.4	(3)	18.2	(5)	3.1	(2)	-11.7	(1)	20.7	(19)
N. hardwoods	1.6	(135)	–		2.8	(40)	-1.2	(49)	-3.1	(28)	14.0	(18)
White oak	3.3	(15)	–		–		–		–		3.3	(15)
N. red oak	.6	(15)	–		-.7	(4)	-8.8	(1)	-8.7	(2)	4.7	(8)
Oak-hickory	.7	(35)	–		6.8	(1)	–		–		.5	(34)
Aspen	4.0	(121)	7.0	(30)	2.0	(23)	1.4	(42)	3.1	(14)	10.8	(12)
Paper birch	.7	(58)	1.0	(36)	1.1	(8)	-5.4	(9)	9.3	(4)	7.8	(1)
All	.9	(822)	-1.1	(292)	2.3	(123)	-.8	(145)	-1.1	(114)	7.1	(148)

Table 4.6. Comparison of empirical yield GIP model and GROW (Brand 1981) in predicting basal area from 1977 to 1990 for selected FIA plots in the Aspen-birch Unit.

Covertype[b]	GIP Model		GROW
	Sample size (plots)	Mean error[a] (%)	Mean error[a] (%)
Red pine	11	-13.85	-2.71
Balsam fir	27	-13.98	10.15
Black spruce	34	-16.01	-6.68
Northern white cedar	22	-9.52	3.33
Elm-ash-soft maple	20	-3.70	-1.09
Maple-basswood	19	-14.31	-7.22
Aspen	121	-5.91	-4.70
Paper birch	37	-10.79	2.58

[a] (Predicted-actual)/actual at end of period.
[b] Covertypes were excluded for which less than 10 remeasured plots were available.

The results, shown in tables 4.7 and 4.8, show an overall prediction error of +16.2 and +11.4 percent for basal area and number of trees, respectively, for undisturbed plots. Sample covertype results are shown in figure 4.7. Table 4.9 describes the sample size by covertype and age class for these tests. However, these values need to be qualified as it is especially important to describe the data set being used for testing. The magnitude of these errors varies depending on the level and type of disturbance on the various categories of plots. These differences are shown in table 4.7.

Table 4.7. Ratio of predicted to actual basal area and number of trees by disturbance category for FIA plots.

Test	No. of test plots	Predicted/Actual		Data conditions
		Basal area	No. of trees	
1	1101	1.10	1.03	No disturbance, no cut trees, regular mortality
2	1698	1.16	1.11	No disturbance, no cut trees
3	3831	1.19	1.13	No cut trees
4	2053	1.22	1.15	No disturbance

In these trials, *no disturbance* used only those plots classified as undisturbed in the FIA aerial photo interpretation effort. However, it is not always possible to detect small amounts of cutting or other minor disturbance from aerial photos. Thus, *no cut trees* meant the elimination of plots with tree records indicating some trees were cut. Note that 355 plots classified as no disturbance were found to have cut trees. Again, this can occur because disturbance on FIA plots is based on the plurality of the ten points

Table 4.8a. GROW model test: Ratio of predicted/actual basal area by covertype for undisturbed FIA plots, 1977 to 1990.

Forest Type	Stand Age Class (years)														
	5	15	25	35	45	55	65	75	85	95	105	115	125	135	Overall
Jack pine	1.20	0.83		1.04	1.17	1.08	0.95		1.09						1.07
Red pine		0.66	0.91	1.03	1.08	1.07	1.15	1.10	1.00	1.02					1.05
White pine					1.00		1.14	1.05		0.92					1.01
Black spruce	1.68	1.41	1.26	1.08	1.10	0.84	1.09	0.83	0.89	1.08	0.88	0.84		0.63	0.98
Balsam fir	2.01	1.41	1.43	0.81	1.33	1.11	0.98	1.44	1.24						1.21
Northern white cedar		0.86	2.75	0.86	1.19	1.05	1.18	1.11	1.08	1.09	1.09	1.21	0.88	1.05	1.07
Tamarack	2.24	1.87	1.85	1.03	0.87	1.13	1.26	1.05	0.89	1.03	0.97	0.84	1.27	0.98	1.07
White spruce			0.84		0.92		1.05	1.34	1.57						1.04
Oak-hickory	4.43	1.42	0.60	1.01	1.03	1.15	1.20	1.09	1.07	1.08	1.03	1.07		1.45	1.13
Elm-ash-soft maple	1.58	2.27	3.09	1.60	1.34	1.19	1.17	1.25	1.32	1.07	1.23		1.66	0.74	1.28
Maple-basswood	1.20	1.62	0.95	1.17	1.18	1.11	1.16	1.17	1.10	1.20	1.15	1.08		1.00	1.15
Aspen	1.73	1.67	1.24	1.20	1.19	1.13	1.19	1.12	1.10	1.44	0.97	0.93			1.18
Paper birch	1.14		1.04	1.28	1.32	1.18	1.21	1.26	1.30	1.11	1.55				1.22
Balsam poplar	2.07	2.40	1.57	1.51	1.09	1.38	1.22	0.95	1.30					1.52	1.31
Overall															1.16

Table 4.8b. GROW model test: Ratio of predicted to actual number of trees by covertype for undisturbed FIA plots, 1977 to 1990.

Forest Type	Stand Age Class (years)														
	5	15	25	35	45	55	65	75	85	95	105	115	125	135	Overall
Jack pine	1.48	0.48		1.06	1.22	1.03	1.01		0.86						1.10
Red pine		0.62	0.99	1.11	1.34	1.21	0.92	1.25	1.07	1.00	0.85				1.07
White pine							0.93	1.10			0.76				0.99
Black spruce	1.24	1.17	1.14	1.04	1.15	0.78	1.06	0.82	0.87	1.12	0.81	0.77		0.64	0.94
Balsam fir	2.13	1.46	1.31	0.78	1.38	1.02	0.89	1.50	1.28						1.18
Northern white cedar	1.00	0.90	3.74	0.82	1.27	0.98	1.37	1.18	1.00	1.09	1.11	1.10	0.88	1.03	1.08
Tamarack	0.95	1.96	2.10	0.94	0.91	1.07	1.21	1.02	0.89	0.97	0.93	0.82	1.18	0.89	1.04
White spruce			0.62		0.74		1.07	1.64	0.87						0.83
Oak-hickory	7.19	2.98	0.48	1.24	0.92	1.16	1.21	1.01	0.98	1.01	0.89	0.68		1.07	1.11
Elm-ash-soft maple	1.28	2.13	1.89	1.70	1.18	1.15	1.12	1.02	1.20	0.99	1.26		1.73	0.77	1.18
Maple-basswood	0.74	1.40	0.91	1.19	1.10	1.08	1.09	0.99	1.05	1.23	0.97	1.17		0.81	1.07
Aspen	1.55	1.61	1.12	1.14	1.15	1.08	1.16	1.08	1.06	1.89	0.96	0.89			1.14
Paper birch	0.94		1.15	1.23	1.22	1.15	1.17	1.28	1.32	0.84	1.83				1.19
Balsam poplar	1.76	1.34	1.46	1.42	0.91	1.26	1.24	0.76	0.83					1.48	1.17
Overall															1.11

Table 4.9. GROW model test: Sample size by covertype for undisturbed FIA plots, 1977 to 1990.

Forest Type	Stand Age Class (years)														
	5	15	25	35	45	55	65	75	85	95	105	115	125	135	Overall
Jack pine	1	2	0	8	22	9	13	0	1	0	0	0	0	0	56
Red pine	0	3	3	4	1	5	6	3	5	1	2	0	0	0	33
White pine	0	0	0	0	0	0	1	4	0	0	2	0	0	0	7
Black spruce	2	9	2	10	11	11	18	9	9	8	5	2		2	98
Balsam fir	8	12	6	2	22	29	13	5	3	0	0	0	0	0	100
Northern white cedar	0	1	1	2	3	2	3	8	10	13	9	9	8	25	94
Tamarack	1	3	6	5	4	7	7	7	5	6	2	6	3	3	65
White spruce	0	0	3	0	2	0	1	1	1	0	0	0	0	0	8
Oak-hickory	1	1	1	3	13	37	29	17	7	9	6	2	0	1	127
Elm-ash-soft maple	12	9	3	5	12	23	31	14	19	12	7		2	1	150
Maple-basswood	6	9	6	7	22	34	39	24	9	7	5	2	0	1	171
Aspen	19	38	27	78	126	158	111	43	6	1	3	1	0	0	611
Paper birch	1	0	1	3	19	41	28	15	4	2	1	0	0	0	115
Balsam poplar	5	3	5	7	12	14	13	2	1	0	0	0	0	1	63
Overall															1,698

comprising the plot. *Regular mortality* constrained the data set further by eliminating plots that had an annual average mortality of more than 5 percent of the trees (51 percent survival over the period 1977–90). Usual mortality is about 1 to 2 percent per year.

These results suggest overprediction is due largely to a failure to include disturbance (fire, insects, disease, wind, some cutting, etc.) in the predictions. Thus, while it is possible to adjust the model, it is difficult to do so for all application data sets. Much depends on rates of disturbance and mortality, both being highly related to weather conditions. Additionally, management that captured the mortality as harvest would reduce these errors. Disturbance in the forest is considerable due both to natural and human factors.

These findings, in terms of magnitude and direction of error, agree with that found by Hansen (1990) for the recent Wisconsin forest survey and adjustments of STEMS since for the 1990 Minnesota survey,[2] i.e., errors of 5 to 15 percent in tree growth are typical of unadjusted applications.

[2] Personal communication from M. H. Hansen, USDA Forest Service, North Central Forest Experiment Station, March 1992.

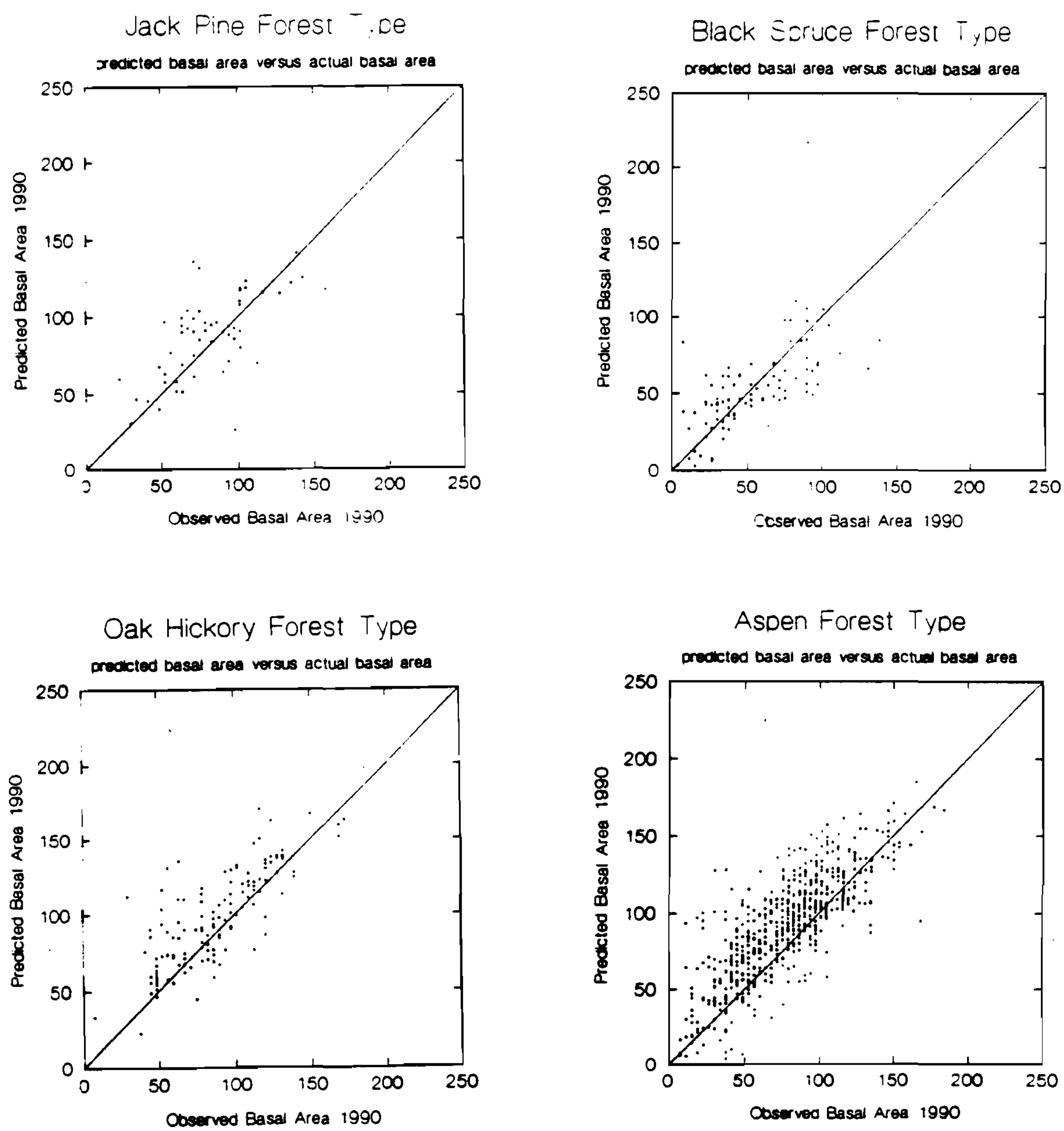


Figure 4.7. Predicted versus actual basal area for selected forest types for GROW model in test 2, undisturbed, no cut trees, 1977 to 1990.

Also, as found by Brand and Holdaway (1989), overprediction is greater for stands of low basal area. Since such stands usually correspond to younger ages, the regeneration model used here, with its use of average tree lists for approximately 15-year-old stands, effectively reduces growth model prediction errors following harvesting that otherwise would develop for younger stands. In brief, error is reduced by beginning growth model usage at age 15 rather than at an earlier age.

Because of the apparent growth model overprediction, the study group implemented newly available correction factors for tree growth and mortality for the second runs. Those corrections involved adjustment procedures similar to those outlined by Holdaway (1985). The actual correction procedure is described in section 4.10.1.

Overestimation by the GROW model is countered to a degree by the fact that, in the first runs, the RXWRITE model made the very conservative assumption that harvesting activities will occur at the start of each period, not at the midpoint. This has the effect of reducing, on average by five years, the estimate of wood increment or growth that occurs during the first rotation.

4.6 Assumptions Used to Prepare the Scenarios

A number of assumptions were needed for the modelling process. Some of these are likely to have a profound effect on the results. As the analytical process continues, attempts have been made to better understand the likely impacts of these assumptions and to make changes where appropriate. Some assumptions, such as those discussed under section 4.4, influence the modelling process itself. Minor changes were made in the general model formulation after reviewing preliminary results. Before drawing general conclusions from the results it is important to understand the basic assumptions surrounding the analysis, and the potential impacts of those assumptions on model results and interpretations.

4.6.1 Demand Levels

FSD Specified Levels of Demand

Demand levels and the time frame within which levels of demand were to be achieved were prescribed by the FSD under section VI "Alternatives Addressed in the GEIS." Three levels were specified: the current level of harvest at 3.2 million cords per year; a level of 4.9 million cords per year estimated to occur within 5 years (1995) if proposed industry expansions occur; and the estimated "maximum" annual volume of timber sustainable for harvest statewide in the year 2000 which is estimated at 7 million cords per year. The EQB set these levels to comply with the rules governing

Minnesota's environmental review program. This requires that the GEIS consider a range of alternatives. These levels of harvest were prescribed to ensure that the GEIS considered the full range, from existing or "change nothing" levels through to the theoretical maximum when assessing impacts. *These levels should not be viewed as being targets or recommendations from the GEIS study group or the EQB.* In prescribing these levels the EQB has introduced the following assumptions:

- Once an industry is established it will continue to demand the same product mix for the remainder of the planning period.
- "Planned" industries used to generate the medium scenario will come into full production in 1997.
- The definition of the high demand "maximum annual volume of timber available for harvest statewide for all tree species in the year 2000" implies first that all unreserved commercial timberland will be available for harvest; and secondly that species for which there are no current economically viable uses will become economically acceptable to future industries.

Target levels were developed for each aggregated species group, for each of three scenarios. The lowest or base demand scenario assumes that the most recent mill intake levels from existing industries and uses will remain constant for the 50-year planning period. Mills have been grouped according to location and the intake quantified by species and grade of wood. The model, as formulated, cannot fully accommodate the fact that wood can be cut and left in the forest or simply left standing. This means that when a stand is clearcut by the model, all merchantable trees are included in the product summaries. To expand on this, the additional volumes of less desirable species groups such as northern hardwoods that are produced in the course of meeting targets for aspen production are accounted for as production by the model, and contribute to the volume figure. This has had the effect of increasing the level of harvesting above the levels set for each of the three scenarios. The implications for various species and product groups are discussed under section 4.7.

Modelled Demand Levels

The maximum demand (1991 levels) at the base scenario is assumed to be made up of 3.7 million cords per year from the northern region and 300 thousand from the southern region, giving a total of 4 million cords per annum. This differs from the amount specified in the FSD, and reflects increased productive capacity developed by industry since the 1988 figures used in the FSD were calculated (see table 4.10). These demands by industry were allocated by product group to arrive at the annual forest products demand for the base scenario (table 4.11).

Table 4.10. Minnesota GEIS—estimated current wood consumption, 1991 (thousands of cords).

	Bfsp	Pine	Otsw	Asp	Brch	Maple	Oak	Balmco	Othw	Total
Blandin, Grand Rapids	44			91						135
Boise-Cascade, Int. Falls	20	70		210						300
Certainteed, Shakopee				15	5				5	25
Champion, Sartell	45			80						125
Diamond, Cloquet				12	6					18
Hennepin, Little Falls	10			10						20
Int. Bildrite, Int. Falls				22						22
L.S. Paper, Duluth	160									160
Lou. Pacific, Two Harbors				100						100
Mac. Blo., Crosby				135						135
Northwood, Solway				210						210
Potlatch, Cloquet		85		250						335
Potlatch, Brainerd		10		100						110
Potlatch, Bemidji		100		360						460
Potlatch, Cook				180						180
Potlatch, Grand Rapids				250						250
Superwood, Duluth				100						100
Superwood, Bemidji				30						30
Total pulpwood	279	265	0	2155	11	0	0	0	5	2715
Total sawlog consumption	37.2	160.7	9.6	146.0	39.1	47.9	64.5	0.3	67.0	581
Total industrial consumption	316.2	425.7	9.6	2301	50.1	47.9	64.5	0.3	72	3296
Fuelwood consumption (DNR data)										530
Special products (DNR data)										72
Net export (DNR data)										80
Total consumption assuming sawmill residues not utilized										3978

Sources: Forest industries and MNDNR (J. Kranz, MNDNR, personal communication). Record standards and detail varies by firm, thus this table is only an approximation.

Table 4.11. Annual forest products demand: Base scenario (thousands of cords).

Northern study region							
Product	Int. Falls	Bemidji	Cook	Grand Rapids	Duluth	Brainerd	Total
Aspen: Pulp	445.00	535.00	175.00	385.00	445.00	200.00	2185.00
Exported					20.00	27.00	47.00
Sawlogs	25.15	25.15	25.15	25.15	25.15	25.15	150.87
Firewood	2.82	4.95	2.82	3.90	2.82	18.16	35.46
Aspen Total	472.96	565.10	202.96	414.04	492.96	270.30	2418.33
Pine: Pulp	70.00	20.00			60.00		150.00
Other Pine Sawlogs	8.66	8.66	8.66	8.66	8.66	8.66	51.94
PineP+OPine Sawlogs	78.66	28.66	8.66	8.66	68.66	8.66	201.94
Red+WhitePine Sawlogs	18.95	93.95	18.95	18.95	18.95	18.95	188.71
Spruce/Fir: Pulp	10.00			50.00	60.00	7.00	127.00
Pulp export					20.00	15.00	35.00
Sawlogs	4.61	4.61	4.61	4.61	4.61	4.61	27.63
Balsam Fir: Pulp	10.00			65.00	100.00	53.00	228.00
Pulp export					10.00		10.00
Spr/F/BF Total	24.61	4.61	4.61	119.61	194.61	79.61	427.63
N Hdwds: Pulp	40.00	10.00			10.00		60.00
Pulp export					15.00		15.00
Sawlogs	13.47	13.47	13.47	13.47	13.47	13.47	80.83
Firewood	25.35	44.58	25.35	35.06	25.35	163.43	319.13
N Hdwds Total	78.83	68.05	38.83	48.53	63.83	176.90	474.96
Red Oak: Sawlogs	4.20	4.20	4.20	4.20	4.20	4.20	25.18
Total	678.20	764.56	278.20	613.98	843.20	558.61	3736.75
Southern study region							
Red oak sawlogs							50.00
All other products							250.00
Total							300.00
Total for the base scenario							4 M cords

The medium scenario (table 4.12) adds the demand anticipated from proposed industrial expansions that are either under construction or currently under study. It raises the annual harvest by 805,000 cords for the northern region to 4.5 million cords and by 60,000 for the southern region to 360,000. This gives a total of approximately 4.9 million cords per annum. For this scenario it was assumed that all of the proposed expansions would become operational in 1997 and remain at that level throughout the remainder of the planning horizon.

Table 4.12. Annual forest products demand: Medium scenario (thousands of cords).

Northern study region							
Product	Int. Falls	Bemidji	Cook	Grand Rapids	Duluth	Brainerd	Total
Northern study region							
Aspen: Pulp	445.00	535.00	175.00	485.00	530.00	230.00	2400.00
Exported					20.00	27.00	47.00
Sawlogs	25.15	25.15	25.15	25.15	25.15	25.15	150.87
Firewood	3.00	5.27	3.00	4.14	3.00	18.47	36.88
Aspen Total	473.14	565.41	203.14	514.29	578.14	300.62	2634.75
Pine: Pulp	70.00	20.00			60.00		150.00
Other Pine Sawlogs	8.66	8.66	8.66	8.66	8.66	8.66	51.94
PineP+OPine Sawlogs	78.66	28.66	8.66	8.66	68.66	8.66	201.94
Red+WhitePine Sawlogs	18.95	93.95	18.95	18.95	18.95	18.95	188.71
Spruce/Fir: Pulp	10.00			70.00	120.00	12.00	212.00
Pulp export					20.00	15.00	35.00
Sawlogs	4.61	4.61	4.61	4.61	4.61	4.61	27.63
Balsam Fir: Pulp	10.00			95.00	200.00	78.00	383.00
Pulp export					10.00		10.00
Spr/F/BF Total	24.61	4.61	4.61	169.61	354.61	109.61	667.63
N Hdwds: Pulp	40.00	10.00			345.00		395.00
Pulp export					15.00		15.00
Sawlogs	13.47	13.47	13.47	13.47	13.47	13.47	80.83
Firewood	26.97	47.42	26.97	37.29	26.97	166.27	331.88
N Hdwds Total	80.44	70.89	40.44	50.77	400.44	179.74	822.71
Red Oak: Sawlogs	4.20	4.20	4.20	4.20	4.20	4.20	25.18
Total	679.99	767.71	279.99	766.46	1424.99	621.77	4540.92
Southern study region							
Red oak sawlogs							60.00
All other products							300.00
Total							360.00
Total for the medium scenario							4.9 M cords

The high scenario (table 4.13) increases the total harvest level for the northern region to 6.6 million cords annually in the year 2000 and then maintains that level throughout the planning horizon. For the southern region the increase is by 100,000 cords per annum to 460,000. The total for this scenario is, therefore, approximately 7.1 million. There were no additional processing plants or plans for such plants upon which to base the high scenario demands. Therefore, the high scenario was developed based on the output from the medium scenario. As discussed in section 4.4.2, demand levels by species and industry were developed by using output from the medium scenario to identify regions with a surplus of wood from suitable species and in sufficient quantities to sustain new processing plants. Table 5.3, in section 5.5, shows the acreage of forest remaining unharvested after the medium harvesting scenario.

Table 4.13. Annual forest products demand: High scenario (thousands of cords).

Product	Int. Falls	Bemidji	Cook	Grand Rapids	Duluth	Brainerd	Total
Northern study region							
Aspen	473.14	565.41	203.14	514.29	578.14	300.62	2,635
Pine pulp	90	90.00	90.00	90.00	90.00	90.00	540
Red+White pine sawlogs							200
Spruce/fir	160.00	160.00	160.00	180.00	370.00	160.00	1,190
N Hdwds	210.00	440.00	210.00	310.00	430.44	410.00	2,010
Red oak: sawlogs							25
Total							6,600
Southern study region							
Red oak sawlogs							60
All other products							400
Total							460
Total for the high scenario							7.06 M cords

4.6.2 Transport

Transport costs are assumed to be $0.15 per cord per mile. A fixed cost of $4.75 per cord to cover loading and unloading, etc., was applied to all timber products. These costs were obtained from the Harvesting Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992e). Assumed transport costs do not reflect differences in the type of road transversed. For example, costs should generally be lower on roads with greater maximum speed limits. Seasonal differences in costs due to accessibility were not considered, as this information was not available.

All products harvested were assumed to be transported to the market yielding the highest net return. However, tests were not included in the model to determine whether it might be more profitable to leave some of the products in the stand if the cost of transport alone exceeded the marginal value of the product at the best market location. For example, if the marginal cost for product C in the most profitable market is $10.00 per cord and the transport cost is $12.25, then this product would be better off left in the woods. It was apparent that, for most products, the marginal values in each market exceed the cost of transporting the product to the market. All harvest cost estimates assume that all products in the stand are harvested.

Specific market locations for the two "sawlog-only" product groups—red oak and red and white pine—were not recognized, as demands for these products involve many small sawmills located throughout the region. Marginal cost estimates, or any fixed prices for these products, relate to the value of these products harvested and loaded on a truck located at the stand. For all three scenarios for the northern study region, it was assumed that the marginal costs for red and white pine are $50 per cord, and shadow prices for red oak sawlogs are $40 per cord. These marginal costs were assumed to remain constant over time. The prices assumed are not equivalent to stumpage prices, as stumpage prices relate to the value before harvesting costs are incurred. The prices assumed for these two sawlog categories are relatively low when compared to recent stumpage prices for these products, yet model results have relatively high production levels over time with these price levels. Despite the fact that the model anticipates only a comparatively low prices for these products, this can be interpreted as meaning that there are sufficient volumes of red and white pine sawlogs produced to meet demand. The model seeks to select management options to maximize the cashflow from each stand.

4.6.3 Stand Sorting

For all harvests, it is assumed that sawlogs will be sorted and sold as such. For species like aspen this means very little, as demand for aspen sawlogs and demand for aspen pulpwood are combined for developing aspen harvest level targets. Only for red oak and red and white pine are sawlogs distinguished as separate products in the model, and sawlog sorting would likely occur in most cases for these more valuable species.

4.6.4 Stand-level Inventory

The modelling approach assumes that all stands defined by FIA plots are homogeneous units. Thus for an FIA plot with a stand size of 20 acres, all of those acres are assumed to have the same characteristics as the approximately one acre plot. Several characteristics of this inventory information have implications for model results. First, each FIA plot has an area expansion factor associated with it. That expansion factor (say 1,500 acres) divided by the stand size is the number of stands of this size and set of characteristics that the subject stand represents in the FIA unit. For modelling purposes, all acres in each of these stands are assumed to be located at the plot location. The lack of further information on specific stand locations represented adds imprecision to the consideration of stand size and spatial location factors, especially as they relate to management costs and accessibility, such as distances to the nearest road.

The FIA data has a shortcoming when used for the purpose of modelling timber supply. By its design, the inventory is not a stand level characterization. The plot based design assumes that all trees measured within each FIA plot are in the same timber stand, but that is not necessarily true. Many plots straddle stand boundaries, thus treating each plot as if it were a single stand could potentially be misleading (see section 4.2.2). From a forest management standpoint, forest stands are the basic management unit, with forest management activities assumed to occur uniformly throughout the stand. If some *stands* are defined by information derived by aggregating information from several stands, then splitting the stands into their constituent pieces would allow more appropriate management activities to be specified. For example, if 80 percent of one inventory plot is a 60-year-old balsam fir stand and 20 percent is a 10-year-old aspen stand, the timings of harvest for these two units would be quite different. But if these are aggregated and assumed to be a stand for analysis, the optimal timing of a harvest for the unit as a whole might be different, and of less value than if each component were managed individually. Thus, management schedules may be imprecise for those survey plots that straddle stand boundaries. This shortcoming adds imprecision, but not necessarily significant inaccuracy, to statewide and ecoregion results. There are no easy solutions to the problem for purposes of this study.

Concern has also been expressed about the loss of species information in growth projections. However, the fact that the growth model used here projects individual trees and not stands mitigates against loss of species detail. The covertypes describing the FIA data (appendix 7) contain a number of species, and the plot species mix is largely retained in projections. Given that trees can grow, die, or be cut in projections, an algorithm can be applied at the end of each projection period to assess stocking and possible covertype changes. The regeneration tree lists described in the next section also carry forward the six major species in a covertype, plus an "other" category containing the less frequently occurring species. Significant loss of tree species information in the projections is thus unlikely. However, in examining future species composition, an approach has been adopted that avoids aggregating species. Briefly, 1990 species composition by forest type and age class were applied to future age class distributions to estimate future compositions. In that way the aggregation of species is avoided.

4.6.5 Management Alternatives

Assumed growth rates for regenerated stands are an important factor in determining future management options for clearcut stands. Decisions to undertake intensive management alternatives depend heavily on these assumptions, as the benefit of intensive management is measured by the increase in yields over the level of yields achieved through natural regeneration.

The model uses 1 of 26 regeneration tree lists (and associated management prescriptions) (see appendix 2) to represent the stand condition after harvest. Three additional tree lists are used to describe red pine plantations on sites of various site quality. For most of the regeneration tree lists, harvests are not possible within the remainder of the 50-year planning horizon. However, these tree lists are used for many analysis areas; and thus, summaries of future inventories are sensitive to the specific regeneration tree lists and their subsequent growth. These tree lists, determined from 10- to 20-year-old stands in the FIA data, are the best statistical information available.

For the initial applications for the northern Minnesota study area, conversion to red pine plantations was considered as an intensive management option for a number of covertypes. The costs associated with this conversion are set out in appendix 2. The model makes no assumptions as to the specific techniques used for this conversion process. Details of commonly used practices were derived from the Silvicultural Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992c) and used to impute possible impacts while the more detailed impact analysis work was done by the other study groups.

Other options were not considered, as site conversion options involving rotations longer than 40 years would not result in any harvests within the planning horizon. The primary value of recognizing intensive management options is in better estimating bare land values, and in describing the likely species mix of the forest for evaluating nontimber concerns. Thus, while conversion options specify conversion to red pine, they should be viewed as conversion to softwoods in general.

4.6.6 The Planning Horizon

Five consecutive 10-year planning periods were used in the analysis, giving a 50-year planning horizon. For the first runs, all harvests for each planning period were assumed to occur at the beginning of the planning period. This is an extremely conservative assumption as, on average, stands harvested each period will grow for one-half of the period before the harvest occurs. As noted earlier, this tended to counter overprediction by the growth model.

The use of 10-year planning periods also has implications for interpreting results. When the planning period length is set to 10 years, the model can only select rotation ages that are multiples of 10. For example, for one forest type the optimal rotation age might be 50 years. But for many stands in this type, the possible rotation ages might be only age 45 or age 55. Furthermore, if supply conditions force the delay of harvest of a stand, it must be delayed at least 10 years. In some aspects, long planning periods can lead to an underestimate of the potential value of the forest.

With only a 50-year planning horizon, there might be concern about the potential of liquidating the inventory during the planning horizon to maintain harvest levels, leaving inadequate levels for periods beyond the planning horizon. This should not be a major concern as the model uses an infinite planning horizon when valuing management alternatives. Product values for periods beyond the end of the planning horizon are assumed to be equal to the estimated values for the last period in the planning horizon. With this assumption, harvest options selected for the last period will not be less than the optimal rotation age under a constant price assumption. This method of valuing ending inventory has significant advantages over other modelling approaches, as inventory values depend on model results.

4.6.7 Availability of Timber

As described earlier, the model applied is an optimization model. Focus has been on achieving production at least cost. *All timberland in the region outside of designated reserved areas, such as the BWCAW, was considered available for harvest in this analysis.* This assumption sets aside, *for these runs,* existing policies which constrain access to timberlands on various ownerships. For example, this includes such policies as those under which the USDA Forest Service will not sell timber on areas considered to be uneconomic to harvest; or policies which lead some counties to impose limits on the harvest from their lands to comply with perceived sustainable cutting level constraints.

Future analyses will test the potential impact of this assumption. For the analysis, lands need not be classified as strictly available or unavailable. The modelling approach has the ability to recognize minimum prices (reservation prices) at which stands become available for timber production. Some stands may have higher reservation prices than others. Timber companies would typically put lower reservation prices on their timberlands than another category of owner, who may value aesthetic appeal more highly.

4.6.8 Balancing Present and Future Costs

All analyses have assumed that a real interest rate, i.e., 4 percent above the rate of inflation, is the appropriate rate to use for discounting to compare benefits with costs. Other discount rates could be examined easily as compared to other model assumptions, but this would still require a substantial amount of work as large data sets are involved, and the interpretation of model results is not a simple task.

4.7 Refinement of the Modelling Process

The base scenario was the first scenario to which the model was applied. Initially, the model was structured with target levels, as shown in table 4.11. Examination of intermediate model results identified potential problems, which required changes to the initial formulation.

The initial marginal costs for red and white pine sawlogs were being driven towards zero, less than the marginal cost for the other-pine category. This occurred because the supply potential of red and white pine sawlogs greatly exceeded the associated target levels for the lower demand scenarios. If this situation arose in the real market, red and white pine sawlogs would be used to achieve the target levels for the other-pine category, and thus, the price for red and white pine sawlogs would not drop below the price for the other-pine category. But the model, as formulated, does not include options to harvest red and white pine sawlogs and utilize them to help meet demand under the other-pine. To overcome this problem, the roadside (price for wood harvested and loaded for transport) price for the red and white pine sawlog category was fixed at $50 per cord. It seems plausible that if harvest levels above the target level could be supplied at this price, then it would be desirable to increase the harvest level for this valuable sawlog category.

A similar situation also developed for the red oak sawlog category. As with the red and white pine sawlog category, the specific target levels were dropped, and roadside prices for red oak sawlogs were fixed at $40 per cord. This is a relatively low value for harvested and loaded (but not transported) red oak sawlogs as it is comparable to current stumpage prices.

Intermediate model results also suggested some changes related to the northern hardwood category. Significant volumes of hardwoods grow within aspen stands that the model allocates for harvest to achieve aspen production targets. These volumes were above the assumed targets for the northern hardwood category. This created a surplus of northern hardwoods, which depressed the marginal costs for this category to between $2 and $8 a cord for delivered wood. This level was insufficient to pay the variable cost of transport once the material has been harvested and loaded on a truck. Since the model forces all volumes harvested to be shipped to market, even if at a loss, the interpretation of marginal costs for these situations needs to be done with caution. Surplus volumes of low value species are often left in the woods. Even for the base scenario, relatively little information was available for establishing target levels for northern hardwoods. To improve model behavior for the base scenario, marginal costs for northern hardwoods were set to $15 per cord delivered.

4.8 Forest and Covertype Area Change

Forest area changes and trends are an important factor in assessing future resource conditions. The approach adopted here uses FIA forest survey area information by FIA unit and county for 1990, 1977, 1962, 1953 and 1934 to suggest trends in total forest area and timberland acreage changes expected by ecoregion during the 50-year study period. This was supplemented by review of causal factors, for example, demographic factors, land development patterns, etc., as appropriate. However, no forest area change was implemented in the first model runs. Additionally, essentially no covertype change and hence no covertype area change was included in these first runs.

4.9 Spatial Pattern Analysis

An analysis of patterns at scales from the stand to landscape levels is considered essential to understanding the impacts of harvesting. Figure 4.8 shows the process used to develop site-specific and statistical characterization of forest patterns at a landscape level. These landscape unit levels are specified because impacts have a strong spatial dimension due to the interspersion of resources. The FIA plots are the smallest scale for which consistent, statewide data are available. Attribute data at this level comes directly from the FIA database or, in the case of projected future forests, from the new plot data generated by the forest change and scheduling model. However, the plot data do not provide the contiguous and full mosaic of type patch size and shape in each locale.

Data assembled for this analysis included new 1:10,000 scale color infrared aerial photography of 30 FIA plot locations and much of the surrounding section. These areas were then photo interpreted to create type maps and detail on spatial characteristics. Subsequently, these areas were visited in the field to verify the maps and interpreted data. The sections were randomly selected from among FIA plot locations with the restriction that sample sizes were 12, 12 and 6 for the Aspen-birch, Northern Pine and Central Hardwood Forest regions. Data collected included ownership, number and size of

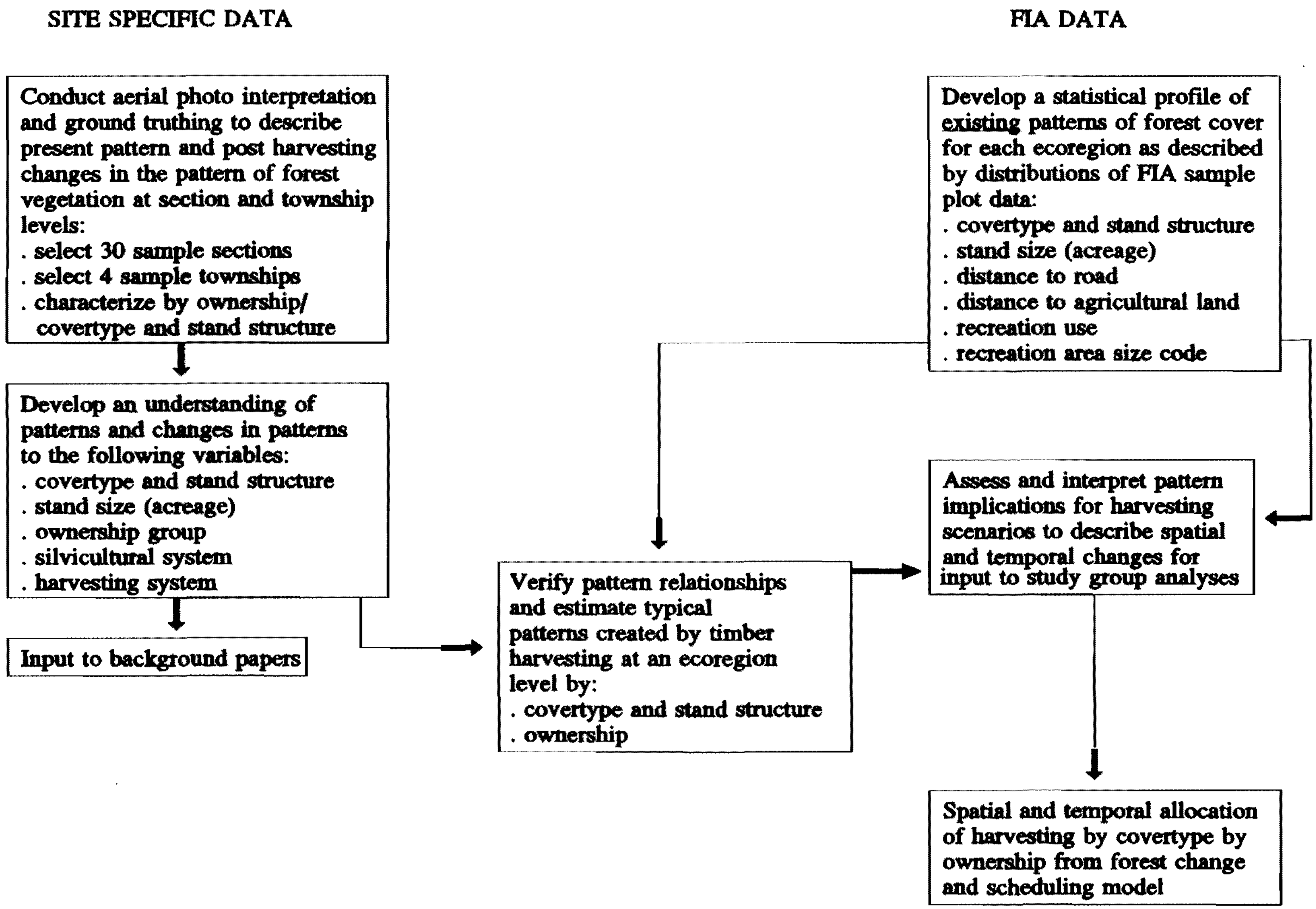


Figure 4.8. Site specific and statistical characterization of forest patterns.

recent clearcuts, proximity of cuts to water, slash disposal patterns, presence of corridors or buffers, distance in time and space between cuts, road patterns, etc. This information was then entered into a geographic information system (ARC/INFO).

This data was supplemented by map databases. Specifically, GIS-compatible databases containing systemic forest covertype information were established for four townships in northern Minnesota. The specific townships are located at T149N-R27W, T150N-R27W, T153N-R29W, and T154N-R29W. Ownership in the two southern townships is divided between federal (49 percent), state (31 percent), county (3 percent) and other (mostly private, at 17 percent). Serious planimetric and attribute discrepancies between basic resource data collected by these different agencies required extensive preprocessing and error mitigation. Data are organized into three main thematic layers: stand inventory, roads, and hydrology.

Data analysis included the placement of buffer zones around lakes and large streams as depicted in the forest stand inventory. Three simulations were conducted using buffer widths of 100, 200, and 300 feet. Buffer zones were regenerated in that same three-level series for streams as depicted in the hydrology layer (derived not from the forest inventory, but rather from the USGS Digital Line Graph Files at a scale of 1:24,000). All three buffer simulations were then repeated for the three classes of roads (well-maintained paved, year-around gravel, and seasonal roads and trails) found in the test area. Output from both the hydrologic buffer and the road type buffer analyses consisted of tables listing commercial acreages, total acreage affected by each buffer zone for each covertype, and percent of commercial acreages affected for each covertype. All simulations used ARC/INFO GIS software; tabular summaries were completed in a spreadsheet.

4.10
Changes in Methodology and Assumptions for Second Runs

The first runs were essentially unconstrained. As such they served to describe the biophysical potential of the forest resource in terms of timber supply and to illustrate impacts of harvesting assuming the absence of ownership constraints. In contrast, the second runs were intended to provide a more realistic portrayal of present and prospective ownership constraints on harvesting and management and the effects of certain additional mitigation practices. Specific model refinements and assumptions for the second runs are described in the following sections.

4.10.1 Formulation of Second Run Scenarios

Some, but not all, of the ownership constraints and mitigation practices identified in the various GEIS technical reports can be assessed for their effectiveness by the second runs of the planning model. From a modelling standpoint, constraints and mitigations are of four types:

1. those that reduce the area available for harvest;
2. those that constrain the amount of timber that can be removed for an ownership;
3. those that constrain the model to harvesting in only certain ways, e.g., thinning and uneven-aged management; and
4. those that allow harvesting but only on extended rotations.

While these steps will affect reduced harvesting and management impacts, such as stream protection, the resulting increased acreage of forest in older age classes may have indirect effects such as increasing or decreasing certain wildlife habitat, exacerbation of forest health problems, etc. Constraints may also shift harvests to other areas and/or drive timber prices upward. Thus it is not always clear which constraint, mitigation or combination is the best choice.

Constraints and mitigations that can not be assessed directly by model runs are those that involve detail not available to the modelling process. For example, slash disposal methods may affect harvest costs, the pattern of regeneration and site nutrient status. Such mitigation can be assessed using a synthesis of the literature and cost considerations, but such detail is not contained in the model.

Modelling capabilities have also progressed since the development and approval of the work plan for this study. One such development is a set of tree growth and mortality correction factors for the forest growth model used. Their use can improve the credibility of the study.

In selecting which constraints, mitigations and modelling refinements to employ in the second runs, it is important to consider

- the complexity, cost and time requirements of the selection;
- the accuracy or realism provided; and
- the comparability the output will have with the first runs.

The GEIS schedule precludes complex alternatives involving lengthy research and/or software development. The existing modelling capabilities also have practical and mathematical limitations that prohibit the incorporation of a large number of options. Thus some selections invariability had to be simplified. Close approximation to reality will aid interpretation and credibility of the study, however, it becomes progressively difficult to accurately characterize reality as projections move farther and farther beyond the present. In effect, estimates of reality become a set of assumptions about the future, which in turn condition the model output. Thus it is important to be critical about building in assumptions. Lastly, major changes from the first runs limit the ability to assess the impact of mitigations, as impacts can become too confounded with other changes to assess cause and effect.

Given this discussion, it is apparent that much was learned from the first runs. Modelling capabilities have improved and the number of possible constraints and mitigations and their variations have grown. Consequently, the second runs as specified below represent a more detailed and realistic look at the specified harvest levels and how they might or might not be attained, given various mitigations.

Given the modelling capabilities available to this study, the following changes from the first runs have been implemented for the second runs.

Total forest area change
Earlier sections of this report have documented past and anticipated changes in total forest area. The second runs implemented those by FIA survey unit (and hence by ecoregion) as identified in table 5.4. Implementation occurred by increasing or reducing plot expansion factors gradually, i.e., the area each plot represents by period through the study period years 1990 to 2040. However, the procedure is not straightforward. Should the area of forest in the southern portion of the state be augmented by just treating younger stands or applied across all plots, regardless of age? For simplicity, the second runs apportioned a constant annual increase in acreage to all plots (proportional to their acreage) and hence all ownerships in the two southern FIA units. The rationale for this comes from table 2.2 showing considerable acreage in the nonforest with trees category of ground land use, i.e., new forest acreage comes from

- natural regeneration;
- artificial regeneration; and
- growth and subsequent reclassification of nonforest with trees to the forest category.

An example is the conversion of wooded pasture to forest that has occurred in southern Minnesota over the last fifteen years. Appendix table 8.1 describes 1977 and 1990 acres by age class for the oak-hickory, elm-ash-soft maple type, and other types that would appear to support this simple but feasible approach, i.e., increases in acres can occur in older as well as younger age classes. Additionally, this approach allows rather direct reinterpretation or adjustment of the acreage projections if more or less acreage increase is assumed. In the two northern FIA units the forest area changes (decreases) were apportioned to only the Other Private lands identified in table 2.7. That assumes Public and Forest Industry acreage in the north will remain constant over the 1990–2040 study period. The estimated acreage change used for the 50-year study period was determined by FIA unit from table 5.4 as presented in section 5.7.

Timberland area change

Timberland area change was assumed to follow the methodology described for total forest area, i.e., acreage associated with timberland plots was increased or reduced by the same process. Public and Forest Industry land acreage in the two northern FIA units were again assumed to remain constant over the study period.

Cover type area change

Covertype areas in the second runs were subjected to two types of change, that occurring at the time of harvest and that due to succession or stand dynamics. The first type of change occurred at harvest and was developed from (1) decision trees for planting and (2) natural regeneration covertype change matrices. Those natural regeneration matrices are analogous to table 4.1, but were developed separately by FIA unit. The actual matrices used are described in appendix 2.

The second type of covertype change was developed from GROW model dynamics, i.e., the model was used to estimate stand development and cover type change or succession. This succession was evaluated by applying a covertype determination algorithm after the second runs to the projected plot tree lists at the end of each ten year projection period. An advantage of this approach is that it retains tree species composition detail and also provides for estimation of covertype dynamics. The covertype algorithm was designed to approximate the FIA covertype determination process and seemed to capture the direction of covertype change in tests so far, but it probably underestimates the actual change somewhat.

The forest type algorithm or procedure used by the FIA was described by Hansen and Hahn (1992). Briefly, it analyzes the stocking by species on each of the ten points comprising an FIA plot to determine the covertype. Unfortunately, projections involving harvesting and regeneration models do not provide information on tree location by point, thus the FIA algorithm is not useful beyond 1990. The algorithm developed here sorted plots into covertypes according to the plurality of basal area. A comparison of the study procedure relative to FIA classification is shown in table 4.14.

The differences in covertype classification illustrate the difficulty of obtaining closely matching results when the plots themselves are very mixed in species composition. Differences are especially evident for white pine and northern white cedar, i.e., results are very sensitive to the algorithm. However, given the tendency to species mixtures, any covertype classification should be interpreted cautiously. As an example, black spruce, balsam fir, northern white cedar, tamarack and white spruce are often mixed as lowland conifers. The total acreage of this group collectively is 3,618,600 for the FIA versus 3,489,000 for the GEIS algorithm, or only a 3.6 percent difference. Thus, use of covertype information needs to be cognizant of the species mixtures within plots and stands.

Table 4.14. Comparison of FIA and GEIS covertype algorithm classifications on timberland for the 1990 FIA test data (acres).

Forest Type	Algorithm/Procedure	
	FIA*	GEIS
Jack pine	446,600	487,100
Red pine	354,700	350,600
White pine	68,600	137,300
Black spruce	1,349,900	1,320,800
Balsam fir	809,200	1,012,500
Northern white cedar	648,400	322,400
Tamarack	719,400	696,200
White spruce	91,700	137,000
Oak-Hickory	1,124,700	1,288,000
Elm-Ash-Soft maple	1,124,600	1,564,200
Maple-Basswood	1,470,200	1,301,800
Aspen	5,242,200	4,496,000
Paper birch	819,000	1,179,300
Balsam poplar	504,200	480,100
Total	14,773,400	14,773,400

*These totals differ slightly from table 2.3 because they were developed directly from the FIA test data constrained to place "nonstocked" and "other" covertypes into one of the basic 14 covertypes.

The advantage of the overall covertype evaluation approach (allowing change at time of harvest and later by succession) is that it *is* sensitive to the level of harvesting. By comparing these results to the first runs, the implications of type change can be much better understood.

The number of regeneration tree lists used in the first runs were increased in the second runs to reflect the various stand treatment classes that were created for mitigation purposes. This meant that a plot in a specific treatment class was linked to a regeneration type and the associated silvicultural options assigned to that treatment class. For example, plots with extended rotations were linked to a regeneration type that also was managed according to extended rotation options. Four covertypes, red pine, oak-hickory, maple-basswood, and aspen were given the option of regenerating stands by artificial regeneration or planting to red pine. The regeneration by natural regeneration for any given covertype followed the stochastic procedure outlined earlier and was based on empirical cover type change matrices following harvesting as developed from the FIA data. When a plot was selected for a clearcut and natural regeneration was simulated, the covertype of the new stand was created by using a random number to select against the probability matrix. This was a major difference in procedure from the first model runs where all cover types that were naturally regenerated were assumed to remain in that covertype. In the second runs, stands converted to a subsequent covertype, according to the probability-based transition matrix.

For the southern study region, the silvicultural decision trees were also developed according to the assigned treatment code. The major difference between decision trees for the northern and southern regions existed for the hardwood covertypes: oak-hickory, maple-basswood, and elm-ash-soft maple. While they utilized the same prescriptions as the northern decision trees for buffer plots, i.e., only random selection of trees for thinnings and no clearcuts, they made extensive use of thinning from above options and de-emphasized clearcutting options. For treatment class 3 (extended rotation forest) the clearcutting options were further reduced to only very long rotation ages.

For implementation, the second runs assumed a continuation of the management practices of the 1977–90 period as they affect regeneration and succession. However, these assumptions could be in error as management moves to address them, say by stand management or covertype conversion practices. Alternatively, budget cuts affecting forest management organizations could slow the implementation of practices. However, there is no choice, but to assume *some* pattern. That is part of the call for realism. These assumptions have little impact on timber volumes, but they are very important to wildlife habitat analyses, since those are heavily dependent upon covertype acreage.

Timberland availability

Ownerships are expected to vary in the actual availability of their lands for timber harvesting. This will be implemented in two ways:

1. by constraints on harvesting or reservation prices as they apply to specific plots depending on their location, conditions, etc.; and
2. by factors developed by ownership category in the background paper on Public Forestry Organizations and Policies (Jaakko Pöyry Consulting, Inc. 1992).

Those factors are shown in table 4.15.

Table 4.15. Availability of timberland by ownership assumed for second runs.

Ownership	Percent Available
National Forests	
Chippewa	87
Superior	53
State	95
County	95
Other public	64
Forest Industry	98
Other Private	90

These factors were implemented by randomly selecting plots prior to the second runs and removing them from consideration for harvest. It is important to avoid double counting, i.e., some of these factors consider water, wildlife and aesthetic concerns. Unfortunately, it is not clear how to assess that overlap without an ownership by ownership assessment of the nature of these constraints. Thus some double counting is unavoidable in the time frame of this study.

Constraints on harvest by ownership

The only ownership that has detailed specification of the allowable cut is the National Forests. Consequently, the availability approach described above was replaced on the national forests by constraints on the amount of harvest. The constraints essentially targeted harvests so as to match the stated allowable cut for any of the study periods for each national forest separately. In doing so, the stated allowable cuts were extended to the end of the study period. This was accomplished by an internal model comparison of accumulated harvest versus allowable cut.

Adjustment of GROW

Since the initial harvest scenarios, the FIA project has developed factors to adjust the tree growth and mortality of the GROW model to achieve close agreement when projecting 1977 plot data to 1990. A check of these adjustments on the test data plots described in table 4.7 indicates 9 and 11 percent overestimates of basal area and number of trees as compared to 16 and 11 percent overestimates with the unadjusted model. Test results are summarized in table 4.16. Assuming the 1977 to 1990 period is an appropriate characterization of the climate for 1990 to 2040, the adjusted GROW model was used for the second runs. This sacrifices some comparability with the first runs, but improves the credibility of the results. For greater realism, model-based harvests for a ten-year period were moved from the beginning of periods (as in the first runs) to the midpoint of the period.

Table 4.16. Adjusted GROW model: ratio of predicted to actual basal area and number of trees by covertype for undisturbed FIA plots, 1977 to 1990.

Forest Type	Ratio of Predicted to Actual	
	Basal Area	Number of Trees
Jack pine	1.04	1.06
Red pine	1.01	1.05
White pine	0.93	0.92
Black spruce	0.99	0.97
Balsam fir	1.10	1.10
Northern white cedar	1.04	1.06
Tamarack	1.05	1.05
White spruce	0.93	0.80
Oak-Hickory	1.07	1.11
Elm-Ash-Soft maple	1.19	1.16
Maple-Basswood	1.09	1.13
Aspen	1.10	1.15
Paper birch	1.09	1.11
Balsam poplar	1.15	1.15
Overall	1.09	1.11

Silvicultural decision trees

The silvicultural decision trees used in the first runs were modified slightly for the second runs. The only covertypes retaining a minimum rotation age of 40 years were aspen and balsam poplar. Minimum rotation ages for all other covertypes were increased by at least ten years. Thinnings for plots in the northern study area, except as noted below, were limited to red pine and white spruce covertypes. For the southern study region, the silvicultural decision trees were developed differently for the hardwood covertypes, i.e., oak-hickory, maple-basswood, and elm-ash-soft maple. These covertypes utilized the same prescriptions as the northern decision trees for buffer plots, i.e., only random thinnings and no clearcuts. However, the southern area utilized extensively, but not exclusively, thinning from the above options and de-emphasized clearcutting options. For plots designated for extended rotation forest, the clearcutting options were further reduced to only very long rotation ages.

Existing policies and practices

Many of the existing or developing policies and practices of the state's forestry organizations reflect the types of mitigations accepted by the

Advisory Committee for further study. Among those amenable to implementation in the second runs were: Extended rotation forests (ERF), greater use of uneven-aged management, old growth designation, BMPs (i.e., thinning or ERF near water) and some wildlife corridors. These practices were incorporated in the second runs to approximate levels of intended implementation as indicated by the various forestry organizations. The specific policies and practices, together with implementation procedures, are described in more detail below.

Rotation length options

Several minimum rotation lengths were lengthened as a result of comments on the Initial Harvesting Scenarios document (Jaakko Pöyry Consulting, Inc. 1991). The revised set of rotation ages are shown in appendix 1. Additionally, extended rotation ages (ERF) are suggested as a mitigation in the wildlife and aesthetics components of the study. The second runs incorporate such rotations for approximately 20 percent of the timberland plots by age class on state and national forest ownerships. These ERF guidelines were developed by the MNDNR by covertype and are listed in appendix 1. In practice, this was implemented by *a priori* random selection of timberland plots. The silvicultural decision trees for the ERF plots were then modified to eliminate any rotation options below the extended rotation ages. The impact of ERF over the first several decades of the study period was expected to be modest since the current rather advanced age class distribution for most forest types precluded harvesting many stands at ages less than the ERF ages anyway. After that, however, ERF was an important constraint on harvest levels.

Partial cutting/Uneven-aged management

Modelling capabilities for simulating this for long periods is limited, however, it was possible to approximate it by thinning as opposed to clearcutting. Thus this was implemented as an option for shade tolerant covertypes and was, in fact, the only form of harvesting allowed for plots within the 100-foot BMPs and 200-foot buffers noted below. This elimination of clearcutting and assignment to a thinning option only was, in effect, an assignment to uneven-aged management. The actual thinning practice removed 33 percent of the plot basal area by selecting trees at random. Such thinning was allowed only at 30-year or longer intervals.

Old Growth

Old growth forest designation was implemented by identifying approximately one to two plots over 120 years old in each covertype (younger when necessary, but no less than 90 years old) and one replacement plot from an adjacent younger age class. Such plots comprised 57,500 acres of old growth and a similar acreage of replacement forest. These plots were then reserved from harvest for the duration of the study period. Much of this acreage was located on state and federal lands.

BMPs

BMPs were implemented in the model by constraining harvesting practices within 100 feet of water to thinning, ERF or uneven-aged management only.

Buffers

Mitigations for forest wildlife suggest 200-foot wide buffers along both banks of lakes or streams in ecoregions 4, 5, 6 and 7. Within the buffer, clearcutting was prohibited. That prohibition was adopted as an extension of BMPs for the two national forests and ecoregion 6 (the southeastern part of the state).

Sensitive Areas

The FIA data is not very site specific, consequently concerns for harvesting in sensitive areas, whether they be concerns for wildlife, recreation, aesthetics or cultural resources were developed from analysis of the second run output. Such analysis considered both the extent of the area affected and the importance of such impacts.

Cumulative effects

The model refinements and mitigations implemented in the second runs satisfy concerns of several study areas. Some combinations of refinements and mitigations may also over- or underestimate impacts. Determination of those over- or underestimates are a part of the second run analyses.

Management investments

The first runs assumed a continuation of existing levels of management investment by landowners. However, that is probably an underestimate for some lands. The impact of more intensive management, e.g., management of hybrid aspen, was analyzed in terms of the impact on long-run sustained yield, but that analysis was conducted outside these model runs in order to avoid confounding of ownership constraints and environmental mitigation measures with timber supply mitigation measures. The options for white pine natural and planted stand establishment have been refined as shown in appendix 2 table A. The acreages by covertype and ownership assigned to the various treatment classes for the second runs are shown in tables 4.17 and 4.18.

Note that BLM timberland availability was set lower than table 4.15 in light of the small area of that ownership. Also, Native American timberland availability was set lower than the other private category it was considered within the background paper. The rationale for that was the current low (relative to allowable cut) harvest rate and uncertainty about ownership objectives. Further, old growth was considered in addition to the acreage categorized as not available. The overall net effect of these modifications is probably a slight underestimate of the timberland acreage actually available.

Table 4.17. Approximate second run acreage by treatment class and covertype for timberland, statewide, 1990.

Forest type	FIA Covertype Code	Total Acres by Covertype and Treatment					Total**	Sum Columns 1-3	Sum Columns 4-5
		Normal harvest (1)	Buffers (2)	Extended rotation (3)	Old growth (4)	Not available* (5)			
Jack pine	1	373,500	12,700	31,200	6,600	22,600	446,600	417,400	29,200
Red pine	2	288,800	11,900	34,100	4,900	15,000	354,700	334,800	19,900
White pine	3	50,300	2,600	6,400	2,500	6,800	68,600	59,300	9,300
Black Spruce	12	1,037,200	87,400	140,700	4,700	79,900	1,349,900	1,265,300	84,600
Balsam fir	13	640,700	55,400	59,600	4,000	49,500	809,200	755,700	53,500
N. white cedar	14	484,500	44,000	71,800	5,900	42,200	648,400	600,300	48,100
Tamarack	15	541,300	36,900	73,700	4,900	62,600	719,400	651,900	67,500
White spruce	16	64,200	1,700	16,400	1,300	8,100	91,700	82,300	9,400
Oak-hickory	50	955,700	45,000	18,600	1,800	102,100	1,124,700	1,019,300	103,900
Elm-ash-soft maple	70	850,700	113,900	43,700	5,400	110,000	1,124,600	1,008,300	115,400
Maple-basswood	80	1,184,800	108,300	46,400	3,500	126,300	1,470,200	1,339,500	129,800
Aspen	91	4,393,700	154,300	269,300	5,100	390,800	5,242,200	4,817,300	395,900
Paper birch	92	648,500	39,800	60,500	5,500	64,700	819,000	748,800	70,200
Balsam poplar	94	409,800	26,400	27,000	1,400	39,600	504,200	463,200	41,000
Total		11,951,600	742,900	899,400	57,500	1,121,400	14,773,400	13,594,500	1,178,900

* Does not include "not available" treatment on national forest lands totaling 663,000 acres. Adding that would reduce the acreage in the "normal harvest" treatment for many species (see also table 4.16).

** These totals differ slightly from table 2.3 because they were developed directly from the FIA test data and constrained to place "nonstocked" and "other" covertypes into one of the basic 14 covertypes.

Table 4.18. Approximate second run acreage by treatment class and ownership for timberland, statewide, 1990.

Ownership	Total Acres by Ownership and Treatment					Total	Sum Columns 1-3	Sum Columns 4-5	Percent Available
	Normal (1)	Buffers (2)	Extended rotation (3)	Old growth (4)	Not available (5)				
Chippewa NF	349,200*	25,200	106,700	12,400	73,700*	567,200	481,100	86,100	**
Superior NF	331,000*	85,800	232,800	15,000	589,300*	1,253,900	649,600	604,300	**
BLM	12,600	900	0	0	12,600	26,100	13,500	12,600	52
Native American	314,700	6,500	0	0	169,400	490,600	321,200	169,400	65
Misc. federal	106,000	8,900	0	0	56,700	171,600	114,900	56,700	67
State	2,232,500	102,500	559,900	30,100	152,900	3,077,900	2,894,900	183,000	94
Cty & Municipal	2,238,400	142,900	0	0	124,300	2,505,600	2,381,300	124,300	95
Other Private	4,975,100	362,800	0	0	591,300	5,929,200	5,337,900	591,300	90
Forest industry	729,700	7,400	0	0	14,200	751,300	737,100	14,200	98
Total	11,289,200	742,900	899,400	57,500	1,784,400	14,773,400	12,931,500	1,841,900	

* USDA Forest Service plots were not assigned to "unavailable" status. Thus the values shown are estimates. Instead the two national forests were constrained so harvest did not exceed allowable cuts in their plans. Net effect was about 87 and 53 percent available for the Chippewa and Superior, respectively.

4.10.2 Changes for Revised Forest Management Scheduling Runs

Harvest Timings Within Periods
In the earlier runs harvests were simulated at the beginning of each planning period to help compensate for the tendency of the GROW model to overestimate growth. Since the growth model was adjusted for the revised runs, harvest levels were assumed to occur at the midpoint of each planning period. This is the approach used in most forest management scheduling models.

Timberland Area Change
Estimates of timberland area change from the 1990 statewide inventory indicate that the statewide total area of timberland changed relatively little between 1977 and 1990. However, estimates suggest that some shifts are occurring. Between 1977 and 1990 the area of timberland decreased by an estimated 22,070 acres per year in the heavily forested region in the north (FIA units 1 and 2) while timberland area increased by 22,500 in the forest-agriculture fringe areas in the central and southeastern portion of the state (FIA units 3 and 4). Changes in forest area were projected into the future by FIA unit using the annual area change estimates described in the previous section. To implement the area change estimates within the scheduling model, acreage expansion factors for survey plots were made time dependent. For acres lost from timberland, the model was conservative in that no harvesting of acres lost was allowed at the time the loss occurred. For acres added to timberland, acres added were assumed to be similar to timberland acres portrayed by the 1990 inventory. The area change assumptions translate into net changes by year 2040 of approximately a 873,125 acre decrease in the northern region and a 974,174 acre increase in the southern region. For the southern region, this is a substantial percentage increase that impacts results. These area changes further confound comparisons of the first and second run results as it is incorrect to assume that differences are due only to the addition of mitigative constraints in the revised runs.

Relative Product Values
The first model runs for the northern region were based on the assumption that red and white pine sawlogs could be valued using a fixed price. In that case, consumption levels for red and white pine sawlogs were allowed to fluctuate with available supply. From strictly a timber production standpoint, this approach had merit in that red and white pine sawlogs are relatively valuable and consumption levels are likely to change based on available supply. Potential problems with this approach are: (1) the scheduled harvest volumes of these products fluctuate substantially between periods, (2) the approach does not lend itself well to trade-off analysis as values are fixed with relatively minor differences in consumption levels of these products between scenarios, and (3) direct comparisons of sawlog prices with marginal

cost estimates (shadow prices) for other products are potentially misleading as not all costs are included in developing marginal cost estimates.

For the second runs for the northern study region, red and white pine sawlogs were included in the product group "pine" with relative value differences defined for products within this group. Specifically, red and white pine sawlogs delivered to the market were assumed to be worth $45 more per cord than pine pulp and $25 more per cord than jack pine sawlogs. In other words, in meeting the harvest targets for pine, the model will spend up to $45 per cord more if red pine sawlogs can be produced rather than pine pulp. This assumed value difference between pulp and sawlogs has an obvious effect on the optimal economic rotation age for stands with substantial pine volumes as higher premiums for sawlogs result in longer rotation lengths. Similar relationships were not assumed for other species as a substantial portion of sawlog size material is used for pulpwood. Producing an additional cord of sawlog size material of these species would probably not increase sawlog consumption by sawmills. The value of producing larger diameter sawlogs is recognized only to the extent that harvest cost estimates (per cord) are lower when larger diameter trees are produced. Summaries of product outputs by size class for each scenario are reported in tables 14.14 to 14.25 in appendix 14.

Updated Consumption Estimates
Estimates of roundwood consumption by market area were updated through correspondence with Minnesota DNR Utilization and Marketing staff. For planned future forest industry expansions associated with the medium scenario, it was assumed that all wood consumed would be procured from Minnesota timberlands. For existing mills, consumption estimates reflect that portion of mill consumption that is obtained from roundwood on Minnesota timberlands. Estimates of wood consumption in each market for the first planning period for the base scenario (1990–99) were developed by summing annual estimates (table 4.19). Detailed breakdowns by mill and market area for the northern region are shown in tables 14.1 to 14.4 in appendix 14.

Estimates of the quantity and timing of specific industry expansions associated with the medium scenario are shown in table 4.20. These quantities were added to the base scenario to form the harvest level estimates for the medium scenario (table 4.21). Detailed breakdowns by mill and market area are shown in tables 14.5 to 14.8 in appendix 14.

For the second runs of the scheduling model, markets with relatively low consumption levels for specific product groups were aggregated into other markets, as modelling low targets for some market and product group combinations complicates the modelling process. This was seen in the results of the first runs where procurement zones for some larger markets essentially encircle the procurement zone for other markets with low consumption

Table 4.19. Summary of base scenario roundwood consumption estimates by market area (1000's of cords per year).

Species Group, Market	Period						1990-99 Ave.	2000+ Ave.
	1990	1991	1992	1993-94	1995-96	1997-99		
Aspen, Bemidji	460	490	605	605	605	580	572	580
Pine, Bemidji	40	114	114	129	129	144	122	144
Spruce-fir, Bemidji	5	6	6	6	6	6	6	6
N. Hardwoods, Bemidji	64	65	87	87	87	87	83	89
subtotal Bemidji	569	675	812	827	827	817	783	819
Aspen, Brainerd	169	169	234	269	289	289	256	289
Pine, Brainerd	49	49	49	49	54	54	52	54
Spruce-fir, Brainerd	70	70	70	70	70	70	70	70
N. Hardwoods, Brainerd	177	181	185	185	196	197	190	198
subtotal Brainerd	465	469	538	573	609	610	568	611
Aspen, Cook	213	213	213	213	213	203	210	203
Pine, Cook	34	34	34	34	34	34	34	34
Spruce-fir, Cook	5	5	5	5	5	5	5	5
N. Hardwoods, Cook	46	46	47	47	48	59	51	59
subtotal Cook	298	298	299	299	300	301	300	301
Aspen, Duluth	510	510	505	505	505	505	506	505
Pine, Duluth	99	99	99	99	99	99	99	99
Spruce-fir, Duluth	207	207	207	207	207	207	207	207
N. Hardwoods, Duluth	87	87	93	93	94	95	93	95
subtotal Duluth	903	903	904	904	905	906	905	906
Aspen, G. Rapids	389	404	414	454	454	434	433	434
Pine, G. Rapids	34	34	34	34	34	44	37	44
Spruce-fir, G. Rapids	85	85	105	105	105	105	101	105
N. Hardwoods, G. Rapids	55	56	57	57	58	69	61	69
subtotal Grand Rapids	563	579	610	650	651	652	632	652
Aspen, I. Falls	213	338	418	443	458	458	415	458
Pine, I. Falls	109	99	89	74	64	64	77	64
Spruce-fir, I. Falls	25	20	20	15	15	15	17	15
N. Hardwoods, I. Falls	46	46	47	47	48	49	48	49
subtotal Int. Falls	393	503	574	579	585	586	557	586
Total, Northern Region	3,191	3,427	3,737	3,832	3,877	3,872	3,745	3,875
Red Oak Sawlogs, South	50	50	50	50	50	50	50	50
Other Wood, South	250	250	250	250	250	250	250	250
Total Southern Region	300	300	300	300	300	300	300	300
Total, North + South	3,491	3,727	4,037	4,132	4,177	4,172	4,045	4,175

levels. Specifically, the pine and spruce-fir product groups were each reduced from six to three markets. For pine, the consumption in the Grand Rapids market was added to the Bemidji market, the consumption in the Cook market was added to the International Falls market, and the consumption in the Brainerd market was added to the Duluth market. For spruce-fir, the consumption estimates for the Bemidji market were added to the Grand Rapids market, the estimates for the International Falls market were split equally between Duluth and Grand Rapids, and the estimates for the Cook market were added to the Duluth market. For spruce-fir under the base scenario, first period consumption estimates for the three market locations no longer explicitly recognized totalled only 7 percent of the total estimated spruce-fir consumption. Under the medium scenario, the percentage would be slightly lower. For pine, the three markets no longer recognized make-up nearly 25 percent of the total pine consumption, but this large a percentage is misleading as a large portion of the Brainerd demand is actually exported to Wisconsin, and likely transported directly through the procurement zone for the Duluth market. Furthermore, most of the estimated pine consumption in these markets is for pine sawlogs which are not precise estimates in terms of market location—pine sawlog demand estimates, except for the large sawmill in Bemidji, were assumed to be distributed equally between markets (appendix table 14.3).

Table 4.20. Assumed roundwood consumption increases for defining the medium harvest level scenario

Year	Increase (cords/year)	Species Group	Location (description)
1997	260,000	N. Hardwood	Duluth (Cloquet Potlatch Expansion)
1997	65,000	Pine	Duluth (Cloquet Potlatch Expansion)
1997	85,000	Aspen	Duluth (Cloquet Potlatch Expansion)
2000	160,000	Spruce-fir	Duluth (Lake Superior Paper)
2000	85,000	Aspen	Grand Rapids (Blandin)
2000	45,000	Spruce-fir	Grand Rapids (Blandin)
2000	30,000	Aspen	Brainerd (Champion International)
2000	30,000	Spruce-fir	Brainerd (Champion International)
2000	50,000	Other Wood	Southern Region
2000	15,000	Red oak Sawlogs	Southern Region

Constraints on National Forest Harvest Levels

Compared to other public forest land in Minnesota, a larger percentage of timberland is considered unavailable for timber harvest on national forest lands. It is current USDA Forest Service policy to regulate timber harvesting on national forest land by allocating an allowable sale quantity to each national forest. These levels are determined at the regional level with consideration given to both national objectives and to opportunities identified by the USDA Forest Service planning process done at the forest level. Estimates of future allowable sale quantities for each national forest were obtained from the USDA Forest Service planning staff for each national forest in Minnesota. The annual allowable sale quantities for all years in the planning horizon were assumed to be 120,000 cords for the Chippewa National Forest and 194,000 cords for the Superior National Forest. To put these numbers in some perspective, approximately 12.3 percent of the timberland in Minnesota is national forest land (table 2.6) while the assumed allowable sale quantities represent 7.5 percent of the statewide annual volume harvest under the base scenario and 6.3 percent of the statewide harvest under the medium scenario.

Table 4.21. Summary of medium scenario roundwood consumption estimates by market area (1,000's of cords per year).

Species, Market	Period						1990-99 Ave.	2000+ Ave.
	1990	1991	1992	1993-94	1995-96	1997-99		
Aspen, Bemidji	460	490	605	605	605	580	572	580
Pine, Bemidji	40	114	114	129	129	144	122	144
Spruce-fir, Bemidji	5	6	6	6	6	6	6	6
N. Hardwoods, Bemidji	64	65	87	87	87	89	83	89
subtotal Bemidji	569	675	812	827	827	819	783	819
Aspen, Brainerd	169	169	234	269	289	289	256	319
Pine, Brainerd	49	49	49	49	54	54	52	54
Spruce-fir, Brainerd	70	70	70	70	70	70	70	100
N. Hardwoods, Brainerd	177	181	185	185	196	197	190	198
subtotal Brainerd	465	469	538	573	609	610	568	671
Aspen, Cook	213	213	213	213	213	203	210	203
Pine, Cook	34	34	34	34	34	34	34	34
Spruce-fir, Cook	5	5	5	5	5	5	5	5
N. Hardwoods, Cook	46	46	47	47	48	59	51	59
subtotal Cook	298	298	299	299	300	301	300	301
Aspen, Duluth	510	510	505	505	505	590	532	590
Pine, Duluth	99	99	99	99	99	164	119	164
Spruce-fir, Duluth	207	207	207	207	207	207	207	367
N. Hardwoods, Duluth	87	87	93	93	94	355	171	355
subtotal Duluth	903	903	904	904	905	1,316	1,029	1,476
Aspen, G. Rapids	389	404	414	454	454	434	433	519
Pine, G. Rapids	34	34	34	34	34	44	37	44
Spruce-fir, G. Rapids	85	85	105	105	105	105	101	150
N. Hardwoods, G. Rapids	55	56	57	57	58	69	61	69
subtotal Grand Rapids	563	579	610	650	651	652	632	782
Aspen, I. Falls	213	338	418	443	458	458	415	458
Pine, I. Falls	109	99	89	74	64	64	77	64
Spruce-fir, I. Falls	25	20	20	15	15	15	17	15
N. Hardwoods, I. Falls	46	46	47	47	48	49	48	49
subtotal Int. Falls	393	503	574	579	585	586	557	586
Total, Northern Region	3,191	3,427	3,737	3,832	3,877	4,284	3,869	4,635
Red Oak Sawlogs, South	50	50	50	50	50	50	50	65
Other Wood, South	250	250	250	250	250	250	250	300
Total Southern Region	300	300	300	300	300	300	300	365
Total, North + South	3,491	3,727	4,037	4,132	4,177	4,584	4,169	5,000

5
CURRENT AND PROJECTED IMPACTS OF FIRST RUNS

5.1
Harvesting Scenario Interim Results

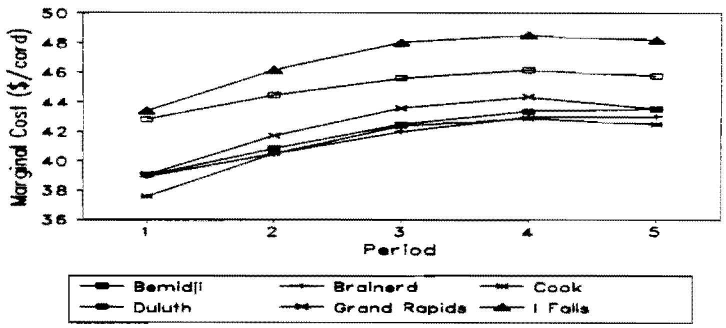
This section describes the output from the first model runs. Outputs are presented under the following headings:

- marginal costs and a comparison of volumes allocated against target levels;
- sources of timber by ownership;
- spatial and temporal patterns of harvesting;
- acres harvested and not harvested by covertype;
- changes in age class harvested in the aspen type;
- size and composition of the forest land base;
- abundance, composition, spatial distribution, age class structure and tree species mix;
- patterns of forest cover;
- summary of key results and impacts of first run analyses; and
- sustained yield considerations.

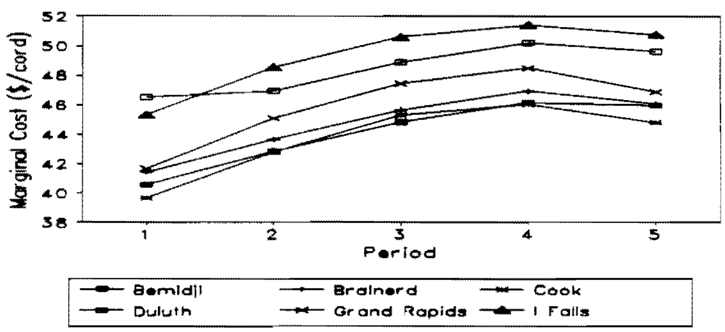
5.2
Marginal Costs and a Comparison of Volumes Allocated Against Target Levels

As discussed in section 4.5.2, marginal costs estimates are an important model output that reflect relative timber supply conditions. Where supplies of a particular product category at a particular location become constrained, the marginal costs increase. Conversely, where supplies are in surplus the marginal costs fall. Therefore, comparison of the marginal costs for products over time for the nominated locations and targets provides an indication of the ability of the forests to produce timber to meet the target. Changes in marginal costs over time also influence the rotation age. When prices are rising it is desirable to hold some timber stands longer to capture the increasing value of timber over time. Conversely, if marginal costs are declining, it will likely be desirable to harvest some stands earlier.

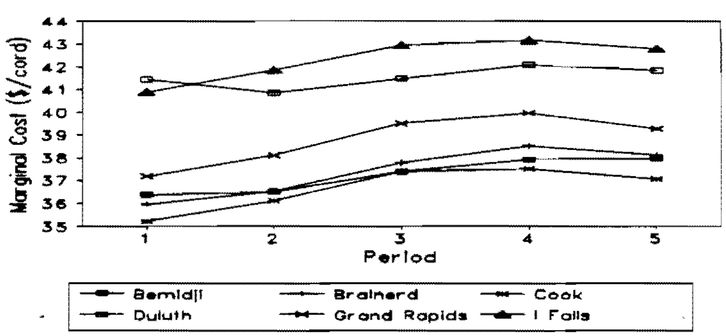
After fixing prices for the two sawlog categories and the northern hardwoods category (see section 4.7), the model had little difficulty in finding marginal costs for the other product categories that produced harvest flows close to the target levels. Figures 5.1 and 5.2 illustrate the marginal costs for two species groups by period and by market. These figures illustrate two different demand/supply situations. Demand for aspen is high, even in the base scenario. Prices rise over time indicating a tightening supply, which is reflected in more expensive management to maintain supply. In the last period, availability of regrowth eases the supply situation and prices level or



Base

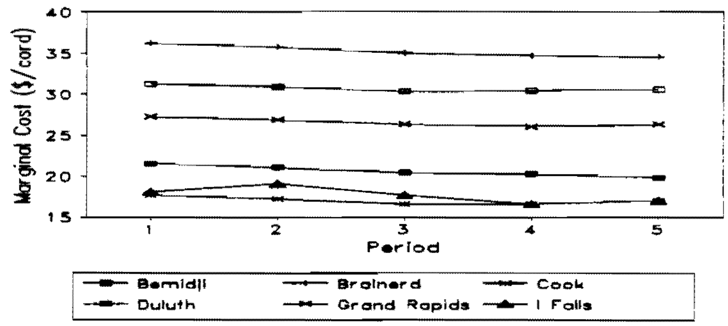


Medium

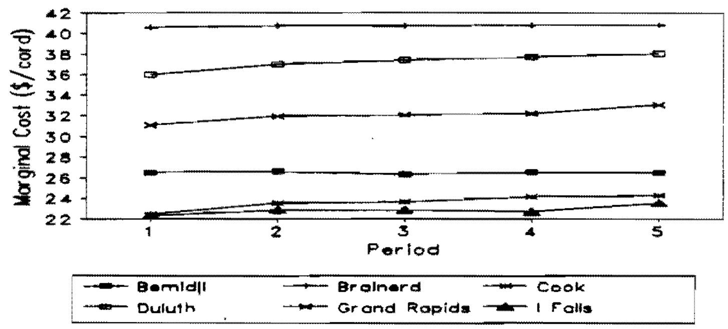


High

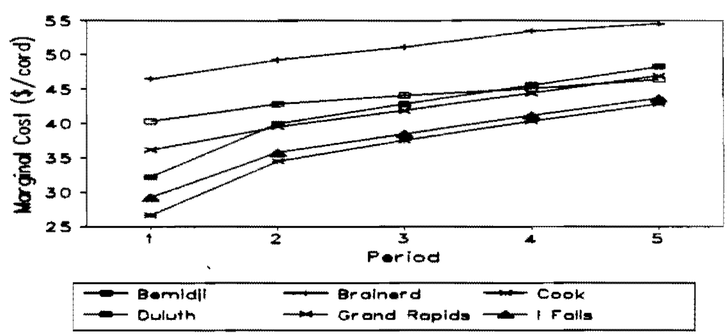
Figure 5.1. Marginal cost estimates for aspen for the 6 market locations by period and scenario. The slight dip in the cost during the last period reflects the move to cutting in the more productive regrowth stands that result from the first cutting period.



Base



Medium



High

Figure 5.2. Marginal cost estimates for spruce-fir for the 6 market locations. The rising cost in the high demand scenario indicates that supply is constrained.

fall slightly. In contrast, estimated marginal costs for spruce-fir are relatively lower and do not increase substantially over time until demand is increased significantly in the high demand scenario.

Comparison of marginal costs for aspen in figure 5.1 shows another interesting difference between scenarios. As one would expect, marginal costs for aspen increase as demand is increased between the base and medium scenarios, however, marginal prices decrease under the high scenario. This is partially explained by the fact that the aspen targets for the high scenario were not increased above the targets for the medium scenario. Hence no shortages of aspen were created that would have increased prices, and the increase in the targets for the other products (mainly northern hardwoods) forces those products to help pay the cost of producing timber.

Figure 5.3 shows the high scenario marginal costs for the four main product groups in one market, for all five planning periods. This comparison is useful for evaluating the targets that were selected for the high scenario. The high and increasing prices for spruce-fir suggest that targets for spruce-fir were probably increased too much, relative to the others. The relatively low prices for the other-pine and northern hardwood categories suggest that those categories might be more likely candidates for the increases needed to achieve levels of demand required for the high scenario.

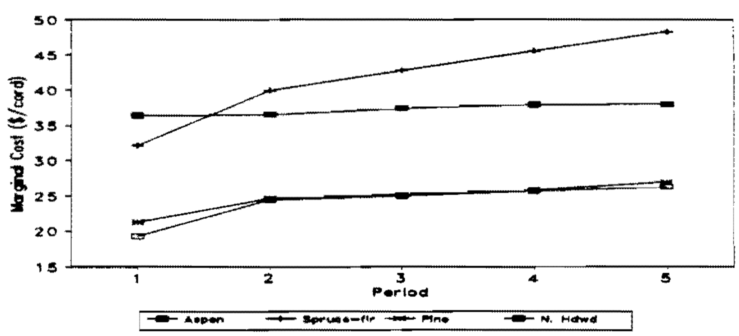


Figure 5.3. **High scenario: Marginal cost estimates for the Bemidji market for main product categories.**

Fixed Price Product Results

The medium scenario used the same modified model formulation, incorporating some fixed prices, as the base scenario with the exception that northern hardwood targets for the Duluth market only were added back into the model. This was due to a proposed Potlatch development in Cloquet which will utilize significant volumes of hardwoods. For the high scenario, targets were increased significantly to utilize the large surplus of these species potentially available.

Under the base scenario, for the products that were assumed to have fixed prices, both sawlog categories showed relatively high levels of production compared with the target levels (the production levels planned for 1992). Based on these results, large increases were made in the target levels for the high scenario.

Southern Region
Output from the southern area runs (figure 5.4) indicates that marginal costs for red oak increase over time for all scenarios. The increase for the base scenario is comparatively low; however, those for the medium and high scenarios are more significant. The fact that the marginal costs do not level out during the period of the study indicates that supplies are becoming increasingly constrained.

In contrast, the model had no difficulty in meeting targets for the other timber category modelled in the southern region. This suggests that maintaining these targets is likely feasible, unless management schedules suggest substantial mitigative measures are necessary.

Success at Meeting Targets
The results from the second runs showed that there were only minor deviations, many less than 1 percent, between the modelled supply levels and the specified targets for the major species/product combinations, including the aspen targets. Some deviations initially appeared large; for example, a 177 percent deviation for spruce-fir in the Bemidji market in period 1. However, the very low volume targets specified for this product at this location mean that any deviation would have no significance when viewed from the perspective of the larger volumes being modelled statewide.

In conclusion, and based on the assumptions described above, the target volumes were achieved for all major species in all major market centers over the 50-year period of the simulation. It must be stressed that these scenarios were unconstrained by considerations of biological/ecological concerns or by existing management practices. In addition, it was assumed that all timberlands, outside of those explicitly reserved for other purposes, would be available. Comparison of these runs with the second runs, which were constrained by incorporating existing and developing policies and practices that reflect consideration of environmental concerns, will provide insight on the *costs* of these strategies. Quantification of these costs, together with an understanding of the nontimber benefits to be gained from these strategies, will provide a sound basis for the task of policy development that will follow.

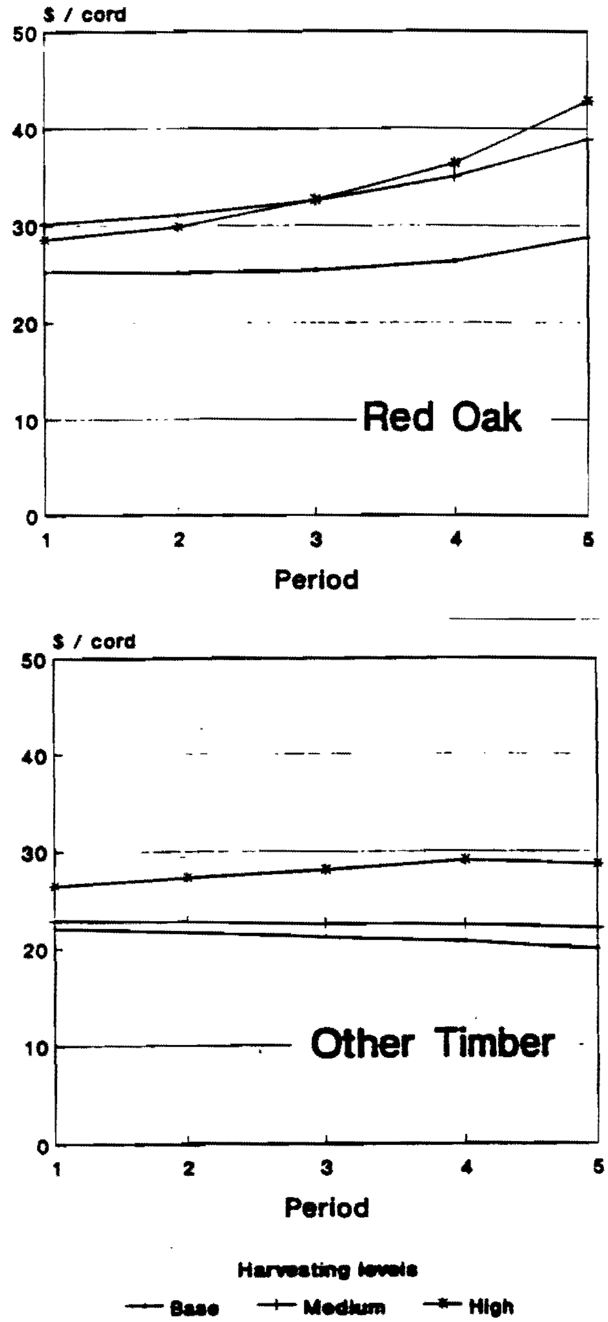


Figure 5.4. Marginal costs for red oak and other timber in the southern region.

5.3
Sources of Timber by Ownership

5.3.1
Modelled Sources of Timber

The model was unconstrained by ownership category when allocating timberland for harvest. Table 5.1 shows the total volume harvested by ownership, region, and scenario. A comparison between the base and high scenarios shows that the harvest from the private property ownership is projected to increase by approximately one-third. This ownership will carry the biggest increase in actual volume harvested. The harvest on federal and state lands is also projected to increase significantly with the percentage increase being greater than that for the private lands. However, the actual volume increase from both state and federal ownerships combined is approximately equal to the increase from private lands.

Table 5.1. Total volume harvested by ownership by study region by scenario in thousands of cords.

	North			South		
Ownership	Base	Medium	High	Base	Medium	High
USFS	27,346	37,684	46,284	0	0	0
Native American	6,257	6,970	8,737	0	0	14
State	35,138	40,251	54,523	1,597	1,995	2,869
Misc. Fed.	1,792	1,966	3,027	757	809	1,089
Co. & munc.	45,671	51,783	64,184	257	263	260
Private	96,610	108,664	133,722	12,660	15,396	20,516

The assumptions regarding availability of timberlands that will be developed for the second runs to reflect constraints on access for harvesting may alter this pattern of harvesting by ownership. For example, the actual volumes of timber products yielded from federal lands are constrained by the limits set in the management plans. Hence, while the timber may exist, it is not necessarily available.

5.3.2
Comparison With Existing Levels of Harvest, by Ownership

Prior to making this comparison, it is important to clearly state that the GEIS is not a *planning* document and that the harvesting scenarios are not meant to predict that specific stands will or will not be harvested. The scenarios were developed as a tool to determine how much of the forest would have to be harvested statewide to meet the levels of demand specified in the FSD. The emphasis was on *statewide*, as this is the level of analysis that the GEIS is directed toward.

As a consequence, all forests, except those in reserved and unproductive categories, were regarded as being available for harvest. The choice of which stand to cut next was made according to economic criteria. It is worth noting that the high harvest scenario could not have been developed without this assumption, as this level is intended to represent the estimated maximum annual volume of timber available statewide (FSD p.8).

The state's timberlands were treated in the model as if the decisionmaking were controlled by a single entity and that meeting the specified wood demands subject to constraints were the only objectives. The model did not recognize the ownership of a plot when allocating harvest. These are obviously simplifications of the real world with its diverse ownerships and even more diverse objectives of management.

Two main areas where differences exist between the modelled scenarios and actual or planned levels of harvest are:

1. the existing constraints for those ownerships that limit the area available for harvest to meet policy objectives; and

2. allocation of harvest levels to achieve a uniform flow of product on a sustainable basis for each ownership or even for certain blocks of timberland within an ownership.

The likely policy-based constraints on harvesting have been identified in the Public Forestry Organizations and Policy background paper (Jaakko Pöyry Consulting, Inc. 1992) and are incorporated into the second runs where possible, via assumptions of the percentage of total timberland that will be available for harvest.

In contrast, the question of allocating harvests between categories of ownerships to meet existing or projected future levels of cutting would add enormous complexity to the model and could not be done within the time or budget available for this study. It is also questionable from a simple analysis viewpoint, as: (1) such constraints would hide the biological potential of the forest, and (2) they may assume policy constancy when changing policy is more likely. In any case, the level of detail entailed would be of no benefit for the central purpose, which is to examine the statewide impacts of an increase in harvest at a statewide level. Therefore, no attempt was made to balance yields from each ownership over time. This led to fluctuations between periods in the levels harvested from some ownerships. Obviously, this may (and does) occur for diverse ownerships such as NIPF lands but is unlikely for an ownership such as the national forests, which have developed short- and medium-term plans for harvests into the early part of the next century. The following interprets the level of harvesting modelled for the national forests. This ownership was selected because it has more or less articulated plans for future levels of harvest.

The USDA Forest Service has planned average annual allowable timber sale volumes from national forests in Minnesota. This shows a trend of increasing volumes over the planning period up to the year 2021.

Figure 5.5 compares the planned levels of harvest over time with the modelled levels for this ownership. The modelled levels for the base and medium scenarios show a fluctuating level of cut in contrast to the substantially lower level envisioned in USDA Forest Service plans.

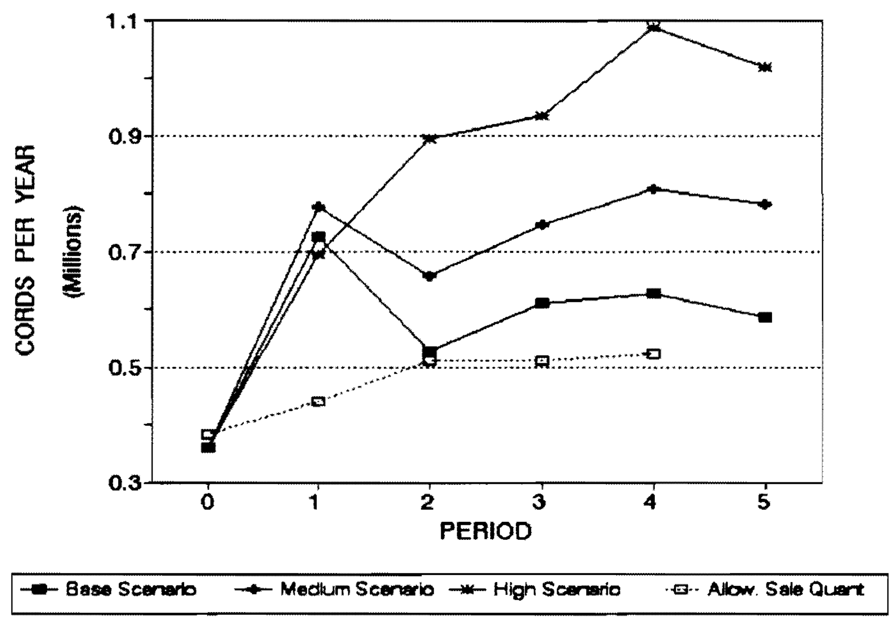


Figure 5.5. Initial projections of annual timber harvest per decade from national forest lands in Minnesota, from 1989 (Period 0) through five decades, for base, medium, and high levels of timber harvest scenarios.

Note that if *all* owners were to have their harvest specified in the model, then gridlock would occur—there would be no reason to carry out many parts of the study. Also, if NIPF ownerships tell us anything, it is that owners do respond to prices. Further, while market signals may be major factors for harvest actions for all forest owners, nontimber values can influence harvesting decisions substantially.

5.4 Spatial and Temporal Patterns in Harvesting by Scenario

Figures 5.6 and 5.7 compare the patterns of harvesting in the northern region for all five periods (fig. 5.6) and for one period (fig. 5.7) for the high and base scenarios. As expected, harvesting activities are more intensive under the high scenario. There is little difference in the spatial extent of harvesting between scenarios and over time. This reflects the good access to most regions and the decentralized nature of the timber industry, meaning that most stands are not ruled out for harvesting because of location.

Figures 5.8 and 5.9 show the same data for the southern region. The scattered patterns of forest cover in the southern region are apparent from the distribution of harvested areas. Similar trends to those seen in the north appear in the southern region.

The size of each dot in the figures is a reasonable approximation of the size of a stand. The dots cover approximately 1,200 acres, and most FIA plots represent about 1,200 to 1,500 acres.

5.5 Acres Harvested and Unharvested by Covertype

Northern Study Region

In each scenario, the acres of each covertype scheduled for harvest has been analyzed for the northern and southern study regions. This analysis is presented as table 5.2. Some caution must be exercised in interpreting this table. For example, a comparison of table 5.2 with table 2.3 suggests that more acres of aspen and black spruce are being harvested than are present in timberland in the 1990 inventory. The values in table 5.2 which are larger than those in table 2.3 are explained by the fact that each acre harvested was counted each time it was harvested. Aspen, balsam fir and black spruce are the only covertypes for which two clearcuts or final harvests were possible within the planning horizon. The actual acreage cut one or more times can be obtained by subtracting uncut acres in table 5.3 from total covertype acreage.

The most striking feature of this table is the predominance of the aspen covertype, as the type with most harvesting scheduled. Aspen acres cut under the high scenario actually decrease from those harvested under the medium scenario. This reflects the interaction of two factors: (1) no aspen demand was added to create the high scenario, and (2) additional sources of lower cost aspen become available from northern hardwood stands logged to meet increased demand for this category of products as part of the high scenario. Therefore, fewer acres of the aspen covertype were needed. This is consistent with the output from the marginal cost analysis (section 5.1).

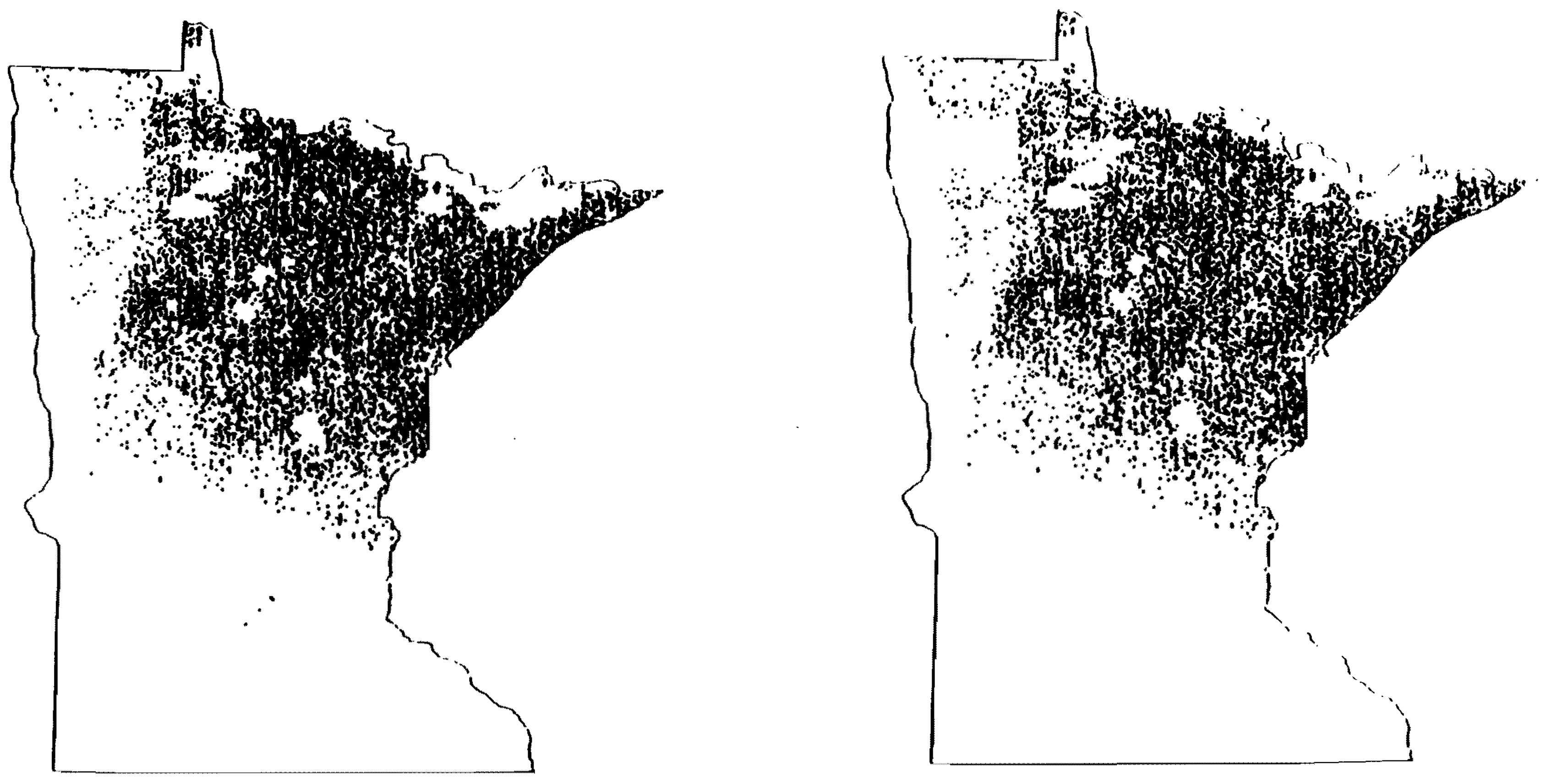


Figure 5.6. Comparison of northern region stands harvested under the high (left) and base (right) demand scenarios.

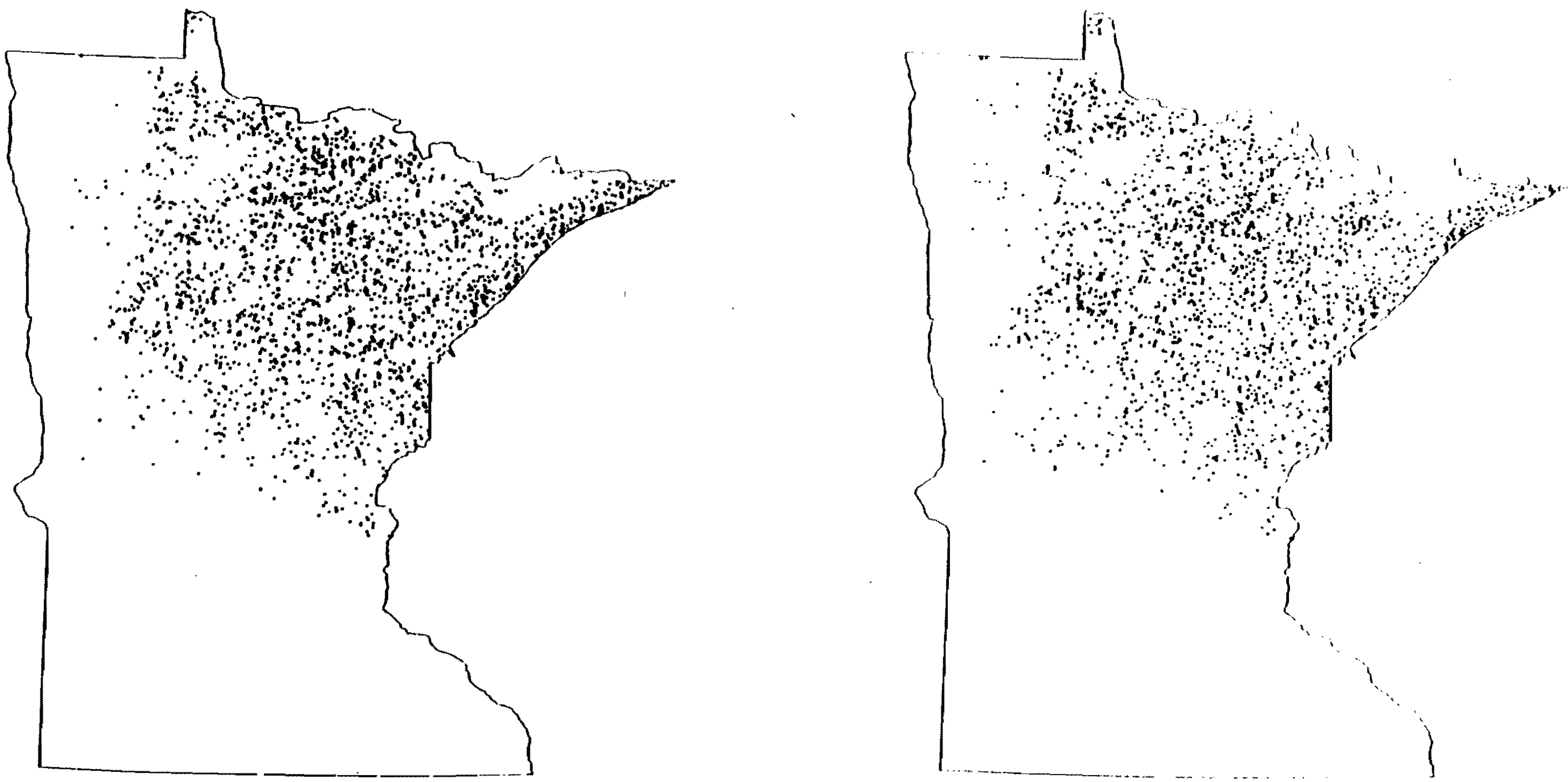


Figure 5.7. Comparison of northern region stands harvested in the third period under high (left) and base (right) demand scenarios.

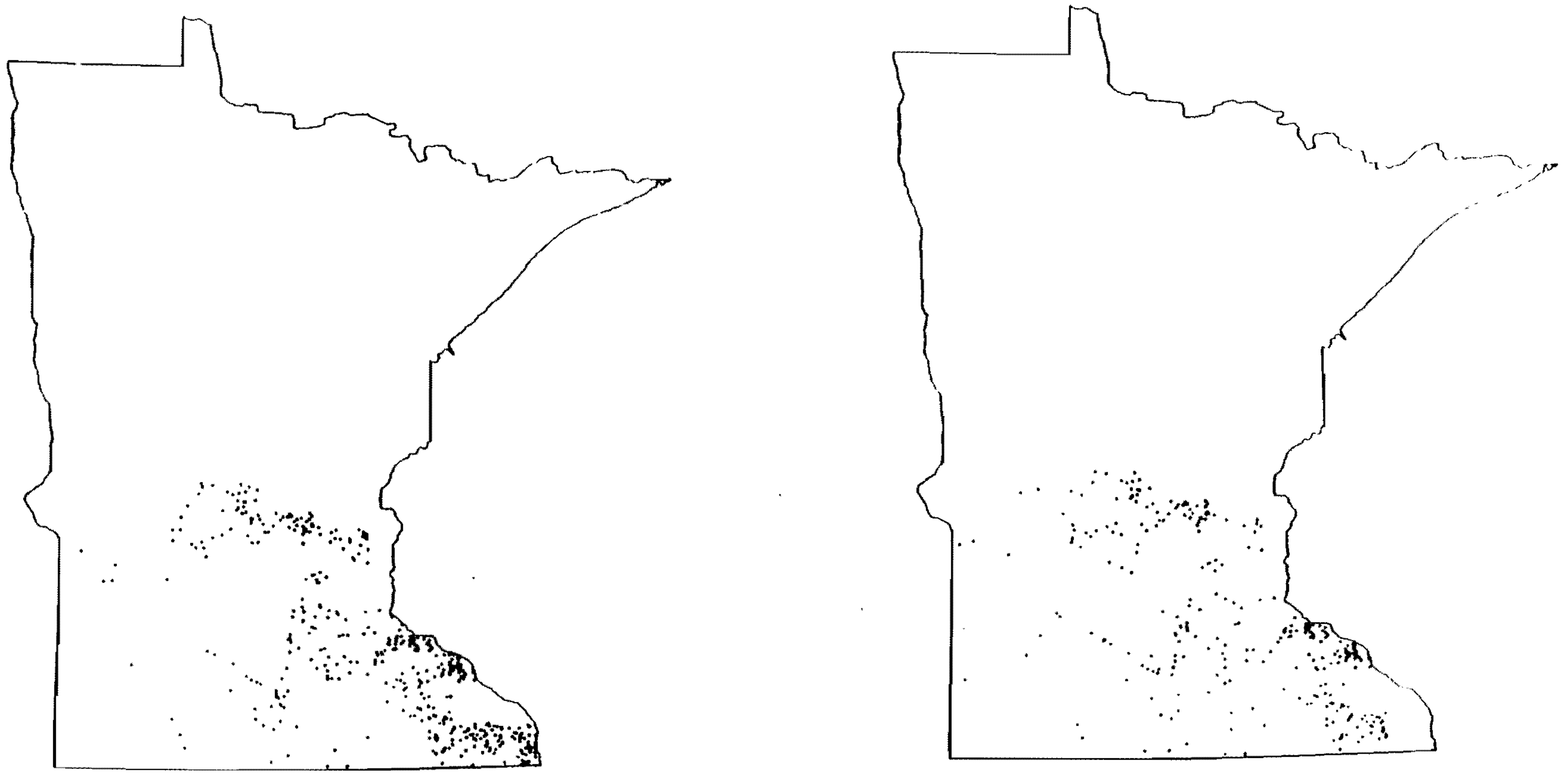


Figure 5.8. Comparison of southern region stands harvested under the high (left) and base (right) demand scenarios.

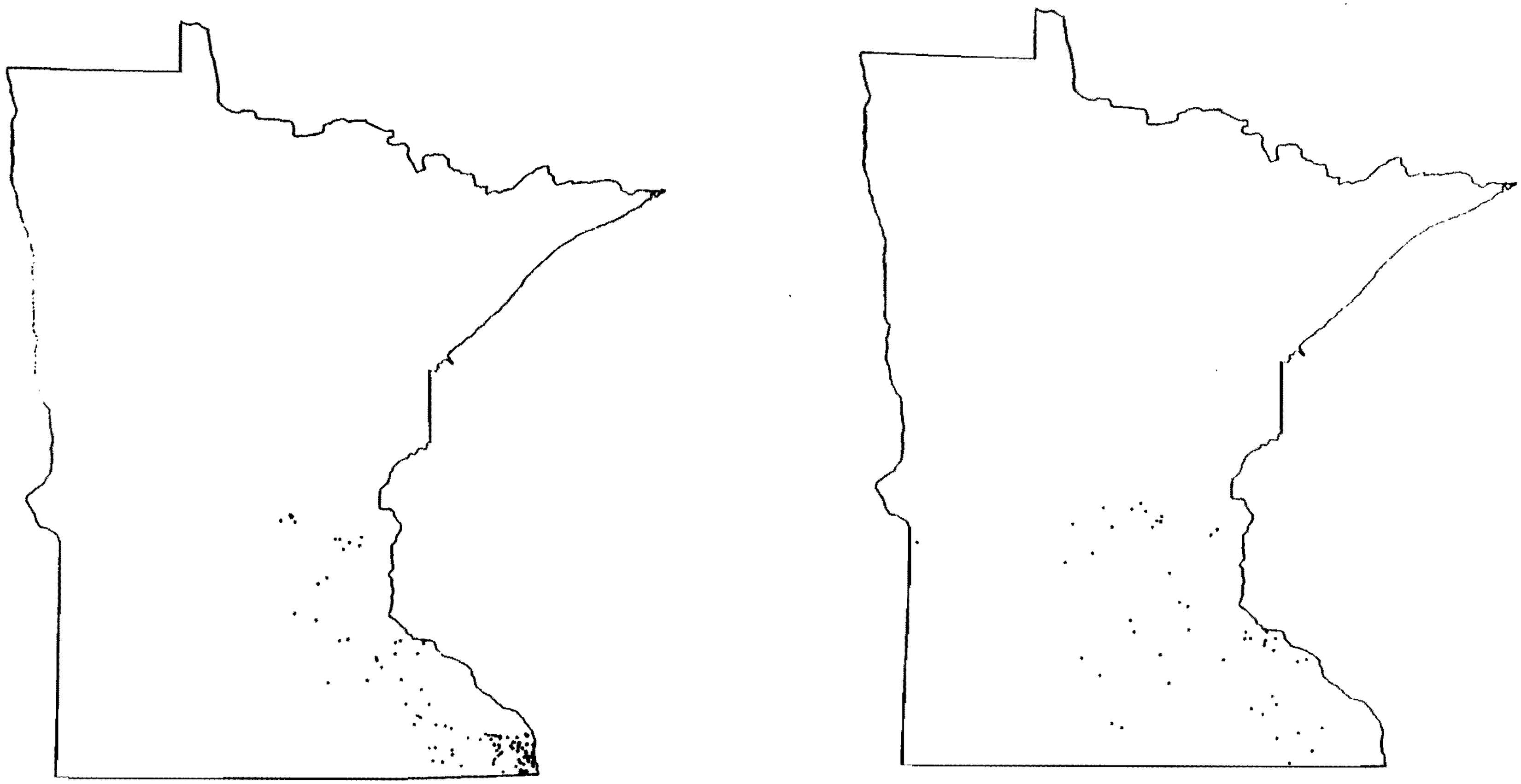


Figure 5.9. Comparison of southern region stands harvested in the third period under high (left) and base (right) demand scenarios.

Table 5.2. Projected acres cut by study region, scenario and covertype.

Covertype	Northern Study Region			Southern Study Region		
	Base Scenario	Medium Scenario	High Scenario	Base Scenario	Medium Scenario	High Scenario
Jack pine	134,400	242,400	419,100	1,300	1,300	1,800
Red pine	339,800	345,700	351,500	1,300	1,300	2,000
White pine	66,500	67,900	67,900	700	700	700
Black spruce	326,600	924,100	1,554,300		1,100	2,000
Balsam fir	272,600	584,500	797,500	NA	NA	NA
N. white cedar	7,400	23,200	41,700	NA	NA	NA
Tamarack	96,600	113,800	606,300	200	2,600	6,700
White spruce	51,500	84,400	90,600	NA	NA	NA
Oak hickory	274,100	383,100	519,100	222,100	261,800	699,500
Elm-ash-soft maple	140,800	418,500	791,100	36,300	43,900	63,000
Maple-basswood	113,200	380,500	831,300	234,500	272,900	346,300
Aspen	5,104,300	5,742,900	5,598,900	54,000	95,200	134,900
Paper birch	220,600	353,000	626,500	13,900	16,200	16,200
Balsam poplar	518,400	564,300	553,900	15,200	17,400	27,100
Other	19,100	22,300	21,200		13,000	14,500
Total	7,685,900	10,250,600	12,870,900	579,500	727,400	1,314,700

Note: Some acres cut are harvested twice over the planning period for some covertypes, especially for the medium and high scenario.

Black spruce and balsam fir show very large increases between the base and medium scenarios. More volume will be harvested from both covertypes if the planned or potential industries used to define the medium scenario are developed (medium scenario). The area of elm-ash-soft maple and maple-basswood harvested under the medium scenario will be over three times the levels harvested under the base scenario.

Table 5.3 shows unharvested acres. The term *unharvested* refers to stands of timberlands that were potentially available for harvest but were not selected during the study period. Stands that were unavailable for harvest, such as those in the reserved or unproductive category (e.g., BWCAW), are additional to this area.

The area by covertype remaining uncut at the end of the medium scenario was earmarked for supplying the additional demand needed to achieve the 7 million cord level specified for the high scenario. Perhaps the biggest change is in the black spruce covertype. Less than 10 percent of the area remaining uncut under the base scenario would be left uncut under the high scenario. In area, this equates to a fivefold increase in the level of harvesting for this covertype between the base and high scenario. Large increases in demand under the high scenario were also modelled for the jack pine, balsam fir, paper birch, oak-hickory, maple-basswood, and elm-ash-soft maple covertypes.

Table 5.3. Projected acres left unharvested by region, scenario and covertype.

Covertype	Northern Study Region			Southern Study Region		
	Base Scenario	Medium Scenario	High Scenario	Base Scenario	Medium Scenario	High Scenario
Jack pine	401,700	202,300	25,600	NA	NA	NA
Red pine	10,900	7,000	1,200	NA	NA	NA
White pine	1,400			NA	NA	NA
Black spruce	695,200	570,500	61,100	2,000	900	
Balsam fir	670,100	230,700	62,600	NA	NA	NA
N. white cedar	629,600	623,800	605,300	NA	NA	NA
Tamarack	597,900	598,900	133,600	5,200	4,100	
White spruce	56,800	7,300	1,100	NA	NA	NA
Oak hickory	396,500	230,900	94,900	217,100	212,900	11,100
Elm-ash-soft maple	607,000	577,100	204,500	72,800	66,200	47,800
Maple birch	822,800	672,200	221,400	89,400	69,700	35,600
Aspen	356,600	210,200	156,100	33,600	6,400	2,200
Paper birch	711,700	449,800	176,300	1,200		
Balsam poplar	29,200	18,700	9,400	2,200		
Other				15,400	2,400	900
Total	5,573,400	4,190,500	1,726,700	423,500	360,200	96,700

The area by covertype remaining uncut at the end of the medium scenario was earmarked for supplying the additional demand needed to achieve the 7 million cord level specified for the high scenario. Perhaps the biggest change is in the black spruce covertype. Less than 10 percent of the area remaining uncut under the base scenario would be left uncut under the high scenario. In area, this equates to a fivefold increase in the level of harvesting for this covertype between the base and high scenario. Large increases in demand under the high scenario were also modelled for the jack pine, balsam fir, paper birch, oak-hickory, maple-basswood, and elm-ash-soft maple covertypes.

Other points of interest include:

- the aspen covertype again shows a different trend with only a slight decrease in acres left uncut; and
- the northern white cedar covertype shows little relative change in the large area never cut across the three scenarios, however, the smaller harvested acreage does increase substantially for the high scenario.

Southern Study Region
The trends for the southern study region show a large increase in the areas of oak-hickory that are cut when comparing the base to the high scenario. There is also an increase of less significance in the area of maple-basswood stands cut (table 5.2).

Table 5.3, acres never cut, shows that the high scenario would require virtually all the oak hickory stands to be harvested during the course of the planning period. This covertype is typically harvested using selection harvesting techniques rather than clearcutting, hence more acres are affected to obtain the equivalent volume.

The elm-ash covertype and maple-basswood covertypes also show large reductions in acres unaffected by harvesting under the high scenario.

5.6
Changes in Age Class Harvested in the Aspen Covertype

Figure 5.10 shows changes in the volumes by age class of aspen stands harvested in the northern region, over the course of the planning period for the three scenarios. The trend to note here is the upsurge in the harvest of younger age classes (regrowth) under all scenarios beyond the fourth planning period. The comparatively short rotations for this species means that stands harvested in the first period become available again in the fifth (based on a 40-year minimum rotation). The increased aspen demand modelled in the medium scenario shows up with a higher proportion of the stands harvested in the younger age class than either the low or high scenarios.

5.7
Size and Composition of the Forest Land Base

The present extent and history of Minnesota's forest land base was summarized in tables 2.1, 2.2 and 2.4. Based on a linear extrapolation of the acreage changes for the period 1977-90, one might see FIA unit and statewide changes as projected in table 5.4. Figure 5.11 suggests how this change might evolve by county and ecoregion. Forest area change by county from past FIA surveys is detailed in appendix 12.

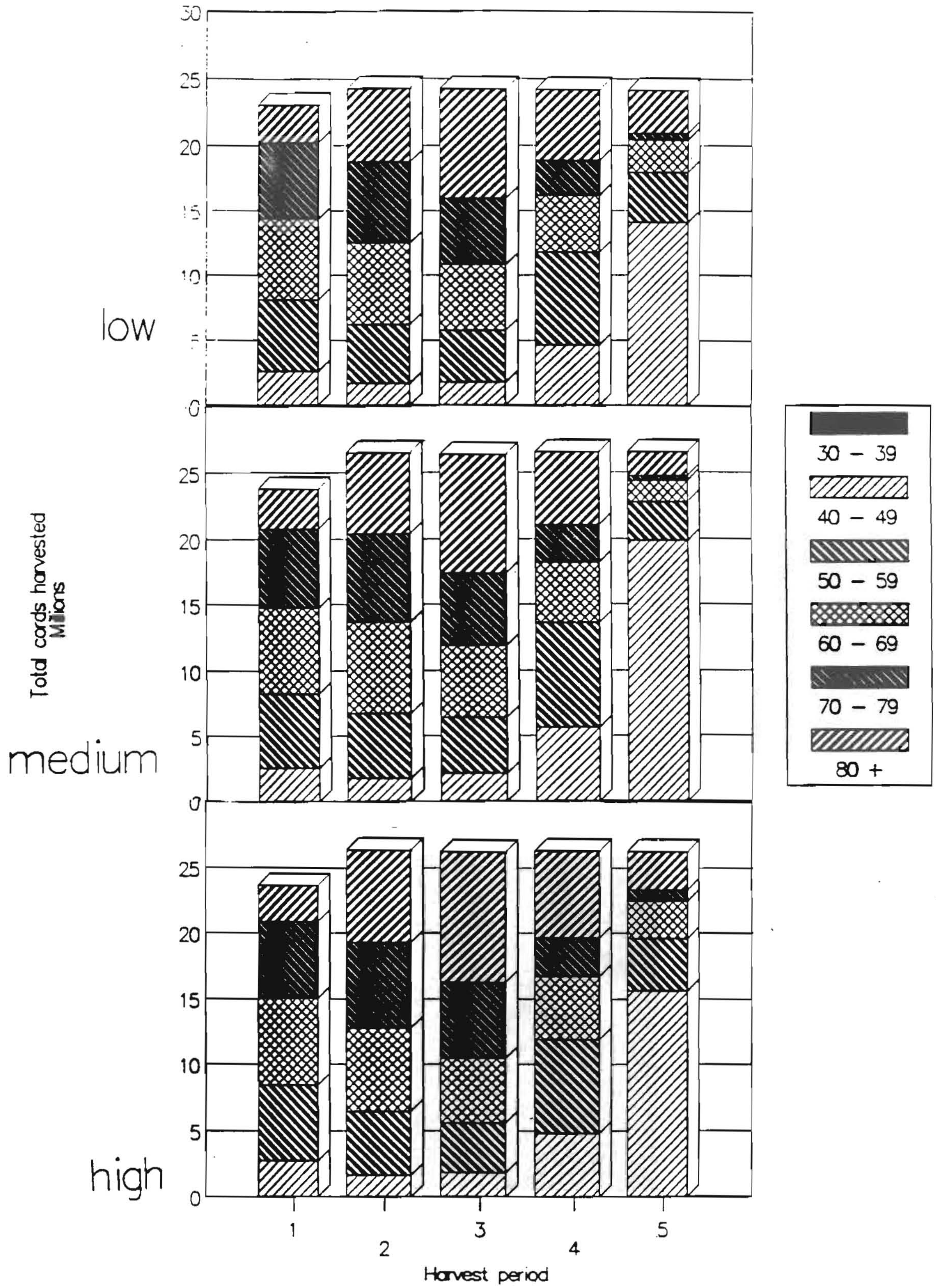


Figure 5.10. Volumes of aspen harvested by stand age class by period and scenario.

Table 5.4. Simple linear projections of total forest land area change by survey unit, 1990–2040.

FIA Unit	1977–90 (percent)	1990–2040 (percent)
Aspen-birch	-1.47	-5.7
Northern pine	-2.70	-10.7
Central hardwood	9.96	34.9
Prairie	13.57	46.0
All units	0.03	0.2

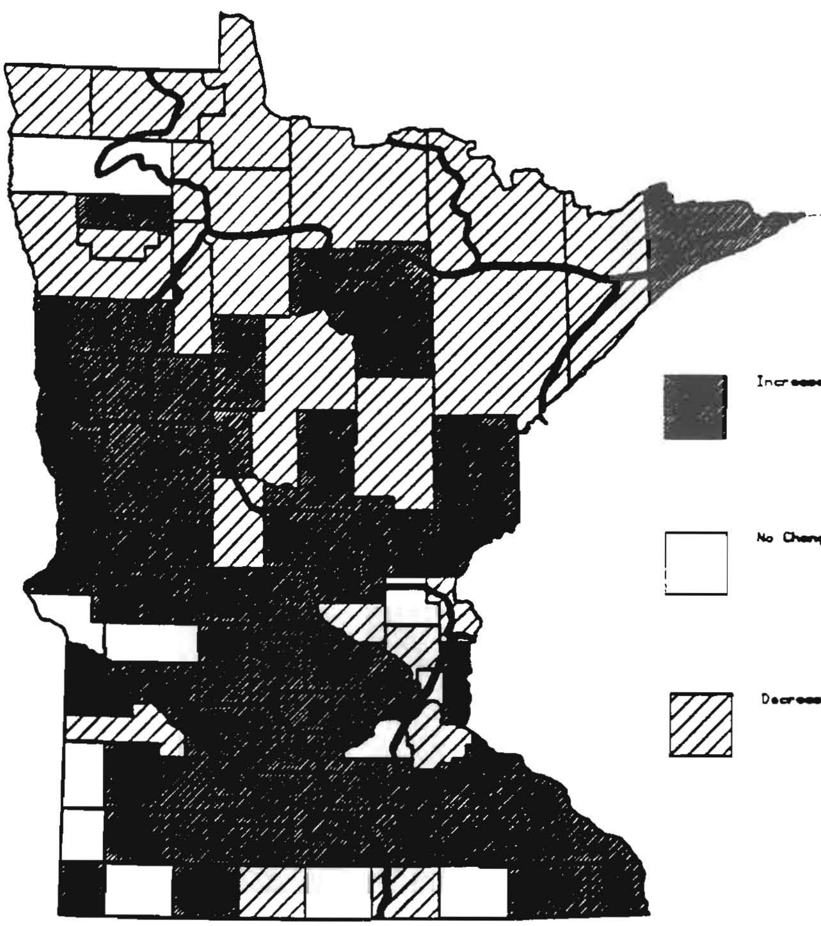


Figure 5.11. Changes in total forest land acreage by county and ecoregion, 1977–90.

These results need to be interpreted with caution. First, the statewide percent change is probably the most reliable. As table 2.4 indicates, total forest land has declined until recently, and is now likely to remain stable.

Projections developed by Plantinga et al. (1989) for Minnesota, Wisconsin and Michigan suggest a continued but slight decline in timberland for Minnesota from 1987 to 2040. Those projections were based on past change and empirical models using change in rural populations, change in median family income and percent of total land covered by timberland.

It was also clear from past studies that results and relationships can vary greatly by county and FIA unit. The literature emphasizes demographic, economic and related ownership factors as most important to forest land acreage changes. Harvesting, per se, is not a factor in forest area. Logging changes the structure and the composition of forest land, but not the land use category. In Minnesota, the population in recent decades has risen but at less than the national average in terms of percent. According to the State Demographer's office, Minnesota's population increase was 7.3 percent from 1980 to 1990. Further, a similar increase and geographic distribution of that is expected for the 1990s and perhaps beyond.[1] However, according to Raup (1980), construction of transportation systems (highways) that claimed a large amount of timberland in the past three decades is near completion and so future losses to this factor will decrease. Also, development of rural areas, which was rapid in the 1960s and 1970s will slow in coming decades, and the existing infrastructure developments will be able to serve rural populations well with only little expansion.

In the aspen-birch unit, where forest is the predominant land use, development will likely come largely from timberland on private ownership—it is unlikely to come from public lands, reserved or unproductive forest (often wetlands). In the northern pine unit, recreational home and other rural development will probably offset gains in forest area due to natural reversion of agricultural lands to forest and conservation programs. The net change is difficult to predict in the unit. The central hardwoods unit is showing a pattern of natural forest regrowth following the decline of agriculture near the major urban center of the state. This is a pattern evident from earlier periods of development in more eastern parts of the U.S. A key question is how much of this new forest acreage will ultimately be converted to *wooded lots* and urban development, and how much will become reserved forest versus timberland. The prairie unit shows an increase in total forest area. Most counties (8 of 42) show an increase. Since the total area of forest in most of these counties is still small, conservation and related tree planting programs could have a major positive

[1]Personal communication from R. Thomas Gillaspy, State Demographer, September 1, 1992.

impact on forest land acreage in the future. Implementation of an agricultural equivalent of forestry best management practices (BMPs) could also lead to increased forest acreage, or at least reveal the decline evident in some counties. Since most of the reserved and unproductive forest is located in the northern part of the state, acreage gains here would be largely in timberland. Even with the large percentage gains in the southern two units, the forest acreage in 1990 is substantially below that found in 1962.

The acreage gain in the state overall, especially for the southern units, is further consistent with patterns of increased forest area in the U.S. and Europe in recent decades. Clawson (1979) points out how forest growing stock and timber growth has been "repeatedly and seriously underestimated" in the U.S. Likewise, Kauppi et al. (1992) show an increase in growing stock and forest area in Europe from 1971 to 1990, despite forest health problems in certain areas. Additionally, projections of U.S. agriculture under a stable climate scenario suggest that cropland needs could decline by one-third by 2030 (Abelson 1992). In the Lake States, major factors in regrowth appear to have been the gradual reduction of livestock-based agriculture and associated woodlot grazing, cropland reversion with a decline in agriculture, conservation and tree planting programs, and continued fire control.

5.8 Species Composition and Age Class Structure

Tree Species Composition

Tree species composition changes can occur in the form of species composition within a covertype, often related to stand age or stage of development, and in terms of covertype acreage. Factors affecting species composition are natural succession and natural and human disturbance, including harvesting and forest management. The most common human disturbance is harvesting. Table 2.24, in section 2.3.8, indicates that natural disturbance rates are nearly equivalent to those from harvesting. However, natural disturbance can have a somewhat different effect on composition than harvesting.

Assuming the covertype acreages in the base, medium and high scenarios, it is possible to estimate future tree species composition by multiplying the future acreages by age class by the 1990 species composition by age class. This approach assumes the probability of each species regenerating is stationary over time. Results are shown in tables 5.5 and 5.6. Detailed tables of results by size class are shown in appendix 11. Table 5.5 presents a summary of 1990 and projected species composition to 2040 for the base, medium and high scenarios across all covertypes. Of the 60 species considered, 28, 27 and 32 are projected to show a reduction in numbers under the various base, medium and high harvesting scenarios, respectively.

Table 5.5. Summary of projected tree species composition for 1990 and 2040 for base, medium and high harvest scenarios on timberlands (thousands of trees $\geq$1.0 inch dbh).

Species	1990	2040		
		Base	Medium	High
Ailanthus	38	36	28	19
American hornbeam	14,406	10,620	10,351	9,883
American basswood	192,081	160,878	152,628	138,376
American elm	150,000	139,328	135,312	128,559
Apple	380	341	383	489
Balsam fir	979,311	1,065,960	1,034,691	952,348
Balsam poplar	266,460	291,779	326,048	409,486
Bigtooth aspen	73,177	66,817	73,747	90,170
Bitternut hickory	8,040	7,981	7,423	6,664
Black ash	527,472	589,708	573,531	524,381
Black cherry	35,420	37,996	38,131	39,492
Black locust	455	127	108	64
Black maple	150	126	97	55
Black oak	704	734	675	574
Black spruce	1,039,092	1,299,302	1,216,865	1,001,909
Black walnut	2,283	2,143	2,030	1,844
Black willow	5,695	5,445	5,793	6,813
Boxelder	66,663	76,881	74,938	70,768
Bur oak	190,433	156,489	154,139	154,830
Butternut	2,934	3,169	3,144	3,115
Chokecherry	33,833	33,348	35,808	42,407
Eastern cottonwood	2,731	2,833	2,773	2,788
Eastern redcedar	14,042	15,694	15,957	16,471
Green ash	86,469	76,754	76,161	77,243
Hackberry	14,704	15,621	14,337	11,795
Hawthorn	8,799	9,258	9,436	9,969
Ironwood	117,978	105,572	106,121	108,026
Jack pine	164,588	158,899	175,403	219,106
Ky. coffee tree	441	182	160	127
Mountain ash	1,489	1,913	1,756	1,265
Mountain maple	15,810	104,542	98,458	81,262
N. white-cedar	386,813	849,539	747,149	434,756
Northern pin oak	5,965	4,528	4,482	4,826
Northern red oak	111,881	85,641	80,854	73,198
Other hardwood	41,150	33,615	27,328	13,919
Paper birch	570,927	486,981	484,997	492,497

Table 5.5. (continued)

Species	1990	2040		
		Base	Medium	High
Peachleaf willow	484	464	516	663
Pincherry	13,132	13,615	14,920	18,307
Ponderosa pine	397	577	707	977
Quaking aspen	1,986,779	2,247,219	2,598,976	3,378,970
Red maple	290,703	213,861	216,431	231,014
Red mulberry	981	1,073	1,075	1,210
Red pine	97,785	108,375	121,457	151,693
River birch	182	818	783	561
Rock elm	1,568	1,427	1,181	854
Scotch pine	1,625	2,375	2,856	3,934
Shagbark hickory	9,138	9,558	9,074	8,221
Siberian elm	394	438	510	658
Silver maple	9,549	10,015	9,563	8,510
Slippery elm	23,005	24,976	24,131	22,224
Striped maple	457	334	313	263
Sugar maple	283,720	204,406	189,080	158,943
Swamp white oak	450	1,182	1,109	757
Tamarack	361,454	467,221	457,633	426,737
White ash	2,486	3,050	2,977	2,784
White oak	10,053	9,545	8,536	6,278
White pine	29,556	23,721	21,212	16,745
White spruce	78,608	75,940	79,297	88,276
Wild plum	5,321	5,494	5,382	5,190
Yellow birch	11,739	17,051	15,952	12,280
Grand Total	8,442,380	9,343,515	9,474,913	9,675,543

Conversely, the balance of the 60 species are projected to show an increase in number. Upon examination, it would appear that species in the maple-basswood covertype are favored more by the base scenario than the high scenario. However, these initial runs assumed little partial cutting, and clearcutting was assumed to fell *all* trees in the stand. The Silvicultural Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992c) indicates that there are often residual trees retained with clearcutting. Caution is also needed when interpreting changes for minor species. Some species, like black locust, are edge or pioneer species that may not show up well in patches of trees large enough to be classified as forest versus nonforest with trees. Also, sampling errors are large. Interestingly, yellow birch is an infrequent species that is favored by harvesting. Note also that those tree species favored by harvesting would appear to decline with less harvesting.

Table 5.6. Summary of 1990 and projected 2040 tree species composition for base, medium and high scenarios on timberlands (thousands of trees ≥ 4.95 inches dbh).

Species	1990 FIA	2040		
		Base	Medium	High
Ailanthus	38	36	28	19
Am. hornbeam	378	187	163	111
American basswood	77,360	54,151	48,179	36,451
American elm	37,879	31,748	29,598	25,586
Apple	4	3	2	2
Balsam fir	201,892	159,902	148,401	125,014
Balsam poplar	81,239	66,377	66,672	73,746
Bigtooth aspen	26,992	16,592	15,590	15,038
Bitternut hickory	2,154	1,508	1,330	1,181
Black ash	125,707	132,014	119,344	87,017
Black cherry	4,097	3,439	3,457	3,555
Black locust	425	119	101	60
Black maple	73	40	32	15
Black oak	518	587	506	345
Black spruce	195,619	242,187	217,260	150,676
Black walnut	1,117	1,201	1,161	1,104
Black willow	3,242	2,900	2,731	2,613
Boxelder	19,717	19,780	18,723	17,123
Bur oak	81,155	61,790	55,522	42,844
Butternut	1,582	1,565	1,463	1,233
Chokecherry	87	73	73	84
East. cottonwood	1,692	1,422	1,282	1,163
Eastern redcedar	3,413	3,685	3,507	3,126
Green ash	23,928	18,852	17,334	14,867
Hackberry	1,895	1,393	1,319	1,239
Hawthorn	208	140	160	208
Ironwood	4,614	4,893	4,589	3,874
Jack pine	85,782	63,803	64,822	73,771
Ky. coffee tree	129	66	68	69
Mountain ash	117	196	192	162
Mountain maple	19	13	11	4
N. white-cedar	165,042	405,774	354,439	193,939
Northern pin oak	3,887	2,515	2,229	2,003
Northern red oak	73,065	45,023	39,719	29,989
Other hardwood	7,295	5,299	4,360	2,203
Paper birch	244,319	169,585	157,533	137,482
Peachleaf willow	24	11	9	6

Species	1990 FIA	2040		
		Base	Medium	High
Pincherry	155	265	261	220
Ponderosa pine	211	304	373	516
Quaking aspen	479,690	362,895	369,900	418,179
Red maple	77,862	49,395	46,789	43,884
Red mulberry	57	88	107	146
Red pine	56,494	59,276	64,463	77,761
River birch	15	20	24	33
Rock elm	483	252	202	141
Scotch pine	801	1,109	1,318	1,813
Shagbark hickory	2,026	1,757	1,525	1,042
Siberian elm	201	194	222	281
Silver maple	4,238	3,568	3,237	2,533
Slippery elm	4,445	4,235	3,883	3,267
Striped maple	36	19	22	26
Sugar maple	74,566	52,316	45,723	32,093
Swamp white oak	144	59	57	56
Tamarack	100,534	138,823	126,495	91,178
White ash	900	971	893	716
White oak	7,055	7,557	6,556	4,259
White pine	15,221	13,902	12,383	9,312
White spruce	31,705	25,301	24,860	24,690
Wild plum	34	14	10	3
Yellow birch	3,584	3,897	3,443	2,272
Grand Total	2,337,161	2,245,086	2,094,655	1,762,343

Unfortunately, tabulations of species composition for reserved and unproductive areas are not possible because most of reserved and many of the unproductive plots were not visited on the ground and/or they do not have tree lists.

Appendix 13 also contains tables describing 1990 and projected species composition for various covertypes. These tables indicate that individual covertypes can have some of the same (as above) species showing significant reductions as well as additional species. Because most species are found in at least several covertypes, results across covertypes are emphasized here.

Table 5.6 repeats this analysis, but only for trees 4.95 inches dbh and larger. In most cases, tree numbers by species are reduced under the high scenario relative to 1990. This pattern is a reflection of harvesting that shifts the forest toward younger age classes and fewer large trees. However, the appendix 8 tables by age class still retain trees in old stand age class. This is because, as noted in section 5.5, not all acres are harvested. Also, reserved and unproductive forest stands would add to these values for older stands, especially in the border lakes ecoregion.

Age Class Structure
The stand age class structures described earlier, by covertype, are revisited. These structures for 1990 for timberland, reserved and unproductive forest are tabulated in appendix 8. Importantly, they suggest balance or lack of it in age class distributions. Imbalance suggests that transition strategies (transition to a balanced age class distribution) may not be smooth and/or that special attention may be needed, from a silvicultural standpoint, to achieve balance. Also, while the age class distributions suggest the opportunity to favor certain types of forest conditions for various timber and nontimber benefits, the diverse ownership pattern would make such efforts quite complicated.

The buildup of growing stock in the state since the 1930s is evidence that the forest is maturing. Achieving balance, as suggested by Sedjo and Lyon (1990) need not require uniformity in management across all regions. In Minnesota, a combination of intensive, extensive and essentially no management may be applied at various covertypes and locations at different times to achieve transition to balanced age class structures and a steady flow of timber and nontimber benefits.

Those covertypes suggesting the greatest challenge to achieving a balance on timberland are those that comprise small acreages, face uncertain markets, and have serious health or regeneration problems. Among these are white pine, northern white cedar, aspen in the short-term, paper birch and perhaps oak, depending upon the ecoregion. On reserved lands, current management which limits human disturbance and has reduced naturally occurring disturbance through fire control will clearly lead to a preponderance of older age classes and succession to more shade tolerant species.

Covertype Change
The above analysis of species composition assumes the covertype proportions of the three harvest scenarios. Logically, the next issue deals with exactly what covertype acreage changes might be expected. Using the remeasured FIA plots and records of stand age and disturbance, it is possible to develop a rough estimate of rates of covertype change with harvesting. Such estimates, in the form of a transition matrix for harvested stands, are shown in tables 4.4 and 4.5. Table 4.4 suggests harvesting in recent times has favored red pine, tamarack, oak-hickory, elm-ash-soft maple, and aspen covertypes. Table 4.5 suggests that stands with ten percent or more aspen are even more likely to convert to that covertype. Conversely, tables 5.7 and 5.8 suggest that stands that are not harvested, particularly the older ones,

will tend to stay the same or change to types in the current species mix, often those that are more shade tolerant or longer lived.

Since these patterns change with stand age, it is difficult to determine overall trends from these data. Given table 2.24 describing stand history, it would appear that covertype change rates for undisturbed stands (tables 5.7 and 5.8) might apply to approximately 79 percent or more of the forest while rates for harvested stands (table 4.5) would apply to about 8.5 percent or less in any one decade. Consequently, a slight decline in the acreage of the aspen covertype seems probable. This follows from the above tables, which show undisturbed aspen stands (the majority in any one decade) convert via succession to other covertypes more frequently than harvested stands of other covertypes with an aspen component convert to aspen. While increased harvesting rates would favor aspen, it is important to note that harvesting rates have not been below 2 million cords per year since the 1870s.

An alternative way of looking at covertype changes is through aggregate survey trends. These are especially informative because they integrate all of the changes that have occurred in the forest. Table 5.9 describes covertype area as reported in past FIA surveys. The table suggests continued decline in the area of jack pine, white pine, balsam fir, aspen, paper birch and balsam poplar. Species that show a trend toward increased acreage are red pine, black spruce, tamarack, northern white cedar, white spruce, maple-basswood and oak hickory. Short rotations will likely slow these trends, particularly for aspen; longer rotations and selection harvesting will likely speed up these trends. However, given site requirements, lowland conifer types will probably remain stable in terms of total area. This means the most visible changes will occur on uplands. Given the fact that a forest area increase in northern Minnesota is unlikely, gains in the acreage of one type will have to come from other types. The type change matrices presented in tables 4.5, 4.6, 5.7 and 5.8 suggest what has happened in the period 1977—90. Since management choices for rotation lengths and regeneration investment have important impacts on such change rates, it seems clear that if goals for covertype can be articulated, the silvicultural tools exist, given appropriate investment, to achieve those goals.

5.9 Patterns of Forest Cover

The present extent of forests in Minnesota agrees with the extent of presettlement vegetation (figure 5.12). However, that forest has clearly been broken up by agricultural and urban development. The current forest acreage is only 53 percent of presettlement conditions. Still, there are major differences in forest areas and conditions among ecoregions and FIA units. Most of these differences can be traced to variation in physiographic, soil and climatic conditions that have influenced forest patterns and development.

Table 5.7. Type change matrix for undisturbed plots, 1977–90, for all FIA covertypes and stand age greater than 30 years—no differentiation made for significance of aspen component. The plots used in creating the following matrix met the following conditions:

1. Remeasured, ground visited plots (sample kinds 2 or 6)
2. Commercial forest (ground land use at each cycle less than 30)
3. Not disturbed by harvesting (disturbance code equal to 0)
4. Naturally regenerated stands (stand origin less than 2)
5. Stand age in 1977 greater than 30 (indicates that it was merchantable)

a) Percent of 1977 forest type plots

		Forest Type 1977														
Forest Type 1990		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Percent of 1977 Total
Jack pine	1	90.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.60	0.00	1.75	102.33
Red pine	2	2.33	95.70	8.33	0.00	2.66	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.73	0.00	130.43
White pine	3	0.00	0.00	74.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.73	0.00	91.67
Black spruce	12	0.00	0.00	0.00	88.75	2.66	0.00	0.00	14.29	0.00	0.00	0.00	0.20	0.00	0.00	93.75
Balsam fir	13	0.00	0.00	0.00	0.00	62.51	2.40	0.00	28.58	0.00	2.32	1.12	2.40	1.46	3.50	94.67
N. white cedar	14	0.00	0.00	0.00	2.50	3.99	96.00	0.00	14.29	0.00	0.00	0.00	0.00	2.19	0.00	107.23
Tamarack	15	0.00	0.00	0.00	3.75	0.00	0.00	93.20	0.00	0.00	0.00	0.00	0.20	0.00	0.00	102.33
White spruce	16	0.00	0.00	0.00	1.25	0.00	0.00	0.00	42.87	0.00	0.00	0.00	0.20	0.00	0.00	71.43
Oak-hickory	50	0.00	4.35	0.00	0.00	0.00	0.00	0.00	0.00	86.25	3.48	5.04	3.60	2.92	0.00	112.78
Elm-ash-soft maple	70	0.00	0.00	0.00	0.00	2.66	0.00	4.66	0.00	0.75	82.36	11.20	2.40	5.11	10.50	140.69
Maple-basswood	80	0.00	0.00	16.66	0.00	2.66	0.00	0.00	0.00	6.75	8.12	77.28	3.60	2.19	1.75	100.00
Aspen	91	6.99	0.00	0.00	0.00	15.96	0.00	0.00	0.00	4.50	1.16	4.48	84.20	15.33	17.50	95.63
Paper birch	92	0.00	0.00	0.00	3.75	5.32	1.20	0.00	0.00	0.75	0.00	1.68	2.20	68.62	0.00	85.40
Balsam poplar	94	0.00	0.00	0.00	0.00	1.33	0.00	2.33	0.00	0.00	2.32	0.00	0.40	0.73	64.75	77.19
Total		100.19	100.05	99.96	100.00	99.75	99.60	100.19	100.03	99.75	99.76	100.80	100.80	100.01	99.75	

Table 5.7. (continued)

b) Number of plots

Forest Type 1990		Forest Type 1977														Total
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	
Jack pine	1	39	0	0	0	0	0	0	0	1	0	0	3	0	1	44
Red pine	2	1	22	1	0	2	0	0	0	0	0	0	3	1	0	30
White pine	3	0	0	9	0	0	0	0	0	0	0	0	1	1	0	11
Black spruce	12	0	0	0	71	2	0	0	1	0	0	0	1	0	0	75
Balsam fir	13	0	0	0	0	47	2	0	2	0	2	2	12	2	2	71
N. white cedar	14	0	0	0	2	3	80	0	1	0	0	0	0	3	0	89
Tamarack	15	0	0	0	3	0	0	40	0	0	0	0	1	0	0	44
White spruce	16	0	0	0	1	0	0	0	3	0	0	0	1	0	0	5
Oak-hickory	50	0	1	0	0	0	0	0	0	115	3	9	18	4	0	150
Elm-ash-soft maple	70	0	0	0	0	2	0	2	0	1	71	20	12	7	6	121
Maple-basswood	80	0	0	2	0	2	0	0	0	9	7	138	18	3	1	180
Aspen	91	3	0	0	0	12	0	0	0	6	1	8	421	21	10	482
Paper birch	92	0	0	0	3	4	1	0	0	1	0	3	11	94	0	117
Balsam poplar	94	0	0	0	0	1	0	1	0	0	2	0	2	1	37	44
Total		43	23	12	80	75	83	43	7	133	86	180	504	137	57	1,463

Table 5.8. Type change matrix for undisturbed plots, 1977-90, for all FIA covertypes and all stand ages—no differentiation made for significance of aspen component. The plots used in creating the following matrix met the following conditions:

1. Remeasured, ground visited plots (sample kinds 2 or 6)
2. Commercial forest (ground land use at each cycle less than 30)
3. Not disturbed by harvesting (disturbance code equal to 0)
4. Naturally regenerated stands (stand origin less than 2)
5. No restriction on stand age

a) Percent of 1977 forest type plots

		Forest Type 1977														
Forest Type 1990		1	2	3	12	13	14	15	16	50	70	80	91	92	94	Percent of 1977 Total
Jack pine	1	84.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	0.00	0.00	0.56	0.61	1.06	98.21
Red pine	2	1.79	95.91	7.69	0.00	1.78	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.61	0.00	133.33
White pine	3	0.00	0.00	69.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.61	0.00	84.62
Black spruce	12	0.00	0.00	0.00	87.12	1.78	0.00	1.56	12.50	0.00	0.00	0.00	0.42	0.00	2.12	94.73
Balsam fir	13	0.00	0.00	7.69	1.76	67.64	4.36	0.00	25.00	0.00	2.55	0.98	2.24	3.05	2.12	100.89
N. white cedar	14	0.00	0.00	0.00	1.76	3.56	93.74	0.00	12.50	0.00	0.85	0.00	0.00	1.83	0.00	105.43
Tamarack	15	0.00	0.00	0.00	5.28	0.00	1.09	93.60	0.00	0.00	0.00	0.00	0.14	0.61	0.00	107.81
White spruce	16	0.00	0.00	0.00	0.88	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.14	0.00	0.00	75.00
Oak-hickory	50	1.79	4.17	0.00	0.00	0.00	0.00	0.00	0.00	80.60	2.55	4.90	3.08	2.44	0.00	106.21
Elm-ash-soft maple	70	0.00	0.00	0.00	0.00	2.67	0.00	3.12	0.00	0.62	84.15	11.76	2.66	5.49	11.66	142.37
Maple-basswood	80	1.79	0.00	15.38	0.00	1.78	0.00	0.00	0.00	11.16	5.95	74.97	3.92	4.88	3.18	108.82
Aspen	91	10.74	0.00	0.00	0.88	15.13	0.00	0.00	0.00	5.58	2.55	5.88	85.96	18.30	20.14	97.00
Paper birch	92	0.00	0.00	0.00	2.64	3.56	1.09	0.00	0.00	0.62	0.00	1.47	2.24	61.61	0.00	78.18
Balsam poplar	94	0.00	0.00	0.00	0.00	1.78	0.00	1.56	0.00	0.00	1.70	0.00	0.56	0.61	59.36	70.21
Total		100.24	100.08	99.97	100.32	99.68	100.28	99.84	100.00	99.82	100.30	99.96	102.62	100.65	99.64	

Table 5.8. (continued)

b) Number of plots

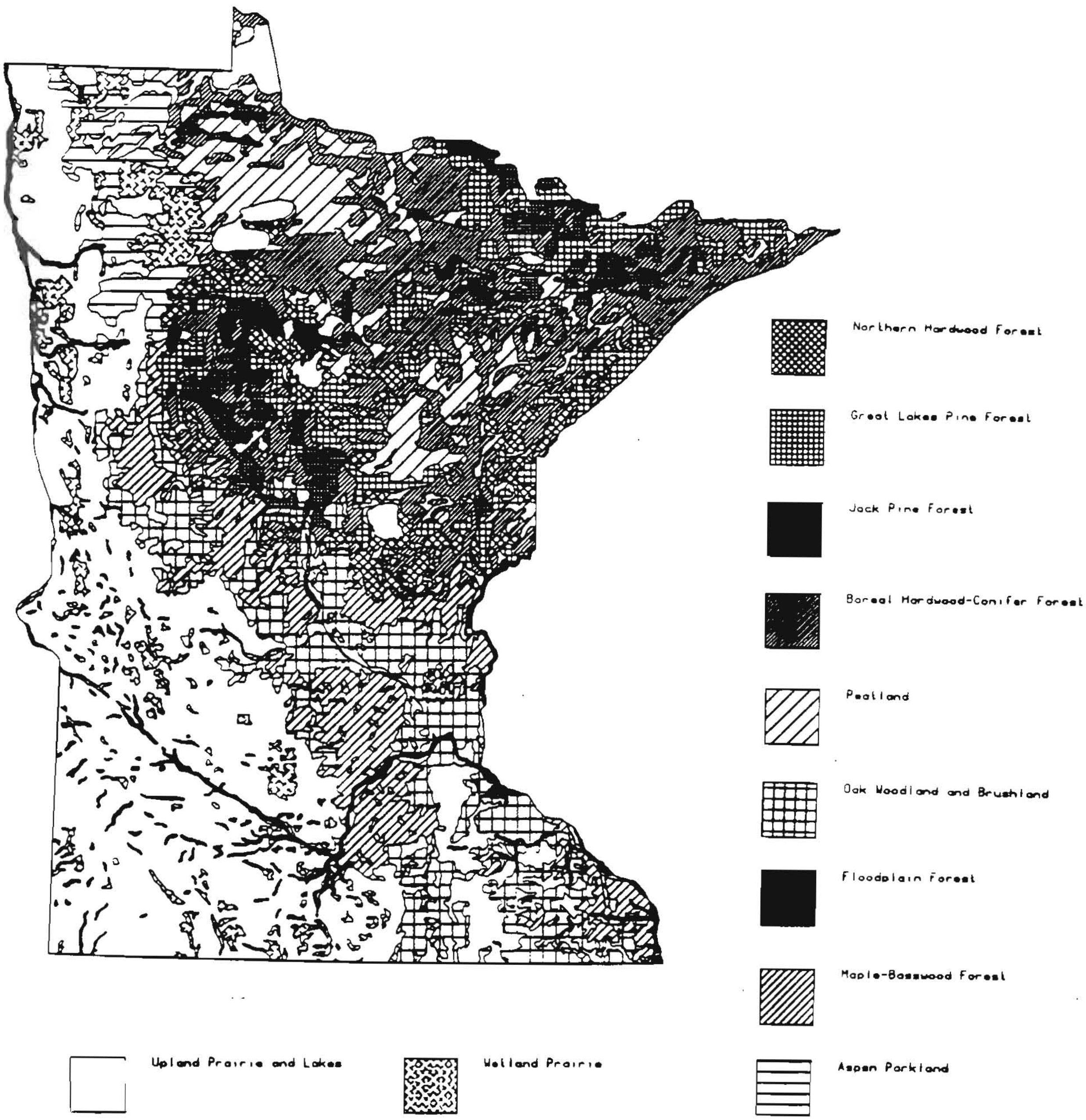
Forest Type 1990		Forest Type 1977														Total
		1	2	3	12	13	14	15	16	50	70	80	91	92	94	
Jack pine	1	47	0	0	0	0	0	0	0	2	0	0	4	1	1	55
Red pine	2	1	23	1	0	2	0	0	0	0	0	0	4	1	0	32
White pine	3	0	0	9	0	0	0	0	0	0	0	0	1	1	0	11
Black spruce	12	0	0	0	99	2	0	1	1	0	0	0	3	0	2	108
Balsam fir	13	0	0	1	2	76	4	0	2	0	3	2	16	5	2	113
N. white cedar	14	0	0	0	2	4	86	0	1	0	1	0	0	3	0	97
Tamarack	15	0	0	0	6	0	1	60	0	0	0	0	1	1	0	69
White spruce	16	0	0	0	1	0	0	0	4	0	0	0	1	0	0	6
Oak-hickory	50	1	1	0	0	0	0	0	0	130	3	10	22	4	0	171
Elm-ash-soft maple	70	0	0	0	0	3	0	2	0	1	99	24	19	9	11	168
Maple-basswood	80	1	0	2	0	2	0	0	0	18	7	153	28	8	3	222
Aspen	91	6	0	0	1	17	0	0	0	9	3	12	614	30	19	711
Paper birch	92	0	0	0	3	4	1	0	0	1	0	3	16	101	0	129
Balsam poplar	94	0	0	0	0	2	0	1	0	0	2	0	4	1	56	66
Total		56	24	13	114	112	92	64	8	161	118	204	733	165	94	1,958

Table 5.9. Forest type acreage in Minnesota, presettlement to 1990 (thousands of acres).

Forest Type	Presettlement	1936	1953	1962	1977	1990
Pine	5,800.0					
Jack pine		1,266.0	986.0	872.0	504.4	447.5
Red pine		170.5	166.0	280.6	246.9	301.6
White pine		233.7	125.0	132.0	65.6	63.2
Coniferous swamp	6,100.0					
Black spruce		1,529.8	1,169.0	1,152.3	1,041.8	1,322.1
Tamarack		656.9	482.0	470.5	465.4	705.1
Spruce-fir	6,300.0					
Balsam fir		1,088.3	1,233.0	907.9	859.1	734.3
Northern white cedar		380.6	284.0	333.7	498.6	680.5
White spruce		[a]	[a]	57.3	79.2	93.8
Maple-basswood	8,400.0					
Maple-basswood		893.6	846.0	1,004.3	1,283.9	1,396.7
Oak-hickory		476.0	1,182.0	1,022.7	893.9	1,190.4
Scrub oak		542.4	[b]	[b]	[b]	[b]
Bottomland hardwoods	2,000.0					
Elm-ash-soft maple		616.1	1,145.0	1,286.4	738.1	1,291.5
Aspen and scrub oak	2,900.0					
Aspen		6,309.8	5,997.0	5,399.8	5,302.3	5,115.4
Scrub aspen		565.5	[c]	[c]	[c]	[c]
Paper birch		[c]	[c]	795.1	997.6	834.7
Balsam poplar		[c]	[c]	447.5	548.9	427.7
Nonstocked		3,486.2	4,483.0	1,249.7	169.4	168.9
Subtotal	31,500.0	18,215.4	18,098.0	15,411.8	13,695.1	14,773.4
Reserved		400.0	428.0	470.1	1,178.6	1,113.1
Unproductive		1,000.0[d]	818.0	2,563.1	1,835.5	828.3
Total	31,500.0	19,615.4	19,344.0	18,445.0	16,709.2	16,714.8

Sources: 1990=Kingsley 1991, Murray 1991, Leatherberry 1991, Roussopoulous 1992; 1997=Jakes 1977; 1962=Stone 1966, Stone and Vasilevski 1963; 1953= Cunningham et al. 1958; 1936 and presettlement=Cunningham and Moser 1938. Presettlement values are for all forest, 1936—90 values show breakdown by covertypes for timberland and totals for reserved and unproductive.

[a] Included with other spruce fir types.
[b] Included with oak hickory.
[c] Included with aspen.
[d] Estimated.



Source: Adapted from *The Original Vegetation of Minnesota*, a map compiled in 1930 by F. K. Marschner from the U.S. General Land Office Survey Notes and published in 1974 under the direction of M. L. Heinselman of the U.S. Forest Service. Published (in color) by the Minnesota Department of Natural Resources 1988.

Figure 5.12. Vegetation of Minnesota at the time of the public land survey: 1847—1907.

The northeastern part of the state is least suited to agriculture in terms of topography and soils. Thus, it is not surprising to find that it still has 79 percent of the area in forest. Fragmentation by infiltration of nonforest land use is not a major problem here, but harvesting has affected the age class structure on a stand-by-stand basis. Stand sizes (see table 2.10) are typically larger here than in the southern part of the state. However, given that timber sales and harvesting practice in the north has tended, especially in recent decades, to follow stand boundaries, further fragmentation of stands is unlikely.

Harvesting may also have affected the pattern of inclusions of small patches of one type within another, but that is not clear from the FIA data. Unfortunately, the recognition and type mapping of such inclusions has varied by agency and over time. Conversely, type mapping in the state often involves lumping of patches in delineating stands, i.e., the forest cover is not very uniform.

The northern pine unit shows only 51 percent of the land base remaining in forest cover. This region, with its favorable topography, has been subject to much agricultural development and more recently considerable nonfarm housing development.[2] However, this area also has large areas of pioneer species covertypes in large stands due in part to the frequency of past fires.

The central hardwoods unit has been heavily fragmented, first by agriculture, and more recently by urban and rural nonfarm development. It was probably never more than two-thirds forested; currently it is 19 percent forest cover. This area also exhibits a pattern of forest regrowth following the decline or abandonment of agriculture near developing urban centers. That is a common historical pattern in the eastern U.S.[3] The prairie unit and ecoregions show an overall increase in forest area since 1977 to 3.4 percent, but the increase is still short of the 4.7 percent forest in 1962. It is these two units that have also had extensive wetland drainage, which in turn allowed clearing of adjacent forest. These units show the classic fragmentation problem—woodlands reduced in size and number, and greater distances between them. It is difficult to tell yet whether recent gains are due more to conservation programs or just economic conditions in agriculture. The FIA data also show smaller average stand size for most covertypes in this region (see table 2.10).

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[2]Nonfarm housing starts in Crow Wing County alone and centered on the Brainerd area have exceeded 1,000 per year for the last three years. Personal communication from George Orring, Project Manager, Statewide Land Use/Cover Update Project, International Coalition for Land and Water Stewardship, Moorhead, MN, April 1992.

[3]Personal communication from Philip M. Raup, Professor Emeritus, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul. August 15, 1991.

In an attempt to clarify patterns, the area around the 30 sample FIA plot locations described in section 4.2 (item 10) were examined to assess landscape features they contained. A summary of that data is shown in table 5.10. Three sample maps are also shown in figure 5.13 to illustrate the change in pattern from northeast to southwest. In addition, the landscapes were classified by predominant land use. Twenty were classified as forested land use versus ten categorized as agricultural, and twelve of the former and three of the latter contained clearcuts.

While the sample size is too small for rigorous statistical analysis (categorical data analysis would be most instructive) the tabulated results (see table 5.11) are instructive, especially with respect to the general magnitude of landscape averages and recent clearcutting practices relating to cut size, use of visual buffers or corridors, shape of clearcuts, slash disposal and proximity of cuts to water. Partial or selection harvests that were not considered in the analyses as areas harvested using these practices are generally not very evident from aerial photography.

While the mapping concentrated on harvests during the past ten years, it was obvious that virtually all of the sample landscapes had been harvested at some time in the last century. Related to that, the landscapes were checked for the presence of stands of large trees, but no such size classes were evident in this sample.

It was also evident that the major type of water of concern for harvesting was wetland (marsh, lowland grass and lowland brush types in table 5.11). Streams and larger bodies of water, particularly in proximity to harvesting, were infrequent compared to wetlands. As is well-known, wetlands are common in the forest areas in the state.

Regarding roads, forested landscapes had fewer roads per square mile than agricultural areas, but the presence of recent clearcutting seemed to coincide with higher road densities compared to forested landscapes without clearcuts. Additionally, there was a significant positive correlation between road density and the number of polygons in the landscape.

The analysis suggests this type of landscape characterization might be useful in monitoring; however, the sample would have to be much larger to be definitive.

Table 5.10. Land use and forest conditions for maps of 30 FIA sample plot locations, 1990.

Land use/Forest type	No. of polygons	Areas (acres)		
		Minimum	Maximum	Mean
Jack pine	2	1.6	3.4	2.5
Red pine	24	1.3	53.9	8.2
White pine	2	3.8	9.7	6.8
Black spruce	24	0.7	50.1	19.0
Black spruce (unproductive)	5	5.4	298.1	89.5
Balsam fir	4	7.8	18.0	12.9
N. white cedar	9	3.2	92.1	44.3
Tamarack	26	0.8	145.5	17.4
White spruce	1	3.7	3.7	3.7
Spruce-fir	19	2.3	233.6	24.8
Oak-hickory	32	1.0	38.7	10.4
Elm-ash-cottonwood	30	1.5	75.2	13.0
Maple-basswood	28	0.8	303.8	40.3
Aspen	118	1.1	123.7	15.8
Aspen-birch	18	1.7	202.8	34.0
Paper birch	10	2.3	50.0	20.2
Balsam poplar	0	0.0	0.0	0.0
Cutover/regeneration	1	5.1	5.1	5.1
Less than 10% stocked				
Lowland grass	16	1.1	110.0	17.0
Upland grass	21	0.8	22.1	6.3
Lowland brush	66	1.3	182.5	23.9
Upland brush	6	2.0	15.2	5.7
Subtotal (9,050.8 acres)	462	0.8	303.8	19.6
Other land use/covertype				
Agriculture	76	1.3	239.7	36.7
Industrial	3	7.3	64.8	28.7
Urban	42	1.3	11.9	3.5
Roads	19	4.0	21.4	8.6
Rock outcrop	1	3.0	3.0	3.0
Permanent water	24	1.6	211.1	33.4
Nonpermanent water	7	1.3	3.9	2.1
Marsh	30	1.2	483.1	33.8
Muskeg	1	3.2	3.2	3.2
Subtotal (5,022.1 acres)	203	24.1	1,042.0	24.7
Unknown	35			

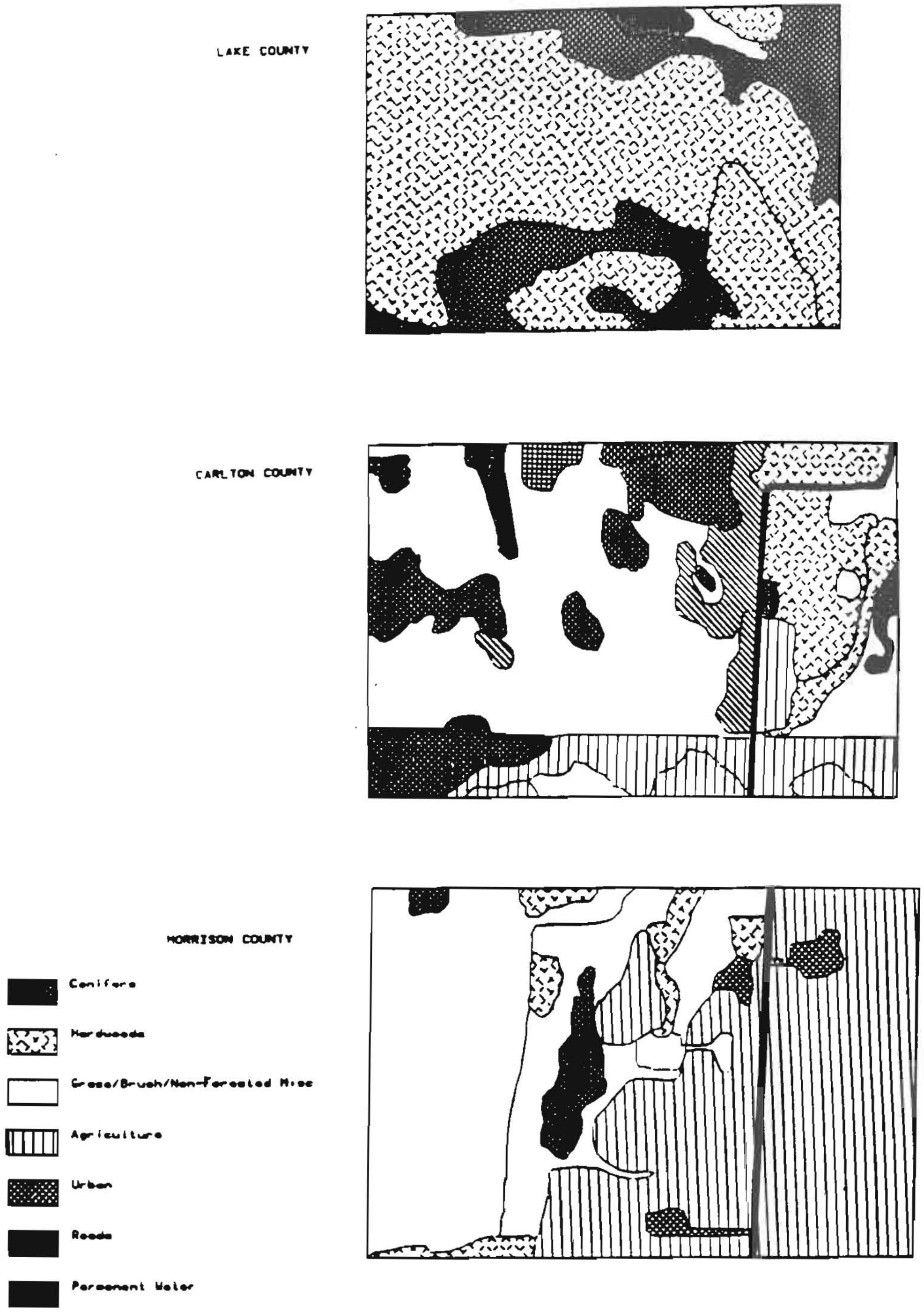


Figure 5.13. Example landscape patterns from mapped sample of FIA plot locations, 1991.

Table 5.11. Comparison of landscape features for areas with and without recent (<10 years old) clearcuts and forest versus agricultural land use from areas around 30 sample FIA plot locations.

	Landscape		Landscape	
Variable	with clearcuts (n=15)	without clearcuts (n=15)	Forest n=20	Agriculture (n=10)
Mean number of owners per sq. mi.	8.4	13.2	7.3	18.0
Mean road miles per sq. mi.	1.7	1.3	1.3	1.9
Mean number of polygons* per sq. mi.	36.6	27.8	30.7	35.9
Mean number of forest polygons per sq. mi.	21.1	13.2	19.0	13.8
Mean largest forest polygon	86	87	112	35
Total number of clearcuts per sq. mi.	2.3		1.5	.6
Number of recent clearcuts: ≤ 10 ac	17 (68)		15 (71)	2 (50)
Number of recent clearcuts: 11-20 ac	3 (12)		2 (10)	1 (25)
Number of recent clearcuts: 21-40 ac	1 (4)		0 (0)	1 (25)
Number of recent clearcuts: >40 ac	4 (16)		4 (19)	
Number of landscapes with clearcuts	15 (100)		12 (60)	3 (30)
Number of landscapes with buffers or corridors between residual stands	7 (47)		7 (35)	1 (25)
Number of clearcuts with buffers or corridors between residual stands	13 (52)		13 (62)	0 (0)
Number of clearcuts with shape being: regular	14 (56)		12 (57)	2 (50)
Number of clearcuts with shape being: irregular	11 (44)		9 (43)	2 (50)
Number of clearcuts with slash: scattered	18 (72)		14 (67)	4 (100)
Number of clearcuts with slash: piled	1 (4)		1 (5)	0 (0)
Number of clearcuts with slash: piled/rows	2 (8)		2 (9)	0 (0)
Number of clearcuts with slash: burned	4 (16)		4 (19)	0 (0)
Mean distance between last two clearcuts on a landscape: (ft)	825 (range 0-3300)		895	260
Mean distance (interval) between last two clearcuts on a landscape: (years)	4		4	1
Number of clearcuts close to water: < 10 ft	4 (16)		3 (14)	1 (25)
Number of clearcuts close to water: 11-100 ft	0 (0)		0 (0)	0 (0)
Number of clearcuts close to water: 101-300 ft	2 (8)		2 (10)	0 (0)

*A polygon is any mapped unit. Polygons range from a general land use (agriculture) to a forest stand.

5.10 Summary of Key Results and Impacts of First Run Analyses

Results for the first model runs indicated that the overall study approach modelling the timber harvesting scenarios was feasible and produced realistic depictions of possible scenarios. Specific results were:

1. Based on assumptions including minimal constraints on harvesting practices, all three levels of harvesting are feasible over the planning period. However, this conclusion does not incorporate all of the biological/ecological concerns which were dealt with in the second model runs, or management intensification that could increase yields.

2. Achieving these harvest levels clearly impacts a large number of stands across all ecoregions. Still, substantial acreage is not disturbed by harvesting.

3. The greatest harvesting pressure will occur in the early part of next century. The number of stands harvested will diminish towards the end of the planning period, reflecting assumed management and harvesting of regenerated stands with improved stocking.

4. Prices for products are dependent on location and harvest levels.

5. The aspen covertype will experience the heaviest level of cutting and is projected to account for between 40 percent (high scenario) and 60 percent (base scenario) of the total area harvested.

6. The average age of aspen stands harvested in the northern region drops significantly in the fifth period of all three scenarios, as the regenerated stands from the first period reach the minimum rotation age specified in the model (40 years).

7. Harvesting modelled in the southern region for the high scenario would affect most of the oak-hickory stands in that part of the state. The high scenario imposes a more intensive program of thinning and calls for cutting on all but 11,000 acres over the 50-year study period. The base scenario envisions 217,000 acres left uncut. In the long-term, the high demand scenario would likely be nonsustainable in these covertypes in this region.

8. A high proportion of the modelled increases in demand are projected to come from private property, particularly for the medium and high scenarios in the northern region.

9. The spruce and balsam fir covertypes would be subjected to much higher levels of cutting under the high scenario compared to the base scenario. Acres never cut in these covertypes under the high scenario are one-tenth those left under the base scenario.

10. The high demand scenario cutting levels for some of the covertypes, e.g., black spruce and the northern hardwoods, led to age-class distributions that suggest these high cutting levels could not be sustained in the long-term. Initial model runs assumed 40-year rotations were feasible for black spruce. Yield estimates associated with such short rotations were also likely overestimated. Rotation lengths were forced to be longer in second run analysis.

11. Analysis of harvest volumes by owner and period for the three scenarios indicate that private ownerships will have to play an increasing role in timber supply, for at least the coming four decades. The role of these ownerships will increase as the level of demand increases. These ownerships would also have the greatest opportunity to intensify management to mitigate timber supply shortfalls elsewhere.

12. The aspen covertype plays an important role in all demand scenarios. Other covertypes such as the northern hardwoods and other softwoods also play an increasing role in the medium and high scenarios. Correspondingly, the acreage never harvested over the 50-year simulation period decreases dramatically for the medium, but especially for the high demand scenario. Proportionally greater increases in other covertypes will be needed to meet the higher demand scenarios. Development of facilities which can process species that are currently unmerchantable will increase the level of utilization in mixed species stands. This will also augment supplies of aspen and other species by making logging of mixed species stands commercially viable.

13. Overall tree species composition on timberlands is moderately affected by harvesting. This assumes most of the impact is due to changing age class distributions and not a reduction or elimination of covertypes. Individual cover types can vary considerably in age related species composition, but the overall effect is small because of the high proportion of mixed species stands.

14. Covertype change trends are still strongly affected by the species and age class structure resulting from the logging and land clearing of the late 1800s and early part of the century. In general, harvesting favors retention of pioneer species such as aspen while long rotations favor more tolerant species such as maple. The long-term trends

suggest a slight decline in aspen acreage and an increase in the maple-basswood covertype. Lowland conifers in general appear to maintain their acreage. Perhaps most significant is that management or lack of it will largely determine the future covertype acreage and age class structure of the forest. Many other characteristics or benefits of forests will then follow from that.

15. Forest and timberland area will likely shrink in the north and expand in central and southern Minnesota over the period 1990–2040. However, constraints on harvesting will likely further reduce the availability of timberland in the north. In the south, the increase in forest area may have more impact than the mitigations.

5.11 Sustained Yield Considerations

In modelling the three timber harvesting scenarios, the overriding objective was to estimate, for each scenario, shadow prices for each product-market-period combination. Based on these shadow prices, total yields from the optimal management alternative for each analysis area are very close to the volumes that correspond with each harvest level scenario. For each analysis area, the optimal management alternative is the one that maximizes the net present worth estimate of the stand, based on the shadow prices and an infinite planning horizon.

The focus of the analysis was on timber harvest levels for the first fifty years—1990 to 2040. Shadow prices for periods beyond the first fifty years were assumed to equal the shadow prices for the last 10-year period. With this assumption, there is no tendency to liquidate the forest in the last period. Harvesting decisions for the last period are based on maximizing all future net returns, under the assumption of constant future prices.

Under the assumption of constant future prices for periods beyond 2040, harvests for each stand in periods beyond 2040 would follow a cycle of optimal economic rotations. No consideration was given to coordinating harvests for periods beyond 2040 to achieve a steady flow of timber statewide. Harvest levels for periods beyond the first 50-year period would probably be irregular under the model assumptions. Furthermore, there is no firm guarantee that the harvest levels maintained over the first fifty years could be sustained indefinitely.

There are at least three reasons for concern about using results of the 50-year analyses as indicators of long-term sustained yields. First, although fifty years is relatively long with respect to financial considerations, it is not even one full rotation for some Minnesota forest types. To examine long-term sustainability, it is necessary to consider a planning horizon of at least one rotation length and preferably longer.

The second reason to consider a longer planning horizon stems from the impact of any *deficit* or *surplus* of existing forest inventory. Forest managers often address sustainability concerns through the concept of forest regulation. A fully-regulated forest is simply a forest where equal forest area is in each age class, and the forest is maintained over time by harvesting and regenerating the oldest age class each period. A fully-regulated forest thus maintains a constant inventory and a constant harvest level over time. In creating a regulated forest, one may have the opportunity of implementing higher than average harvest levels by liquidating surplus inventories during the early stages of this transition.

The third reason is the impact that changes in management practices or plant materials (genetic improvements) can have on sustainability concerns, and the relatively long time lag involved before such improvements are realized. Certainly some will argue that future yields can be increased substantially above current yields just through better harvesting practices aimed to ensure that forest regeneration occurs successfully across the entire site. Many of these practices have already been implemented, especially on the larger ownerships, yet benefits are not fully realized without considering a longer time horizon.

Identifying the ideal future *regulated* state is difficult, if not impossible. Many factors are involved. Two of the most important factors are the intensity of forest management and the size of the forest land base from which timber production is feasible. Forest management decisions can obviously influence both of these factors, and thus the sustainable harvest level is one that can be controlled to a fair degree.

An examination of the projected age class distributions of major forest types at the end of the simulation period gives some indications about the potential of the forest to sustain harvest levels over time (table 8.2, appendix 8). Several factors need to be remembered when making such comparisons. First, forest management needs to be considered as a whole. Considering each forest type individually is a simplification. Acres in each forest type will shift over time as part of natural succession. Intervention to protect areas from fires has an influence on future forest type mixes, especially when viewed in the long-run. It is desirable to maintain a broad mix of forest types over time, but the composition of that mix is a subject for debate. It is very simplistic to assume that the objective should be to maintain the mix of forest types in the same proportion as exhibited by the recent statewide inventory.

When considering the age distribution of forest types, it is important to realize that not all stands in the forest type should necessarily be managed based on the same rotation length. Even from a purely financial perspective, optimal rotations for a given forest type can vary depending on the quality, accessibility and location of the site with respect to market. Some stands are located so that it is uneconomical to manage them for timber production unless future timber prices rise substantially. It is an extreme simplification to assume that the age distribution of each forest type should resemble that of a fully-regulated forest based on a single rotation age.

The age class distributions in 2040 for the different forest types exhibit several similarities. The occurrence of bimodal distributions, with a surplus of very old stands, points to the existence of many marginal stands that were not needed to meet the harvest levels of both the base and medium scenarios. These surpluses varied substantially by covertype and were generally small for the high scenario. The higher shadow prices for the high scenario reflect the need to operate at a price level that will make most stands economically feasible to harvest.

The following discusses the age class distribution of the various forest covertypes at the end of the 50-year study period, based on the results of the first model runs.

Jack Pine

The year 2040 age class distributions for jack pine indicate that the jack pine forest type was not harvested heavily for either the base or medium scenario. This is reflected in the low marginal cost estimates for pine in the base and medium scenarios. In fact, prices are so low for the last period that it would be undesirable to harvest a jack pine stand in this period, unless it also contained volumes of more valuable products. The situation is different for the high scenario, as larger acreages in the younger age classes in 2040 reflect much higher harvest levels for jack pine in all but the first period. From a simplified regulation standpoint, the high scenario is generally on track if regulation is based on a 60-year rotation, and all jack pine acres remain in the jack pine forest type and are managed for timber production. However, most of the acres remaining in the older age classes in 2040 are quite old and would have higher management costs than stands harvested during the planning horizon.

Red Pine

The final red pine age distributions in 2040 were very similar for all three scenarios. This can be explained by the fact that red pine sawlog prices were assumed to be fixed at a constant level for all three scenarios. The 40- to 50-year age class in 2040 contains a relatively large proportion of the acres. This is because the 1990 age distribution of red pine had a substantial number of acres that were already financially mature and harvested in the first period and then fell in the 40- to 50-year age class in 2040. The relatively few acres in 2040 over age 50 suggest some temporary supply concerns for periods shortly after 2040, unless 50-year rotations are used.

White Pine
Results for white pine are very similar to red pine, as 2040 age class distributions are similar for all three scenarios and reflect the harvesting of financially overmature stands in early periods. The final age distribution for white pine is even more skewed than that for red pine, as there are relatively few acres of young white pine in the 1990 inventory.

Black Spruce
Age distributions for 2040 for the base and medium scenarios show many acres in the older age classes. This suggests potential for increasing harvest levels for this forest type above the levels for the medium scenario. The 2040 age distribution resembles a fully-regulated forest but based on only a 40-year rotation. However, it is likely that natural regeneration and yields were overestimated for the initial runs. Rotations of 60 to 90 years are probably more appropriate.

Balsam Fir
Results for balsam fir are very similar to black spruce, showing a substantial number of acres not harvested for the base and medium scenarios and near-regulated ending conditions for the high scenario based on a 40-year rotation. Future work will need to examine the feasibility of 40-year rotations for balsam fir, and the expected yield. Based on the assumed yields and constant product prices, this was the optimal economic rotation.

Northern White-Cedar
Very few acres of this forest type were harvested, as northern white cedar was not considered to be a commercial covertype. Thus, harvested cedar came from harvest of other types where it was a minor species. Most acres simply increased in age by 50 years.

Tamarack
There was little harvest of this forest type in the base and medium scenarios. Silvicultural guidelines suggest a 50-year rotation. For the high scenario a substantial number of acres were cut in the last two periods. These acreages are approximately equal to the area that would be cut for a fully-regulated forest, based on a 50-year rotation, assuming all acres are available for timber production.

White Spruce
This forest type covers a relatively small area—less than 1 percent of the total area analyzed. Of this area, approximately 94 percent was harvested

over the planning horizon for the high scenario, 78 percent for the medium scenario and 60 percent for the base scenario.

Oak-Hickory
The age class distribution for 1990 indicates that few acres are present in the younger age classes. The age class distribution for oak in southern Minnesota is of real concern, as harvest levels in the south will be difficult to sustain.

Elm-Ash-Soft Maple and Maple-Basswood
For all three scenarios, marginal cost estimates for northern hardwoods remain relatively low. This is reflected in the age class distributions with the large acres remaining in the older age classes, as only the *low-cost* stands are needed during the planning horizon. Only for the high scenario should there be any question of sustaining harvest levels indefinitely.

Aspen
Problems with aspen supply involve short-term deficits (20 to 30 years) that would result from existing imbalances in the age class distribution for this covertype. Problems for periods beyond the end of the planning horizon are of less concern. For all three scenarios, substantial areas of aspen in the 40 to 50-year age class remain after the end of the planning horizon.

Paper Birch
The age class distributions for 2040 show a definite bimodal distribution for both the base and medium scenarios, reflecting the relatively low prices for hardwoods—many of the older stands were not economical to harvest at the low prices. For the second, third, and fourth periods of the high scenario, large acreages of the birch forest type were harvested. Fewer acres were harvested in the fifth period, as fewer acres of young birch stands were present in the initial inventory, and demand (prices) for hardwoods in the fifth period were not high enough to justify harvesting the older, more costly birch stands. From the age class distributions for the high scenario in 2040, it is unclear whether the high harvest levels could be sustained indefinitely, even if all acres were available for timber production.

Balsam Poplar
All three harvesting scenarios were very similar and reflect the situation for the aspen forest type. For all three scenarios, this forest type is close to being regulated, based on a 40-year rotation.

Conversion to Sustained Yield - Simulations with ACES Program
The visual inspection and interpretation of the age class distributions for individual covertypes by harvest scenarios provide an indication of long-term sustainability. However, this approach does not provide a precise analysis of long-term sustainable yields. To look more closely at this concern, the

ACES model (Rose 1991) was utilized to estimate allowable cuts based on long-term (200-year) management for each covertype, starting with the years 1990 and 2040 age class distributions resulting from each of the three harvesting scenarios.

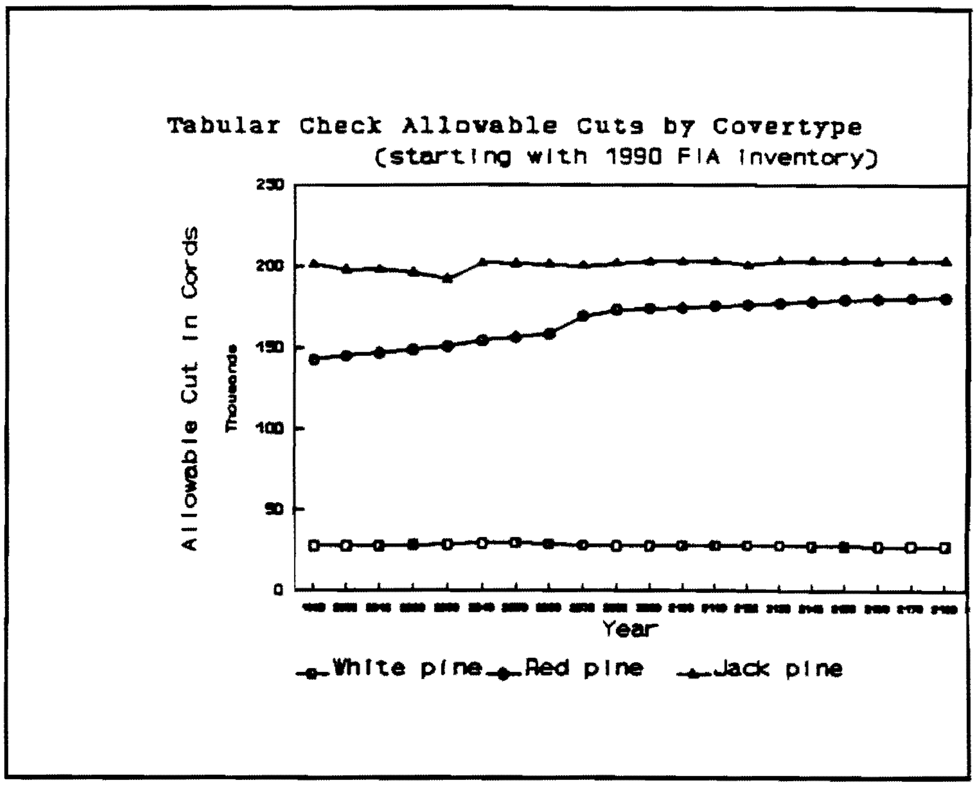
ACES is a microcomputer program that allows the user to calculate and simulate allowable cuts using one of six volume control methods or area control with adjustment for site productivity. Input data required to run the program include stand data describing current inventories of the covertype for which allowable cuts are to be calculated, and a number of run parameters. The ACES model output provides the periodic changes in growth, growing stock, and the allowable cut.

For all simulations, an allowable cut according to the Tabular Check method (Barnes 1951) was calculated at ten-year intervals for a 200-year simulation period. The Tabular Check method uses an iterative process to calculate an allowable cut that will liquidate total growing volumes of an inventory once over the specified rotation. Tabular Check, therefore, has certain similarities to area control, which would cut all acres once in one rotation. Tabular Check has the advantage of maintaining harvest volumes constant, while area control can result in substantial swings in volumes harvested. The rotation lengths recommended in the Silvicultural Systems Background Paper (Jaakko Pöyry Consulting, Inc. 1992) were utilized. Rotation lengths assumed had relatively minor impact on the long-term sustainable yield estimates, but sustainable harvest levels over the transition period were sensitive to the rotation length assumed. Generally, longer rotation lengths force a buildup of larger inventories as shorter rotations are not allowed during the transition period. The growth model within ACES was the GIP empirical yield model developed by Walters and Ek (1991). Background on this approach is given below, followed by some of the key findings.

Table 5.12 describes estimates of the allowable cut by covertype at the end of a 200-year simulation starting in 1990 and 2040. Figure 5.14 illustrates these results over the 200-year simulation period. It is not surprising that allowable cuts for all covertypes, after a long simulation period which allows conversion to more or less full regulation, are similar and independent of the starting age class distribution. For all covertypes, allowable cuts stabilized at the indicated levels after 50 to 100 years of simulation. There were, however, distinct differences in the allowable cut levels during the transition from unregulated conditions in 2040 to full regulation between the harvest scenarios. For example, the high harvest scenario for some covertypes required lower allowable cuts during the transition to full regulation. The total sustainable allowable cut across all scenarios is very similar, approximately 6 million cords per year. Given that figure, it is important to qualify it. Allowable cut simulation models like ACES make a number of assumptions that need to be taken into account when looking at such sustained yield. ACES ignores the economic feasibility of cutting stands, and schedules all stands for cutting depending on the their age-site priority for harvest. That is, it harvests the oldest stands and best sites first. Additionally, the GIP growth model (Walters and Ek 1991) used in the simulation is a very conservative growth model. GIP uses curves of average yield with respect to age and site index to approximate current stand growth rates. Being an empirical yield model, it reflects the recent (1990) stocking conditions in the state. Those conditions average less than full stocking and not the potential yields of carefully managed stands. Such managed yields could be twice as high as indicated by the GIP model. In ACES, stands after harvest grow at the same rate as the GIP model, i.e., like the average current Minnesota timber stand of that covertype. All of the following GIP-based cut figures should, therefore, be interpreted as conservative or lower bound estimates of allowable cuts, assuming all timberland is available for harvest. A similar sustained yield analysis using the GROW model might present upper bounds for allowable cuts, and this is discussed below.

Table 5.12. Annual allowable cuts after full regulation determined from 200-year ACES model simulations based on 1990 and 2040 initial conditions.

	Harvest Scenario beginning in			
	1990	2040		
Covertype		Base	Medium	High
Jack Pine	203,431	204,132	202,116	203,166
Red Pine	180,834	179,375	178,718	178,041
White Pine	27,487	26,752	27,013	27,019
Black Spruce	277,127	282,529	282,131	279,217
Balsam Fir	297,370	315,970	311,626	312,411
N. White Cedar	169,981	174,483	173,443	173,694
Tamarack	113,432	101,098	116,296	114,219
White Spruce	30,410	30,473	30,533	30,162
Oak-Hickory	370,770	374,180	373,582	367,693
Elm-Ash-Soft Maple	343,146	347,180	345,909	341,344
Maple Birch	547,617	580,989	580,603	582,051
Aspen	2,798,747	2,774,748	2,764,607	2,770,013
Paper Birch	313,356	309,086	309,422	309,382
Balsam Poplar	233,587	235,151	234,660	235,421
Total	5,907,295	5,936,146	5,930,659	5,923,833



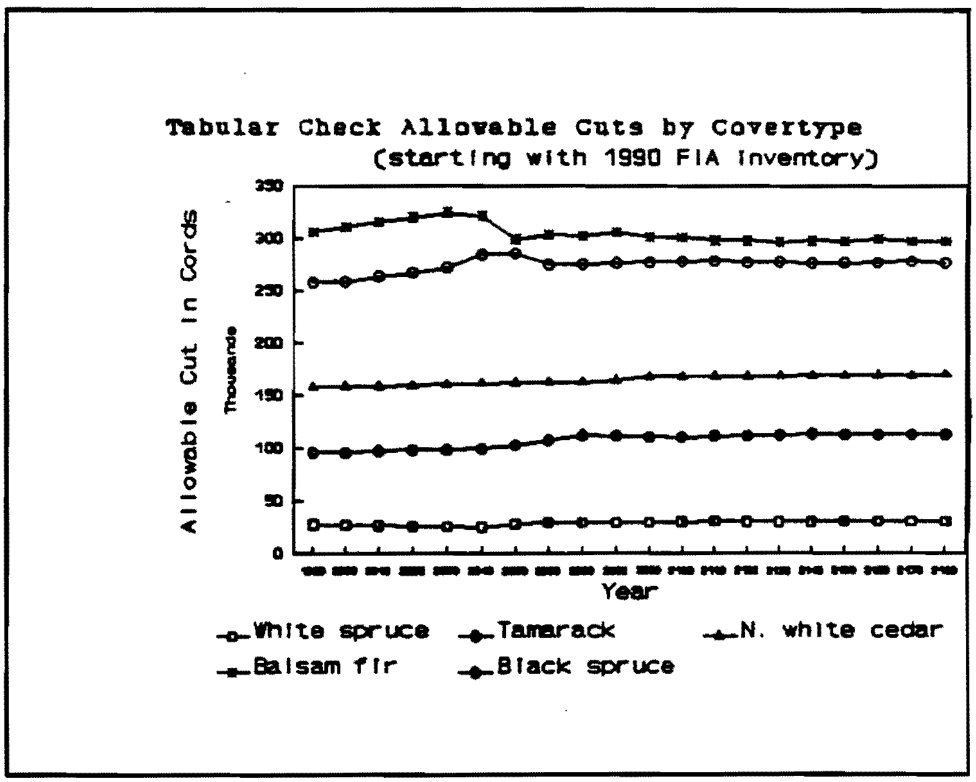
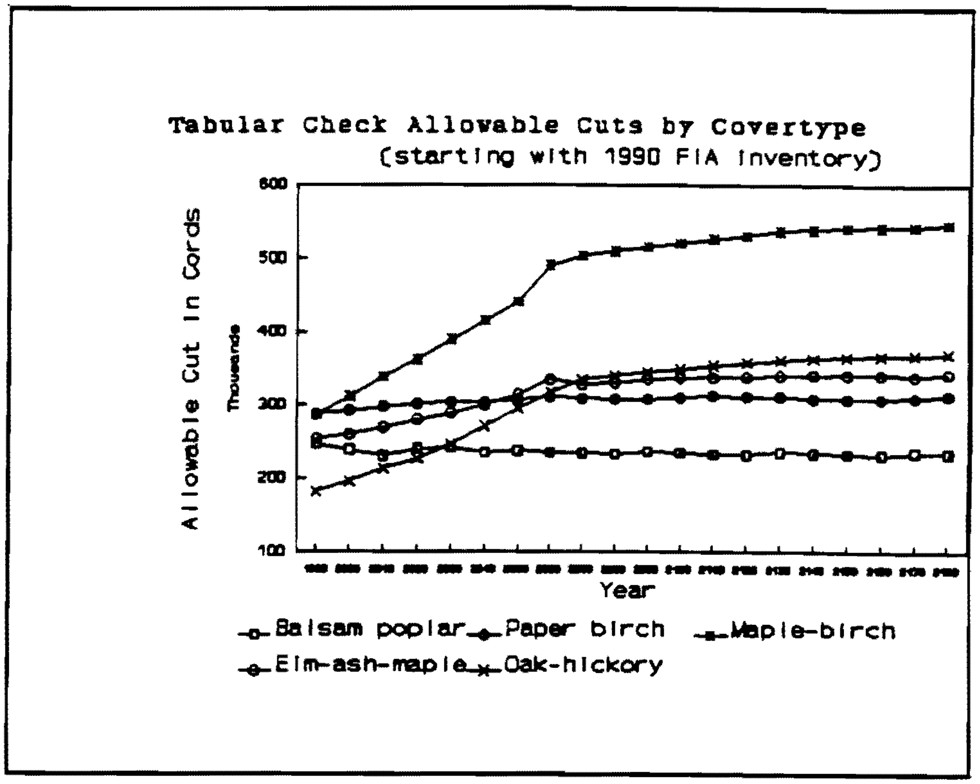


Figure 5.14. Tabular check allowable cuts by covertype based on a 200-year simulation starting with 1990 FIA inventory.



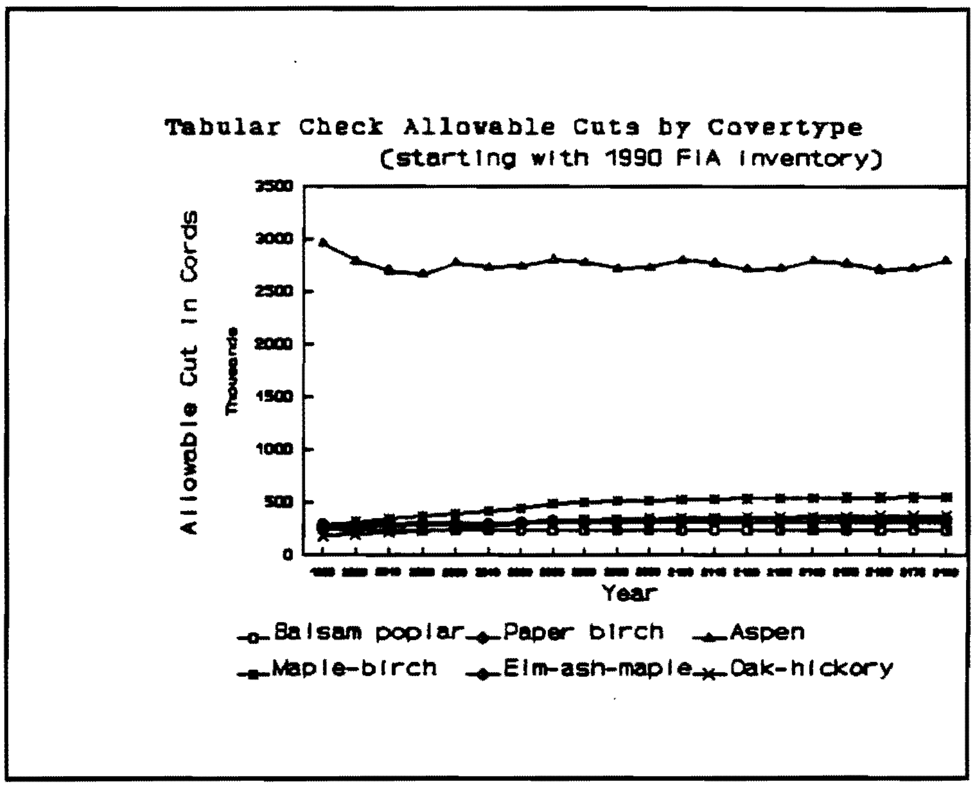


Figure 5.14. (continued)

Results of Allowable Cut Simulations Starting in 1990 and 2040
The annual allowable cut for jack pine could be maintained at approximately the long-run sustained yield (LRSY) level of 203,000 cords, starting in 1990 (see appendix 10). The high harvest scenario creates an inventory condition in 2040 that would require cutting at a lower level of 160,000 cords per year, with the potential to increase cutting to the LRSY level after about 20 years. The base and medium harvest scenarios underutilizes the resource, leading to potential cutting levels of 260,000 to 270,000 cords annually in 2040 followed by a slow decline to LRSY over 40 to 50 years.

In order to convert to a regulated forest with 90-year rotations, allowable cuts for red pine would need to be kept slightly below LRSY levels for at least 100 years. Annual cutting levels starting at 160,000 cords in 1990 could eventually increase to about 178,000 cords annually. All three harvest scenarios actually create an annual allowable cut above that from the 1990 based simulation.

The allowable cut for white pine could be maintained at approximately the LRSY level starting in 1990. The age distributions resulting in year 2040 for the three scenarios would require substantially lower harvest levels during the transition period, as most existing white pine stands were economical to harvest during the fifty-year planning horizon. Survey estimates for 1990 indicate that there are strikingly few acres of white pine less than age 30.

The annual allowable cut for black spruce could increase slowly from about 250,000 cords in 1990 to about 280,000 cords, after about 50 years. Harvest levels for both the base and medium harvest scenarios were below this potential yield as allowable cuts of about 50,000 cords above LRSY were estimated for these scenario results.

The annual allowable cut for balsam fir could increase initially from about 305,000 cords in 1990, to about 320,000 cords 50 years later. The cut will eventually stabilize at 300,000 cords. The high harvest scenario leaves an ending inventory in 2040 that could initially permit annual cutting of about 90,000 cords above LRSY, followed by steady declines to the LRSY level. The medium and base harvest scenarios could initially permit cutting levels of 490,000 and 660,000 cords, as harvest levels for these scenarios were well below the LRSY level.

The demand specified in all three harvest scenarios is below the potential yield from this covertype. This could initially permit annual harvest levels in 2040 of about 230,000 cords, followed by steady declines over about 100 years to the LRSY level of 200,000 cords annually.

The annual allowable cut for tamarack could be increased steadily from about 95,000 cords in 1990, to its LRSY level of about 115,000 cords. Demand under both the base and medium harvest scenarios is below the long LRSY level, which could permit initial annual harvest levels in 2040 of 160,000 cords. The high demand scenario creates a situation where initial cutting in 2040 could be at approximately the LRSY level.

Few acres are present in the white spruce cover type. Harvests for the base and medium harvest scenarios are cutting below the LRSY level as initial annual cutting levels of 48,000 and 60,000 cords, respectively, could be possible, followed by steady declines to the LRSY level of 30,000 cords. Demand under the high harvest scenario is approximately equal to the sustainable level.

The LRSY of oak-hickory of about 370,000 cords would be reached after more than 100 years of a slowly rising allowable cut. That rise would start from the 1990 level of about 190,000 cords annually. All three harvest scenarios will permit harvest levels in 2040 of about 300,000 to 320,000 cords annually, with steady increases over 60 to 80 years to the LRSY level of 370,000 cords.

The LRSY of elm-ash-maple of about 340,000 cords annually would be reached after more than 100 years of a slowly rising annual allowable cut, starting with a level of about 190,000 cords in 1990. This trend is very similar to the oak-hickory covertype. All three harvest scenarios would permit annual harvest levels in 2040 above LRSY levels with about 390,000, 420,000, and 440,000 cords for the high, medium, and base scenarios, respectively.

The LRSY of maple-basswood of about 550,000 cords annually would be reached after more than 100 years of a slowly rising allowable cut, starting with a level of about 300,000 cords annually in 1990. This trend is very similar to the oak-hickory and elm-ash-maple covertypes. All three harvest scenarios would permit harvest levels in 2040 above LRSY levels with about 600,000, 720,000, and 780,000 cords annually for the high, medium, and base scenarios, respectively.

The annual allowable cut for aspen in 1990 is close to the LRSY level of 2.8 million cords. All three demand scenarios will permit initial harvests above LRSY in 2040. For the high and medium scenarios, this level would be about 3 million cords; and for the base scenario, it would be about 3.4 million cords. In all three cases, allowable cuts would then decrease over about 20 to 30 years to the LRSY level.

The annual allowable cut for paper birch in 1990 is below the LRSY level of 310,000 cords. The annual allowable cuts can increase slowly from about 290,00 cords in 1990 over the next 40 years to the LRSY level. The medium and base harvest scenarios would permit harvest levels in 2040 above LRSY levels, with about 420,000 and 480,000 cords respectively, followed by steady declines over 60 to 70 years to the LRSY level. The high scenario would require cutting in 2040 at about 300,000 cords followed by a 30-year decline to 260,000 cords with a subsequent steady increase over 30 years to the LRSY level.

The annual allowable cut for balsam poplar in 1990 is approximately at the LRSY level of 235,000 cords. All three harvest scenarios would permit cutting very close to the LRSY level in 2040.

Again, these results need considerable interpretation, particularly in terms of the assumed rotation length and conversion period, i.e., from present to LRSY and timber availability. Markets by species have historically slowed or hindered the move to a regulated forest or balanced age class distribution. Such market conditions should be expected to continue, and thus the harvest levels during the conversion periods are only hypothetical plans that would need frequent adjustments in response to changes. Additionally, this analysis assumes all timberland is and would continue to be available for harvest.

Additional Estimates of Sustained Yield

The applications of ACES to estimate sustainable harvest levels were based on the GIP yield model, the recommended silvicultural rotation for each forest type, and the Tabular Check method for estimating the harvest level. To consider the impact of some of these assumptions on the LRSY estimates, LRSY were also addressed using a simple area-control approach. Area control has been the basic approach used by the MNDNR to estimate recommended harvests. Area control, as the name implies, focuses on the forest area cut each year. If the forest was a fully-regulated forest, then equal areas of the forest would be cut each year and the forest would remain in a steady state indefinitely. The size of the area cut would equal *1/r*th of the total area, where *r* is the rotation age for the regulated forest. When fully regulated, the volume cut each year would also always equal the volume in the oldest age class.

Area control was applied separately for each forest type by specified site quality class combinations. These combinations were used in modelling regeneration in the analyses done to consider the three harvesting scenarios over a 50-year horizon. As with the applications of the ACES model, all acres of timberland were considered available for timber production. Timber yield estimates were the same estimates used for regenerated stands in the 50-year analyses. Rather than assume an optimal rotation age for each forest type, separate estimates of yields from a regulated forest were determined for each forest type based on low, medium and high estimate of the rotation age for the regulated forest. For all three sets of estimates, acres in each forest type were assumed to be the 1990 distribution, as indicated by the recent statewide forest survey.

A fourth set of sustainable yield estimates was determined to examine the potential impact that intensified management could have on long-term sustained yields. For this set, the medium rotation ages were used, and approximately 9 percent of the forest was assumed to be converted to softwood plantations. The 1.2 million acres were assumed to be established in medium and high site red pine plantations. The 600,000 acres in each red pine site class were assumed to have come in 200,000 acre blocks each from medium and low site aspen, paper birch, and low site oak-hickory, maple-basswood, and the elm-ash-soft maple covertypes. Acres converted were those that were considered to have the greatest potential value increase from conversion.

Results are summarized in table 5.13. Appendix 9 shows more detailed outputs from these model runs. Results show estimates of specific breakdowns of product yields form each forest type. The rotation age assumptions have little impact on the total sustained yield estimates. Different rotations, however, significantly change the breakdown by product classes resulting from these harvest levels (see tables in appendix 9). In general, regulated forests based on the longer rotations would be more expensive to create, as these forests require the development and maintenance of larger forest inventories. The estimates of sustainable harvest levels with this approach are larger than those based on the ACES model. Most of the differences are due to the growth model used and not the modelling approach.

Table 5.13. Steady state allowable cut in cords by major covertypes.

Study Region	Steady State Annual Allowable Cut in Cords			
	Short Rotations	Medium Rotations	Long Rotations	Medium Rotations plus Conifer Plantations
North	7,240,348	7,389,961	7,393,615	8,029,487
South	565,600	556,773	529,399	556,773
Total	7,805,948	7,946,734	7,923,014	8,586,260

The sets of estimates that utilize more softwood plantations illustrate the ability to influence sustainable yield with increased management. Increased conifer planting programs on 10 percent of the forest acreage can increase allowable cuts by about 640,000 cords or 8 percent. Clearly, this would come at some cost, with the desirable level of management intensification difficult to estimate because of the long planning horizons involved. Other measures such as short-rotation hybrid poplar plantations could have even greater impact if carried out on a similar scale.

These are long-run steady state values that are achievable only after full regulation has been achieved on all acres of timberland. The ACES model was run additionally to make statements about the conversion period from initial unbalanced age class conditions to full regulation.

A key conclusion is that rotation age will not significantly affect long-run sustained yield levels, at least under the assumed extensive management systems that are being widely practiced in Minnesota. However, rotation lengths will influence harvest flows and financial returns during the transition period since longer rotations require carrying a larger forest inventory.

6
CURRENT AND PROJECTED IMPACTS OF SECOND RUNS

6.1
Harvesting Scenario Results

The second model runs introduced ownership constraints that limited availability of certain categories of timberlands. These constraints reflect current and prospective management procedures and policies applied by the major forest land managers. Examples of availability constraints include riparian lands and old growth forests. Other constraints include management on longer rotations for a proportion of stands in some ownerships and covertypes. In addition to existing constraints, the mitigation strategies developed in the course of the GEIS study were included. The second runs also applied the agency developed allowable harvest limits for the two national forests in Minnesota.

Results of the second runs showed important differences from the first runs in terms of the ability to achieve aspen harvest targets; acres cut and left unharvested; distribution of the harvest; age class distributions; and covertype acreage. The specifics of these findings are described under the following headings:

- feasibility of runs;
- marginal cost estimates for harvest level targets;
- breakdown of harvest volumes by product group;
- sources of timber by ownership;
- acres harvested and not harvested by covertype;
- spatial and temporal patterns of harvesting;
- changes in age class structure;
- size and composition of the forest land base;
- tree species mix;
- patterns of forest cover; and
- revised sustained yield analyses.

6.2
Feasibility of Runs

When the ownership constraints and mitigations were incorporated in the scheduling model, the base scenario was found to be infeasible as the aspen consumption level could not be met when using even unrealistically high aspen shadow prices. One reason for the infeasibility is the substantial shift of acres into categories considered unavailable for harvest, not immediately available because of longer rotation lengths and restrictions on clearcutting. Another major reason is likely due to the changes in the growth model used.

Review of the intermediate results of the revised runs also suggested that a contributing factor was related to the method in which the scheduling model values ending inventory.

Scheduling model usage must be concerned about any tendency to simply liquidate the forest inventory in the last planning period without regard for periods beyond the end of the planning horizon. Although only a fifty year planning horizon was assumed necessary for the GEIS, the DTRAN model uses an infinite planning horizon in developing schedules. Shadow prices for flows beyond the end of the planning horizon were estimated assuming that future shadow prices are a function of shadow price estimates for the planning horizon. For the GEIS applications, it was assumed that the shadow prices associated with the last planning period were the best estimate for shadow prices for all periods beyond the end of the planning horizon. Under this assumption and with the revised growth model estimates, the optimal rotation length for acres regenerated as aspen is fifty years for most stands if aspen prices, delivered to the market, are less than $60 per cord. In the earlier runs using the same valuation process, the optimal rotation length for aspen was forty years on most sites. For the earlier runs the model utilized the second rotation of *aspen* stands harvested in period 1 to satisfy much of the aspen harvest in period 5. For the revised model runs this generally does not occur as the method for valuing ending inventory suggests that it is more desirable to carry most of those acres into ending inventory.

An important question is whether or not it is desirable to temporarily manage at least some acres of aspen on a forty year rotation if such management would help overcome problems associated with an aspen age class imbalance. Clearly, that does not mean that all acres of aspen should follow a forty year rotation. But at least temporarily shortening the rotation of aspen stands to forty years might be desirable at the time when aspen is in relatively short supply. If aspen is to be managed on a fifty year rotation, the relative shortfall would occur in the fifth planning period. To help address the problem of potential shortfalls of aspen it was decided to lengthen the planning horizon from fifty to sixty years for runs of the scheduling model. This would allow the model to adjust shadow prices such that more acres could be temporarily managed on a forty year rotation while maintaining a fifty year rotation for most aspen acres entering *ending inventory* in year 60 of the planning horizon.

Sensitivity of Harvest to Price Levels
To help understand the production potential of the forest in terms of the costs, constraints and mitigations recognized in the model, a series of analyses were performed to examine the sensitivity of harvest levels to timber price levels when harvest levels are unconstrained. These analyses simply identify and tally, from the list of possible management options for each

inventory plot, the option that maximizes net returns from timber production based on the assumed timber prices over time. Those plots that represent buffer areas or are limited to extended rotations, are factors recognized in the analysis. To keep the analysis simple, relative value differences were not recognized between timber products.

Table 6.1 summarizes the volume harvested for various timber price levels assuming timber prices remain constant over time. Results of these analyses help clarify concerns about the age class imbalance of the existing inventory. For most product groups and all but the lowest price level, large volumes are financially mature in period 1 (1990–99) with large harvest volume declines after period 1. These drops appear most substantial for aspen but are also present for other product groups. With constant prices, harvest levels for the northern region are very low at the $25 per cord level and rise substantially with increasing prices until levelling off at the $40 per cord level (table 6.2). In contrast, even at the $25 per cord level the harvest levels are relatively high for the southern region. This is because transport costs were not considered in the southern region. For both regions, increases in prices near the highest price levels examined causes relatively little increase in the volume of timber harvested. In fact, the average annual harvest volume actually decreases for aspen for higher prices. This is potentially misleading as higher prices suggest shorter rotations for aspen. With the higher prices, more aspen acres are harvested and regenerated earlier making for older aspen acres in the inventory at the end of the planning horizon. For example, at the $35 per cord level, much of the aspen cover type is harvested in period 1 and then again in period 6. As prices are increased, rotation lengths for the second rotation are forty years on more acres until at the $75 price level most of the aspen acres harvested in period 1 are harvested on a 40-year rotation again in period 5.

The analyses summarized in table 6.2 add some insight to the timber supply situation, but it is important to realize that this analysis is very simplified and thus caution must be used in interpreting results. The average annual harvest volumes are not necessarily good estimates of sustainable harvest levels for longer periods. Because of the age class imbalance for aspen and its relatively short optimal economic rotation, a large proportion of the acres in the aspen forest type are harvested in period 1 and then again in period 5 or period 6; thus a large portion of acres are clearcut twice over the sixty years. This impacts not only the aspen volumes reported, but also the other product groups as well since the aspen type is large and contains large volumes of other species.

Table 6.1. Scheduled harvest of roundwood over time for various constant timber price levels (thousands of cords per year)

Product Group	Delivered Price ($/cd)[a]	Period						Average for all Years
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49	
Northern Region								
Aspen	25	273	639	514	595	581	608	535
	30	2,415	1,376	1,031	1,273	906	1,803	1,468
	35	4,178	1,250	1,163	1,369	537	5,313	2,303
	40	4,854	1,112	1,234	1,221	1,602	5,424	2,575
	50	5,247	1,027	1,189	1,200	2,113	5,524	2,717
	75	5,308	1,003	1,152	1,182	5,026	1,437	2,518
	100	5,324	992	1,135	1,183	5,129	1,325	2,516
Spruce-fir	25	22	59	81	95	165	138	94
	30	425	310	286	328	337	338	337
	35	1,085	419	370	414	286	742	552
	40	1,485	429	410	406	387	780	650
	50	1,752	407	390	420	415	819	702
	75	1,812	423	367	426	724	540	716
	100	1,834	419	361	426	737	543	720
Pine	25	36	126	156	195	291	311	186
	30	411	377	332	518	644	692	496
	35	1,026	567	451	618	630	982	712
	40	1,371	562	458	602	665	1,121	797
	50	1,541	509	422	641	629	1,205	825
	75	1,575	512	417	603	1,014	796	820
	100	1,583	518	399	601	1,027	792	821
Hardwoods	25	198	444	403	502	509	567	438
	30	1,829	1,323	1,176	912	679	922	1,141
	35	3,513	1,394	970	803	516	1,502	1,449
	40	4,234	1,269	903	713	622	1,520	1,544
	50	4,596	1,127	840	673	691	1,635	1,595
	75	4,703	1,099	813	662	1,311	1,008	1,600
	100	4,725	1,086	811	666	1,331	1,002	1,603
Southern Region								
All Species	25	440	407	517	479	321	438	434
	30	595	435	518	428	270	438	447
	35	651	447	534	404	391	341	462
	40	671	456	524	429	384	326	466
	50	691	454	521	440	360	333	467
	75	706	468	495	479	377	360	481
	100	714	465	492	480	364	367	480
Statewide								
All Species	25	969	1,675	1,671	1,866	1,867	2,062	1,687
	30	5,675	3,821	3,343	3,459	2,836	4,193	3,889
	35	10,453	4,077	3,488	3,608	2,360	8,880	5,478
	40	12,615	3,828	3,529	3,371	3,660	9,171	6,032
	50	13,827	3,524	3,362	3,374	4,208	9,516	6,306
	75	14,104	3,505	3,244	3,352	8,452	4,141	6,135
	100	14,180	3,480	3,198	3,356	8,588	4,029	6,140

[a] Prices are delivered prices assuming timber is delivered to the closest market. Transport costs are not considered in the southern region.

Table 6.2. Scheduled harvest of roundwood from national forest timberland over time for various constant timber price levels (thousands of cord per year).

National Forest	Delivered Price ($/cd)[a]	Period						Average for all Years
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49	
Chippewa	25	32	91	112	89	176	233	122
	30	431	220	178	238	309	283	277
	35	669	187	180	213	189	559	333
	40	703	175	182	219	332	389	333
	50	725	157	171	229	337	377	333
	75	737	159	168	229	477	182	325
	100	744	159	169	227	477	185	327
Superior	25	6	52	25	19	45	29	29
	30	212	135	74	133	207	286	175
	35	603	234	213	243	234	767	382
	40	970	292	320	281	283	845	499
	50	1245	212	278	304	320	1111	578
	75	1294	219	271	303	817	465	562
	100	1324	225	256	304	834	464	568
Total, National Forest timberland	25	38	143	137	108	221	262	151
	30	643	355	252	371	516	569	452
	35	1,272	421	393	456	423	1,326	715
	40	1,673	467	502	500	615	1,234	832
	50	1,970	369	449	533	657	1,488	911
	75	2,031	378	439	532	1,294	647	887
	100	2,019	376	442	532	1,154	842	895

[a] Prices are assumed to be equal for all species and markets over time with wood delivered to the closest market

Another factor to consider when examining the results in table 6.1 is that some additional volume can likely be realized by postponing harvests until later periods. It could be argued that it is unrealistic to assume that the large volumes of wood financially mature in period 1 (under constant prices) will be harvested in period 1. Holding many of those stands until period 2 (or later) could result in substantial volume increases. Stands financially mature in period 1 are growing at less than the interest rate, but even over one 10-year period and with only a 2 percent annual growth rate, volumes would increase by over 22 percent.

Results of the analyses with constant timber prices and unconstrained harvest flows also provide insight on the production potential of different ownership groups. The revised scheduling runs also show a comparison of the potential of national forest timberlands to the allowable sale quantities that are assumed for the revised runs. Table 6.2 summarizes the flows of timber from national forest timberland under various timber price levels. As discussed earlier, the assumed annual allowable sale quantities were 120,000 cords for the Chippewa National Forest and 194,000 cords for the Superior

National Forest. Again, caution must be exercised in interpreting table 6.2 as it summarizes a very simplified analysis. But from the results it is clear that both national forests have the potential to produce substantially more timber than is reflected in their allowable sale quantities. Furthermore, much of this timber is currently financially mature under the assumption of constant timber prices.

Tables 14.9 through 14.13 in appendix 14 summarize the results of these analyses for each market in the northern region. As prices are equal for all regions, these tables provide an interesting breakdown of volumes harvested with respect to markets.

Another analysis was conducted using all FIA plots considered in the revised runs, with harvest levels unconstrained and timber prices rising over time. This analysis demonstrates the potential impact that rising prices have on the financial maturity of the existing forest inventory in Minnesota. Delivered prices were assumed to be $30 per cord in the first decade, rising by $10 per cord per decade for the next fifty years. Prices were assumed to drop by $10 per cord in the last decade to reflect the impact that the age imbalance will likely have on future timber supplies and future timber prices. The results are summarized in table 6.3. In contrast to the analysis assuming constant prices, very little of the existing inventory is financially mature in the first decade. At first this might seem somewhat surprising, but the shift is relatively easy to explain. At the $30 per cord price level, a substantial portion of the inventory is profitable to harvest in period 1 (table 6.1); however, a rise to $40 per cord over a single decade would be a large price increase. For example, for a stand that would cost $20 per cord to harvest and $7 per cord to transport to market in both periods, this translates to stumpage prices increasing from $3 per cord in the first decade to $13 per cord in the second decade—an average annual stumpage price increase of over 15 percent. Stand volume growth would need to be substantially negative (high mortality) over the decade before there would not be any incentive to capitalize on the price increase. In contrast, the increase from $13 per cord to $23 per cord over the next decade would still be large, but in percentage terms much smaller, less than six percent annually.

The results of the analysis under rising timber prices (table 6.3) addresses some of the concerns raised about the results of the analyses based on constant timber prices (table 6.1). First, with rising prices, relatively few stands in the aspen forest type are being harvested twice over the sixty-year period. Second, because most of the acres are not harvested until later periods, the results reflect some of the potential volume growth that might be realized by holding stands for harvest until later periods. This impact cannot be isolated from the overall results, but it is interesting to compare average annual yields for the higher price levels in table 6.1 with average annual yields in table 6.3: (1) the averages decrease substantially for aspen,

(2) modest increases are seen for the northern hardwoods group, and (3) the two softwood categories show relatively minor differences.

Table 6.3. Scheduled harvest of roundwood over time assuming rising timber prices for fifty years (thousands of cords per year).[a]

Product Group	Period 1990-99	2000-09	2010-19	2020-29	2030-39	2040-49	Average for all Years
Northern Region							
Aspen							
Bemidji	19	682	746	772	509	268	499
Brainerd	8	306	388	512	236	144	266
Cook	33	461	344	396	336	133	284
Duluth	17	408	458	559	482	144	345
Grand Rapids	16	447	439	551	272	246	329
I. Falls	2	184	246	344	262	82	187
Total, aspen	95	2,488	2,621	3,134	2,097	1,017	1,910
Spruce-fir							
Brainerd	0	27	47	114	68	38	49
Duluth	16	152	340	469	437	74	248
Grand Rapids	18	302	493	833	616	103	394
Total, spruce-fir	34	481	880	1,416	1,121	215	691
Pine							
Bemidji	3	265	468	815	853	137	424
Duluth	4	91	141	407	681	115	240
I. Falls	2	108	108	327	357	66	161
Total, Pine	9	464	717	1,549	1,891	318	825
N. Hardwoods							
Bemidji	3	292	586	893	348	105	371
Brainerd	3	246	657	1640	569	183	550
Cook	11	158	177	210	104	49	118
Duluth	11	214	459	806	434	117	340
Grand Rapids	4	236	618	531	204	95	281
I. Falls	1	38	62	110	97	30	56
Total, N. hardwoods	33	1,184	2,559	4,190	1,756	579	1,716
Total, Northern Region	171	4,617	6,777	10,289	6,865	2,129	5,142
Southern Region							
Red Oak	14	57	157	90	57	5	63
Other wood	62	303	761	815	581	206	455
Total, Southern Region	76	360	918	905	638	211	518
Statewide Total	247	4,977	7,695	11,194	7,503	2,340	5,660

[a] Delivered prices were assumed to rise by $10 per cord per decade from $30 per cord in the first decade to $70 per cord in the fifth decade. Price in the last decade was assumed to fall back to $60 per cord. Wood was assumed to be delivered to the closest market in the northern region. Transport costs are not considered in the southern region.

Table 6.4 shows the resulting harvest levels for the two national forests for the analysis where timber prices were assumed to rise over time. Harvest levels are more than double the assumed future allowable sale quantities for both forests.

Table 6.4. Scheduled harvest on national forest timberland over time assuming rising timber prices for fifty years (thousands of cords per year).[a]

National Forest	Period						Average for all Years
	1990-99	2000-09	2010-19	2020-29	2030-39	2040-49	
Chippewa	5	335	415	553	403	221	322
Superior	18	535	424	717	1003	183	480
Total	23	870	839	1,270	1,406	404	802

[a] Delivered prices were assumed to rise by $10 per cord per decade from $30 per cord in the first decade to $70 per cord in the fifth decade. Price in the last decade was assumed to fall back to $60 per cord. Wood was assumed to be delivered to the closest market in the northern region.

The results of the analyses with the unconstrained harvest flows and specific price assumptions are unrealistic, in that they all showed dramatic shifts in harvest levels between periods. Nonetheless, these simple analyses are in many ways very similar to the forest management scheduling model applied. The key difference is in what is fixed and what is allowed to fluctuate in each analysis. In these analyses, prices were assumed to be fixed and forest outputs were allowed to fluctuate so that the net present value of each FIA plot could be maximized within the bounds of the management alternatives considered feasible. With the scheduling model, forestwide outputs were fixed and shadow prices are allowed to fluctuate for each product, period, and market so that the low cost management schedule can be determined for producing the fixed level of outputs over time. Such an analysis will result in a flow of outputs as defined by the assumed target harvest levels for each scenario, if the corresponding shadow prices found in the modelling process are used to value and select management alternatives. The shadow prices can also be interpreted as the marginal cost of production associated with their corresponding product, time period and market; in other words, the cost of producing the last unit of the corresponding product for the corresponding time period and market.

Adjusting Targets to Achieve Feasibility

Lengthening the planning horizon to sixty years did not overcome the infeasibility problems of achieving the aspen harvest targets for even the base scenario. To overcome this problem, it became apparent that with the mitigative measures assumed, it would be necessary to either eliminate some of the mitigative measures or lower the aspen harvest target levels. Work proceeded first on the medium scenario under the assumption that some percentage of the aspen demand would need to shift to other species in future periods of the planning horizon. It is likely that decreasing aspen supplies, along with associated increases in aspen prices relative to other species, will stimulate a substantial shift. Predicting the extent of the shift is difficult as a long time horizon is involved. Only twenty years ago aspen was considered a weed species and not in demand.

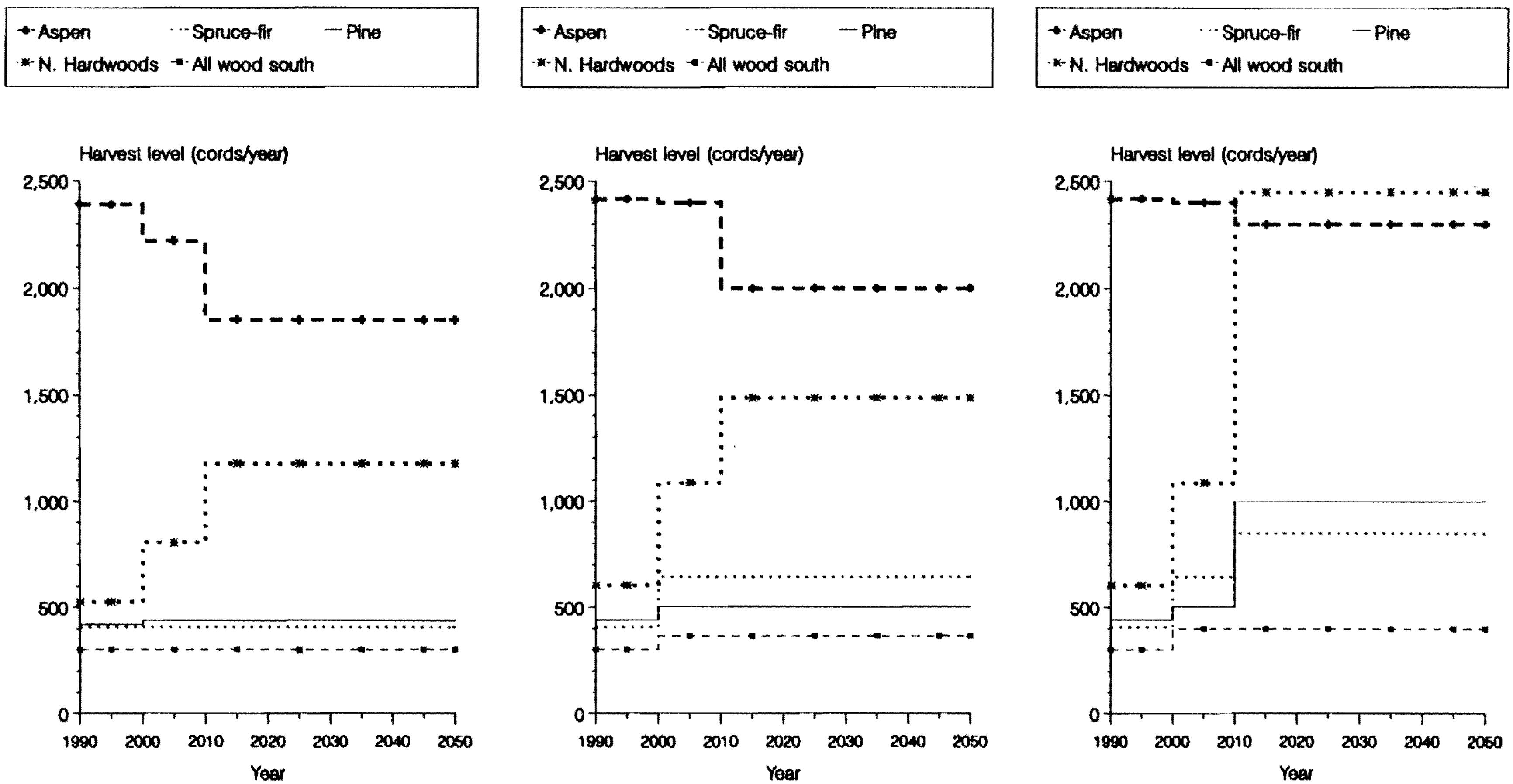
It was assumed that the shift in the projected aspen consumption would be to hardwoods, as hardwoods exhibited the lowest marginal costs of product for the initial model runs. For the medium scenario, it was found that harvest levels could be achieved if 10 percent of the aspen harvest level was shifted to northern hardwoods by the year 2000, with an additional shift in year 2010 for a total shift of 25 percent. Shifts as high as 20 percent were examined without finding a feasible schedule with aspen marginal costs of production as high as $100 per cord. For the base scenario, the same 25 percent shift was assumed, even though it was clear that feasible schedules could be developed with somewhat smaller shifts. Final shadow price estimates for the base and medium scenarios served as general guides for developing targets for the highest scenario. A summary of the target levels used for each of the three scenarios is shown in figure 6.1, with more details in table 6.5.

6.3
Marginal Cost Estimates for Harvest Level Targets

Table 6.6 shows the marginal cost estimates resulting from the scheduling model applications. These shadow prices add insight to the timber supply situation in Minnesota. Shadow prices are reported for each market and time period. In general, shadow prices for the same product group in different markets are highly correlated. Figure 6.2 compares the marginal cost estimates between markets for the aspen and northern hardwood product groups under the medium scenario. Clearly, for aspen under the medium scenario, shadow prices for each market follow the same general trend with markets generally maintaining the same relative position in terms of price differences between markets. Differences in prices between markets for each period reflect differences in general procurement zone boundaries. For example, the $3.68 difference between the shadow prices for aspen in the Duluth and Grand Rapids markets for period 1 under the medium scenario (55.11 - 51.43) indicates that the boundary between the Duluth and Grand Rapids procurement zones are points where transport costs to Duluth are $3.68 more per cord than transport costs to Grand Rapids.

Table 6.5. Comparison of assumed roundwood consumption levels by species group and market for the three harvest scenarios for the second runs (1,000's of cords per year).

Species Group Market	Period 1 (1990 - 1999)			Period 2 (2000-2009)			Periods 3-6 (2010-2049)		
	Base	Medium	High	Base	Medium	High	Base	Medium	High
Aspen									
Bemidji	572	572	572	522	522	522	435	435	450
Brainerd	256	256	256	260.1	287.1	287.1	216.75	239.25	300
Cook	210	210	210	182.7	182.7	182.7	152.25	152.25	300
Duluth	506	532	532	454.5	531	531	378.75	442.5	450
Grand Rapids	433	433	433	390.6	467.1	467.1	325.5	389.25	400
I. Falls	415	415	415	412.2	412.2	412.2	343.5	343.5	400
subtotal	2,392	2,418	2,418	2,222.1	2,402.1	2,402.1	1,851.75	2,001.75	2,300
Spruce-fir									
Brainerd	70	70	70	70	100	100	70	100	150
Duluth	220.5	220.5	220.5	219.5	379.5	379.5	219.5	379.5	400
Grand Rapids	115.5	115.5	115.5	118.5	163.5	163.5	118.5	163.5	300
subtotal	406	406	406	408	643	643	408	643	850
Pine									
Bemidji	159	159	159	188	188	188	188	188	370
Duluth	151	171	171	153	218	218	153	218	370
I. Falls	111	111	111	98	98	98	98	98	260
subtotal	421	441	441	439	504	504	439	504	1,000
Northern Hdwds									
Bemidji	83	83	83	147	147	147	234	234	400
Brainerd	190	190	190	226.9	229.9	229.9	270.25	277.75	600
Cook	51	51	51	79.3	79.3	79.3	109.75	109.75	250
Duluth	93	171	171	145.5	414	414	221.25	502.5	550
Grand Rapids	61	61	61	112.4	120.9	120.9	177.5	198.75	400
I. Falls	48	48	48	94.8	94.8	94.8	163.5	163.5	250
subtotal	526	604	604	805.9	1,085.9	1,085.9	1,176.25	1,486.25	2,450
Total, North	3,745	3,869	3,869	3,875	4,635	4,635	3,875	4,635	6,600
Southern Region									
Red oak sawlogs	50	50	50	50	65	70	50	65	70
Other wood	250	250	250	250	300	330	250	300	330
Total, South	300	300	300	300	365	400	300	365	400
Total, Statewide	4,045	4,169	4,169	4,175	5,000	5,035	4,175	5,000	7,000



a) Base scenario

b) Medium scenario

c) High scenario

Figure 6.1. Harvest levels for each of the three scenarios for the second runs.

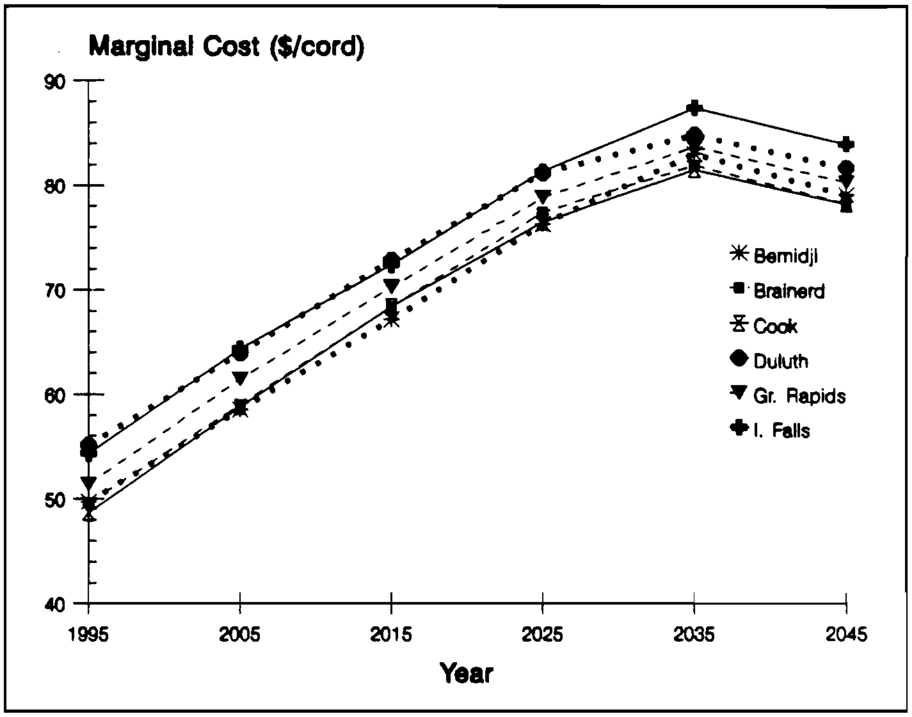
Table 6.6. Marginal cost estimates for the harvest level targets assumed for the scheduling model second runs ($ per cord).

Target Group Market	Harvest Level Scenario	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Aspen							
Bemidji	base	44.38	49.54	53.83	58.08	61.64	57.71
	med	49.71	58.55	67.18	76.31	83.05	79.10
	high	50.32	59.99	68.62	78.93	74.89	68.58
Brainerd	base	43.87	49.43	54.04	58.39	59.07	55.10
	med	49.64	59.02	68.40	77.45	81.95	78.25
	high	50.98	61.17	70.02	80.10	74.96	68.11
Cook	base	43.05	49.22	53.87	57.43	58.83	55.18
	med	48.66	58.80	68.43	76.48	81.56	78.25
	high	49.22	60.31	72.35	81.74	75.05	69.83
Duluth	base	48.86	53.49	56.95	60.33	61.33	57.61
	med	55.11	63.95	72.85	81.19	84.84	81.71
	high	54.84	64.05	73.34	82.50	73.46	67.54
Grand Rapids	base	45.45	51.11	55.08	58.98	60.51	56.60
	med	51.43	61.47	70.30	78.86	83.72	80.35
	high	51.74	62.70	71.49	81.16	75.69	69.52
I. Falls	base	48.64	54.84	58.93	63.04	65.35	61.78
	med	54.33	64.35	72.44	81.34	87.43	84.01
	high	54.90	65.66	74.93	84.82	80.63	74.88
Spruce-fir							
Brainerd	base	34.61	35.16	35.37	35.51	34.73	33.11
	med	42.10	47.47	51.30	56.71	61.84	66.06
	high	39.92	46.70	54.00	62.90	74.21	85.13
Duluth	base	32.54	33.37	33.81	35.19	36.47	37.42
	med	40.13	46.59	52.44	58.58	65.45	72.48
	high	35.55	43.03	50.43	59.93	72.76	87.59
Grand Rapids	base	26.11	26.77	26.90	27.45	28.22	29.22
	med	33.26	38.14	43.16	48.87	55.72	61.97
	high	29.90	37.14	45.33	54.73	67.20	81.06
Pine (values are in terms of red and white pine sawlogs)							
Bemidji	base	51.24	50.51	48.35	44.87	42.23	42.04
	med	53.16	52.77	51.72	48.38	45.96	47.13
	high	60.14	63.87	70.45	75.85	80.61	90.02
Duluth	base	57.18	56.65	54.03	49.51	47.92	47.22
	med	60.58	61.06	59.50	56.64	55.57	53.77
	high	67.53	71.39	77.24	81.34	87.60	94.28
I. Falls	base	55.62	55.43	54.32	51.83	47.40	45.75
	med	57.66	58.00	57.35	54.93	50.84	48.97
	high	64.54	68.71	76.03	82.73	87.11	94.41

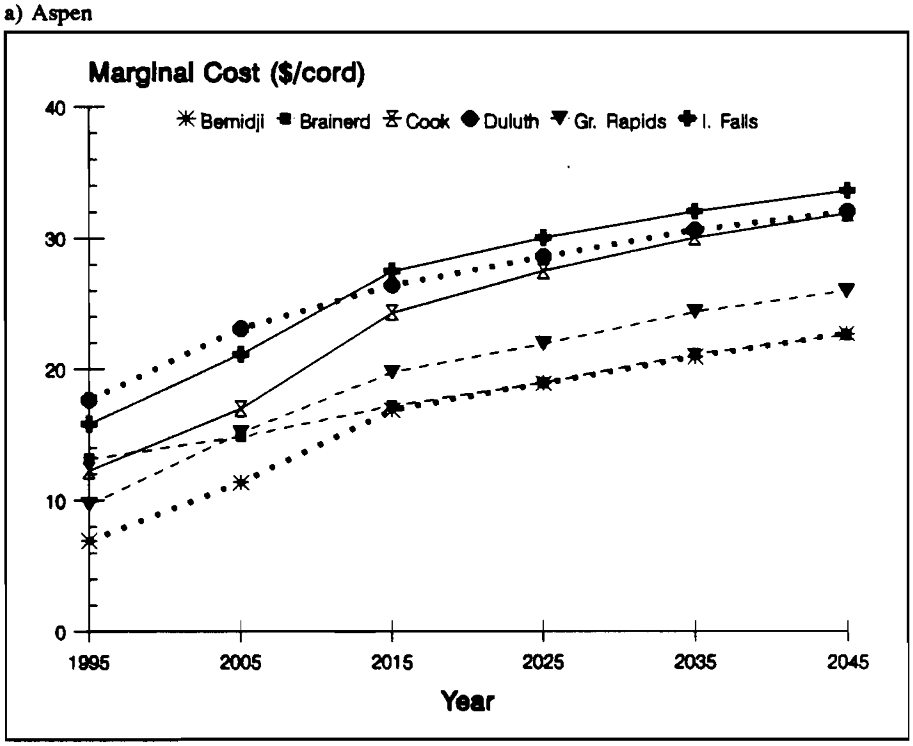
Table 6.6. (continued)

Target Group Market	Harvest Level Scenario	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Northern Hardwoods							
Bemidji	base	9.23	13.21	18.01	20.23	21.52	22.79
	med	6.95	11.35	16.85	18.89	20.92	22.69
	high	25.72	36.09	58.00	75.15	99.01	128.07
Brainerd	base	13.72	14.49	16.52	18.00	19.51	20.53
	med	13.14	14.83	17.20	18.96	21.14	22.59
	high	32.16	40.78	58.36	75.68	98.79	127.80
Cook	base	11.68	16.86	23.28	25.54	26.63	27.24
	med	12.26	16.98	24.31	27.48	30.04	31.87
	high	29.19	40.03	64.99	84.45	108.68	138.47
Duluth	base	11.02	15.32	19.30	20.96	22.09	22.67
	med	17.62	23.08	26.40	28.56	30.62	32.01
	high	35.07	46.72	62.45	80.13	103.68	132.99
Grand Rapids	base	9.32	13.42	18.10	19.77	21.35	22.29
	med	9.68	15.15	19.76	21.91	24.35	25.95
	high	27.62	39.25	59.70	78.04	102.47	133.34
I. Falls	base	7.28	22.51	28.55	30.54	32.17	33.00
	med	15.81	21.11	27.49	30.03	32.05	33.64
	high	33.38	44.67	68.63	86.18	110.48	139.58
Southern Region							
Red Oak Sawlogs	base	22.37	21.46	21.07	20.37	20.74	24.01
	med	26.00	27.68	29.44	32.58	36.13	42.81
	high	28.05	30.93	34.07	39.17	44.94	53.07
Other Wood	base	22.43	21.80	21.04	20.18	19.47	18.21
	med	22.54	21.99	21.30	20.25	19.71	18.48
	high	22.96	22.59	22.04	21.04	20.66	19.53
National Forest Volume Limits							
Chippewa Forest	base	11.16	13.66	15.03	16.47	16.85	15.62
	med	14.73	19.44	22.96	27.06	28.95	28.74
	high	--[a]	--	--	--	--	--
Superior Forest	base	7.61	10.08	8.94	9.69	10.10	10.55
	med	12.93	18.86	21.29	26.25	30.48	33.24
	high	--[a]	--	--	--	--	--

[a] Volume limits on harvests from national forest land were removed for the high scenario.



a) Aspen



b) Northern Hardwoods

Figure 6.2. Comparison of marginal cost estimates for the six markets in the northern region for selected product groups for the medium scenario in the second runs.

As shown in figure 6.2, the relative differences in marginal costs between markets are greater for northern hardwoods than for aspen under the medium scenario. However, even for northern hardwoods, marginal costs follow the same general trend over time for all markets. Marginal costs for northern hardwoods tended to be higher for the Cook and International Falls markets because there are generally fewer hardwoods in the most northern part of the state. Compared to marginal costs of hardwoods in other markets, marginal costs for northern hardwoods are also relatively high for the Duluth market under the medium scenario, as the harvest level for the Duluth market is higher with the large Potlatch expansion and its planned use of northern hardwoods.

The general level of the shadow price estimates give some indication of relative timber supply. For example, the shadow price for northern hardwoods in Bemidji is only $9.23 per cord for the base scenario. Clearly, wood from any hardwood stand could not be harvested and transported to Bemidji for this price. Stands near Bemidji with a predominant hardwood component are not scheduled for harvest in period 1 by the scheduling model. Hardwood volumes for the Bemidji market in period 1 under this scenario are obtained from mixed species stands, where it is the higher value of other species groups that makes it profitable to harvest the stand. The results of the analyses with unconstrained harvest levels with constant timber prices (table 6.1) suggest that almost all aspen stands are economically feasible to harvest at the price level reflected by the aspen shadow prices for the base scenario. Aspen stands contain substantial volumes of hardwoods and likely supply much of the northern hardwood harvest.

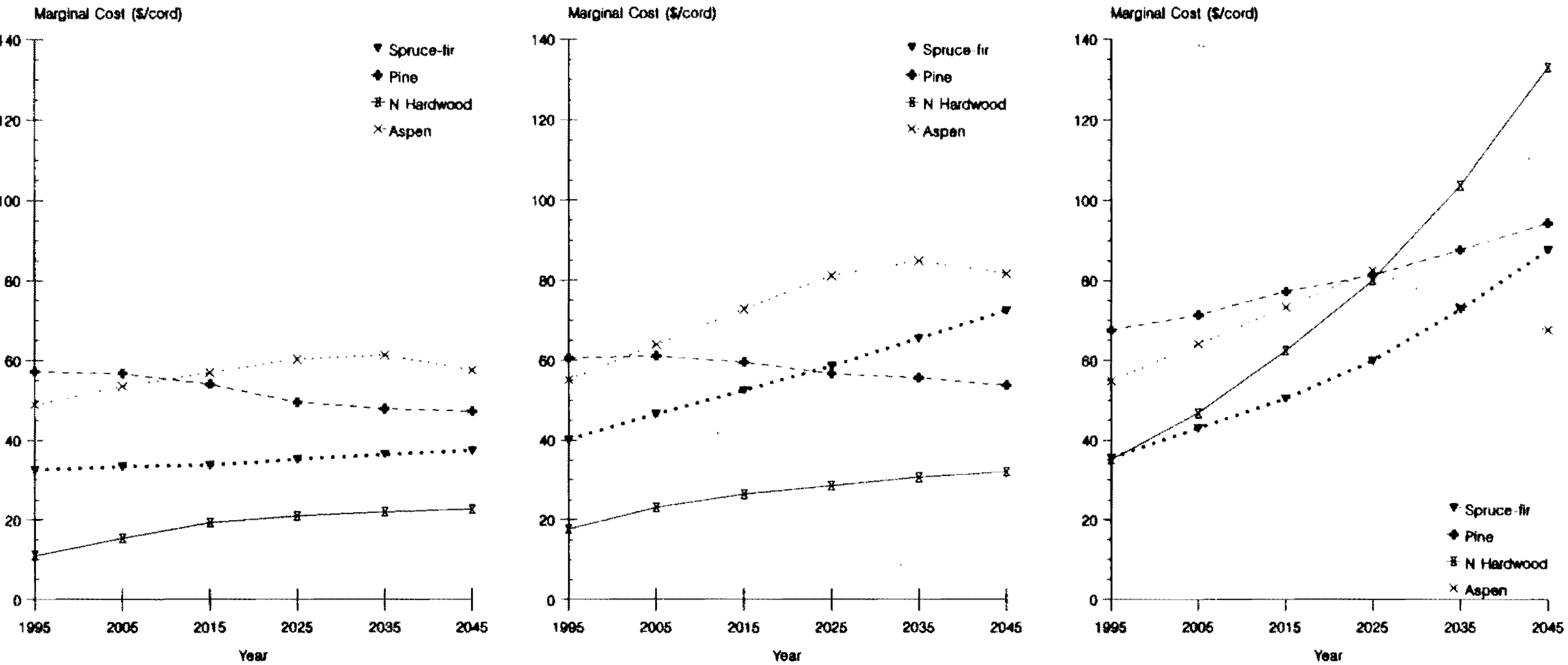
Results for the pine group are more difficult to compare to the results of the analyses with unconstrained harvest levels, as value differences were recognized for specific products within the pine group. Values reported for pine in table 6.6 are in terms of red and white pine sawlogs, the most valuable product type in the pine group. In general, in comparing shadow prices it is important to consider potential interactions between product groups, as most forest stands in Minnesota contain multiple species. The interactions make the situation complex, thus making it difficult to explain results with simple generalizations.

For a given product group and market, changes in shadow prices over time lend insight into changes in supply conditions over time. By definition, prices over time reflect higher costs of producing timber at the margin in future periods. However, it is important to consider all of the costs that are measured by the shadow prices. Besides harvest and transport costs, there is the opportunity cost associated with the potential to shift harvests to other time periods. For example, the $45.45 marginal cost estimate for aspen for the Grand Rapids market under the base scenario for period 1 indicates that cutting an additional cord of aspen in period 1 and transporting it to Grand

Rapids would cost approximately $45. Some stands remaining in the inventory after the period 1 harvest is completed could be cut and transported to Grand Rapids for less, but these stands also have potential value for future periods. The $45.45 estimate includes the opportunity cost associated with utilizing the *marginal cord* today rather than saving the cord, with any growth (or mortality), for some later period. This cost depends on both the potential growth of the stand and the marginal costs of production in the future periods of possible harvest. The cost is higher with higher potential growth rates or when the associated future marginal costs are higher. Similarly, potential future benefits of harvesting are also considered, as there is potential benefit from harvesting earlier to increase returns from future harvests. This benefit is greatest when marginal costs (shadow prices) are high for periods when harvests from future rotations could be realized.

Figure 6.3 compares the marginal cost of each of the four product groups for the Duluth market. At least in general terms, these estimates are representative of all markets in the northern region. Under the base scenario, the rising and higher marginal costs for aspen confirm that the future supply of aspen should be a concern. Marginal costs for the pine group under the base scenario actually drop substantially over the planning horizon. This drop is likely due to past red pine reforestation efforts as many plantations will reach harvestable age in later periods of the planning horizon. Of significance is the relatively short planning horizon as compared to typical rotation lengths for red and white pine. Specifically, achieving target harvest levels of pine over only a 60-year horizon does not address the issue of current pine reforestation needs to meet potential harvest level targets for periods beyond the length of the planning horizon. Had a longer planning horizon been considered, marginal costs associated with pine in later periods might need to be higher to reflect the need for reforestation efforts. The marginal cost estimates for northern hardwoods are based on the assumption that a 25 percent shift from aspen consumption to hardwoods consumption will occur by year 2010. Even with this assumed shift, the marginal cost of producing northern hardwoods remains low over time as compared to all other species groups.

Marginal cost estimates also suggest that aspen is the species in shortest relative supply under the medium scenario (figure 6.3b). Marginal cost estimates rise to over $80 per cord for aspen, while those for northern hardwoods remain relatively low. Marginal costs for spruce-fir under the medium scenario rise consistently over the planning horizon and approach $80 per cord by the end of the planning horizon. As with the base scenario, marginal costs for pine decline over the planning horizon.



a) Base scenario

b) Medium scenario

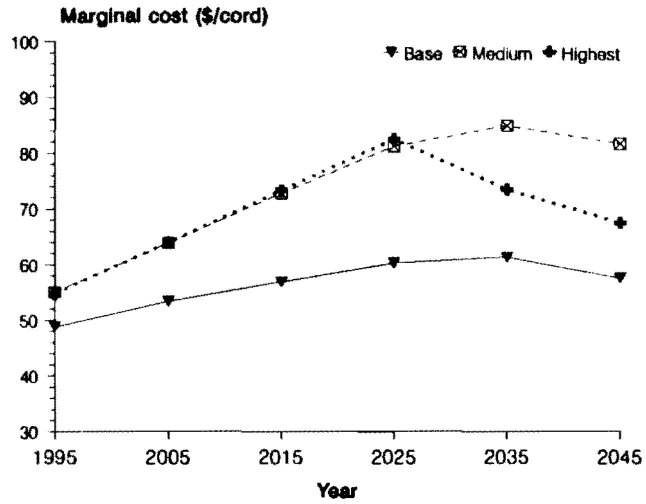
c) High scenario

Figure 6.3. Comparison of marginal costs for the different product groups for the Duluth market in the second runs.

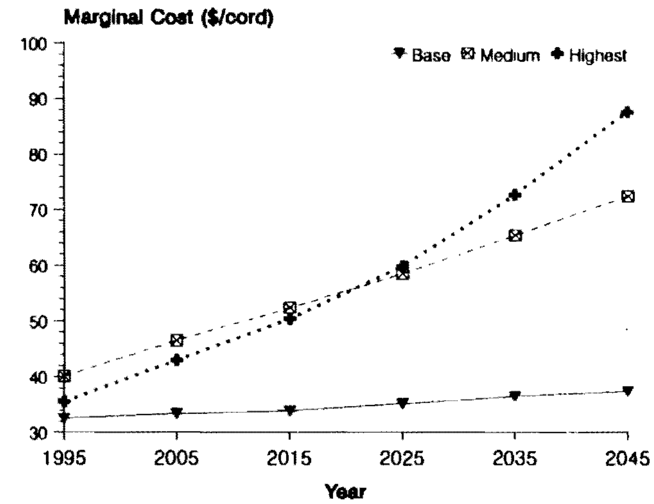
The marginal cost estimates for the highest scenario (figure 6.3c) increase substantially for all species over time. Of significance is the large increase for northern hardwoods. For the high scenario, the marginal cost of producing hardwoods rises substantially above the marginal cost of other species by the end of the planning horizon. This suggests that in raising the targets to reach a 7 million cord level, targets for northern hardwoods were set too high. The high marginal costs for all species by the end of the planning horizon also suggests that these harvest levels could not be maintained over a longer time horizon without either reducing the mitigative measures imposed or implementing intensive forest management options not considered in this analysis. The drop in the marginal cost of aspen after the fourth period suggests some potential relative supply increases for aspen. However, caution must be exercised in interpreting this drop, as there is an interaction between this drop and the higher and rising northern hardwood shadow prices.

Figure 6.4 compares the marginal cost estimates across scenarios for each product group for the Duluth market. The Duluth market was chosen for illustration as it is the only market in which targets were recognized for all four product groups. Trends for the Duluth market are representative of trends for other markets. The aspen marginal cost estimates are of particular interest. For all three scenarios, the marginal cost estimates drop between period 5 and period 6. This drop makes it advantageous to harvest most aspen stands regenerated in period 1 and again in period 5. In other words, the drop in price suggests at least a temporary shortening of aspen rotations to forty years to help overcome the aspen age class imbalance. For periods beyond the end of the planning horizon, the assumed rotation length depends on the harvest level scenario. For the base scenario, the shadow price estimates for the last period are in the $55 to $60 per cord range for most markets. Based on the growth projections used and this price level, most acres in the aspen cover type that are age forty in the last planning period will be held as ending inventory, rather than be harvested in the last period. This is evident from the earlier analyses assuming constant prices, as a 50-year rotation is optimal for most regenerated aspen stands up until approximately a $60 per cord price level (table 14.9). But with prices constant and above approximately $70 per cord, a 40-year rotation is desirable for many aspen stands. Therefore, many of the aspen stands age forty in the last planning period are harvested in the last period under the medium scenario, as shadow prices for aspen will have risen above $70 per cord by the last period.

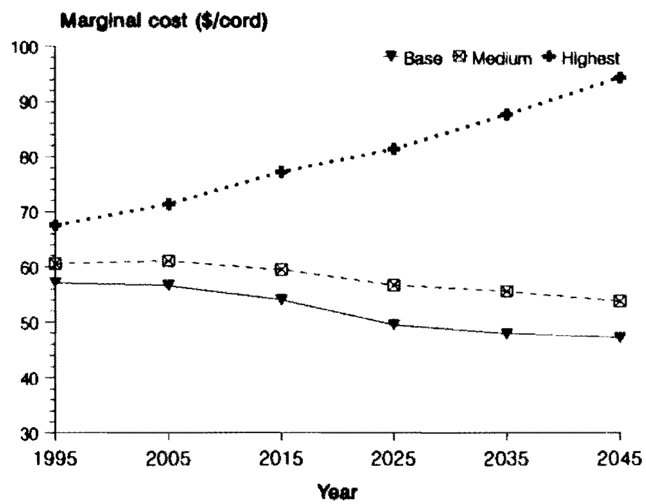
Marginal cost estimates for pine changed relatively little between the base and medium scenario. Pine shadow prices are substantially greater for the highest scenario, reflecting the much higher targets for pine under the highest scenario. Marginal cost estimates for spruce-fir changed substantially between the base and medium scenario, suggesting that the large spruce-fir



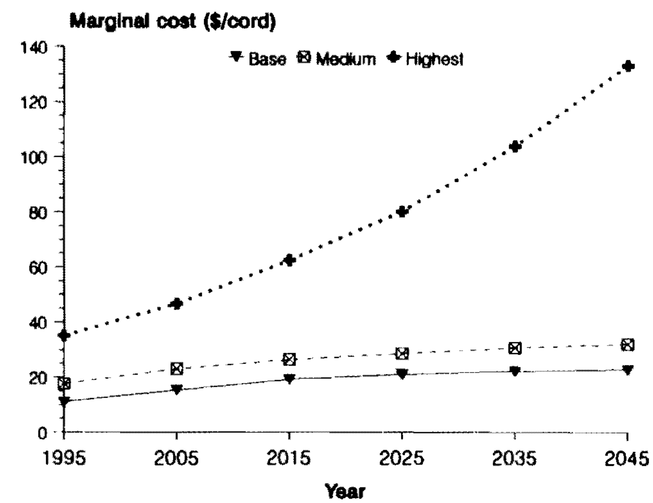
a) Aspen



b) Spruce-fir



c) Pine (red and white pine sawlogs)



d) Northern Hardwoods

Figure 6.4. A comparison of marginal estimates for the three scenarios for the Duluth market in the second runs.

harvest level increases will have a large impact on the future production cost and price for spruce fir. In general, spruce-fir shadow prices are perhaps underestimated, as the harvest cost model used in the study does not explicitly recognize the species effect on estimated logging costs. Generally, spruce-fir stands are more costly to harvest because of the greater delimbing costs involved.

Marginal costs for hardwoods change little between the base and medium scenario, even though there is a substantial increase in the harvest level targets. The large increase between the medium and high scenarios suggests that the highest scenario has raised targets to unrealistically high levels if all the mitigative strategies are imposed. With the high scenario, much of the accumulated inventory of hardwoods is being liquidated at a rate that could not be sustained without shifting to another species or intensive forest management on a major scale.

To implement the allowable sale quantities for each national forest, constraints were included that set the harvest level targets for each national forest for each time period. Associated with each constraint is a marginal cost estimate that measures the cost savings that could be achieved if an additional cord could be harvested from national forest timberland to help meet the assumed harvest level targets (table 6.7). Another interpretation of these marginal costs would be that they are the taxes (per cord) necessary on timber production from national forest timberland to keep production at the allowable sale quantities if national forest timberlands were managed in coordination with all timberland in the region with the objective of minimizing the overall net discounted cost of meeting regional harvest level targets over time. For both the base and medium scenarios, these costs were substantial—as high as $28.95 per cord. Marginal cost estimates are not reported for the high scenario, as constraints defining allowable sale quantities could not be imposed for the high scenario if the 7 million cord harvest target was to be met. Trial model runs for the high scenario suggested that harvest level targets could not be met for the high scenario over the planning horizon without additional harvesting on national forest timberland.

Figure 6.5 shows the marginal cost estimates for the southern region. These costs are not directly comparable with the costs for the northern study region, as the analysis for the southern region did not include transportation costs as one of the timber production cost components. As might be expected, marginal costs for red oak are higher and tend to rise quickly over time for scenarios with higher red oak harvest levels. Perhaps of some surprise is the relatively constant marginal cost level for the "other wood" group for all three scenarios. The relatively low level would suggest that the harvest level targets for this group could have been raised more for the high scenario. However, this region contains a relatively small component of the statewide timber supply and certainly could not support a large increase as compared to the increases assumed for the northern region under the highest scenario. Modelling timber supply for this region is also complicated more by the assumptions concerning timberland area change estimates. In relative terms, the percentage of acres in timberland has the potential to increase substantially over time in this region.

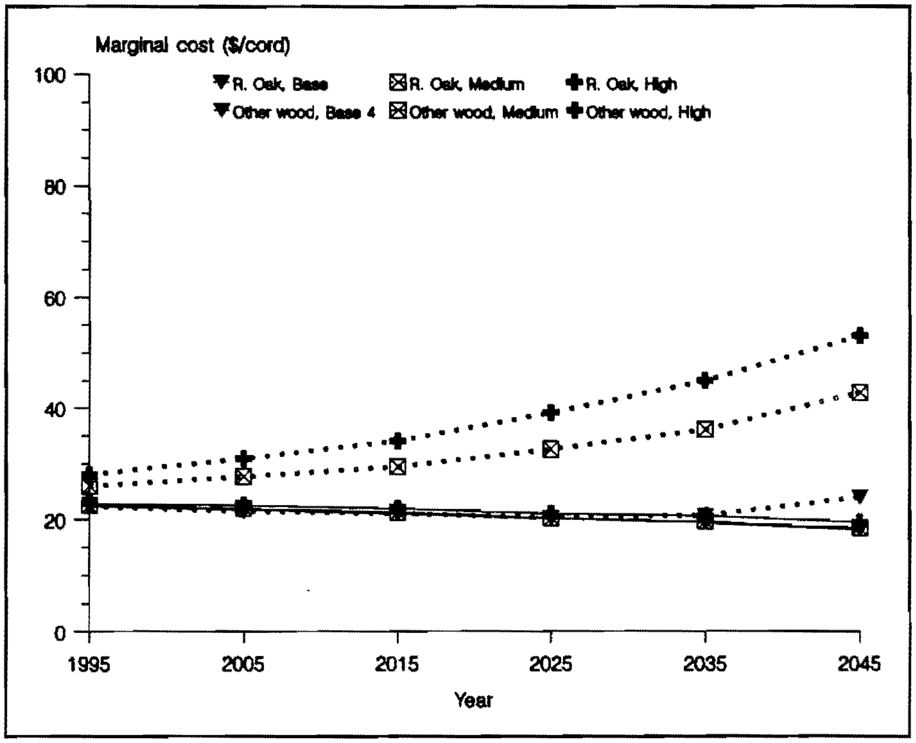


Figure 6.5. Marginal cost estimates for the southern region in the second runs.

6.4 Breakdown of Harvest Volumes by Product Group

In developing management schedules, target outputs were defined for product groups. Relative value differences were recognized for products within the pine group. Tables 6.7, 6.8, and 6.9 summarize the scheduled harvests for products within each group for the northern region. In comparing sawlog volumes with pulp volumes, it is important to note that the schedules do not necessarily imply that all of the sawlog quality material will be used as sawlogs. This was a major consideration in developing relative product values. Higher values were not assumed for aspen, spruce-fir, or northern hardwood sawlogs as at least some of this material will be used as pulpwood. Under the base scenario, only for aspen is there a large reduction in the quantity of sawlogs produced over time, dropping from over 1 million cords per year in period 1 to approximately 475,000 cords in period 4 (table 6.8). Drops are similar for both the medium or high scenario. However, even with the drop, production of aspen sawlog size material is still substantially above the estimate of 210,000 cord estimate of current annual consumption of aspen sawlogs by sawmills (appendix table 14.1)

Table 6.7. Scheduling model harvest summary for the northern region under the base scenario second runs (thousands of cords per year).

Product Group	Component	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Aspen	Aspen pulp	1,297.7	1,281.2	1,276.80	1,379.1	1,334.6	1,375.4
	Aspen saw	1,083.8	956.5	587.70	475.3	532.2	481.4
	Total	2,381.8	2,237.6	1,864.70	1,854.4	1,866.7	1,856.6
	Target	2,392	2,222.1	1,851.75	1,851.75	1,851.75	1,851.75
Spruce-fir	S-fir pulp	240.2	204.3	176.10	156.9	159.5	144.5
	S-fir saw	165.1	204.3	229.60	244.4	252.5	264.4
	Total	405.3	408.5	405.60	401.3	412.1	408.8
	Target	406	408	408.00	408	408	408
Pine	Pine pulp	77.1	93	79.80	74	108.1	119.5
	R&W saw	303.1	258.7	283.90	311.5	243	212.9
	Other saw	34.6	89.5	71.50	52.3	91.1	109.9
	Total	414.8	441.1	435.30	437.9	442.1	442.2
	Target	421	439	439.00	439	439	439
N. Hardwoods	pulp	406.5	552.1	746.40	698	695.5	676.7
	R Oak saw	45.7	74.3	136.70	133.3	102.9	59.5
	Other saw	78.4	175.3	293.80	343.7	373.1	438.9
	Total	530.8	801.4	1,176.80	1,175	1,171.4	1,174.9
	Target	526	805.9	1,176.25	1,176.25	1,176.25	1,176.25
All Groups	Total	3,732.7	3,888.6	3,882.4	3,868.6	3,892.3	3,882.5
	Target	3,745	3,875	3,875	3,875	3,875	3,875

Table 6.8. Scheduling model harvest summary for the northern region under the medium scenario, second runs (thousands of cords per year).

Product Group	Component	Period 1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Aspen	Aspen pulp	1,294	1,333.9	1,350	1,484.1	1,401.5	1,483.2
	Aspen saw	1,117	1,046.1	639	463.5	539.9	508.5
	Total	2,411.1	2,380.1	1,989	1,947.6	1,941.5	1,991.5
	Target	2,418	2,402.1	2,001.75	2,001.75	2,001.75	2,001.75
Spruce-fir	S-fir pulp	244.6	344.9	310.7	297.7	293.2	254.5
	S-fir saw	161.5	294.9	329.2	342.8	325.8	364.4
	Total	405.9	639.7	640	640.5	618.9	618.8
	Target	406	643	643	643	643	643
Pine	Pine pulp	62.6	93.9	85.8	76.8	111.7	125.5
	R&W saw	219.6	209	214	267.1	203.6	145.8
	Other saw	35.5	104.3	100	60.9	98.1	133.9
	Total	317.7	407.2	399.7	404.7	413.4	405.3
	Target	330	406	406	406	406	406
N. Hardwoods	pulp	483.9	749.1	932.3	897.5	895.1	853.1
	R Oak saw	40.4	86.4	175.7	134.6	103.2	56.5
	Other saw	104.1	251.8	381	469.6	495.7	578.2
	Total	628.5	1,087.1	1,489	1,501.5	1,493.8	1,488
	Target	604	1,085.9	1,486.25	1,486.25	1,486.25	1,486.25
All Groups	Total	3,763.2	4,517.4	4,517.7	4,494.3	4,467.6	4,503.6
	Target	3,758	4,537	4,537	4,537	4,537	4,537

Under all three scenarios, pine sawlog production is above current pine sawlog consumption by sawmills. The highest scenario assumed more than a doubling of the pine consumption level over the medium scenario as this product group appeared to have the potential for a large increase.

Table 6.10 summarizes the schedules developed for each of the national forests in Minnesota. For the base and medium scenarios, the scheduled outputs are very close to the targets assumed for each forest. For the high scenario, harvest flow quantities from national forest timberland were not constrained, as initial runs using constraints suggested that the levels were not feasible without increased harvesting from national forest timberland. In the high scenario, scheduled harvest levels, for both national forests, averaged over 2.5 times the allowable sale quantity. This indicates that if harvest levels were to be increased to the 7 million cord level in the state and the constraints and mitigation measures considered were implemented, a substantial increase in the harvest from national forest timberlands would likely be necessary.

Table 6.9. Scheduling model harvest summary for the northern region under the high scenario, second runs (thousands of cords per year).

Product Group	Component	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Aspen	Aspen pulp	1,277.1	1,344.9	1,441.3	1,665.5	1,653.7	1,639.9
	Aspen saw	1,120.9	1,043.1	816.4	578.0	611.8	635.4
	Total	2,398.	2,387.8	2,257.9	2,243.4	2,265.6	2,275.2
	Target	2,418	2,402.1	2,300	2,300	2,300	2,300
Spruce-fir	S-fir pulp	247.4	345.	399.9	373.1	399.8	352.
	S-fir saw	160.3	301.6	443.	474.8	441.5	474.7
	Total	407.6	646.4	842.8	847.9	841.3	826.7
	Target	406	643	850	850	850	850
Pine	Pine pulp	92.4	130.9	239.5	245.2	286.4	394.4
	R&W saw	281.5	233.5	487.2	512.2	466.1	218.9
	Other saw	65.7	140.1	265.8	236.3	219.5	360.7
	Total	439.6	504.6	992.5	993.7	971.9	974.1
	Target	441	504	1,000	1,000	1,000	1,000
N. Hardwoods	pulp	453.	761.3	1,498.5	1,412.3	1,371.1	1,338.1
	R Oak saw	43.8	59.7	257.9	172.6	80.5	46.4
	Other saw	108.9	266.	647.8	776.	875.8	884.2
	Total	605.6	1,087.1	2,404.1	2,360.8	2,327.3	2,268.8
	Target	604	1,085.9	2,450	2,450	2,450	2,450
All Groups	Total	3,850.8	4,625.9	6,497.3	6,445.8	6,406.1	6,344.8
	Target	3,869	4,635	6,650	6,600	6,600	6,600

Tables 6.11, 6.12 and 6.13 summarize the scheduled harvests for products within each group for the southern region. These tables also show that the scheduling model was very successful in developing schedules with harvests that are very close to the target harvest levels for each scenario. Considerable detail in species breakdown was recognized in the southern region because results suggest a broad mix of species will continue to be harvested. Also an increase in the production of aspen and maple/basswood over time in this region is expected. However, even with the increase, aspen is only a minor component of the forest in this region.

Table 6.10. Harvest volume levels from national forest timberland for the second runs.

National Forest	Period	Estimated Allowable Sale Quantity (M cords/yr)	Wood Volume Scheduled for Harvest (M cords/yr)		
			Base Scenario	Medium Scenario	High Scenario
Chippewa	1990-99	120	117.94	125.68	263.51
	2000-09	120	119.44	110.54	272.96
	2010-19	120	121.82	126.19	386.45
	2020-29	120	116.35	123.27	375.20
	2030-39	120	119.74	119.01	372.30
	2040-49	120	123.02	122.40	304.40
Average	1990-2049	120	119.72	121.18	329.14
Superior	1990-99	194	191.30	192.26	342.72
	2000-09	194	191.45	197.09	542.33
	2010-19	194	193.07	193.33	506.97
	2020-29	194	198.83	206.46	626.44
	2030-39	194	188.79	190.06	613.38
	2040-49	194	189.86	188.11	605.06
Average	1990-2049	194	192.22	194.55	539.48
Total, all national forest timberland	1990-99	314	309.24	317.94	606.23
	2000-09	314	310.89	307.63	815.29
	2010-19	314	314.89	319.52	893.42
	2020-29	314	315.18	329.73	1,001.64
	2030-39	314	308.53	309.07	985.68
	2040-49	314	312.88	310.51	909.46
Average	1990-2049	314	311.94	315.73	868.62

Table 6.11. Harvest summary for the southern region under the base scenario, second runs (1000's of cords per year).

Product Group	Category	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Red Oak Sawlogs		50.29	50.37	49.34	50.14	49.91	49.58
	Target	50	50	50	50	50	50
Other Wood	Aspen pulp	3.88	3.60	1.74	1.91	5.45	7.16
	Aspen saw	2.78	5.72	3.59	5.48	15.86	25.36
	Balm of G pulp	2.71	0.21	0.29	2.00	0.29	2.92
	Balm of G. saw	8.15	0.51	0.72	2.46	0.68	5.60
	Balsam fir pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Balsam fir saw	0.00	0.00	0.00	0.00	0.00	0.00
	Birch pulp	2.47	3.96	3.03	1.78	3.76	4.29
	Birch saw	1.14	3.17	2.62	0.80	3.80	4.06
	Maple Bass. pulp	18.38	22.80	29.22	17.38	32.19	26.69
	Maple Bass saw	25.86	36.37	38.24	19.38	32.29	40.98
	N. Hdwd pulp	64.68	69.10	64.10	68.19	53.39	41.42
	N.Hdwd saw	79.93	60.89	73.12	87.13	66.50	41.63
	Jack pine pulp	0.31	0.00	0.00	0.63	0.01	0.00
	Jack pine saw	0.78	0.00	0.00	2.82	0.04	0.00
	Red & W pine pulp	0.42	3.41	0.97	1.05	0.00	1.73
	Red & W pine saw	1.26	5.59	4.96	8.75	0.00	10.62
	Red oak pulp	33.44	34.52	32.83	34.07	32.43	31.54
	Spruce pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Spruce saw	0.00	0.00	0.00	0.00	0.00	0.00
	Total	246.2	249.9	255.4	253.8	246.7	244.0
	Target	250	250	250	250	250	250
All Groups	Total	296.49	300.27	304.74	303.94	296.61	293.58
	Target	300	300	300	300	300	300

Table 6.12. Volume harvest summary for the southern region under the medium scenario, second runs (1000's of cords per year).

Product Group	Category	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Red Oak Sawlogs		50.07	66.73	62.53	65.72	64.59	64.26
	Target	50	65	65	65	65	65
Other Wood	Aspen pulp	1.37	5.37	4.41	3.70	5.98	8.02
	Aspen saw	1.70	8.67	5.71	10.88	17.38	27.31
	Balm of G pulp	2.71	0.32	0.68	2.07	0.29	2.09
	Balm of G. saw	8.14	0.76	1.67	2.63	0.68	4.58
	Balsam fir pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Balsam fir saw	0.00	0.00	0.00	0.00	0.00	0.00
	Birch pulp	2.40	4.87	4.92	1.18	6.33	5.19
	Birch saw	1.14	4.01	4.50	0.94	4.32	3.34
	Maple Bass. pulp	18.49	28.66	35.47	27.02	41.78	33.66
	Maple Bass saw	26.09	44.85	43.91	33.96	33.04	49.12
	N. Hdwd pulp	67.12	78.53	71.67	74.62	72.92	59.69
	N.Hdwd saw	84.44	73.29	78.93	91.79	73.47	56.42
	Jack pine pulp	0.31	0.04	0.00	0.63	0.00	0.00
	Jack pine saw	0.78	0.20	0.00	2.82	0.00	0.00
	Red & W pine pulp	0.42	3.41	0.97	1.05	0.00	1.73
	Red & W pine saw	1.26	5.59	4.96	8.75	0.00	10.62
	Red oak pulp	32.15	43.41	40.57	42.37	38.08	38.26
	Spruce pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Spruce saw	0.00	0.00	0.00	0.00	0.00	0.00
	Total	248.5	302.0	298.4	304.4	294.3	300.0
	Target	250	300	300	300	300	300
All Groups	Total	298.57	368.73	360.93	370.12	358.89	364.26
	Target	300	365	365	365	365	365

Table 6.13. Volume harvest summary for the southern region under the high scenario, second runs (1000's of cords/year).

Product Group	Category	Period					
		1990-99	2000-09	2010-19	2020-29	2030-39	2040-49
Red Oak Sawlogs		49.89	70.63	68.52	71.60	66.73	70.76
	Target	50	70	70	70	70	70
Other Wood	Aspen pulp	1.37	5.63	7.59	3.60	8.11	9.23
	Aspen saw	1.70	9.65	9.70	10.50	22.39	32.48
	Balm of G pulp	2.67	0.37	0.93	2.37	0.03	4.41
	Balm of G. saw	8.03	0.86	2.34	3.21	0.08	9.29
	Balsam fir pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Balsam fir saw	0.00	0.00	0.00	0.00	0.00	0.00
	Birch pulp	1.91	6.15	4.96	1.49	8.66	7.24
	Birch saw	1.05	4.66	4.51	0.85	4.45	4.47
	Maple Bass. pulp	17.99	32.44	35.87	33.34	43.03	31.88
	Maple Bass saw	25.30	49.61	49.30	41.80	32.60	40.99
	N. Hdwd pulp	70.14	82.85	76.25	83.30	87.58	75.35
	N.Hdwd saw	86.59	80.15	85.60	97.72	84.03	64.03
	Jack pine pulp	0.00	0.36	0.87	0.63	0.00	0.00
	Jack pine saw	0.00	1.15	1.66	2.82	0.00	0.00
	Red & W pine pulp	0.15	3.87	0.97	1.05	0.00	1.73
	Red & W pine saw	0.74	6.52	4.96	8.75	0.00	10.62
	Red oak pulp	31.98	46.17	43.29	43.35	38.86	42.11
	Spruce pulp	0.00	0.00	0.00	0.00	0.00	0.00
	Spruce saw	0.00	0.00	0.00	0.00	0.00	0.00
	Total	249.6	330.5	328.8	334.8	329.8	333.8
	Target	250	330	330	330	330	330
All Groups	Total	299.49	401.13	397.32	406.4	396.53	404.56
	Target	300	400	400	400	400	400

6.5 Sources of Timber by Ownership

The constraints by ownership for the second runs as described in table 4.18 direct harvesting to available acres. This clearly directed more demand to nonfederal lands as compared to the first runs for the base and medium scenario. Adding to that pressure, the projected decline in timberland acreage in the north meant more of the harvest had to come from state, county and industry lands. Table 6.14 describes that distribution of harvest by scenario and provides a comparative percentage for ownership.

Results in table 6.14 suggest that county, industry and NIPF are likely to be the strongest contributors to timber supply, i.e., they would provide a percentage of harvest close to or in excess of their percentage of total timberland for all scenarios over the study period.

Table 6.14. Original acres harvested by ownership by scenario, second runs, 1990-2040.

Ownership	Scenario						Timberland	
	Base		Medium		High			
	Acres Harvested	Percent	Acres Harvested	Percent	Acres Harvested	Percent	Acres Harvested	Percent
Chippewa National Forest	160,200	2.23	170,200	1.98	451,800	4.32	567,200	3.84
Superior National Forest	349,500	4.87	352,100	4.09	991,000	9.47	1,253,900	8.49
Miscellaneous federal	53,700	0.75	62,900	0.73	82,800	0.79	197,700	1.34
Native American	171,200	2.39	193,800	2.25	234,500	2.24	490,600	3.32
State	1,296,900	18.08	1,741,400	20.21	1,958,400	18.71	3,077,900	20.83
County and municipal	1,612,800	22.48	1,924,700	22.34	2,057,800	19.66	2,505,600	16.96
Forestry industry	451,400	6.29	561,200	6.51	597,900	5.71	751,300	5.09
Other private	3,077,700	42.90	3,610,700	41.90	4,091,000	39.09	5,929,200	40.13
Total	7,173,400	100.00	8,617,000	100.00	10,465,200	100.00	14,773,400	100.00

6.6
Acres Harvested and Not Harvested by Covertype

Results of the mitigation runs with respect to harvest acreage are summarized in a number of tables in appendix 15. For each of the three demand scenarios tables display information on total acres, acres uncut, acres clearcut once in 50 years, acres clearcut twice, acres thinned but never clearcut, acres thinned and clearcut for both the southern and the northern study region combined. All these tables were generated by unit number, ecoregion, and period by both covertype and ownership codes. Table 6.15 summarizes these results.

The summary in table 6.15 indicates that the base, medium and high scenarios would lead to harvesting on approximately 7.1, 8.6 and 10.5 million acres of timberland, respectively, over the next 50 years. Conversely, adding the area never cut to that not considered in the scheduling model, shows that 7.6, 6.2 and 4.3 million acres of timberland *would not* be harvested during the study period for the base, medium, and high scenarios, respectively. Additionally, the reserved and unproductive forest acreage represents another 1.9 million acres that would not be disturbed by harvesting.

Table 6.16 shows the acreage harvested and not harvested by covertype for the three scenarios. Results for aspen and northern hardwoods show the effect of a shift in demand to the latter necessary to achieve scheduling model run feasibility. The acreages are displayed by the initial FIA covertype. A second clearcut was possible within the 50-year planning horizon only for aspen and balsam poplar because only these covertypes permitted a minimum rotation of 40 years for normal treatment stands. Any other covertype acreage that shows a second clearcut in the table represents acres that were regenerated via the stochastic transition process to aspen or balsam poplar in the first planning period.

The table shows an almost across the board increase in harvesting activity in all covertypes from the base to the high scenario. In absolute terms, however, most of the harvesting activity is concentrated in the aspen and hardwood covertypes. Note that for the medium and high scenarios, the percentage contribution of aspen to total harvest acreage actually is lower than for the base scenario. With the increasing demands of the medium and high scenario, the absolute acreage of acres clearcut twice and acres thinned increases, but the percentage increases of clearcut twice acres are higher for the high demand scenario, and in the case of thinning acres, the percentages increase from the base to the high scenario.

Table 6.15. Summary of original timberland acres clearcut and/or thinned for three timber harvesting scenarios for the second runs, 1990-2040.

Action Category*		Base Scenario			Medium Scenario			High Scenario		
		North	South	Total	North	South	Total	North	South	Total
1	Total Timberland			14,773,400			14,773,400			14,773,400
2	Not Considered			1,356,500			1,356,500			1,356,500
3	Considered	12,409,900	1,007,000	13,416,900	12,409,900	1,007,000	13,416,900	12,409,900	1,007,000	13,416,900
4	Never cut	5,591,300	652,200	6,243,500	4,217,100	582,800	4,799,900	2,416,600	535,100	2,951,700
5	Clearcut once	5,775,300	320,700	6,096,000	6,931,200	376,900	7,308,100	8,182,900	408,800	8,591,700
6	Clearcut twice	846,000	0	846,000	970,200	0	970,200	1,353,000	0	1,353,000
7	Thinned but not clearcut	197,300	34,100	231,400	291,400	47,300	338,700	457,400	63,100	520,500
8	Thinned and clearcut	2,100	19,900	22,000	7,300	37,400	44,700	17,700	46,500	64,200
9	Total never cut, sum (2+4)			7,600,000			6,516,400			4,308,200
10	Total cut, sum (5-7)			7,173,400			8,617,000			10,465,200

**Not considered* are those plots representing young stands, old growth or areas assumed not available and therefore not considered for harvest in the period 1990-2040. *Considered* are those plots representing stands that are available and in terms of age, etc., feasible to consider for harvest during the 50-year study period. Action category 8, thinned and clearcut, is included in the clearcut once category.

Table 6.16. Projected acres harvested and not harvested by scenario and initial covertype for the second runs.

Forest Type	Clearcut Once	Clearcut Twice	Thinned	Total Acres Harvested	Total Acres	Acres Never Harvested	Harvest Acres as % of Total Acres	Harvest Acres as % of Total Harvest	Forest Type Acres as % of Acres
Base Scenario									
Jack pine	117,700	5,900	1,100	124,700	446,600	321,900	27.9	1.7	3.0
Red pine	188,900	6,700	11,600	207,200	354,700	147,500	58.4	2.9	2.4
White pine	37,900	1,700	0	39,600	68,600	29,000	57.7	0.6	0.5
Black spruce	281,900	15,500	5,200	302,600	1,349,900	1,047,300	22.4	4.2	9.1
Balsam fir	311,000	46,400	16,800	374,200	809,200	435,000	46.2	5.2	5.5
Northern white cedar	10,200	0	0	10,200	648,400	638,200	1.6	0.1	4.4
Tamarack	45,300	0	4,000	49,300	719,400	670,100	6.9	0.7	4.9
White spruce	23,700	1,300	2,900	27,900	91,700	63,800	30.4	0.4	0.6
Oak-Hickory	466,900	0	23,200	490,100	1,124,700	634,600	43.6	6.8	7.6
Elm-Ash-Soft maple	248,800	2,900	13,400	265,100	1,124,600	859,500	23.6	3.7	7.6
Maple-Basswood	314,400	3,100	17,900	335,400	1,470,200	1,134,800	22.8	4.7	10.0
Aspen	3,436,600	660,300	112,200	4,209,100	5,242,200	1,033,100	80.3	58.7	35.5
Paper birch	335,500	4,000	8,200	347,700	819,000	471,300	42.5	4.8	5.5
Balsam poplar	277,200	98,200	14,000	389,400	504,200	114,800	77.2	5.4	3.4
Other	0	0	900	900					
Total	6,096,000	846,000	231,400	7,173,400	14,773,400	7,600,900	48.6	100.0	100.0

Table 6.16. (continued)

Forest Type	Clearcut Once	Clearcut Twice	Thinned	Total Acres Harvested	Total Acres	Acres Never Harvested	Harvest Acres as % of Total Acres	Harvest Acres as % of Total Harvest	Forest Type Acres as % of Acres
Medium Scenario									
Jack pine	171,200	11,600	1,100	183,900	446,600	262,700	41.2	2.1	3.0
Red pine	180,400	8,100	9,200	197,700	354,700	157,000	55.7	2.3	2.4
White pine	32,800	6,500	0	39,300	68,600	29,300	57.3	0.5	0.5
Black spruce	653,600	15,700	46,100	715,400	1,349,900	634,500	53.0	8.3	9.1
Balsam fir	458,200	54,100	28,700	541,000	809,200	268,200	66.9	6.3	5.5
Northern white cedar	30,900	5,600	900	37,400	648,400	611,000	5.8	0.4	4.4
Tamarack	112,600	0	6,300	118,900	719,400	600,500	16.5	1.4	4.9
White spruce	37,100	0	2,900	40,000	91,700	51,700	43.6	0.5	0.6
Oak-Hickory	539,600	0	34,400	574,000	1,124,700	550,700	51.0	6.7	7.6
Elm-Ash-Soft maple	385,400	3,300	22,500	411,200	1,124,600	713,400	36.6	4.8	7.6
Maple-Basswood	496,000	3,100	29,700	528,800	1,470,200	941,400	36.0	6.1	10.0
Aspen	3,464,500	749,000	123,700	4,337,200	5,242,200	905,000	82.7	50.3	35.5
Paper birch	461,100	6,700	12,000	479,800	819,000	339,200	58.6	5.6	5.5
Balsam poplar	284,700	106,500	20,300	411,500	504,200	92,700	81.6	4.8	3.4
Other	0	0	900	900					
Total	7,308,100	970,200	338,700	8,617,000	14,773,400	6,157,300	58.3	100.0	100.0

Table 6.16. (continued)

Forest Type	Clearcut Once	Clearcut Twice	Thinned	Total Acres Harvested	Total Acres	Acres Never Harvested	Harvest Acres as % of Total Acres	Harvest Acres as % of Total Harvest	Forest Type Acres as % of Acres
High Scenario									
Jack pine	337,100	18,300	11,100	366,500	446,600	80,100	82.1	3.5	3.0
Red pine	218,900	23,800	17,000	259,700	354,700	95,000	73.2	2.5	2.4
White pine	43,100	5,500	0	48,600	68,600	20,000	70.8	0.5	0.5
Black spruce	748,600	39,700	50,100	838,400	1,349,900	511,500	62.1	8.0	9.1
Balsam fir	556,900	60,500	47,100	664,500	809,200	144,700	82.1	6.3	5.5
Northern white cedar	101,800	13,400	7,600	122,800	648,400	525,600	18.9	1.2	4.4
Tamarack	298,400	0	9,100	307,500	719,400	411,900	42.7	2.9	4.9
White spruce	46,900	1,700	2,900	51,500	91,700	40,200	56.2	0.5	0.6
Oak-Hickory	622,900	0	53,900	676,800	1,124,700	447,900	60.2	6.5	7.6
Elm-Ash-Soft maple	550,900	2,300	60,200	613,400	1,124,600	511,200	54.5	5.9	7.6
Maple-Basswood	772,800	700	66,100	839,600	1,470,200	630,600	57.1	8.0	10.0
Aspen	3,368,500	1,037,900	143,700	4,550,100	5,242,200	692,100	86.8	43.5	35.5
Paper birch	638,800	18,400	29,200	686,400	819,000	132,600	83.8	6.6	5.5
Balsam poplar	272,600	130,400	21,600	424,600	504,200	79,600	84.2	4.1	3.4
Other	13,500	400	900	14,800					
Total	8,591,700	1,353,000	520,500	10,465,200	14,773,400	4,323,000	70.8	100.0	100.0

6.7
Spatial and Temporal Patterns in Harvesting by Scenario

Table 6.17 describes the harvesting by ecoregion in the second runs. The major change from the first run scenarios was implementation of ownership constraints, particularly availability of timberland. However, since the selection of plots to be designated as not available was by a random process, the result was that the geographical extent of harvesting was the same as for the first runs. Likewise, since plots designated as old growth and those noted in buffers were scattered, they also had little effect on the broad scale pattern of harvesting. However, constraining harvests to a lesser number of acres did reduce the total harvested acreage as compared to the first runs.

6.8
Changes in Age Class Structure

A summary of age classes from 1977-2040 for the three harvest scenarios is shown in table 6.18. Forest development from 1977 to 1990 indicates the average age of all covertypes, despite harvesting, continued to advance. Continued aging is shown for the base scenario for most species. The clear exceptions are aspen and balsam poplar, which are major pulpwood species with potentially short rotation ages. With the high scenario harvest rates, average stand ages decline. An important factor in the continued aging is the second run designation of timberland as not available, old growth, ERF or otherwise constrained with respect to harvesting. A tabulation of future age class distributions in appendix table 8.3 shows a buildup of older age classes as compared to the first (unconstrained) runs (see appendix table 8.2). However, comparisons of those appendix tables is difficult because of covertype change incorporated in the second runs.

A simple interpretation of these results is that Minnesota's forests will continue to age under the base or medium scenario, and there will be distinctly more acreage of the older age classes for most covertypes than at present. The high scenario is likely to lead to an age class structure similar to the present, but with acreage in both the young and older age classes, i.e., more balanced, but drawn out age class structures.

Table 6.17. Original acres cut and never cut by ecoregion and scenario, second runs, 1990-2040.

	Ecoregion							Total
	1	2	3	4	5	6	7	
Total forest land acres	3,372,000	2,023,700	903,000	8,172,900	934,700	637,200	666,300	16,714,800
Reserve/unproductive	509,600	973,900	36,300	359,800	24,400	17,300	20,100	1,941,400
Timberland acres (1-2)	2,862,400	1,049,800	871,700	7,813,100	910,300	619,900	646,200	14,773,400
Acres never cut, base	1,566,000	619,200	546,900	3,447,300	629,200	408,200	378,200	7,600,000
Acres cut, base	1,296,400	430,600	319,800	4,365,800	281,100	211,700	268,000	7,173,400
Acres never cut, medium	1,207,500	566,800	413,100	2,668,600	567,800	364,400	363,200	6,156,400
Acres cut, medium	1,654,900	483,000	453,600	5,144,500	342,500	255,500	283,000	8,617,000
Acres never cut, high	992,900	231,600	224,300	1,179,000	423,100	330,700	321,600	4,308,200
Acres cut, high	1,869,500	818,200	642,400	6,034,100	487,200	289,200	324,600	10,465,200

Table 6.18. Average stand age by covertype and harvest scenario for timberland 1977-2040.

	Average Age of FIA Plots*				
			2040		
Forest Type	1977	1990	Base	Medium	High
Jack pine	42	48	77	69	42
Red pine	43	44	54	54	41
White pine	73	80	104	102	87
Black spruce	46	59	89	61	50
Balsam fir	42	46	82	71	58
Northern white cedar	82	97	116	106	94
Tamarack	52	57	99	85	55
White spruce	33	42	90	82	76
Oak-Hickory	63	69	78	71	63
Elm-Ash-Soft maple	56	56	86	75	60
Maple-Basswood	61	58	90	80	58
Aspen	38	41	34	33	28
Paper birch	49	58	92	81	61
Balsam poplar	39	41	33	31	31

*Weighted by acreage.

6.9
Size and Composition of the Forest Land Base

The history, present extent and projections of Minnesota's forest land base was described in section 5.7. Section 4.10.1 also described how estimates of the forest and timberland and covertype change were implemented for the second runs. However, peculiarities of the FIA database and projection methodologies precluded achievement of the exact percentages of forest area suggested as appropriate by table 5.4. The 1990 to 2040 acreage changes actually obtained in the projection process are shown in table 6.19. Further, these results need to be interpreted with caution. The statewide percent change is probably the most reliable.

Table 6.20 describes the projected covertype acreages for timberland, reserved and unproductive forest land. Important among the results for timberland are:

1. The jack pine type declines in acreage, due to both succession to other types and with increased harvesting (from 427,100 to 329,600 acres for timberland in the base scenario).

Table 6.19. Projections of total forest land area change by survey unit for the second runs, 1990–2040.

a) Timberland

FIA Unit	1990	2040	Change	Percent Change
Aspen-birch	5,878,700	5,524,119	-354,581	-6.0
Northern pine	5,975,500	5,456,956	-518,544	-14.6
Central hardwood	2,275,400	2,988,059	+712,659	+31.3
Prairie	643,000	910,315	+266,515	+41.4
All units	14,773,400	14,879,449	+106,049	+0.7

b) Total Forest Area

FIA Unit	1990	2040	Change	Percent Change
Aspen-birch	7,362,000	7,007,419	-354,581	-4.8
Northern pine	6,336,400	5,816,556	519,844	-8.2
Central hardwood	2,357,200	3,098,307	741,107	+31.5
Prairie	660,400	934,697	274,297	+41.5
All units	16,714,800	16,714,800	142,179	+0.8

2. The red pine covertype increases by approximately 100,000 acres, but that appears due more to retention of that longlived species and succession than to planting or natural regeneration.

3. The white pine covertype increases in acreage. However, reference to the covertype algorithm used (see table 4.14) suggests that most of the gain from 1990 was really due to the difference between the FIA covertype algorithm used versus the GEIS algorithm used in 2040.

4. The acreage in the black spruce covertype appears to have declined by 2040 with subsequent gains to the tamarack and aspen covertype acreages. (For timberland the decline was from 1,320,800 to 1,001,200 acres for the base scenario.)

5. Again, with reference to the algorithm used, the balsam fir acreage declined from 1990 to 2040 from 1,012,500 to less than 700,000 acres under all three scenarios. The aspen covertype appears to be a major recipient of that acreage.

Table 6.20. Forest type acreage for FIA timberland, reserved and unproductive plots, 1990 and projected for the second runs to 2040, statewide (thousand acres).

Forest Type	1990				2040					
	Timberland*	Reserved	Unproductive	Total	Timberland Base Scenario	Timberland Medium Scenario	Timberland High Scenario	Reserved	Unproductive	Total Base Scenario
Jack pine	(427.1) 447.5	131.5	0	579.0	329.6	307.4	272.6	56.2	1.2	386.8
Red pine	(350.6) 301.6	80.4	0	382.0	452.4	454.4	433.2	87.7	.9	537.4
White pine	(137.3) 63.2	3.8	1.3	68.3	141.0	136.0	120.2	32.6	1.3	174.9
Black spruce	(1,320.8) 1,322.1	126.6	533.7	1,982.4	1,001.2	945.4	957.8	88.3	547.5	1,637.0
Balsam fir	(1,012.5) 734.3	93.1	12.5	839.9	657.4	598.4	589.6	72.9	18.5	748.8
Northern white cedar	(322.4) 680.5	25.1	38.3	743.9	360.9	370.4	370.6	8.5	40.7	410.1
Tamarack	(696.2) 705.1	8.9	110.7	824.7	678.7	704.4	701.7	6.9	118.2	803.8
White spruce	(137.0) 93.8	39.9	0	133.7	227.9	202.7	158.2	106.7	0	334.6
Oak-Hickory	(1,288.0) 1,190.4	9.5	13.4	1,213.3	1,370.2	1,322.3	1,354.1	18.6	18.8	1,418.7
Elm-Ash-Soft maple	(1,564.2) 1,291.5	42.8	33.1	1,367.4	1,744.0	1,714.8	1,721.5	95.4	35.2	1,864.0
Maple-Basswood	(1,301.8) 1,396.7	17.0	0	1,413.7	1,460.2	1,368.6	1,255.2	34.8	2.1	1,506.1
Aspen	(4,496.0) 5,115.4	422.1	30.3	5,567.8	5,238.7	5,496.5	5,730.0	393.5	36.8	5,667.8
Paper birch	(1,179.3) 834.7	94.9	2.1	931.7	803.4	806.2	741.7	123.6	6.5	931.0
Balsam poplar	(480.1) 427.7	7.1	8.4	443.2	413.7	451.8	473.0	14.5	9.5	436.0
Nonstocked	(0) 168.9		43.5	222.8						
Other	(0) 0	10.4	1.0	0						
Total	14,773.4	1,113.1	828.3	16,714.8	14,879.4	14,879.4	14879.4	1,140.2	837.3	16,857.0

Source: Timberland acreage by forest type for 1990 were developed from survey unit reports by Kingsley (1991), Murray (1991), Leatherberry (1991) and Roussopoulous (1992). Reserved and unproductive acreages for 1990 were developed from FIA test data.

*Values in parentheses are 1990 acres as determined by GEIS covertype algorithm (see table 4.14).

6. The northern white cedar type acreage appears stable over the study period and across the harvest scenarios.

7. The acreage of tamarack appears to increase slightly over the study period for the medium and high harvest scenarios.

8. The white spruce covertype acreage, like that for white pine, is very sensitive to the covertype algorithm used. While it decreases as harvesting level increases, it is higher than that for 1990 for all harvest scenarios.

9. Oak-hickory covertype acreage appears to increase over 1990 for all harvest scenarios (from 1,288,000 to 1,370,200 acres for timberland in the base scenario or 6 percent).

10. Elm-ash-soft maple covertype acreage increased substantially over the study period, in part due to forest area increase in the southern portion of the state.

11. Maple-basswood covertype acreage increased for the base scenario, then declined for the higher harvest levels.

12. Aspen covertype acreage appears to increase 14, 18, and 22 percent over its initial extent (4,496,000 acres) for the base, medium and high scenarios, respectively, considered over the 50-year study period. However, interpretation should recognize that several other covertypes, notably paper birch and balsam fir, have stands with high proportions of aspen that could, by a slight change in species composition or the algorithm for determining that, be called aspen. Likewise, much of the aspen acreage is mixed and could change slightly and be reclassified as paper birch, balsam fir, jack pine, etc.

13. The paper birch covertype appears to decline by several hundred thousand acres. However, like aspen many of these acres are of mixed species and thus while acreage has changed, the overall species composition change of the original areas probably changed less than the covertype area change suggests. As shown in table 6.18, the aging of this type is also a factor contributing to succession to other species.

14. The balsam poplar covertype acreage declined with the base scenario and then increased with higher harvesting levels.

15. When the harvesting level increased from the base to the medium scenario, covertype acreage declined for eight covertypes. When the harvesting level increased from the medium to the high scenario, five

of these eight continued to decline and three others also declined. Six covertypes showed an increase in acreage from the medium to the high scenario.

16. In the northern region of the state, large percentage declines in acreage in reserved areas were noted for jack pine, black spruce, balsam fir, and northern white cedar. Large percentage increases were noted for white pine and white spruce. Reserved acreage increases in the south are due largely to the assumptions incorporated into the model regarding forest area increases there.

17. The acreage of the major unproductive forest types (black spruce, tamarack, northern white cedar and aspen) appear stable over the study period.

A further caution in interpreting these results is that long-term covertype change, in the absence of harvesting, is strongly affected by new trees growing into a stand. The absence of an ingrowth model to estimate that probably leads to underestimation of natural processes of stand dynamics, species replacement and covertype change.

Reference to the acres harvested and not harvested by covertype in table 6.16 also suggests the effect that harvesting might have on covertype acreage. For example, more than doubling the black spruce harvest acreage from 302,600 to 715,400 acres led to a decline of only 55,800 acres in this covertype. However, harvesting in other covertypes that subsequently were classified as black spruce probably mask the full effect on the acres originally classified as black spruce.

Overall, results suggest that future covertype area *is* sensitive to the level of harvesting and that the response is species or covertype specific. In the case of several covertypes, increases or decreases over a 50-year period can exceed 40 percent of the current acreage. In considering practices to contain or direct such changes, however, it is important to recognize that natural stand dynamics and succession can be important contributors to covertype change. Finally, covertype designation and interpretation, despite quantitative algorithms for classification, is still subjective and needs to recognize the highly mixed species structure of the forests in Minnesota.

6.10 Species Composition and Age Class Structure

Tree Species Composition

Tree species composition changes can occur in the form of species composition within a covertype, often related to stand age or stage of development, and in terms of covertype acreage. For the second runs, future species composition was estimated as in the first runs, by multiplying the future acreages by age class by the 1990 species composition by age class. Results are shown in tables 6.21. Detailed tables of results by covertype are shown in appendix 13. Table 6.21 presents a summary of 1990 and projected species composition to 2040 for the base, medium and high scenarios across all covertypes.

Upon examination, it would appear that the ownership constraints and mitigations have been very effective in moderating changes in species statewide. This is evident for upland, lowland and riparian species. Changes across scenarios, as a percent of 1990 values, are small for most species. The species showing large percentage declines are, with two exceptions, a subset of those found to have a significant impact in the first runs: Ailanthus, black locust, black maple, Kentucky coffee tree, other hardwoods, and rock elm. The exceptions were black spruce (a major forest species) and Scotch pine. Black spruce tree numbers, while still large, showed a 26 and 34 percent decline from 1990 tree numbers for the medium and high harvest scenarios.

Much of the decline in black spruce tree numbers can be attributed to the reduction in covertype acreage for the three scenarios. Also, unlike aspen which reaches breast height (and hence 0.95 inches dbh) in one to two years, regenerated stands of black spruce can take a decade or more to reach measurable size. Thus, young stands of black spruce may actually have fewer measurable stems per acre than stands that are a decade or more older. Related to that, the base, medium and high harvest scenarios led to progressively more acres in the 5-, 15-, and 25-year age classes, and dramatically fewer acres in the 35- to 105-year age classes which in 1990 contained most of the trees in the covertype. At the same time, the harvest scenarios, because of ownership constraints and mitigations, allowed considerable acreage to advance to older and less well-stocked age classes.

Because most species are found in many covertypes, results across covertypes are emphasized here. The pattern was found to be similar for trees of Dbh $\geq$ 4.5 inches as well (see appendix tables 13.69 to 13.72). Unfortunately, a lack of FIA plot data for reserved and some unproductive plots precludes a separate analysis for those categories of forest.

Table 6.21. Summary of projected tree species composition for 1990 and 2040 for base, medium and high harvest scenarios on timberlands for the second runs (thousands of trees $\geq$1.0 inch dbh).*

Species	1990	2040		
		Base	Medium	High
Ailanthus	39	15	14	13
American hornbeam	14,419	12,049	12,500	11,521
American basswood	192,090	191,702	184,698	176,313
American elm	150,006	147,215	146,216	148,778
Apple	386	430	509	641
Balsam fir	979,317	863,263	849,201	796,018
Balsam poplar	266,466	283,080	314,295	358,967
Bigtooth aspen	73,184	82,074	88,197	97,201
Bitternut hickory	8,044	8,573	8,590	9,880
Black ash	527,482	662,467	640,214	607,040
Black cherry	35,429	46,605	48,805	52,004
Black locust	455	133	129	135
Black maple	154	125	101	82
Black oak	710	792	735	799
Black spruce	1,039,098	911,752	769,542	686,000
Black walnut	2,289	2,222	2,277	2,443
Black willow	5,702	4,721	5,453	6,373
Boxelder	66,672	82,430	81,689	83,114
Bur oak	190,446	183,028	186,455	189,174
Butternut	2,941	4,442	4,235	4,409
Chokecherry	33,848	36,689	39,035	42,337
Eastern cottonwood	2,735	2,272	2,340	2,363
Eastern redcedar	14,051	17,977	19,194	20,913
Green ash	86,474	79,551	80,027	84,869
Hackberry	14,714	14,842	14,054	13,220
Hawthorn	8,810	8,922	9,476	11,435
Ironwood	117,990	130,328	134,496	143,275
Jack pine	164,593	93,530	98,865	126,646
Ky. coffee tree	445	142	143	157
Mountain ash	1,497	3,273	3,122	2,366
Mountain maple	105,825	115,557	107,763	89,360
N. white-cedar	386,818	615,904	530,282	416,061
Northern pin oak	5,975	5,541	5,865	6,465
Northern red oak	111,893	97,402	97,153	97,435

Table 6.21. (continued)

Species	1990	2040		
		Base	Medium	High
Other hardwood	41,155	32,342	27,419	20,636
Paper birch	570,934	440,801	459,276	461,745
Peachleaf willow	489	642	678	706
Pincherry	13,140	16,541	17,905	19,499
Ponderosa pine	398	387	434	795
Quaking aspen	1,986,789	2,730,630	2,930,033	3,418,737
Red maple	290,717	223,765	237,572	249,212
Red mulberry	988	985	1,172	1,532
Red pine	97,800	107,691	112,701	132,128
River birch	185	1,682	1,660	1,408
Rock elm	1,572	1,881	1,609	891
Scotch pine	1,630	1,123	1,346	1,746
Shagbark hickory	9,145	11,075	11,376	12,691
Siberian elm	399	391	562	699
Silver maple	9,552	8,890	8,239	7,550
Slippery elm	23,016	27,284	27,220	27,155
Striped maple	463	397	370	367
Sugar maple	283,728	266,355	243,789	213,820
Swamp white oak	454	1310	1,118	776
Tamarack	361,461	299,180	306,991	291,762
White ash	2,494	2,835	2,936	2,701
White oak	10,058	11,377	10,607	10,519
White pine	29,566	29,709	29,298	23,520
White spruce	78,620	76,604	77,665	73,822
Wild plum	5,331	5,361	5,824	6,953
Yellow birch	11,746	20,882	19,500	14,772
Grand Total	8,442,827	9,029,168	9,022,970	9,283,949

* The numbers in the 1990 column differ from those for the first runs (see table 5.6) because the second runs used the GEIS rather than the FIA covertype algorithm.

6.11 Patterns of Forest Cover

The ownership constraints and mitigations implemented in the second runs have important implications. First, any given ecoregion should, over time, develop a broad range of age classes. That will come about through old growth reservation, extended rotation forest, riparian zone management via

BMPs and forest that is not available for harvesting. The expansion of forest area in the southern part of the state should also aid the linking of important habitat. The uncertainty is the degree to which land use change and development and the attendant infrastructure will diminish the linking of forest areas.

6.12 Summary of Key Results and Impacts

Analysis of the results of the first runs led to modelling refinements and the incorporation of ownership constraints and possible mitigations. Consequently, the second runs represent a more detailed and realistic look at the specified harvest levels and how they might be achieved, given various mitigations.

Among the existing and prospective agency policies and procedures and mitigations, accepted and/or modified by the Advisory Committee, those that were amenable to implementation in the second runs were:

- ERF, i.e., lengthened (usually by 50 percent) minimum rotation ages for approximately 20 percent of the timberland on state and USDA Forest Service ownerships;
- greater use of uneven-aged management (approximated by thinning practices);
- designation and reservation of old growth and acreage that might replace that;
- BMPs, i.e., thinning or ERF within 100 feet of water; and
- wildlife buffers (thinning only within 200 feet of water) on the national forests and in the southeastern part of the state.

In addition, estimates of the actual availability of timberlands for harvest or management, developed separately by ownership, were used to set aside a portion of the timberland as *not available* for various economic, environmental and social concerns.

Other model changes for the second runs included refinement of the silvicultural decision trees used in the first runs to lengthen minimum rotation ages from 40 to 50 or more years. The exceptions were for aspen and balsam poplar where minimum rotation ages were retained at 40 years. Thinning options were also refined, notably to reflect desired practice within buffers and for approximating and encouraging uneven-aged management.

Forest and timberland area change from 1990 to 2040 was also implemented gradually throughout the 50-year period using estimates of annual change rates. Changes in forest area were assumed to occur on nonindustrial private lands in the northern part of the state with equal percentage changes applied across all forest types. For the southern part of the state, changes were assumed to occur equally across all ownerships. The area change translated into a 873,125 acre decrease in timberland in the two northern FIA units and a 979,174 acre increase in the southern two FIA units by the year 2040. While the net change is small, these changes clearly impact results.

Covertype areas were further subjected to change occurring at the time of harvest and later via stand dynamics or succession. Change occurring at harvest was developed from (1) decision trees for planting and (2) covertype change determined from natural regeneration patterns. Subsequent to harvest, the individual tree-based growth model projections were evaluated by a covertype determination algorithm at the end of each ten-year projection period. This evaluation allowed for estimating covertype change due to stand dynamics and successional processes. This was a major difference in procedure from the first model runs, where essentially all cover types that were naturally regenerated were assumed to remain in that covertype.

Since the first runs, the USDA Forest Service FIA project has developed factors to adjust the tree growth and mortality in the growth model used. These factors were implemented in the second runs to improve predictions. In most cases, the adjustment factors served to reduce estimates of forest growth.

Harvests from national forests were also constrained to the allowable sale quantities in their respective forest plans, with the exception of the high scenario.

Timber product values and consumption by various markets were also updated as new information became available.

The various model changes do confound comparisons with the first runs as differences are due both to the addition of mitigative constraints and model changes in the revised runs.

Impacts of Constraints and Mitigations on Results

With all the ownership constraints, mitigative measures and model changes incorporated in the second runs, the base scenario was at first found to be infeasible, as the aspen consumption level could not be met even when using unrealistically high aspen shadow prices. Shadow prices are equivalent to the marginal costs of producing an addition unit of the associated product. Major reasons for the infeasibility were (1) the substantial shift of acres into categories considered unavailable for harvest or requiring long rotation lengths, (2) reduced forest growth estimates, and (3) reductions of timberland area in the north. Further review also suggested that contributing factors were (1) the short planning period and (2) the existing age-class imbalance of the forest.

Adjustments to achieve feasibility involved lengthening the planning horizon to sixty years, but that in itself did not overcome the infeasibility problems. To finally overcome this problem it was necessary to lower the aspen harvest target levels. This meant that some of the aspen demand would need to shift to other species in future periods of the planning horizon. It is likely that decreasing aspen supplies along with associated increases in prices relative to other species will stimulate a substantial shift in demand to those other species. Predicting the extent of the shift, however, is fraught with uncertainty. To move forward, it was assumed that the shift in the projected aspen consumption would be to hardwoods, as hardwoods exhibited the lowest marginal costs of production for the first model runs. For the medium scenario, it was found that harvest levels could be achieved if 10 percent of the aspen harvest level was shifted to northern hardwoods by the year 2000, with an additional shift in year 2010 for a total shift of 25 percent. For the base scenario, the same 25 percent shift was assumed even though it was clear that feasible schedules could be developed with somewhat smaller shifts. Final marginal cost estimates for the base and medium scenarios served to guide the development of targets for the high scenario. Given these assumptions, specific second run findings were:

1. Under the *base scenario*, the rising and higher marginal costs for aspen confirm concerns for the future supply of aspen. Marginal costs for the pine group under the base scenario actually drop substantially over the planning horizon. This drop is likely due to past red pine reforestation efforts, as many plantations will reach harvestable age in later periods of the planning horizon. However, compared to typical rotation lengths for red and white pine, the short planning horizon does not fully address pine reforestation needs to meet potential harvest level targets for periods beyond 2040. Had a longer planning horizon been considered, marginal costs associated with pine might need to be higher to reflect the need for reforestation efforts. Compared to all other species groups, marginal costs for northern hardwoods remain low over time.

2. Under the *medium scenario*, marginal cost estimates again suggest that aspen is the species in shortest relative supply. Marginal costs rise to over $80 per cord delivered for aspen while those for northern hardwoods remain relatively low. Marginal costs for spruce-fir under the medium scenario rise steadily and approach $80 per cord by the end of the planning horizon. As with the base scenario, marginal costs for pine decline.

3. For the *high scenario*, marginal cost estimates increase substantially for all species. The marginal cost of producing hardwoods also rises substantially above the marginal cost of other species by the end of the planning horizon. This suggests that in achieving a seven million

cord harvest level, the harvest for northern hardwoods was set too high. The high marginal costs for all species by the end of the planning horizon also suggests that these harvest levels could not be maintained over a longer time horizon. Maintaining them would require either reducing the constraints and mitigations imposed or implementing intensive forest management options not considered in these runs and doing so on a large-scale.

4. Marginal cost estimates for pine changed relatively little between the base and medium scenario. Substantially higher costs for the highest scenario reflect the much higher harvest targets for pine under that scenario. Marginal costs for spruce-fir changed substantially between the base and medium scenario, suggesting that a large spruce-fir harvest level increase will have a large impact on the future production cost and price for spruce-fir.

5. Constraints to implement the allowable sale quantities for each national forest carried a marginal cost estimate measuring the cost savings that could be achieved if an additional cord could be harvested from national forest timberland. Marginal cost estimates were not developed for the high scenario as constraints defining allowable sale quantities were not imposed with that scenario. Considering the potential of national forest timberlands, it is apparent that both national forests have the potential to produce substantially more timber than is reflected in their allowable sale quantities. Model runs for the high scenario suggested that harvest level targets could not be met without additional harvesting on the national forests.

6. The southern region of the state showed marginal costs for red oak are higher and tend to rise rapidly over time for scenarios with higher red oak harvest levels. A relatively constant and low marginal cost for the "other wood" group for all three scenarios suggests that the harvest level targets for this group could have been raised more for the high scenario. However, this region contains a relatively small component of the statewide timber supply and could not support a large increase.

7. The breakdown of harvest volumes by product category showed some changes in utilization. Under the base scenario, only aspen shows a large reduction in the quantity of sawlogs produced over time, dropping from over 1 million cords per year in period 1 to approximately 475,000 cords in period 4. This reduction is due to a change in age class and associated size of available timber as the scenario progresses. Similar drops occurred for the medium and high scenarios. However, even with the drop, production of aspen

sawlog size material is still substantially above the estimate of 210,000 cords for current annual consumption of aspen sawlogs by sawmills. Under all three scenarios, pine sawlog production is above current pine sawlog consumption by sawmills. The highest scenario assumed more than a doubling of the pine sawlog consumption level over the medium scenario, as this product group appeared to have the potential for a large increase.

8. Results for the southern region of the state suggest a broad mix of species will continue to be harvested, with an increase in the production of aspen and maple-basswood over time.

9. Harvest acreages for each scenario are summarized in table 6.22. The acres cut category includes those acres clearcut once, acres clearcut twice, acres thinned but never clearcut, and acres thinned and clearcut. Compared to the first model runs, the second runs reduced the overall acreage subject to harvesting over the 50-year planning horizon and did so by harvesting some acres more frequently. This reduction of acreage subject to harvesting uses a result of increased management constraints.

Table 6.22. Original acres cut one or more times and never cut in first and second runs, 1990–2040.

Forest land use and harvest status	First model runs Total (acres)	Second model runs Total (acres)
Total forest land acres	16,714,800	16,714,800
Reserved/unproductive	1,941,400	1,941,400
Timberland	14,773,400	14,773,400
Base Scenario		
Acres never cut	5,996,900	7,600,000
Acres cut	8,776,500	7,173,400
Medium Scenario		
Acres never cut	4,550,700	6,156,400
Acres cut	10,222,700	8,617,000
High Scenario		
Acres never cut	1,823,400	4,308,200
Acres cut	12,950,000	10,465,200

10. Changes in results for the second runs are not surprising. The forest area in the southern part of the state expanded and that in the north declined. Additionally, several constraints reduce the proportion of forest area available for harvest overall, especially on public lands. The growth model adjustment further reduced estimated yields and the ERF options slowed realization of some of those yields. Prices

thus rose, making management investments more attractive and probably increasing the harvest on private lands. Areas with harvesting constraints likewise tend to reduce the long-term sustained yield. In terms of the resource, there is a slight buildup in the acreage of older age classes and values associated with that. In total, these changes will likely reduce the timber yield unless counteracted by investments in management that in themselves do not conflict with mitigations for other purposes. In reviewing the results, it is important to remember that these results are still not a plan, but a refinement of the first run assessments.

11. Revised long-term sustained yield analyses were performed (see section 6.13) in much the same manner as the earlier long-term sustained yield analyses. However, there were some key differences. The revised analyses are based on the updated growth model and take into account ownership constraints, mitigative strategies and the results of the revised timber harvest scheduling runs. Specifically, the long-run supply analyses used area control methods. Also, the ending inventory from the scheduling model was analyzed using the marginal costs as timber prices to determine the management alternative for each FIA inventory plot that maximizes the soil expectation value of the plot. Using that alternative, average annual yields were determined for each plot and then summed over all plots representing timberland potentially available for harvest. Results varied substantially depending on whether the marginal costs of the base, medium or highest harvest level scenario were used in selecting the optimal management alternative. The biggest difference between scenarios was the area considered profitable for timber production. The resulting profitable acreage was 7.4, 9.7 and 12.5 million acres for the base, medium, and high scenarios, respectively.

12. Using the above approach to analyze long-term sustainable yield, the acres harvested within the aspen forest type changed relatively little between scenarios, but the optimal rotation age for most aspen acres is sensitive to the prices assumed.

13. The lack of acreage in the red pine plantation category is a concern. Even under the highest scenario, shadow prices were not high enough to suggest shifting acres into this forest type. However, results would have been different if a longer planning horizon had been used, giving more consideration to longer-term harvest level objectives. The growth model may also have shortcomings in predicting plantation yields. In terms of a sustained yield, shifting acres into the red pine plantation category would increase the sustainable yield, as average annual growth rates for red pine are very high compared to most other species.

14. The *base scenario* analysis led to an estimate that a timberland area of approximately 7.4 million acres could sustain close to a 4 million cord annual harvest level. This would leave over 7 million potentially harvestable acres unharvested over the long-term. This explains why the forest industry sees development opportunities in Minnesota. The analysis further suggests that annual harvest levels higher than 4 million cords could be sustained in the long-term once the forest is regulated, i.e., when the age class structure is balanced. It also suggests that large areas of timberland could at least potentially be shifted towards other management objectives without severely impacting timber production at the 4 million cord level in the long-term.

15. The *medium scenario* analysis indicates that long-term sustained yield levels could be maintained at the 5 million cord annual harvest level by utilizing less that 10 million acres of timberland. With the potential to shift additional acreage to plantations or more intensive management options, results strongly suggest that a five million cord level could be maintained in the long-term once a regulated condition is achieved.

16. The *high scenario* analysis utilized most of the timberland acreage assumed to be available and yet fell over 1.5 million cords short of the assumed 7 million cord annual harvest level. This suggests that the high level could not be maintained in the long-term without a substantial increase in management intensification and/or reducing the loss of timberland acreage to other land uses. As one moves from the medium to the high scenario, the sustainable harvest level increases 680,000 cords but requires adding 2.7 million acres to the harvested land base. This is an average increase of only 0.25 cords per acre compared to an average annual harvest level of 0.53 cords acre, based on the land base assumed for the base scenario. Clearly those additional acres are less productive sites. This highlights the need to recognize differences in site quality in decisions affecting timber production.

17. As in the first runs, overall, tree species composition on timberlands was only moderately affected by these harvesting scenarios. Ownership constraints and mitigations also served to reduce the number of species that showed large declines in tree numbers.

18. Covertype change trends remain strongly affected by the species and age class structure resulting from the logging and land clearing of the past. In general, the higher harvesting scenarios favored an increase in aspen (14, 18 and 22 percent under the base, medium and high scenarios, respectively, over the 50-year planning horizon). Long-

term trends also seem to show a significant decline in jack pine and black spruce covertype acreage. However, those changes are suspected to be due as much to stand dynamics and natural succession and the imprecision of covertype determination as they are to harvesting. For mixed species stands like these, even small changes can lead to a new covertype designation—yet overall species composition is affected very little. Conversely, red and white pine covertype acreage increased. However, those changes are suspected to be due in large part to succession and/or covertype determination procedures as opposed to harvesting and management.

19. Reserved forest, though not subjected to harvesting, also changed through stand aging processes and successional processes.

20. Preferred mitigations to maintain the forest resource base include incentives for afforestation, reforestation and policy instruments that would reduce the loss of forest land, notably timberland, to other land uses. Preferred mitigations to improve the productivity of forest lands are management investments, including but not limited to species-site matching, regeneration to full stocking levels, capturing mortality through shorter rotations and thinnings. The net effect of such investments can be enhanced timber supply and reduced conflict with other forest uses by improving per acre productivity, thereby reducing the acreage that might need to be harvested to meet any particular level of demand.

6.13 Sustained Yield Considerations

Revised Long-term Sustained Yield Analyses

Section 5.11 described several reasons for developing an analysis of sustained yield beyond the 1990-2040 study period. Given that the second runs involved numerous model refinements, changes in assumptions, ownership constraints and mitigations, a similar analysis of the second runs is also appropriate.

The revised harvest scheduling model runs used an updated growth model and mitigative strategies such as buffers along sensitive areas and extended rotations for a large portion of the forest. Other timberland areas were considered unavailable for timber harvest and at least some acres available for harvest were not scheduled for harvest as shadow prices suggested it was undesirable. The revised harvest scheduling runs also extended the planning horizon to 60 years, but 60 years is still too short for considering concerns related to long-term sustainable harvest levels. A 60-year planning horizon is also too short to address reforestation needs, as benefits of many reforestation alternatives would not be realized within the planning horizon.

Although the scheduling model values ending inventory and holds financially immature timber for periods beyond the planning horizon, there is still concern about the age imbalance of the forest. Specifically, attention is focused on the extent to which older, financially mature timber might be liquidated during the planning horizon. That could result in a harvest level that could not be sustained in the long-term.

The revised long-term sustained yield analyses were performed in much the same manner as the earlier long-term sustained yield analyses and as performed by the Minnesota DNR. However, there were some key differences. The revised analyses are based on the updated growth model and take into account ownership constraints, mitigative strategies and the results of the second runs. Specifically, the long-run sustained yield analyses used area control (see section 5.11.1 to 5.11.3), where the ending inventory from the scheduling model was analyzed using the shadow prices as timber prices to determine the management alternative for each FIA inventory plot that maximizes the soil expectation value of the plot. Impacts of mitigative strategies such as extended rotations and buffer zones were considered by limiting the harvest and management alternatives for plots representing those areas. Using the alternative that maximizes the soil expectation value, average annual yields were determined for each plot and then simply summed over all FIA plots representing timberland area that is potentially available for harvest.

Results of this long-term sustained yield analysis varied substantially, depending on whether the results (shadow prices) of the base, medium or highest harvest level scenario were used in selecting the optimal management alternative. The biggest difference between scenarios was the area considered desirable for timber production, based on the corresponding shadow prices. Total acreages are summarized in table 6.23 below.

Table 6.23. Summary of area that is economically available for harvesting (thousand acres).

	Scenario		
Profitability status	Base	Medium	High
Profitable area	7,396.3	9,742.3	12,453.6
Not Profitable area	6,020.6	3,674.6	963.3
Total area potentially available for harvest	13,416.9	13,416.9	13,416.9

This summary is based on the assumption that the statewide total of timberland will not change over time from the acreage estimated from the 1990 FIA survey. The long-term sustained yield analysis was repeated to consider the impact of the estimated change in the timberland area. As might be expected, results for the state as a whole varied very little as the net change for the state as a whole was very small.

For both the base and medium scenarios, constraints were included in the harvest scheduling runs to limit timber volumes harvested from national forest lands. Shadow prices associated with these constraints were also used in the long-term sustained yield analysis. A substantial portion of the increase in *profitable* acres for the highest scenario is attributable to the fact that the constraint (*tax*) on national forest timber production was dropped for the highest scenario in the second runs.

With this approach to analyze long-term sustainable yield, all acres within a given forest type *are not* assumed to be managed according to a single rotation age. Table 6.24 shows the distribution of acres by forest type and rotation age for each of the long-term sustained yield analyses. Note that the acres harvested within the aspen forest type change relatively little between scenarios, but the optimal rotation age for most aspen acres is sensitive to the price level assumed. For the analysis based on the shadow price estimates associated with the highest scenario, most aspen acres are managed on a 40-year rotation. The older rotations for some acres reflect acres representing buffer areas or areas assigned to extended rotations.

Another important point to recognize concerning the long-term analyses is the lack of acreage in the red pine plantation category. Even under the highest scenario, shadow prices were not high enough to suggest shifting acres into this forest type. This result should be questioned. Perhaps results would have been different if a longer planning horizon had been used, giving more consideration to longer-term harvest level objectives. In terms of a sustained yield, shifting acres into the red pine plantation category would increase the sustainable yield as average annual growth rates for red pine are very high compared to most other species.

Table 6.25 summarizes the results of the long-term supply analyses. The base scenario analysis shows that a timberland area of approximately 7.4 million acres could sustain close to a 4 million cord annual harvest level. This would leave over 7.5 million potentially harvestable acres unharvested over the long-term. This result helps explain why forest industry sees development opportunities in Minnesota. It strongly suggests that annual harvest levels higher than 4 million cords could be sustained in the long-term from a biological perspective once the forest age class structure is regulated. It also suggests that large areas of timberland could potentially be shifted towards other management objectives; for example, wildlife habitat, without severely impacting timber production at the 4 million cord level in the long-term.

Table 6.24. Forest type area by rotation age for the revised long-term sustained yield analyses for the second runs (thousands of acres).

Forest type	Scenario	Total Acres	Rotation Length (years) 40	50	60	70	80	90	100	110	120
Jack pine	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	59.1	0.0	0.0	0.0	0.0	2.5	5.1	51.5	0.0	0.0
	high	233.2	0.0	202.7	0.0	22.7	0.0	0.0	7.8	0.0	0.0
Red pine plantation	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	high	3.7	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0
Red pine natural	base	241.2	0.0	0.0	15.8	115.8	54.7	8.8	17.9	17.0	11.2
	medium	259.1	0.0	0.0	53.8	156.8	28.8	1.1	9.1	0.0	9.5
	high	360.9	0.0	0.0	79.0	227.0	23.1	0.0	12.1	0.0	19.7
White pine	base	34.4	0.0	0.0	0.0	0.0	10.9	0.0	0.0	22.1	1.4
	medium	33.6	0.0	0.0	0.0	3.4	28.8	0.0	0.0	0.0	1.4
	high	59.1	0.0	0.0	2.5	52.1	0.0	1.4	0.0	0.0	3.1
Black spruce	base	367.6	0.0	0.0	214.9	28.9	59.6	8.7	9.0	4.7	41.8
	medium	666.6	0.0	0.0	564.3	7.2	41.8	0.0	0.0	0.0	53.3
	high	882.3	0.0	0.0	750.9	0.0	72.4	0.0	0.0	0.0	59.0
Balsam fir	base	129.1	0.0	38.3	65.6	8.9	0.0	2.0	14.3	0.0	0.0
	medium	312.4	0.0	278.6	0.0	14.3	0.0	0.0	19.5	0.0	0.0
	high	438.8	0.0	378.0	0.0	31.6	0.0	0.0	29.2	0.0	0.0
Northern white cedar	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	high	160.5	0.0	0.0	0.0	160.5	0.0	0.0	0.0	0.0	0.0
Tamarack	base	15.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	11.8
	medium	298.9	0.0	0.0	73.4	152.8	38.1	10.0	0.0	1.1	23.5
	high	703.4	0.0	0.0	582.9	0.0	73.5	0.0	0.0	0.0	47.0
White spruce natural	base	31.1	0.0	0.0	21.0	0.0	2.2	0.0	0.0	4.5	3.4
	medium	46.7	0.0	0.0	34.6	3.0	5.7	0.0	0.0	0.0	3.4
	high	51.5	0.0	0.0	42.4	0.0	5.7	0.0	0.0	0.0	3.4
Oak-Hickory	base	179.5	0.0	0.0	3.7	24.8	0.0	139.1	0.0	0.0	11.9
	medium	670.7	0.0	0.0	159.5	79.9	3.8	116.5	284.9	0.0	26.1
	high	842.9	0.0	0.0	508.2	0.0	10.0	0.0	288.4	0.0	36.3
Elm-Ash-Maple	base	593.8	0.0	0.0	335.5	127.0	20.6	0.0	0.3	0.0	110.4
	medium	919.2	0.0	0.0	747.0	6.3	34.5	0.0	0.3	0.0	131.1
	high	1252.9	0.0	0.0	1016.1	0.0	63.9	0.0	0.5	0.0	172.4
Maple-Basswood	base	364.9	0.0	0.0	0.0	100.8	0.0	45.0	102.5	0.0	116.6
	medium	607.1	0.0	0.0	0.0	335.3	0.0	60.8	93.6	0.0	117.4
	high	874.0	0.0	0.0	0.0	600.9	0.0	28.7	98.4	0.0	146.0
Aspen	base	4814.5	1172.8	3191.6	274.2	1.6	174.3	0.0	0.0	0.0	0.0
	medium	5076.4	1211.7	3378.4	301.1	0.0	185.2	0.0	0.0	0.0	0.0
	high	5553.1	5001.6	0.0	322.2	0.0	229.3	0.0	0.0	0.0	0.0
Paper birch	base	234.3	0.0	23.6	63.3	37.2	81.8	1.1	27.3	0.0	0.0
	medium	376.1	0.0	322.5	3.8	17.2	1.3	0.0	31.3	0.0	0.0
	high	557.4	0.0	476.5	0.0	38.5	0.0	0.0	42.4	0.0	0.0
Balsam poplar	base	390.3	303.5	48.5	17.3	0.0	21.0	0.0	0.0	0.0	0.0
	medium	416.4	368.1	7.1	20.2	0.0	21.0	0.0	0.0	0.0	0.0
	high	479.9	424.2	0.0	19.7	0.0	36.0	0.0	0.0	0.0	0.0
	base	7396.3	1476.3	3302.0	1011.3	445.0	425.1	204.7	171.3	52.1	308.5
	medium	9742.3	1579.8	3986.6	1957.7	776.2	391.5	193.5	490.2	1.1	365.7
Total	high	12453.6	5425.8	1057.2	3327.6	1133.3	513.9	30.1	478.8	0.0	486.9

Table 6.25. Volume yield by forest type and product group for the revised long-term sustained yield analyses of the second runs.

Forest type	Scenario	Total Volume	Aspen		Spruce-fir		Pine			Hardwoods		
			pulp	saw	pulp	saw	pulp	red & white saw	other pine saw	pulp	red oak saw	other saw
Jack pine	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	15.3	0.4	1.8	0.1	0.1	5.2	1.0	6.1	0.5	0.0	0.1
	high	103.4	8.7	1.2	1.7	0.9	67.1	0.9	20.3	1.8	0.0	0.8
Red pine plantation	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	high	3.8	0.1	0.0	0.0	0.0	0.6	3.1	0.0	0.0	0.0	0.0
Red pine natural	base	191.9	1.3	1.0	0.5	0.0	26.5	133.6	29.0	0.0	0.0	0.0
	medium	201.2	2.4	1.0	0.9	0.0	29.2	136.9	30.8	0.0	0.0	0.0
	high	284.3	3.6	1.4	1.3	0.0	41.9	194.7	41.4	0.0	0.0	0.0
White pine	base	24.0	0.2	0.4	0.0	0.0	4.6	16.7	1.9	0.2	0.0	0.0
	medium	20.4	0.5	0.8	0.1	0.0	4.4	12.8	1.4	0.4	0.0	0.0
	high	33.0	2.6	0.3	0.6	0.0	9.8	16.9	1.9	0.9	0.0	0.0
Black spruce	base	89.9	12.6	16.1	24.4	18.0	4.4	0.0	9.6	3.6	0.0	1.2
	medium	162.3	24.0	23.9	53.5	29.9	8.4	0.0	14.8	6.3	0.0	1.5
	high	214.1	31.3	31.4	71.3	39.8	11.2	0.0	18.8	8.3	0.0	2.0
Balsam fir	base	51.8	5.4	4.5	11.6	10.9	4.0	0.0	9.7	3.7	0.0	2.0
	medium	126.7	12.7	9.7	29.7	28.1	12.4	0.0	20.1	9.3	0.0	4.7
	high	176.1	17.5	13.4	40.9	39.1	17.4	0.0	28.4	13.0	0.0	6.4
Northern white cedar	base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	medium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	high	14.5	1.6	0.8	8.1	1.2	1.1	0.0	0.8	0.7	0.0	0.2
Tamarack	base	2.5	0.2	0.5	0.0	0.0	0.2	0.0	1.4	0.1	0.0	0.1
	medium	61.7	5.2	7.2	5.3	3.6	15.1	0.0	20.6	3.3	0.0	1.4
	high	143.9	11.1	14.7	15.3	9.1	44.1	0.0	39.1	8.1	0.0	2.4
White spruce natural	base	13.9	1.1	0.2	5.1	6.2	0.4	0.0	0.7	0.1	0.0	0.1
	medium	22.1	1.6	0.3	8.8	9.5	0.6	0.0	1.0	0.2	0.0	0.1
	high	24.3	1.8	0.4	10.0	10.2	0.6	0.0	1.0	0.2	0.0	0.1
Oak-Hickory	base	69.9	2.4	4.5	0.0	0.0	3.5	0.0	13.1	30.8	10.1	5.5
	medium	278.4	10.6	21.2	0.0	0.0	14.1	0.0	47.2	116.6	47.8	20.9
	high	345.6	17.4	24.4	0.0	0.0	21.0	0.0	57.6	144.0	56.0	25.2
Elm-Ash-Maple	base	194.5	31.0	33.9	3.5	5.0	7.3	0.0	27.4	56.3	0.0	30.1
	medium	299.5	45.6	49.9	7.7	7.4	16.8	0.0	40.1	87.0	0.0	45.0
	high	402.9	60.2	65.9	11.1	9.9	23.9	0.0	55.0	116.5	0.0	60.4
Maple-Basswood	base	160.5	10.9	24.9	0.0	0.0	6.8	0.0	27.7	40.0	0.0	50.2
	medium	265.0	18.7	37.2	0.0	0.0	18.8	0.0	43.6	70.5	0.0	76.2
	high	376.6	27.2	50.6	0.0	0.0	31.6	0.0	59.5	103.2	0.0	104.5
Aspen	base	2871.8	1619.2	518.8	67.4	106.6	91.4	0.0	113.2	258.4	0.0	96.8
	medium	3023.6	1704.9	545.5	71.1	112.6	96.8	0.0	119.9	271.4	0.0	101.4
	high	2940.3	1527.1	563.4	81.9	130.9	117.0	0.0	115.5	302.7	0.0	101.8
Paper birch	base	88.6	10.2	8.4	2.6	5.2	5.3	0.0	14.2	26.5	0.0	16.2
	medium	145.9	20.1	11.5	6.1	9.3	10.5	0.0	18.2	50.1	0.0	20.1
	high	213.1	30.0	17.2	8.9	13.5	15.7	0.0	26.0	72.6	0.0	29.2
Balsam poplar	base	156.5	99.0	15.7	3.8	5.5	3.9	0.0	5.3	17.6	0.0	5.7
	medium	165.7	104.6	16.2	4.1	6.1	4.2	0.0	5.5	18.9	0.0	6.1
	high	191.4	120.9	18.6	4.8	7.0	4.9	0.0	6.4	21.8	0.0	7.0
Total	base	3915.8	1793.5	628.9	118.9	157.4	158.3	150.3	253.2	437.3	10.1	207.9
	medium	4787.8	1951.3	726.2	187.4	206.6	236.5	150.7	369.3	634.5	47.8	277.5
	high	5467.3	1861.1	803.7	255.9	261.6	407.9	215.6	471.7	793.8	56.0	340.0

The medium scenario analysis suggests that long-term sustained yield levels could be maintained at a level close to the 5 million cord annual harvest level by utilizing less that 10 million acres of timberland. With the potential to shift additional acreage to plantations or more intensive management options, results strongly suggest that a five million cord level could be maintained in the long-term once a regulated condition is achieved. Table 6.25 shows the breakdown of the annual harvest volume by product group. Over the 60-year planning horizon used for the second runs, much of the shortfall in aspen supply is assumed to be overcome by shifting a large percentage of the demand to other hardwoods. Results of the long-term sustained yield analysis suggest that this shift must be temporary, as sustainable levels for hardwoods are less than annual harvest levels assumed.

Results of the long-term analysis based on the highest scenario utilizes most of the timberland acreage available and yet falls over 1.5 million cords short of the assumed 7 million cord annual harvest level. Clearly, this result suggests that the highest level scenario could not be maintained in the long-term without a substantial increase in the level of management.

In comparing the analysis used on the medium scenario with that based on the highest scenario, the marginal increase in the sustainable harvest level is also of interest. The sustainable harvest level is increased by approximately 680,000 cords by adding 2,711,000 million acres to the harvested land base. This is an average increase of only 0.25 cords, compared to an average annual harvest level of 0.53 cords per acre for the land base assumed under the analysis corresponding to the base scenario. Clearly, this points to the need to recognize differences in site quality for timber production when making decisions regarding management for other objectives.

7 SIGNIFICANT IMPACTS

7.1 Significant Impacts Criteria

Impacts identified in the course of this study will vary in their significance, and therefore, in the need to develop a specific mitigation response. This is a critical stage of the study process, as these tests of significance will ultimately define the scope of policy recommendations developed by the GEIS (figure 7.1).

Identification of an impact as being significant does not automatically prescribe a specific mitigation response. The significance criteria have been developed to be inclusive rather than exclusive. Their purpose is to identify the issues and circumstances where policy initiatives will be required. The range of possible policy responses, the factors used to choose between them, and the implications of selecting a particular response are all evaluated by subsequent criteria.

Criteria have been developed for each of the issues of concern in the FSD and are identified in the second section of this document. Therefore, because the criteria underpin the impact assessments to be undertaken in subsequent stages of the study, this aspect of the study will be made as clear as possible for interested readers.

The categories of impacts to be considered are set out in the FSD within the Issues of Concern (section viii, page 8). Eighteen *categories* of impacts have been identified, based on the ten issue areas in the FSD. The categories are as follows:

1. The sustainability of harvesting forest resources;
2. Size and composition of Minnesota's forest land base;
3. Abundance, composition, spatial distribution, age class structure, genetic variability and tree species mixture of Minnesota's forests;
4. Risk of disease and insect infestation;
5. Biological diversity at a genetic, species or ecosystem level;
6. Patterns of forest cover;
7. Federal or state listed species of special concern, threatened, or endangered species or their habitats;
8. Old growth forests;
9. Populations of (10 groups) of forest dependent wildlife and fish and their habitats;
10. Level of sedimentation, nutrient loading, and runoff in lakes, rivers, streams and wetlands;
11. Water quality of ground and surface waters;

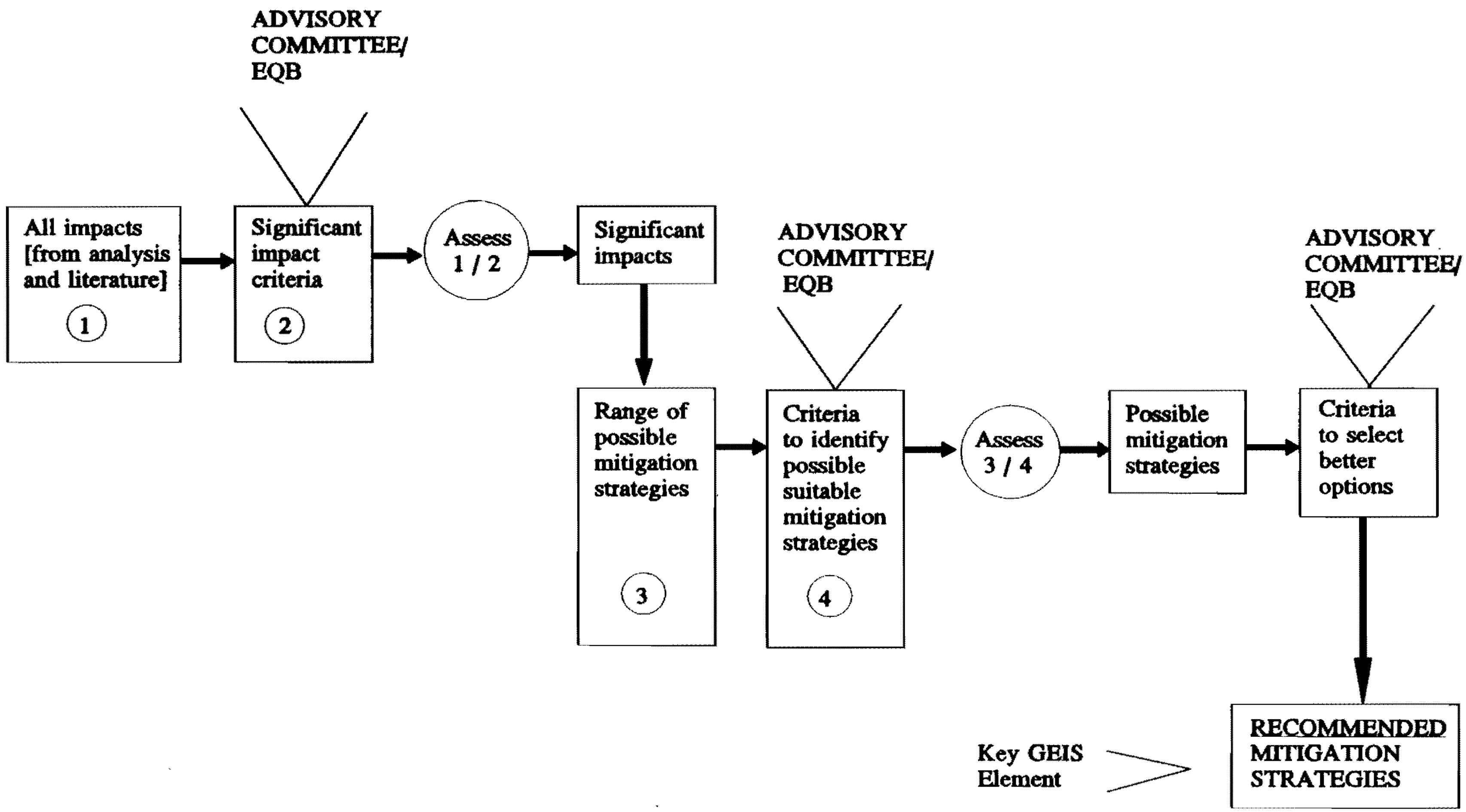


Figure 7.1. Process for criteria and mitigation strategy development.

12. Aquatic ecosystems, wetlands and peatlands;
13. Soil erosion;
14. Forest soil productivity;
15. Recreational use;
16. Regional and state economies;
17. Historical and cultural resources; and
18. Visual quality.

For each significance criterion developed, several background factors were used to determine levels or thresholds when impacts are likely to be considered significant. They include:

- severity and spatial extent of impact;
- certainty of impacts;
- duration of impact (irreversibility);
- consideration of existing guidelines and standards; and
- biological and economic implications.

The first factor identifies the likely extent and severity of an impact. Impact extent varies considerably, ranging from very localized site specific impacts to those impacting a watershed, physiographic region, soil type, covertype, ecoregion or the entire state. The second factor identifies the degree of certainty that a predicted impact will occur. The key factors influencing certainty are identified for each criterion. The third factor incorporates the anticipated duration of the impact, and whether or not it is reversible. Duration is defined as very short-term—less than 2 years; short-term—2 to 10 years; medium-term—10 to 50 years; long-term—greater than 50 years; and irreversible. The fourth factor incorporates those existing standards and guidelines that are applicable to the respective issue areas. The fifth factor identifies the key biological and economic implications of the impact. These are particularly important in those circumstances where impacts are indirect.

7.2
Changes to Minnesota Forests - Size and Composition of Forest Land Base (public and private).

An impact is considered significant if it is projected that there will be cumulative over the 50-year study period:
- A change of 3 percent in the size of the total Minnesota forest land base.
- A change of 3 percent in the area of timberland (commercial forest land) available for wood production.
- A change of 7 percent in the area of the total forest land base by ecoregion.
- A change of 7 percent in the area of timberland by ecoregion.

Severity and/or extent. The total area of forest and the proportion available for harvesting will change over time. Conversion to (and from) agricultural uses and urbanization, and not harvesting and forest management, are the main factors likely to change the total forest land base in Minnesota. Records of past changes (trends) in areas converted will be used to estimate future changes. The proportion of the total forest land base available for harvesting will also change over time. The proportion available will be dependent on the policies and objectives of the various ownerships.

Because changes to the forest land base and availability of timberland are such important issues, thresholds have been set at the lowest levels of resolution possible given the precision of the data available on base conditions and trends. The threshold values represent levels that are detectable.

The criterion will be applied statewide and by ecoregion to assess cumulative changes over the 50-year study period. Significant impacts will be further identified when cumulative changes are projected to exceed thresholds.

Understanding the possible changes to Minnesota's forest land base, and the relative proportions allocated to different uses, is fundamental to many of the issues identified in the FSD. Loss of forest land base does not occur as a direct consequence of harvesting and forest management activities, except where regeneration has been repeatedly unsuccessful. However, the loss of forest land base will have major impacts on some elements of the forest industry and will compound other impacts that are attributable to harvesting.

Certainty of impact. The certainty that changes will occur to the total area of forest and permitted uses will be dependent on economic, management and policy decisions of landowners. Past trends will be used to predict likely future scenarios. These are summarized by ownership below:

National forest—it is unlikely that substantial blocks of timberland will be redesignated for nonharvesting uses. Smaller areas will continue to be set aside to reflect policy decisions regarding maintenance of habitat, water quality and recreation/aesthetics. There is uncertainty about availability of areas of designated timberland that could become unavailable because of so called *below cost* timber sales regulations. The total forest area is likely to increase over time because of the current policy to purchase private forest lands to partially offset reductions to the area of timberlands through redesignation, as described above.

State—Minnesota state policy is to support the timber industry as a vehicle to stimulate economic activity. However, it is likely that additional areas of timberland will be transferred to the productive reserved category to meet other policy objectives, such as reservation of the old growth study areas.

County—the focus of management of county lands has been to provide revenue to meet the cost of land administration and to support other community functions. The requirement to generate income will continue, however, there will also be increasing pressures to recognize noncommodity uses. No major change in county forest area is expected.

Industrial forests—forest industry timberlands have traditionally been used as strategic holdings to ensure a steady flow of raw materials, and as a means to restrain short-term increases in stumpage prices. No major changes are envisioned to either the total forest land base or the area of timberlands.

Nonindustrial private forests (NIPF)—this ownership category will experience the largest changes, particularly in the total forest land base category as forest is cleared for agriculture and/or sold to others, including parties with development interests.

Analysis of trends indicate that not all NIPF forests would be available for harvesting at any particular time; however, most will likely be available at some time over the 50-year study period. This reflects changes in individual owner's circumstances and changes in ownership.

Duration of impact (irreversibility). The total forest land base will change as land owners convert forest land to agricultural land and land for urban developments. Conversion to agriculture is considered a medium- to long-term change, on the basis that a period of more than 40 years would be required to re-establish mature size trees. Conversion to urban uses is regarded as irreversible.

Changes to the proportion of the total forest land base that is available for timber harvesting will be regarded as long-term. The only exception will be national forest excluded from harvesting under the below cost timber sale rules. These exclusions will be treated as short- to medium-term.

Existing guidelines and standards. Not applicable.

Biological implications. The criterion assesses changes to the total forest land base and also to the proportion available for harvesting. The total area and the area remaining uncut at various stages over the study period and beyond will be important indicators for change in biodiversity and availability of forest habitat within the state.

There are examples of covertypes that were once common in Minnesota, but extensive areas have been cleared in the course of agricultural development and other human activities. Irreversible and long-term losses of uncommon covertypes, particularly in the more sparsely forested regions in the southern and western sectors of the state, will represent a significant loss, further reducing availability of increasingly important habitat.

Economic implications. Minnesota's forests provide the raw materials to sustain the state's forest-based industries. Therefore, changes to the area of forest available to industry will affect the level of industry that can be sustained.

The forests also provide the setting for outdoor recreation that underpins the state's recreation/tourism industries in the north of the state. Loss of forests could adversely affect these industries.

7.2.1 Results and Discussion

The estimated trends by FIA unit for total forest area are shown in table 5.4 and illustrated on a county basis in figure 5.10. By superimposing ecoregions on the county map and using 1977 to 1990 changes shown in table A of appendix 11, results for ecoregions are developed in table 7.1.

Table 7.1. Estimated direction of changes in total forest area and timberland by ecoregion, 1990–2040.

	Change in Forest Area			
	All Forest Land		Timberland	
Ecoregion	Direction	Significance	Direction	Significance
1	-	*	-	*
2	no change		-	*
3	-	*	-	*
4	-		-	*
5	+	*	+	*
6	+	*	+	*
7	+		+	
Statewide	no change		-	*

* Significant.

Estimates like these are always hazardous. They may seem exaggerated. However, the past history of forest clearing, regrowth, harvesting and reservation here and in other regions, notably from Wisconsin to New England to Europe, suggests changes can be large and rapid. Additionally, the U.S. and state population is expected to grow substantially over the period to 2040.

Statewide. Total forest area is expected to remain stable over the period 1990–2040, but a significant drop (greater than 3 but less than 7 percent) is expected in commercial forest or timberland area. This drop is anticipated due to additional reservation of timberland and more importantly, from the implementation of constraints on forest management and harvesting to meet real and perceived concerns for nontimber values. Reservation will occur primarily on public lands; constraints will develop on all lands with public lands leading the way. However, this comparatively static statewide picture encompasses considerable variation in the direction and magnitude of changes when assessed at the ecoregion level. These are described below:

Ecoregion 1, Glacial Lake Plains. This region will continue to decline in total forest area, due primarily to conversion to agriculture in the west. That change could be moderated by conservation programs. Unproductive areas will remain as such, thus development will occur on productive uplands or timberland. These changes are considered significant for both total forest area and timberland.

Ecoregion 2, Border Lakes. This region has a large proportion of reserved forest land and is not well-suited to development. No significant change in forest area is expected, but projected timberland availability will be reduced by constraints on management and harvest practices. These constraints will effectively diminish the area of available timberland. The reduction in timberland actually available will likely exceed 7 percent and is considered a significant impact.

Ecoregion 3, Lake Superior Highlands. This relatively small region will likely see a significant (greater than 7 percent) decline in forest area and timberland from 1990 to 2040, due primarily to recreation-related development along the North Shore, located primarily in the southern portion of the region. Since it is primarily forest now, any development will diminish the area of private timberland.

Ecoregion 4, Central Pine-hardwood Forest. This ecoregion will likely see an overall decrease in forest land and a somewhat greater reduction in the area of timberland. However, conditions will vary widely across this region due to differences in agricultural history, recreation potential and proximity to existing urban areas. Federal, state and county ownership is large in the region and those areas will remain in forest. Lowland forest acreage will remain stable. Timberland availability will be reduced by constraints on management and harvest practices that will effectively diminish the area available for timber production. The estimated decrease in forest area will be 3 to 7 percent. The corresponding decrease in timberland will likely exceed 7 percent and is considered significant.

Ecoregion 5, Western Prairie/Forest Transition Zone. Forest area in this ecoregion is likely to increase in excess of 7 percent. However, available timberland acreage will be reduced to a lesser extent near existing urban centers. Land use will shift from agriculture, back to forest and then, for some areas, to urban development or reservation. In its western parts, this region could benefit significantly from conservation programs.

Ecoregion 6, Eastern Prairie/Forest Transition Zone. Forests in this ecoregion have benefitted from the decline of livestock-based agriculture over the last several decades. Reduced grazing, watershed management concerns and a decline in agriculture have led to a substantial percentage increase in forest area. Both total forest area and timberland acreage are estimated to show significant (greater than 7 percent) increases. However, urbanization and nonfarm rural development will slow positive changes in timberland actually available, relative to total forest area.

Ecoregion 7, Western Prairies. The natural forest regrowth potential of regions 5, 6, and 7 has been grossly underestimated in previous analyses. Total forest area and timberland acreage in this region, though a small portion of the state total, will increase significantly (in excess of 7 percent). Although it will take 3 to 4 decades before this regrowth can contribute much to timber supply, it will be important before then for nontimber values.

7.3
Changes to Minnesota Forests - Patterns of Forest Cover in Areas of Mixed Land Use

> An impact is considered significant if noncontiguous forested tracts or patches less than 300 acres in size are projected to experience clearcutting of more than 20 percent of the tract or patch in any one decade.

This criterion addresses the issue of clearcutting remaining tracts of forest and larger size patches of forest in those parts of the state (assessed by ecoregion) where the proportion of agricultural or urban lands is more than one-third of the total land area. Noncontiguous patches are those separated from the nearest forest by more than a quarter mile of nonforest vegetation. The patch size and proportion cut reflect an interrelationship between remnant patch size and habitat value for animals, particularly forest interior bird species. The patch size and proportion cut used to define the significance threshold in the criterion are consistent with research findings by the U.S. Fish and Wildlife Service. Use of thinning or uneven-age management to maintain crown closure can have less impact on habitat values.

Severity and/or extent. Important wildlife habitat is found in tracts of forest within largely developed areas, such as those in the southern part of the state. Clearcutting large portions of tracts disrupts habitat conditions for some species, to the extent they may be lost from the tract and perhaps the broader landscape. In addition, patches can constitute *stepping stones* for migratory species.

Certainty of impact. Most forest land in the areas of mixed land use (i.e., nonforestry land uses exceed one-third of total land area) are in private ownership. Therefore, whether these forests are logged and how logging is conducted will be the result of ad hoc decisions with few constraints. Therefore, as pressure for access to the wood resources within these forests increases, the likelihood of impacts occurring will also increase.

Duration of impact (irreversibility). Impacts are likely in the medium- to long-term. Medium- to long-term impacts result where patches are clearcut and take long periods to recover habitat values. Irreversible impacts would occur where native covertypes are replaced by plantation or are cleared for agriculture.

Existing guidelines and standards. Not applicable.

Biological implications. Increased fragmentation of the patches of forest within regions of mixed land use can have the following impacts on wildlife:

- further spread of exotics and parasitism;
- potential loss of habitat for interior species;
- increased habitat for species favored by early succession and mixed age forest, particularly game species;
- change in predation success; and
- potential to reduce water quality.

Economic implications. Not applicable.

7.3.1 Results and Discussion

Statistics on the regrowth of the oak and elm-ash-cottonwood forest types common to agricultural regions (see table 5.11) suggest that forest cover is returning to ecoregions 5, 6 and 7 quite rapidly on a percentage basis. However, even the large percentage increases estimated for the next 50 years would just return these regions to the forest acreage levels of the 1950s. Additionally, the concentration of oak-hickory in older age classes (see appendix 8), coupled with currently high harvest levels could negatively affect the overall habitat value of existing forest patches. Given the small average stand sizes in this covertype and these ecoregions (see estimates in table 2.10 and 5.11) and the projected acreage of unharvested stands by scenario (see table 5.3), it is evident that this is occurring and that it is a significant impact. However, data limitations in this study preclude the ability to document it on a site specific basis.

7.4 Changes to Minnesota Forests—Tree Species Mix

An impact is considered significant if projected gross changes in the relative proportion of any tree species exceeds 25 percent for the respective covertypes over the 50-year planning period.

Severity and/or extent. Minor species are important components of forest communities. A covertype or forest type classification is attributed to each of the USDA Forest Service Forest Inventory and Analysis (FIA) plots. The covertype is classified on the basis of the species comprising a plurality of live tree stocking. Projected changes in the relative proportions of these species will be important indicators of change within a covertype. Such changes can also lead to a change in covertype area. Increasing as well as decreasing proportions will be assessed. For example, where aspen rotation is shortened, shade-tolerant conifers such as spruce and fir will become less common. Other species such as yellow birch may be comparatively scarce due to earlier highgrading, and a projected reduction in the proportion of this species will be of concern.

Certainty of impact. Changes will be interpreted based on the degree to which known requirements of the minor species are met by the assumed silvicultural activities and management objectives for each ownership.

The 1990 FIA will be used to provide the base data on species composition.

Duration of impact (irreversibility). Medium- to long-term impacts will occur because in many cases a reduction in minor species may only appear in the stand many decades after harvesting.

Existing guidelines and standards. Not applicable.

Biological implications. A reduction in these minor species can reduce biodiversity and change wildlife habitat values. For example, loss of a conifer understory reduces the habitat value of aspen stands for some species. A reduction in the diversity of a stand can increase the risk of pest and disease.

Economic implications. Possible changes in availability of desirable commercial species.

7.4.1 Results and Discussion

The harvesting scenarios would affect the age class structure and thereby the species composition of Minnesota's forest. Tables 5.7 and 5.8 document the overall tree species composition for 1990 and the projected changes for the three harvest scenarios to 2040 for the first runs. Results are summarized in table 7.2.

Table 7.2. Projected changes in timberland tree species composition by harvesting scenario, statewide for the first runs, from 1990 to 2040.

Number of Species	Harvesting Scenario at 2040		
	Base	Medium	High
a) Trees ≥ 0.95 inch dbh			
Increase	32	33	28
Decrease	22	16	19
Significant decrease*	6	11	13
b) Trees ≥ 4.95 inches dbh			
Increase	19	13	10
Decrease	18	22	16
Significant decrease*	23	25	34

* A significant decrease is a gross change that exceeds 24 percent.

The greater number of declining species in table 7.2 for trees ≥4.95 inches dbh compared to trees ≥0.95 inch dbh is a reflection of a greater proportion of young stands under the various harvesting scenarios. Those young stands have considerably more trees per acre than mature stands. Species that would appear to be significantly impacted in a negative manner by the harvesting scenarios are shown in table 7.3. Note that the number of significantly impacted species is reduced in the second runs. Also, no species would be reduced to a level that would appear to jeopardize their continued presence in the forest.

These results, plus the generally rich tree species composition by forest type, (see appendix 13) suggest that major species composition changes within types will not occur, except for those changes associated with stand age. For example, tables 44 to 50 from Hahn and Raile (1982) show a generally increasing proportion of balsam fir in the aspen type with advancing age. Species composition changes do occur from implementation of harvesting or silvicultural practices in specific stands. However, the aggregate of natural forces, plus a changing mix of management objectives and harvest operations over time, do not show a clear pattern of change in species composition within types. For the first runs, the overall covertype acreage trends in table 5.9 show a decline in aspen acreage and an increase in maple-basswood and oak-hickory acreage. Acreage in conifers shows a decline for upland types and considerable dynamics among lowland types. Given the high frequency of mixed species stands, future directions for type acreage could be largely determined by consistent choice of rotation age and harvest practices.

Table 7.3. Tree species projected to be significantly impacted (negatively) by the changing age class structure and associated species composition implied by the harvest scenarios.

	Scenario					
	Base		Medium		High	
Species (trees ≥0.95 inch dbh)	1st run	2d run	1st run	2d run	1st run	2d run
Ailanthus		X	X	X	X	X
American hornbeam	X		X		X	
American basswood					X	
Black locust	X	X	X	X	X	X
Black spruce				X		X
Black maple			X	X	X	X
Jack pine		X		X		
Kentucky coffee tree	X	X	X	X	X	X
Northern red oak			X		X	
Other hardwoods			X	X	X	X
Red maple	X		X			
Rock elm					X	X
Scotch pine		X				
Striped maple*	X		X		X	
Sugar maple	X		X		X	
White oak					X	
White pine			X		X	

*** This species may be confused with other small maples.**

The second runs show a slightly different trend. Future covertypes do appear to be sensitive to the level of harvesting, both in retaining covertypes and in favoring change to other species. Results are clouded because of an imprecision in determining forest covertypes both now and in the future. This imprecision is due in large part to the mixed species composition of Minnesota's forest. However, results suggest the harvesting scenarios will contribute to diminishing the area of the jack pine, black spruce, balsam fir and paper birch by as much as 44, 27, 42 and 37 percent, respectively. However, because many stands have very mixed species composition, the translation of these changes will not necessarily change the vegetation drastically overall or on specific sites. Instead, a major species may simply become less abundant or a minor species on a particular site. Because of this mixed species effect, and despite the changes in covertype area, the only major species to show a significant harvesting-related decline in tree numbers was black spruce in the medium and high scenarios.

Perhaps of greatest concern is the suggested trend to more aspen covertype acreage with increased harvesting levels. That trend can be controlled or altered, but to do so would require specific rotation age, harvesting and silvicultural practices.

7.5
Changes to Minnesota Forests - Age Class Structure.

> An impact is considered significant if the projected replacement age class structure of forests, by covertype, at the end of the 50-year planning period, is insufficient to provide replacement of mature stand acreage (i.e., sustainability of forest communities).

Severity and/or extent. Minnesota's forests as depicted by the 1990 FIA database have important age class distribution features. This criterion seeks to identify the circumstances leading to a change in the age class distribution. The criterion does not suggest that changes in one direction or another are necessarily desirable or undesirable. Nor does it presume that the current age class distribution is necessarily appropriate. The criterion will detect shifts in age classes, and the implication of those shifts will be assessed against the current distribution to determine the positive and negative aspects of the change.

The concern of changing age class structure is not so much about increasing numbers and distributions of some species, as it is about detecting major declines in any species or covertype area. The species composition, structure and dynamics of forests clearly can change as stands age. These changes have an important bearing on factors such as the habitat value for different species. Numerous implications will be developed in the technical papers. The threshold of significance is subjective because the degree of imbalance can vary with management intensity, harvest levels, and the definition of mature as linked to rotation age or other ownership objectives. The criterion will use the FIA estimate of age for each stand and will then compare the initial age class distribution with that projected for the end of the study period.

Certainty of impact. The certainty of impacts resulting from changing forest age class structure depends on several variables, such as the existing forest age class structure and management objectives of landowners, particularly as reflected in the rotation ages and silvicultural systems employed. In reality, it will be important to compare existing and projected age class structures, i.e., assess sustainability for timberlands separately and then for all of the forest, including reserved and unproductive reserved lands. Such a process treats both sustainability of harvest and habitat concerns.

Certainty of impact will vary between ownerships. State and national forests will likely maintain a more diverse age class structure in response to explicit policies that set aside timberland to meet other management objectives: old growth; maintenance of wildlife habitat; water quality buffers; and aesthetics. These ownerships control substantial areas of reserved forest lands that are managed in such a way as to promote old forest (e.g. BWCAW, Itasca State Park).

County-managed lands will likely have less variation in the range of age classes. This reflects their narrower management objectives, which typically emphasize timber production rather than the wider objectives of other public ownerships. On average, timberlands owned by forest product industries will likely be managed on shorter rotations to maximize timber productivity.

Only a relatively small proportion of NIPF owners actually manage their forests. Therefore, the age at which an NIPF forest is harvested will depend more on the owner's financial needs than any management objectives. Consequently, the concept of replacement of mature stands is not normally a management objective on NIPF lands. A proportion of NIPF owners will elect to forego harvesting. However, the high turnover of ownership means that little certainty can be attached to such a decision because subsequent owners may not adopt the same management strategy.

In addition to differences between the objectives of owners, there are differences between species. Some, such as aspen and balsam fir are comparatively short-lived species. Others, such as sugar maple, may live for much longer periods, often with commensurately slower growth rates.

Duration of impact (irreversibility). Deliberate changes to age class distributions can only be achieved over very long periods if the objective is to replace mature stand acreage.

Biological implications. Stand age is important in determining the potential for stand growth and species succession. Changes in age class distribution reflecting shortened rotation lengths tend to increase average growth rates and reduce the likelihood of successional change in managed forests.

From a plant and animal diversity standpoint, the justification for a complete representation of forest age classes is that each age class provides habitat for a given set of plants and animals. Maximum biodiversity, therefore, is associated with a complete range of age classes for each forest covertype in each ecoregion.

Site nutrient balance is also sensitive to changes in age class distribution, particularly for certain covertype/soil type combinations.

Pest and disease susceptibility and vulnerability also change as the stand ages.

Economic implications. The growth rate and product mix yielded from a stand change as the stand becomes older. For even-age stands, growth rates typically increase following establishment, reach a peak as canopy closure is achieved and then show a decline as the stand matures. Net growth rates can show a more dramatic decline with increasing age, due to losses to defect caused by insect and disease attack. The size of individual trees increases as the stand ages. Larger diameter logs can be used to produce a wider range of products than smaller diameter logs. Size (diameter) is an important criterion used in the selection of logs by the solid wood-based industries, especially sawmills. Size is of less importance to pulp-based industries.

Therefore, shorter rotation ages may reduce the availability of larger logs, while increasing the productivity of the forest in terms of overall volume production. Longer rotations may increase the availability of large logs but sacrifice overall volume production. Either change would have impacts for industries set up to utilize the respective product categories. Rotation length can also be of importance to forest owners, as it can determine the term over which an investment in forest improvement must be carried before returns are realized.

Tree size is an important aspect of forest aesthetics. The presence of large diameter older trees is an important element in recreational use of some areas, which has implications for tourism/recreational industries set up to service these users.

7.5.1 Results and Discussion

This criterion requires examination of age class structures (appendix 8) at the end of the 50-year study to assess the feasibility of relatively short-term sustainability. Upon doing so, it is apparent that the replacement age class structure for timberland appears deficient for (1) white pine, (2) northern white cedar, (3) white spruce, and (4) paper birch. These covertypes, because of their current age class structure imbalance and/or lack of acreage in the case of white pine, remain unbalanced through the study period. Thus, these covertypes are considered to exhibit a significant impact. However, among these, white cedar is projected to have a very low harvest.

Second run results show increased or stable acreages for all of these but paper birch. However, much of that acreage increase is due to covertype definition or determination procedure or succession from other covertypes. Thus, concern for the present or 1990 acreage remains.

8
POTENTIAL MITIGATION MEASURES TO ADDRESS SIGNIFICANT IMPACTS

While the demands established by the three harvesting scenarios were met in the first model runs, a true assessment of limits on supply need to be based on harvest schedules that are subject to environmental considerations. The first model runs established the base for the impact analyses without such considerations. However, the second round of model runs incorporated existing policies and/or management practices, thereby establishing a more realistic picture of impacts on productivity and the resource base. Those runs further clarified the effect of potential mitigations on both long term timber supply and the resource base itself.

The following section identifies and discusses potential options for addressing those impacts identified in section 7 as being significant. As the reader will discover in reviewing these mitigation options, the strategies needed to address significant impacts projected to occur on the forest resource base typically have a *broader focus* than those mitigations that address specific environmental concerns. Many of these latter concerns can be effectively dealt with through modification of site specific forest management and/or harvesting practices such as altering the design or specifications for a timber sale. An example would be redirecting use and/or disposal of slash (residual biomass) associated with harvesting.

However, the focus of strategies needed to correct problems associated with adverse changes to macro aspects of the forest land base really address long-term policy commitments that encompass both public and private forest ownerships. Only when the major land management organizations and owners (both public and private) indicate a long-term commitment to these policies will their resultant programs and practices have a meaningful impact on addressing the identified problems.

8.1
Mitigation Alternatives Criteria

These criteria will identify mitigation actions with the potential to address the significant impacts previously identified. The purpose behind this stage of the process is to identify mitigation actions which are effective and practical in a physical context, as well as the political, financial, and administrative environments in Minnesota.

Input from the technical experts, Advisory Committee, and the EQB are reflected in the criteria presented. Unlike the significance criteria, the criteria developed to identify potential mitigation alternatives will be applied uniformly across all issue areas documented in the FSD (MEQB 1990).

Major considerations used in the development of criteria to identify mitigation alternatives include:

- financial considerations;
- administrative considerations;
- certainty of effectiveness; and
- social implications.

A mitigation alternative to address identified significant impacts will be considered if the mitigation is physically and biologically *feasible to implement*[1] in Minnesota taking into account the:
- administrative requirements to implement and oversee policy changes;
- the financial requirements to undertake the action; and
- social considerations (ability to organize support and effect implementation).

The mitigation action must also be supported by some degree of certainty regarding its effectiveness, both in terms of the relative extent of mitigating the impact and its duration at maintaining the mitigative effectiveness.

In practice, the verbal and written input from the Advisory Committee on the potential mitigation strategies led to acceptance, rejection and/or refinement of the potential strategies. These results were then approved by the EQB and comprise the strategies considered and evaluated in detail.

8.2 Size and Composition of Forest Land Base

The size and composition of the forest land base has changed considerably since presettlement times. Further, it will continue to change through a combination of factors including, land use conversion, harvesting, and natural stand development processes. Impact assessment projected significant losses to the forest land and timberland base in several northern ecoregions—losses not offset by projected increases in other areas.

[1]*Feasible* implies that the mitigation action can realistically be implemented and addresses the impact being considered.

Additionally, the age class structure resulting from these factors can lead to conditions that reduce the environmental and/or economic value of the forest. Mitigations to address these concerns are described below.

8.2.1 Measures to Reduce the Area of Forest Converted to Other Land Uses

Existing federal, state, and county policy instruments should be implemented to discourage conversion of forest land to other uses such as agriculture, rural nonfarm parcellation, and urbanization. This initiative should include a policy of NO NET LOSS of forest and timberland. Such policy should be formally adopted by the state.

In order to satisfy both environmental and economic objectives associated with forest resources, it is fundamentally important to ensure there is, and will continue to be, an adequate forest land base. While no overall losses of forest land are projected to be significant, there is expected to be a significant drop (greater than 3 but less than 7 percent) in the state's primary forest and timberland area, as losses of forest acreage in northern Minnesota to land conversion (e.g., agriculture, urbanization, etc.) are not expected to be offset by any gains in the forest and timberland base that might occur in the southern part of the state. Therefore, strategies are needed to protect further erosion of Minnesota's forest and timberland base.

Ongoing erosion of the area of land available for timber production will occur as the area of forest is reduced. In addition, policy decisions by the various ownerships will likely decrease the total proportion of timberland that is available. Further, other policy decisions will likely involve adoption of mitigations that restrict harvesting in areas formerly classified as timberlands, thereby reducing timber supplies further. The situation is further complicated as such policy decisions will not necessarily favor all environmental values of interest, as reservation of lands from harvesting does not stop natural processes.

Effectiveness
Minnesota currently has a number of policy instruments (e.g., local zoning regulations, property tax incentives, conservation, and afforestation and reforestation incentives) that can be effective tools in maintaining and enhancing the state's private timberland acreage base, both individually and collectively. Because the projected loss of forest land is expected to occur primarily on private lands, these tools have the potential to effectively limit further erosion of the state's forest and timberland base. Doing so, however, requires their full implementation. At present, counties often have considerable discretion in administering some of these policy instruments, for example, zoning and property taxes. Many of these tools also have the

potential to reduce the forest area cleared and fragmented for other land use purposes.

However, some loss of timberland will occur on public lands. For example, increasing restrictions on timber harvesting are evident for a variety of nontimber uses on public lands. While some programs will need to appeal to private owners, the erosion of availability of timberland for harvesting on public lands is the major concern to forest industry. Thus, policy that favors multiple use on public lands with a primary emphasis on timber production needs to be articulated for a meaningful portion of the public ownership.

Workability

This mitigation is complicated by the fact that the forces that lead to loss of forest and timberland are complex, and are dependent on the interaction of many factors. In the case of clearing for agricultural use, the decision is likely made at an individual operator level, with little involvement of outside agencies. In contrast, development and planning of a new subdivision may involve decisions by developers, as well as local government. Likewise, decisions on public land use can involve many interest groups. The actual decisions are often justified by marginal analysis for small areas but the cumulative effect of many small decisions is large. As previously stated, local governments may resist loss of autonomy in implementing these policies.

Action to design and implement appropriate initiatives should be prefaced by a review of statewide goals for forest species composition, age class structure and productivity across ownerships.

Current Minnesota state policy with regard to land acquisition is to consolidate ownership, protect unique features, and provide a public land base for multiple use forestry. Maintaining the area of productive timberlands could be assisted if the state systematically identified nonstocked timberlands and, in cooperation with existing owners, regenerated these lands.

8.2.2 Increase the Rate of Forest Establishment

The State of Minnesota should implement a policy to encourage establishment of new forest and timberland acreage to supplement the gaps in replacement age class distributions for covertypes with severely imbalanced age class distributions and/or where losses in acreage to other land uses has been severe.

The present and projected forests show age class imbalances that will likely lead to declines in the acreage of certain wildlife habitat and timber supplies.

Establishing new acreage is one tool for adding to and perpetuating resource conditions deemed important to environmental and economic interests.

Effectiveness
Such stands may be established on nonforest land or by converting existing forest acreage to the desired covertype. The focus here is on policy. Policy implementation would entail the development of a process that involves (1) periodic examination of resource trends, particularly acreage losses and age class imbalances; and (2) development of specific strategies to address the problem.

An example of a high priority species for such efforts would be white pine. The history of red pine and white spruce plantings suggests a concerted long-term effort can be successful. However, white pine has significant insect and disease problems and it is likely that a substantial portion of this new acreage would be established through enrichment of existing forest acreage, rather than as new plantations. New timberland stands may be established on nonforest land or by converting existing forest acreage to the desired covertype. A high priority for such efforts would be fast growing native species on good sites. In any case, knowledge available from research in silviculture and restoration ecology could lead to tailoring such plantations to meet a variety of interests in the resource.

Workability
Many species have particular regeneration and site requirements or herbivory problems that preclude widespread efforts to establish them. Additionally, any such effort would involve thousands of acres and present important infrastructure, logistic and investment problems. For example, seed or propagates would have to be available in quantity.

Complicating implementation is the fact that practices, even for timberland, would need to be tailored to achieve public acceptance with respect to aesthetic and other values of the forest. In some cases research may be a prerequisite to success. Lacking a substantial commitment of resources, success would be modest at best.

Costs of such efforts would likely lie in the range of typical forest regeneration experience. Thus the treatment of large acreages will require substantial investments.

8.2.3 Improving Productivity

The State of Minnesota should adopt policies and practices to improve the productivity of existing forests to offset losses of timberland.

Improving the productivity of timberlands can offset losses in timberland acreage and at the same time reduce the acreage upon which there might be conflicts among users.

Effectiveness
This is an alternative to reliance on maintenance of the gross area of timberlands as a measure of future resource security. The scope for productivity increases by ownership were identified previously in section 3.1.4. As described in that section, timber productivity per acre can be greatly increased, however, this will typically require investments in management.

The factors acting to influence productivity of forests were identified in figure 3.1. Several of the factors for improving productivity have been categorized as follows:

- increase utilization of existing stands, and
- increase productivity of existing and future stands.

The following illustrate the types of initiatives that could significantly improve timber supply and productivity of the resource base.

Increase Utilization of Existing Stands
The State of Minnesota should encourage existing and new wood processing capacity in Minnesota to increase use of currently unmerchantable or underutilized species such as birch and other northern hardwoods.

Where feasible, industry should relax timber specifications to reduce the volume of unmerchantable size wood left in the forest under current harvesting practices.

Increased use of currently unmerchantable species will take harvesting pressure off species such as aspen, which may be in short supply relative to demand. Such practice can also provide more aspen from harvesting of mixed stands where it is a minor component and where logging costs would otherwise be prohibitive. Additionally, multiproduct marketing and increased utilization of small-size material can increase yields from acreage that is already subject to harvesting.

Increase Productivity of Existing and Future Stands
The State of Minnesota should adopt a policy that all harvested forests should be regenerated to full stocking levels with species-site matching that effectively utilizes site resources.

Management of stand density through thinnings where economical and not damaging to residual stands should be encouraged to capture mortality before it is lost.

Lack of management investments and consequent delayed or low stocking levels effectively reduces the amount of timber produced on affected lands. This primarily affects NIPF lands, where the lack of access to professional forest management advice can result in poor harvesting practices and a lack of provision for stand regeneration.

Strategies available to target NIPF lands are:

- expand current technical assistance and extension services to reach dramatically more than the estimated 15 percent of landholders currently served;
- encourage the increase of technical assistance efforts from forest industry to provide silvicultural advice and development of harvest plans as part of the stumpage purchase process;
- support extension programs aimed at improving the silvicultural knowledge of loggers;
- establish regionally-based forest management cooperatives. Such cooperatives would have as their objectives improvement of management on NIPF lands; and
- expand incentives for forest management.

Public lands usually have the staff expertise to implement practices that improve productivity. The problem area has been the lack of consistent agency and legislative commitment to such long-term investments.

Workability

Even-aged silvicultural systems involving readily regenerated species such as aspen require a minimum of silvicultural management. However, even there much of the mortality that occurs through competition and insect and disease attacks can still be captured before it occurs. Such early salvage would be a part of silviculture to manage stand density.

In contrast, uneven-aged silvicultural systems involving selection harvesting often require skill to ensure minimization of residual stand damage, adequacy of regeneration, and effective management of the stand. In the absence of professional forestry advice, selection harvests can degenerate into high grading where only the merchantable trees are taken. This practice leaves the remaining stand unproductive from the standpoint of future merchantable timber yields, especially sawtimber, and may degrade the genetic base.

8.3 Patterns of Forest Cover in Areas of Mixed Land Use

The amount and pattern of forest cover in areas that are predominantly urban and/or agricultural is crucial to the effectiveness of that cover as habitat and as a connection between habitat islands. As this concern is closely linked to the amount of forest land, a priority response is the mitigations under section 8.2 to: (1) reduce the loss of forest land and (2) increase the rate of forest establishment. Additionally, the following mitigation is important.

8.3.1 Measures to Reduce the Site Specific Impacts of Harvesting

The State of Minnesota should encourage harvesting practices that minimize habitat disturbance in isolated forest patches.

A variety of practices would minimize habitat disturbance as compared to clearcutting. Examples are thinning or uneven-aged management where feasible, and limiting harvesting and especially clearcutting to small portions of isolated forest patches in any one decade.

Effectiveness
These mitigations are a concern primarily for the southern and prairie fringe ecoregions. Unfortunately, there is little data available to characterize forest patterns, their effectiveness and the changes in pattern that are occurring. While forest area is increasing in most counties in these ecoregions, harvesting and development continue, suggesting that important habitat values are being modified or lost. Where harvesting is conducted, the practices noted above will greatly reduce the impact on habitat and provide for continuity in those and other environmental values. However, since harvesting practice is usually partial cutting as opposed to clearcutting, this mitigation may have little overall effect.

Workability
Given that private ownership is predominant in these ecoregions, the education, incentive and assistance programs described under section 8.2.3 are appropriate. However, success will be highly dependent upon funding commitments to the agencies involved. Regulation of such practice is an alternative, but the large area and scattered forest ownership would likely make such an approach very expensive compared to the other programs described here.

8.3.2
Public Acquisition of Key Patches of Forest Land

Where forest patches of high environmental value are threatened, the State of Minnesota should seek conservation easements or move to acquire the land.

Effectiveness
Such easements or acquisition can be locally important to the connectivity of patches with respect to habitat.

Workability
Precedents in the wetland and habitat areas suggest the procedure is available and that it can be effective.

8.4
Changing Tree Species Mix

Minor species are important components of Minnesota's forest communities and the mix of species is highly dependent upon the age class structure of the forest. The following mitigations address the maintenance of a desired mix of species.

8.4.1
Alter Age Class Structure

Alter the age class structure of the forest.

Effectiveness
The age class structure of forest covertypes is a major determinant of the constituent tree species mix. The age class structure for any region can be altered through harvesting, extension of rotation ages and reservation in some combination.

Workability
The current age class imbalance for many forest covertypes favors constituent species common to mature forest conditions. Allowing forests to mature further over large areas will increase the difficulty of regenerating some of those covertypes and the opportunity for returning to younger age classes of those covertypes may be lost. There is much interest in extended rotation ages, but much less interest in shorter rotation ages and often insufficient market demand to make age class balancing economical. Increasing the rate of forest establishment as considered in section 8.2.2 will treat a portion of the problem, but in the long run, all acres will need to be considered in a coordinated manner across all ownerships.

8.4.2
Alter Species Composition

Alter the species composition of regenerating and existing stands.

Effectiveness
The species composition of a new stand can be affected by harvesting practice that creates or maintains conditions that favor certain species. Examples are practices such as leaving residual stems standing to reduce aspen sprouting or skidding that exposes mineral soil to favor pine regeneration. Additionally, silvicultural practices such as thinning can remove one species to favor another in established stands.

Workability
A wide range of harvesting, site preparation and silvicultural practices to effect desired species composition are available. However, some have significant implementation costs that may not be easily recovered from harvest or stand treatment income. For the timber producer and/or landowner, such practices may increase costs and reduce returns. In other cases, the necessary degree of site disturbance to effect change may itself be considered an important impact. In most cases, management agencies would need to develop guidelines for specific practices and species composition goals.

8.4.3
Enrichment Plantings on Public and Private Lands

Planting or other establishment of underrepresented species on public lands can enhance the biodiversity of public forests.

Effectiveness
Such plantings or other modes of establishing underrepresented species on a site can be used to create a change in covertype or the enrichment of that site. The latter approach may lead eventually to a change in covertype.

Workability
Many species have particular regeneration and site requirements or herbivory problems that preclude widespread efforts to establish them. Additionally, any such effort could involve thousands of acres and present important infrastructure, logistic and investment problems. For example, seed or propagates would have to be available in quantity. In some cases research may be a prerequisite to success. Lacking a substantial long-term commitment of resources, success would be modest at best. Implementation is complicated by the need to tailor practices to achieve public acceptance, with respect to aesthetic and other values of the forest. For NIPF lands, a

range of incentives would be needed plus a clear description of the benefits for other purposes such as aesthetics, wildlife habitat, etc.

8.5
Age Class Structure of the Forest

8.5.1
Balance the Forest Age Class Structure

The imbalance in the present age class structure should be addressed by a combination of practices across ownerships leading to approximately equal representation of all age classes of commercial and ecological value.

Effectiveness
Any forest type that can be regenerated can be balanced. The key points, as described in section 5.8, are appropriate choice of conversion period, harvest strategy and the level of investment in regeneration and subsequent management. This further assumes appropriate markets. Fortunately, the sustained yield analysis found that average annual stand yield is often very similar over a range of rotation ages. Consequently, long-term (post-2040) sustainability offers a choice of rotation ages with little change in long-term sustained yield.

Workability
In practice, the difficulty of conversion to younger age classes would be exacerbated by concern for sustainability of ecological characteristics of the forest community. This is a special concern for three forest types: white pine, northern white cedar and paper birch. The broader problem is one of setting goals for forest age class structure and covertype acreage. Lacking that, the forest will still change. The question then is the acceptability of the direction of change. Many tools to effect change are available—landowners and the public need to decide the extent of the usage of these tools. Some of the tools may involve substantial site disturbance, especially for early successional stage species.

9
PREFERRED MITIGATION STRATEGIES

9.1
Mitigation Alternatives Criteria

The significant impacts identified in sections 5 and 6 are those likely to occur at the three levels of harvesting if management practices including selected mitigations are applied as described for the first and second runs. The impacts also include exogenous factors such as land use change. The significance criteria applied in section 7 identify those impacts that exceed threshold levels and therefore require a mitigative policy response. Section 8 identifies the range of possible mitigations that could be applied to address these significant impacts. In addition, significant impacts which cannot be mitigated are also identified. The current section describes criteria for selecting preferred mitigation alternatives.

A variety of strategies can mitigate against adverse impacts of timber harvesting and forest management and exogenous factors affecting the resource. The final criteria document (Jaakko Pöyry Consulting, Inc. 1992a) describes how such strategies would be identified and selected.

Framework for analyzing mitigations and selecting preferred mitigation strategies

Criteria for selecting strategies are drawn from the final criteria document noted above and reproduced below:

> Based on an analysis of mitigation alternatives identified, preferred mitigation strategies will be selected by considering in relative terms:
> 1. the effectiveness at mitigating the identified significant impacts;
> 2. the beneficial effects on other resource values;
> 3. the adverse effects on other resource values;
> 4. the physical, biological, administrative (implementation and oversight), financial (costs, public and private, direct and indirect), and social (ability to organize, support and effect implementation) feasibility; and
> 5. the probability of success and duration of success.

In practice, the verbal and written input from the Advisory Committee on the potential mitigation strategies led to acceptance, rejection and/or refinement of the potential strategies. These results were then approved by the EQB and comprise the strategies considered and evaluated in detail. Additionally, for this analysis the above criteria were grouped as follows:

1. *Effectiveness* addresses a mitigation strategy in terms of its ability to either avoid or reduce the identified impacts.

2. *Feasibility* addresses the likelihood that the mitigation strategy can be implemented, based on existing or future economic, social, biophysical, or administrative constraints.

3. *Duration* of mitigation can best be scored into four classes: 1=long-term—greater than 50 years and irreversible; 2=medium-term—10 to 50 years; 3=short-term—2 to ten years; 4=very short-term—less than 2 years.

4. *Concomitant effects* refers to those strategies that have the potential to significantly affect other resources. It is clearly fallacious to consider that any forest management practice will only affect a single resource; forests are intricately interacting ecosystems, and each practice affects many resources.

5. *Probability of success*, though not tabulated explicitly in the following tables, is a combination of effectiveness, feasibility and duration with minimal negative concomitant effects. The strategies identified as highly effective, highly feasible, of long duration and with minimal negative concomitant effects are assumed to have the greatest chance of success in the long-term.

These criteria were then applied to the various mitigation strategies for the purpose of comparison among them and to help determine preferred mitigation strategies.

Evaluation of Specific Strategies
A variety of strategies can mitigate potential adverse impacts of forest harvesting on soil nutrients. A comparison of the strategies considered is summarized in table 6.1.

9.2 Mitigation Strategies

The rankings of mitigation strategies with respect to the above criteria have been grouped by impact and are presented below. Explanations of the ranks for these mitigation strategies are provided in the discussion.

9.2.1 Evaluation of Specific Strategies—Loss of Forest Statewide and by Ecoregion

Two possible mitigation strategies are considered for the impacts of loss of forest land. These are summarized in table 9.1.

Measures to reduce the area of forest land converted to other land uses seek to discourage landholders from converting forest land to other forms of land use. Such conversions will likely take place almost exclusively on private lands. Therefore, any initiatives that seek to limit or control uses must be framed in ways that recognize private property rights, including the rights of owners to use their land for its highest economic use. There are a variety of policy instruments that are available at the federal, state and local level. The effectiveness of these policy instruments to compete with economic forces varies considerably across the state. They are likely to be less effective and/or more costly closer to major urban areas, where the value of the land for other purposes increases. Conversely, in the northern part of the state, these instruments will likely be more effective where they are applied as the unit value of land decreases. Overall, the alternative is rated as being moderately feasible. This is because most of the conversion from forest to other land uses is occurring in the north of the state. However, there are limited stocks of nonforest land in this region. Therefore, *any* change in land use in this part of the state will likely reduce the area of forest land. Changes brought about under this mitigation are likely to persist over the medium-term.

Table 9.1. Evaluation of mitigation strategies for minimizing negative impacts of loss of forest land on forest productivity and the forest resource base. Rankings for effectiveness and feasibility from 1=high to 3=low, and for duration from 1=long- to 4=very short-term. Concomitant effects refers to potential positive (+) or negative (-) effects on issues of concern from the FSD.

Mitigation Strategy	Effectiveness	Feasibility	Duration[a]	Concomitant Effects (+)[b]
Reduce loss of forest area - northern ecoregions	2	2	2	Wildlife (+)
- southern ecoregions	2	3	2	Wildlife (+)
Increase rate of forest establishment	2	2	1	Biodiversity (+)

[a]1 =long-term—greater than 50 years; 2=medium-term—10 to 50 years; 3=short-term—2 to ten years; 4=very short-term—less than 2 years.
[b] Effects that are noted are those with potential to *significantly* affect another resource.

Increasing the rate of forest establishment can reduce the net loss of forest lands. There are a range of federal and state government incentives to promote reforestation activities on private lands. These programs are not necessarily aimed at increasing the area of forest *per se* but do achieve this as a side effect of efforts to reduce the area of cropland or to reduce soil losses. The effectiveness and feasibility of this mitigation will likely be governed by the degree to which the objectives of these existing reforestation programs could be achieved while at the same time meeting the age class and covertype changes identified as being desirable. If funds do not become available through these programs, the feasibility of this alternative is likely to be constrained by the comparatively low returns from independent forest plantation enterprises. Low returns are unlikely to motivate private growers to expand their area of forest. Where forest is established, the duration of the effect is long-term.

Preferred Mitigation(s)
Both potential mitigations are likely to be moderately effective, but reducing the loss of forest land allows use of a variety of policy instruments tailored

to the situations that require them. Thus it is the preferred mitigation. However, interest in establishing new forests will continue and should be encouraged, especially where environmental protection needs are evident, such as in riparian areas.

9.2.2 Evaluation of Specific Strategies—Loss of Timberland Statewide and by Ecoregion

Four possible mitigation strategies are considered for the impacts of loss of timberland. These are summarized in table 9.2.

Table 9.2. Evaluation of mitigation strategies for minimizing negative impacts of loss of timberland on forest productivity and the forest resource base. Rankings for effectiveness and feasibility from 1=high to 3=low, and for duration from 1=long- to 4=very short-term. Concomitant effects refers to potential positive (+) or negative (-) effects on issues of concern from the FSD.

Mitigation Strategy	Effectiveness	Feasibility	Duration[a]	Concomitant Effects (+)[b]
Increase afforestation rate for selected covertypes	2	2	1	Biodiversity (+)
No net loss of timberlands policy	3	3	1	
Increase utilization of harvested stands	2	2	1	Economics (+) Soils (-) Wildlife (-) Biodiversity (-)
Increase productivity	1	2	1	Biodiversity (-)

[a] 1=long-term—greater than 50 years; 2=medium-term—10 to 50 years; 3=short-term—2 to ten years; 4=very short-term—less than 2 years.
[b] Effects that are noted are those with potential to *significantly* affect another resource.

Increasing the afforestation rate for selected covertypes would decrease the net loss of timberland as described in the previous section.

No net loss of timberlands would maintain the area of timberlands available for timber production. This policy may be effective in maintaining the land base; however, this is only one part of the timber supply equation. The productivity of timberlands is equally important. Therefore, while this alternative is appealing in its simplicity, it would be of limited effectiveness. This alternative is also not likely to be highly feasible because of budget constraints applying to the major state and federal agencies. None of these agencies has active timberland acquisition programs, although some land exchanges continue. The forest industries are the in the best position to give effect to this mitigation, and are also the most likely to benefit.

Increasing utilization would raise per acre yields thereby avoiding the need to increase the area harvested to obtain additional wood. This mitigation could be achieved by using more of each stem harvested by reducing minimum top diameter and log length specifications of logs; and by changing production processes to accept the range of species available from the forest rather than only a proportion of the species available. The feasibility of this alternative is dependent on the ability of the forest products industry to adapt to changing input specifications while remaining competitive with other domestic and international competitors. Additionally, such utilization would need to be cognizant of concerns about soils and wildlife habitat. Proposed new industries are moving in this direction; retrofitting existing industries will be more difficult. The benefits from this alternative would be long-term.

Increasing productivity of existing and future stands will likely be a more effective way to maintain future resource security than reliance on gross area. There are many ways to increase productivity of timberlands. Regeneration to full stocking levels and site-species matching are the two most readily implemented on a statewide scale. However, achieving fully stocked stand conditions and the matching of species to sites could adversely affect biodiversity. This mitigation would be feasible, as much can be achieved by changing the way harvesting is done, and by improved site survey and planning. Additionally, some practices could be expensive to the extent of reducing feasibility. The focus of this mitigation is on private lands where the standards of planning and management can be most improved. Improving these standards, and therefore productivity, is feasible using a combination of landowner education and wider ranging BMPs that include good harvesting practices likely to maximize regrowth success. This alternative would provide long-term mitigation.

Preferred Mitigation(s)

There is considerable difference in establishing a no net loss policy and actually implementing it with appropriate funding. Consequently, increasing utilization and productivity are the preferred alternatives. However, increasing productivity will require a commitment to management investments on a large-scale over long-term horizons.

9.2.3 Evaluation of Specific Strategies—Patterns of Forest Cover in Areas of Mixed Land Use

Two possible mitigation strategies are considered for the negative impacts of patterns of forest land. These are summarized in table 9.3.

Reducing site specific impacts would involve thinning or uneven-aged management where feasible, and limiting harvesting and especially harvesting of small portions of any given tract in any one decade. Since most such lands are in private ownership, education, incentive and assistance programs would likely be most cost effective. Regulation of practices is an alternative, but likely a very expensive alternative, due to the scattered ownership. In reality, partial cutting, as opposed to clearcutting, is feasible and the most common practice in such regions. The impacts are likely to be long-term, but subject to the vagaries of changing ownership.

Table 9.3. Evaluation of mitigation strategies for minimizing negative impacts of patterns of timberland on forest productivity and the forest resource base. Rankings for effectiveness and feasibility from 1=high to 3=low, and for duration from 1=long- to 4=very short-term. Concomitant effects refers to potential positive (+) or negative (-) effects on issues of concern from the FSD.

Mitigation Strategy	Effectiveness	Feasibility	Duration[a]	Concomitant Effects (+)[b]
Reduce site specific impacts	2	2	1	Biodiversity/ Wildlife (+)
Acquisition of key patches	1	2	1	Biodiversity/ Wildlife (+)

[a]1 =long-term—greater than 50 years; 2=medium-term—10 to 50 years; 3=short-term—2 to ten years; 4=very short-term—less than 2 years.
[b] Effects that are noted are those with potential to *significantly* affect another resource.

Acquisition of key forest patches is a strategy most appropriate to patches that are very important as habitat and to the connectivity of habitat. Easements or purchase may both be useful. In the case of wetlands, precedents provide experience with the approach and suggest it is feasible and effective. A practical limitation is the availability of funding.

Preferred Mitigation(s)
Both strategies can be effective and feasible, depending on program funding. Both should be pursued to encompass a large area in a cost-effective manner.

9.2.4 Evaluation of Specific Strategies—Tree Species Mix

Four possible mitigation strategies are considered for the impacts of loss of timberland. These are summarized in table 9.4.

Altering stand age class structure in many cases affects stand age-related species composition for both trees and understory vegetation. This mitigation is very feasible and could be coordinated with the existing extended rotation forest programs of the MNDNR and USDA Forest Service. Since changes in age class structure would be implemented through harvesting, manipulation of large numbers of stands would be a long-term process.

Altering tree species composition could also be achieved by varying harvesting and silvicultural practices. This mitigation relies on development of guidelines for management of types to promote desirable species or to effect covertype changes. These mitigations would logically apply to public ownerships which have a mandate for managing to promote biodiversity at a state or national level. This mitigation is very feasible and could be coordinated with the existing extended rotation forest programs of the MNDNR and USDA Forest Service. Manipulation of stands to effect species or covertype changes would necessarily be a long-term process. The feasibility of this alternative would be constrained by the ability to obtain funds for this purpose. It is unlikely that the costs of such conversions could be justified by returns from timber production alone. The contribution of such stands to maintenance of biodiversity and provision of other values would make these expenditures by public ownerships more justifiable.

Table 9.4. Evaluation of mitigation strategies for minimizing negative impacts of tree species mix on forest productivity and the resource base. Rankings for effectiveness and feasibility from 1 = high to 3 = low, and for duration from 1 = long- to 4 = very short-term. Concomitant effects refers to potential positive (+) or negative (-) effects on issues of concern from the FSD.

Mitigation Strategy	Effectiveness	Feasibility	Duration[a]	Concomitant Effects (+)[b]
Alter age class structure	1	1	1	Biodiversity (+)
Alter species composition	1	2	1	
Enrichment of species composition on private lands	2	2	1	Forest Health (+) Biodiversity/ wildlife (+)

[a] 1 = long-term—greater than 50 years; 2 = medium-term—10 to 50 years; 3 = short-term—2 to ten years; 4 = very short-term—less than 2 years.
[b] Effects that are noted are those with potential to *significantly* affect another resource.

Changing species composition would require wider application of existing species site matching guidelines. Application of these guidelines would be effective at preventing offsite planting. The MNDNR, USDA Forest Service, larger counties and forest industries lands typically already implement these guidelines. Therefore, increasing the use of guidelines is feasible assuming the MNDNR takes a leadership role to promote their use by NIPF ownerships via existing extension services. This mitigation would have significant positive impact on forest health. Once established, the forests will provide long-term benefits.

Enrichment of species composition can be effective, especially on public lands. It can be used to create a change in covertype or simply to enrich a stand. Difficulties are matching species regeneration requirements with site conditions and dealing with herbivory. Also, establishing meaningful enrichment over a large area would require substantial management investment over a long time period. For private ownerships, success would require a range of incentives, technical expertise and a clear description of the benefits for other purposes such as aesthetics, wildlife food or habitat, etc.

Preferred Mitigation(s)
Altering the age class distribution through harvesting is the preferred mitigation. Where that is not sufficient to achieve covertype or species composition goals, alteration of species composition directly is appropriate. Enrichment is the most expensive approach and likely to be limited by practical considerations to only a few species and site conditions.

9.2.5
Evaluation of Specific Strategies—Age Class Structure

Only one possible mitigation strategies was considered for the impacts of age class structure on forest productivity and the resource base. This mitigation is summarized in table 9.5.

Table 9.5. Evaluation of mitigation strategies for minimizing negative impacts of forest age class structure on forest productivity and the forest resource base. Rankings for effectiveness and feasibility from 1=high to 3=low, and for duration from 1=long- to 4=very short-term. Concomitant effects refers to potential positive (+) or negative (-) effects on issues of concern from the FSD.

Mitigation Strategy	Effectiveness	Feasibility	Duration[a]	Concomitant Effects (+)[b]
Balance the age class structure	2	2	2	Wildlife (±)

[a]1=long-term—greater than 50 years; 2=medium-term—10 to 50 years; 3=short-term—2 to ten years; 4=very short-term—less than 2 years.
[b] Effects that are noted are those with potential to *significantly* affect another resource.

Balancing age classes is technically feasible; however, in practical terms it depends on markets and/or management investments to fund implementation. Such investments are most likely to develop for species with commercial value. This balance also needs to be considered in the context of desired species composition for the forest and long-term goals for that. The task is complicated by the varied forest land ownership. Depending on the forest type and existing age class distribution, the process will invariably affect some wildlife species positively and some negatively.

Preferred Mitigation(s)
Balancing age classes in conjunction with changes in species composition is the preferred approach.

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