Forest Harvest Levels in Minnesota

Effects of Selected Forest Management Practices on Sustained Timber Yields

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Executive Summary

Purpose

One key recommendation of the 2007 Governor's Task Force on the Competitiveness of Minnesota's Primary Forest Products Industry was to explore the feasibility of increasing total statewide timber production across all ownerships to 5.5 million cords per year (mil cd yr^{-1}) in an environmentally sustainable manner. Statewide harvest levels have averaged approximately 3.69 mil cd yr^{-1} over the past ten years, thus achieving the task force recommendation might require a significant change in land management practices. One objective of this analysis is to determine if a sustained timber yield of 5.5 mil cd yr^{-1} is achievable and to quantify changes in management practices that could potentially increase utilization toward this level. This study starts from the existing state of forest management as well as biologically maximum growth and then explores potential forest management scenarios between these two endpoints using model and data-based approaches.

This analysis was done in order to provide information to policymakers, forest managers, and proposers of new industrial facilities to help assess future timber yields and forest age classes under a range of potential management and policy options that might help increase statewide harvest levels. The focus is largely on resource analysis, i.e., potential yields rather than social, environmental or economic, and as such the study is far more limited in scope than the 1994 Generic Environmental Impact Statement on Timber Harvesting (GEIS). However, the study did incorporate the Minnesota Forest Resources Council guidelines, reserved forest areas, consideration of old growth, etc. Thus aspects of various social, economic, and environmental considerations were incorporated.

Methods

An Advisory Group formed by the State Forester provided assistance through peer review and advice during preparation of the analysis and report. The Advisory Group also made recommendations on future analysis needs beyond the scope of this original work.

A state-of-the-art forest estate modeling framework (Remsoft, Fredericton, NB, Canada) was used to model sustainable harvest levels across all ownerships in Minnesota. The modeled land base was derived from Minnesota 2005 Forest Inventory and Analysis (FIA) data. Only nonreserve, productive, stocked timberland was included, resulting in 14,743,269 acres represented by 6,331 field plots. Each plot was placed into a development type: a unique combination of five-year age class, forest type, site productivity class, and ownership class. Each development type had its own parameterization, e.g., rotation ages, extent of extended rotation forestry, and timber yield stream, and was projected 50 years into the future using ten five-year planning periods. Development types were assigned one of four generic management activities (even-aged vs. uneven-aged management, commercial thinning, or no entry). The resulting schedule represented the highest sustainable harvest level over the 50-year period subject to constraints that reflect how timberlands are currently managed. This baseline harvest scenario was then augmented by alternative scenarios that explored changes in sustainable harvest levels relative to changes in forest management practices. In conjunction with these scenarios, FIA-based estimates of growth were used to determine if the forest land base can supply enough roundwood to meet the key recommendation. The effect of management practices on sustainable timber yield levels was quantified by modeling alternative management practices singly as follows: (1) addressing market and process constraints or inefficiencies in current practices (e.g., insuring that, within no longer than five years, all tracts identified for management are fully operationalized, from setup through to scaling), (2) reducing the amount of effective extended rotation forestry on public lands, (3) allowing federal lands to be managed for timber productivity, (4) assuming full cross-ownership cooperation, (5) removing operability concerns in white cedar and black ash types, (6) placing less emphasis on regulated age class distributions, (7) adopting more aggressive thinning regimes, (8) allowing for intensive management to restore full productivity, (9) reducing rotation ages for even-aged systems, (10) augmenting the land base (increased access to private lands), and (11) utilization of logging residue.

The focus of this analysis was to examine harvest-level impacts of various management and policy options. Harvest-level impacts are only one important consideration when examining forest management and policy options and the analysis is not designed to explicitly examine the social or environmental desirability of these options.

Results

Under current practices the sustainable harvest level was capped at the 1996-2005 average of 3.69 mil cd yr^{-1}. Most roundwood volume was generated in even-aged systems at final harvest, 87% by volume and 81% by area treated. The aspen type played a pivotal role: 69% of the statewide total harvested volume and 59% of all harvest activity by area was in the aggregated aspen type. Overall yield, total volume harvest divided by total acres treated, was 19.5 cd ac^{-1}. FIA-based estimates of growth exceeded current practices and the recommended 5.5 mil cd yr^{-1} target, i.e., maximum biological growth (12.56 mil cd yr^{-1}) > gross growth (9.56 mil cd yr^{-1}) > net growth (5.00 mil cd yr^{-1}) > current harvest levels. Mortality based on fire, animal damage, insect and disease, and overstocking totaled 1.04 mil cd yr^{-1} in 2005. These estimates of gross and net growth also suggest that capture of a greater portion of mortality has the potential to increase net growth and thus sustainable harvest levels. While complete capture is not possible, it is notable that capture of 40% would increase sustainable harvest levels by 1.8 mil cd yr^{-1} and would satisfy the 5.5 mil cd yr^{-1} recommendation.

The inclusion of logging residue (increased utilization) in the context of working biomass markets would increase effective harvest levels by 640,000 cd yr^{-1}. In terms of more traditional roundwood silviculture, changes in forest management practice that led to significant increases (≥10% change) in sustainable harvest levels were: (1) addressing market and process constraints, e.g., ensuring that all stands selected for treatment result in harvested and scaled volume within one planning period or, ideally, one year (+509,000 cd yr^{-1}); (2) more aggressive and intensive thinning regimes (+478,000 cd yr^{-1}); and (3) the use of timber stand improvements, i.e., precommercial activities designed to allow a stand to reach its full biological productivity (+520,000 cd yr^{-1}). When applied in concert these changes alone could augment sustainable harvest levels by 2.15 mil cd yr^{-1} thereby increasing harvest by 58% to 5.84 mil cd yr^{-1} over the 50-year planning horizon.

The main scenarios (Tables 4-5 & 8) quantify the change in harvest level relative to changing one management policy. Beyond this, one additional scenario was added at the request of several Advisory Group members to address a desire for analysis of a single harvest or timber yield level, overall and by species that would be achievable given several altered constraints. To estimate these harvest levels an additional scenario was designed that removed "market" constraints, eased even-flow constraints on several forest types, and altered three policies or practices at once. A timber yield of approximately 6 million cords annually was found to be achievable under these constraints and conditions. This is not a "recommended" harvest level, but is instead an examination of timber yields and age-class impacts given the scenario parameters and constraints (see Appendix B for details).

Conclusions

In conclusion, the current harvest level has showed little variation for the 1996-2005 period and falls short of FIA-based estimates of maximum, gross, and net growth. Improved markets and processes, more frequent thinnings, removing greater volume (i.e., utilization of nonmerchantable stems as biomass) with each entry, the use of precommercial forest management activities (e.g., seedbed preparation, fertilization, removing overtopped specimens) to restore full productivity, and increased utilization (particularly in the form of logging residue) all have potential to sustainably meet and exceed the 5.5 mil cd yr^{-1} harvest level recommendation on timberlands in Minnesota. While decisions on forest management policies and/or and investment levels are outside the scope of this analysis, quantification of potential harvest volume effects is one important factor that can be considered by decision makers, in addition to environmental and social benefits.

This study should be seen as one important step in the continuing process of analyzing forest management practices, policies and opportunities. Advisory Group recommendations for the future include maintaining and expanding capacity to do a range of statewide analyses in a timely manner, including regular harvest-level analyses updates. Additional analyses should be expanded and integrated to address:

- A wide range of important ecosystem services (water quality, wildlife habitat, carbon sequestration, etc.)
- Information and assumptions related to private lands timber availability
- Economics, including high valued-added products, forest management investment opportunities, transportation needs, and impacts of potential budget limitations
- Opportunities for integrating/mitigating increased biofuels production with timber production and ecosystem services
- Potential utilization and marketing opportunities and likely impacts

Introduction

Contemporary forest resource management faces numerous challenges in Minnesota. These range from parcelization and fragmentation of the forested land base, sluggish economic demand for forest products, emerging biomass markets, and increased competitive pressure from globalized markets. These challenges formed the backdrop for the 2007 Governor's Task Force on the Competitiveness of Minnesota's Primary Forest Products Industry (MN DNR, 2007). One key recommendation of this task force was to explore the feasibility of increasing total statewide timber production across all ownerships to 5.5 mil cd yr^{-1}. Statewide harvest levels have averaged 3.69 mil cd yr^{-1} over the 1996-2005 period, with little variation. This history suggests that achieving this benchmark might require significant changes in land management practices. Furthermore, any potential changes in current land management practices must be carefully considered in the context of sustainability that references forest growth, timber production, and nontimber values such as wildlife habitat.

This analysis was done in order to provide information to policymakers, forest managers and proposers of new industrial facilities to help assess future timber yields and forest age classes under a range of potential management and policy options that might help increase statewide harvest levels. The focus is largely on resource analysis, i.e., potential yields rather than social, environmental or economic, and as such the study is far more limited in scope than the 1994 Generic Environmental Impact Statement on Timber Harvesting (GEIS). However, the study did incorporate the Minnesota Forest Resources Council guidelines, reserved forest areas, consideration of old growth, etc. Thus aspects of various social, economic, and environmental considerations were incorporated.

This analysis starts from the existing state of forest management and then estimates an upper limit on timber productivity based on maximum biological growth. Management scenarios, implemented in a forest estate model driven by linear optimization, are then used to explore potential harvest levels between these two endpoints. The objectives of this analysis are fourfold: (1) to develop a modeled baseline scenario of the forestry situation in Minnesota that mimics current practices and outputs; (2) to determine, using alternative scenarios and ancillary data, if the forested land base in Minnesota can provide a sustainable harvest level of 5.5 mil cd yr^{-1}; (3) to quantify changes in harvest levels as a function of management practices and (4) to provide harvest level volume impacts as one important part of informing decisions on potential changes to current management regimes to achieve the key 5.5 mil cd yr^{-1} recommendation. Clearly, policymakers will need to also consider environmental and social impacts of any management changes.

Methods

An Advisory Group formed by the State Forester provided assistance through peer review and advice during development of the analysis and report. The Advisory Group also made recommendations for future analysis beyond the scope of this original work.

Baseline Scenario

The modeled land base was drawn from the 2005 Forest Inventory and Analysis (FIA) data for Minnesota. For this study the field plot level compilation of FIA data was used (Miles and Pugh, 2007). Only nonreserve, productive, stocked timberland (i.e., commercial forest) was included, resulting in 14,743,269 acres represented by 6,331 field plots. Each plot was then placed into a development type: a unique combination of five-year age class, forest type (Table 1), site productivity class, and ownership (Table 2)[1]. Development type area was calculated using volume-based expansion factor (VEF)[2]. Site productivity classes were bins of five site index unit increments from 20 to 90.

While the use of FIA data enables analysis across the whole state, there are two important caveats. First, FIA data is inherently aspatial. Each plot represents, on average, 2,000–3,000 acres and there is no clear sense of adjacency between plots or stand boundaries. This poses problems for analyzing any aspect of forest management where spatiality is important, e.g., parcelization, fragmentation, and wildlife habitat. The latter was addressed in an aspatial manner by tracking effective extended rotation forestry (EERF). This is a concept used in the forest planning process on state-owned lands (MN DNR, n.d.) and refers to the portion of a type-specific age class distribution where stands are purposely held past normal rotation ages to facilitate nontimber values. This concept was applied as a threshold, i.e., a fixed percentage of EERF by type was an explicit target. These thresholds were applied to state and federal lands only on primarily even-aged systems (Appendix Table A1) and deal only with wildlife species that may require later successional forest types, and age classes beyond biological or economic rotation, as habitat.

The second caveat concerns ownership. In the 2005 FIA there are only four major categories (Table 2) and private ownership lacks any differentiation between, for example, nonindustrial private forest owners (NIPF), timber investment management organizations (TIMOS), real estate investment trusts (REITS), or the other (typically held by vertically integrated firms) industrial land base. As management regimes can be expected to vary among these subgroups the modeled results for private ownership are aggregated and can only be sensibly interpreted as broad averages. Furthermore, estimates of the percentage of total private land holdings available for management activity vary. Birch (1996) reported that landowners representing 86% of private land holdings, by area, were amenable to harvest activity either in the next decade or indefinitely. The GEIS on Timber Harvesting and Forest Management in Minnesota (Jaakko Pöyry Consulting, Inc., 1994) assumed 90% of private lands were open to management activity. The UPM/Blandin Paper Thunderhawk Project (Thunderhawk) (Johnson et al., 2006) assumed that

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[1] An FIA inventory data error in assigning state/county ownership was discovered late in the process of preparing this analysis and report. Approximately 272,820 acres classified as county land in 2003 data were erroneously classified as state land in the 2005 data (6/23/09 personal communication, Pat Miles, FIA Analyst). Figures in this study related to county and state ownerships should be adjusted accordingly.

[2] FIA data offer two expansion factors: VEF, used to scale plot level volumes, and an area-based version (AEF), used to scale plot level areas. As the key recommendation is formulated in terms of harvested volume VEF was used by the model internally to characterize plot area. However, areal extent of harvest is also of interest so an aggregated relationship between VEF and AEF across all plots was developed: 1 ac VEF = 0.75 ac AEF. This was used to estimate areal extent of harvest for all development types.

the willingness to harvest on private land was linked to initial age class, cover type, and scenario. However, despite this nuanced approach volumes harvested on private lands showed little variability across scenarios with the exception of both *HighAspen* scenarios. Under these scenarios there was a significant increase in harvest volumes on private lands, primarily a function of removing a statewide volume cap in the modeling framework and not a function of private land availability *per se*. For this study we assumed 90% of private lands, by area, were available to be harvested, i.e., were operable with the modeling framework determining which parcels were excluded relative to the objective function and management scenario. It is noteworthy that this only applies to cover types without additional operability constraints, e.g., low productivity elm-ash-cottonwood (see below). On such types the more restrictive limits were used. Growth and yield was invariant across all ownership subgroups and all model outputs reference private ownership in the aggregate.

This analysis used three silvicultural systems: even-aged and uneven-aged management, and thinning. The parameterization of each even-aged system varied by ownership (Appendix Table A1). Uneven-aged management and thinning were invariant across all ownerships and assumed that each thinning removed a fixed percentage (= 33%) of standing volume (Appendix Table A2 & A3). The northern white cedar, elm-ash-cottonwood (lowland hardwoods), and maple-birch types (northern hardwoods) were further constrained by operability limits, the latter two solely on poor sites (site index < 50). The areal extent of management activity in each of these types is limited to a fixed percentage of the operable land base (1%, 10%, and 10% respectively) for this study period. Similarly, the amount of harvested volume for tamarack species was capped at its current utilization rate of 70,000 cd yr^{-1}. These limits represent current practices dictated by silvicultural challenges in regeneration, lack of markets, forest health, and type-specific wildlife habitat concerns (Jacobson, 2007).

Existing best management practices (BMPs), with emphasis on riparian areas and, where applicable, seed trees were addressed through a single aggregated silvicultural parameter: each stand was required to leave a fixed percentage (= 5%) of volume on site.

Growth and yield tables for development types (irrespective of ownership) were estimated at the midpoint of each five-year age class using a modified version of Walters and Ek (1993; hereafter WE93). The WE93 study detailed several equations for predicting gross volume metrics and stand characteristics, e.g., gross volumes, quadratic mean diameter (QMD), at the stand level as functions of stand type, site index, and stand age. WE93 was developed using 1977 FIA data from the Aspen-Birch Unit of Minnesota. For this study the equations used in WE93 for basal area (BA) and QMD, which serve as arguments for the volume equations, were recalibrated using 2005 FIA data; the functional form was maintained but coefficients were re-estimated using current FIA data. This was done to correct a large bias, due to changes in plot protocols and typing procedures, when using the original WE93 equations on the 2005 FIA plot data. Mean bias of gross merchantable volume, BA, and QMD in the aspen type was -387.02 ft^3, -13.59 ft^2, and -0.79" respectively using the original WE93 and -174.06 ft^3, -0.13 ft^2, and 0" after re-estimation based on the 2005 FIA. A scaling factor was also used (WE93, pg. 84) for each type to correct for systematic over- or under-estimation of merchantable volumes. Finally, merchantable gross volumes using WE93 were a function of a fixed stump height (1') and top diameter outside bark (dob = 3").

Two enhancements of WE93 were also applied. First, it is known that stands, after some age and barring human disturbance or calamity, begin to decline and ultimately transition to a different type. This is generally associated with a loss of merchantable volume. However, WE93 volumes are monotonically increasing functions of age. In order to add more realism to WE93 each aggregated cover type was assigned a maximum rotation age (MRA) based on the Minnesota Department of Natural Resources (MN DNR) internal forest planning procedures (MN DNR, n.d.). After MRA stand volume was assumed to decline. To implement that decline, the volume metrics associated with the age class just after MRA were no longer estimated using base WE93 equations. Instead they were assigned to the same values corresponding to one age class prior to MRA, e.g., volume one year past MRA was set equal to volume one year prior to MRA although no stand's volume could decline below the 20-year base WE93 result. Conceptually the trajectory of volume metrics retreats back down the curve after MRA is reached. This approach is assumed to better reflect the reality of stand progression and forest succession.

The second enhancement relates to increases in productivity based on intensive management. WE93 is a cross-sectional study of plot-level volume metrics. The assumption is that the modeled response surface applies in a longitudinal context. However, WE93, when applied longitudinally, reflects net change as opposed to any inherent growth potential. While realistic under business as usual scenarios within some limits the original WE93 cannot reflect yield gains associated with multiple entries, e.g., "thinning early, often, and heavy". Given this limitation, WE93 model fitting information was used to develop a more realistic alternative for describing the yields from intensive management. The original WE93 reported root mean square errors (RMSE) for most equations, including BA and QMD. An RMSE is simply a measure of spread of the error, the discrepancy between observed and predicted values. As WE93 plots used in fitting were not filtered and include stands with various degrees of management through time, the RMSE can be used as a proxy for more productive strands. Specifically, adding one RMSE to the predicted value places that stand in a more productive subset relative to the mean predicted value from the base WE93 equations. Adding one RMSE to both BA and QMD (and subsequently propagating these enhanced predictions throughout the full system of WE93) results in stands with higher volume, more BA, and larger but fewer trees. For this modeling exercise the RMSE for the re-estimated equations were used, in absence of scaling factors, to depict stands with enhanced productivity relative to their baseline counterparts. In general stands were projected with these enhanced yield equations only as a result of a modeled management action. However, white spruce and red pine plantations were always modeled with enhanced yield equations.

WE93 utilized only 14 aggregated forest types. Consequently, forest type and forest type groups present in the 2005 Minnesota FIA data were mapped to these aggregated types using the closest and best match (Table 1). In order to calculate volume by species, as opposed to volume by type, a species composition analysis based on net volume of growing stock on timberland acres from the 2005 Minnesota FIA was done. The percentage of type volume in a given species was calculated using the average percent composition across all plots in a given type and was invariant across ownership, age, and site productivity.

In addition to merchantable volumes (cd ac^{-1}), QMD, and BA, logging residue (cd ac^{-1}) were also tracked for each development type. Logging residue is the amount of expected residue remaining after a typical final harvest operation adjusted for recoverability and management guidelines. Residue figures used here were drawn from the 2006 Minnesota Logged Area Residue Analysis Study (Sorensen, 2007) and are the sum of all residual types excluding standing volumes and assume 50% recoverability (Table 3).

While not an explicit part of the yield tables, succession is an important component of growth and yield. A successional matrix was developed using background information presented in the GEIS. In this report, all plots that were harvested and visited both during the 1977 and 1990 FIA periodic surveys had their cover type designations in 1977 and 1990 tabulated, effectively tracking succession of one type to other types following harvest[3].

In order to examine scenarios, the above land base, growth and yield tables, and parameterizations for management entries were subsequently implemented in Remsoft (Remsoft® Inc., 2008), a forest estate and harvest scheduling model based on linear programming.

Linear programming is an optimization technique where an algorithm searches for the "best" solution—best being that solution that "satisfies" a mathematical objective function, e.g., maximization total cordwood volume harvested relative to a set of management constraints. Since harvest level sustainability requires a longer-term time horizon, a 50-year planning horizon consisting of ten five-year planning periods was used throughout. Thus all stands were projected 50 years into the future based on initial conditions in the 2005 FIA data. All management activities (yield metrics) occur (were calculated) at the midpoint of any planning period. Regulation over time in even-aged systems was encouraged with even flow constraints[4]. Such ownership-specific even flow constraints reflect a lack of cooperation across land administrators. Harvested volumes from the federal ownership class were constrained to not exceed 387,000 cd yr^{-1} (see Thunderhawk). This figure is based on current annual targets on the Chippewa and Superior National Forests and assumes that the volume per acre yield from the National Forests applies to all lands in the federal ownership class. Finally, overall harvest levels were capped at the 1996-2005 average at 3.69 mil cd yr^{-1} (Jacobson, 2007).

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[3] The tabulation used in this study was a weighted average between Tables 4.1 and 4.2 (assigned weights of 67% and 33%, respectively) from Chapter 4 of the GEIS Forest Productivity Technical Report and was used in a probabilistic fashion, e.g., a paper birch stand after final harvest will regenerate to red pine 4% of the time with each regeneration outcome determined via a random number generator.

[4] These function by restricting fluctuations in a given output over all planning periods. In the baseline scenario(s) even flow constraints of 5% (the minimum value was constrained to be ≥ 95% of the maximum value) were applied. These constraints were used for every combination of aggregated cover type (Table 1) and ownership (Table 2). In addition, even flow of the statewide aggregated harvest volume, in total and for each ownership singly, was also controlled at 5%.

Maximum Biological Growth

Whereas the baseline scenario is designed to reasonably reproduce current management practices and their outputs, e.g., treatment areas and volume harvested, maximum biological growth serves only as a theoretical upper limit on harvest volume. Maximum growth was not determined using Remsoft® but rather under a set of simplified assumptions and FIA estimates of gross productivity at culmination of mean annual increment (CMAI). The FIA compilation used in this study (Miles and Pugh, 2007) contains a site productivity rating (SPCLASS) that provides a range of gross volume growth ($ft^3\ ac^{-1}\ yr^{-1}$) for each plot at CMAI assuming only a 1' stump. CMAI was used to estimate maximum biological growth as follows: (1) For each developmental type the shortest rotation age (Appendix 1) was used, uneven-aged systems had a 120-year rotation and were treated as even-aged systems for this exercise. (2) These rotation ages were then used to determine the areal extent of final harvest annually in an area control context assuming a uniform age class distribution. For example, this exercise used 40 years for the aspen type rotation age meaning that 2.5% of all aspen area was harvested annually with areas harvested within SPCLASS proportional to their extent. (3) The growth of these stands, i.e., the product of CMAI and area, was determined using the midpoint of each CMAI range (converted using 79 ft^3 =1 cd). (4) For the remaining age classes growth was estimated in the same manner; effectively assuming that average growth across the entire age class distribution in a regulated forest is approximated by CMAI. (5) Finally, CMAI is based on gross, not merchantable volume. Simulations using WE93 showed that increasing dob from 0" to 3", i.e., moving from gross to merchantable volume, reduced volume by 15%. This adjustment was used to scale raw CMAI-based growth to the current standard of 3" dob.

Alternative Scenario Development

Between the baseline scenario and the theoretical upper limit of potential harvest as constrained by maximum biological growth there are an infinite number of plausible management outcomes. As only a finite amount of these outcomes may be explored, 15 alternative scenarios were chosen (Table 4). These scenarios were picked (1) to reflect management strategies that represent the more feasible practices or serve as benchmarks similar to maximal biological growth and (2) to quantify opportunity costs or gains relative to existing management practices. For example, total harvest under the Cooperation scenario minus the same under the State Harvest scenario quantified the gain in sustainable harvest level that would result from cross-ownership cooperation. The difference between these two scenarios (Table 4) is that the ownership cooperation parameter (Table 5) was changed from Nil (State Harvest) to Yes (Cooperation). Each alternative scenario was developed by altering a single management constraint or parameter (Table 4) relative to a benchmark scenario[5]. This approach allowed for the effects of multiple changes in management policies to be aggregated. A key assumption was that the gains in sustainable harvest volumes were additive. This assumption was tested with two additional scenarios where five and ten management polices were altered simultaneously and contrasted with altering the same polices singly. The underlying growth and yield equations, land base, and time horizon were identical in all scenarios.

[5] The Baseline (Federal Harvest) scenario was used to benchmark the State Harvest (Federal Unconstrained) scenario. Otherwise the State Harvest scenario was used as a benchmark.

Results and Discussion

Comparison of Baseline Scenario to Current Practices and FIA-based Growth Estimates

The baseline scenario approximated recent forest management practice and utilization trends in Minnesota. The targeted 3.69 mil cd yr^{-1} harvest level was achieved and the aspen harvest level, which included bigtooth aspen, quaking aspen and balsam polar species, was within the range of recently published estimates (Table 6). Harvest share, the percentage of volume harvested by ownership class, was in good agreement with current practices; within 10% of harvest share for private and county ownerships and within 1% for the state ownership. For federal lands the discrepancy was proportionally larger (338,000 modeled vs. 239,000 actual cd yr^{-1}) and was related to allowable sale quantities (ASQ). The modeled system assumes full achievement and harvest of planned ASQs whereas recent practice reveals that only 50% of planned federal ASQs were achieved (USDA Forest Service, 2007, 2008a). Furthermore, not all sold volume was harvested, e.g., on the Superior National Forest 98%, 56%, and 48% of sold volume was harvested in fiscal years 2005, 2006, and 2007 respectively (USDA Forest Service, 2007, 2008b,c). Remotely sensed estimates of statewide harvest activity including 2005 satellite imagery ranged from 117,000 to 161,000 ac yr$^{-1,}$ depending on the temporal and spatial coverage of the base satellite imagery, and were accurate to ± 11,500 (Rack et al., 2007). These remote-sensed estimates were likely underestimates of change as they excluded any harvest <5 ac and failed to detect all partial harvest activity (Rack et al., 2007). The baseline scenario in Thunderhawk (Johnson et al., 2007, Table C-36) showed harvest levels ranging from 133,000 to 171,000 ac yr^{-1} over the 40-year planning horizon used. The modeled 189,000 ac yr^{-1} areal harvest extent was higher than both estimates but within 10%. Beyond harvest area and cordwood, the baseline scenario produced 640,000 cd yr^{-1} in logging residue. Most roundwood volume was generated in even-aged systems at final harvest, 87% by volume and 81% by area treated (cf. Puettman and Ek, 1999). Furthermore, the aspen type played a pivotal role: 69% of the statewide total harvested volume and 59% of all harvest activity by area was in the aggregated aspen type.

In contrast to the baseline scenario, FIA-based estimates of growth exceeded current practices, most prescriptive scenarios (Table 7), and the recommended 5.5 mil cd yr^{-1} target, i.e., maximum biological growth (12.56 mil cd yr^{-1})> gross growth (9.56 mil cd yr^{-1})> net growth (5.00 mil cd yr^{-1})> current harvest levels (3.56–3.82 mil cd yr^{-1}). The baseline harvest level was 30% of maximum biological growth, 40% of gross growth, and 75% of net growth. FIA-based estimates of mortality are linked to a proximate cause of death. Mortality based on causes of death that management activities can directly impact, i.e., fire, animal damage, insect, diseases, and overstocking, totaled 1.04 mil cd yr^{-1} in 2005 (Miles, 2008). While it is not possible (or perhaps even desirable) to capture (harvest prior to) all mortality, complete capture of net growth and this portion of mortality would increase sustainable harvest levels by 2.35 mil cd yr^{-1}, and in excess of the 5.5 mil cd yr^{-1} recommendation, to 6.04 mil cd yr^{-1}. Furthermore, FIA data provides some guidance on relevant management actions to increase timber productivity. Each plot is assigned a treatment opportunity code (Miles and Pugh, 2007), i.e., a recommended management activity to restore a stand to full productivity. In the current Minnesota FIA 9.8 mil ac were assumed to require either site preparation, stand conversion, thinning (partial, commercial, or precommercial) or final harvest (Miles, 2008) with 4.3 mil ac (=44%) alone requiring final harvest. These FIA-based figures are an order of magnitude greater than current and modeled harvest rates, which range from 189,000 to 382,000 ac yr^{-1} depending on scenario. Even under the scenario modeling the greatest acceleration in annual harvest acreages, 26 years would be required to solely liquidate the current backlog of deferred management.

Changes in Timber Outputs by Scenario

While comparisons between the baseline scenario and FIA-based estimates of growth offer some insight into whether and how harvest levels could be increased toward the 5.5 mil cd yr^{-1} goal, a more detailed understanding can be had using the remaining 15 prescriptive scenarios. These alternative scenarios provided a means to quantify the cost, in terms of timber production, of existing management practices and to project age class distributions and harvest by species, type, and ownership through time. Social and environmental consequences of management practices, while important, were not addressed.

In general, gains in harvested volume by scenario (Table 8) were roughly proportional to the amount of area in each ownership group. This excluded the federal ownership, which was constrained in most scenarios due to the difficultly in changing harvesting patterns on that ownership. Apart from this, in most instances the amount of wood available for harvest increased in all ownerships. Three exceptions to this occurred: the scenario reducing EERF on state lands caused a less than 1% increase in harvest level in that ownership. This was enough to offset some of the overall scenario-based increase on other ownerships because the suddenly available state lands had, on average, higher productivity and yield than the acreages on county and private lands they displaced. A similar dynamic occurred with allowing full access to private lands and removing ASQs or EERF on federal lands. These scenarios shared that a single ownership being targeted.

The increases in harvest level by scenario did not include logging residue (=0.64 mil cd yr^{-1} in the Baseline scenario), which can also be used toward meeting the 5.5 mil cd yr^{-1} goal. This averaged 0.73 mil cd yr^{-1}, was lowest in the Baseline scenario, and highest under No Even Flow (=0.78 mil cd yr^{-1}). The areal proportion of harvest activity by treatment type and the percentage of all volume in aspen species were relatively constant. The proportion of clearcut acres was within 71–80% except for Accelerated Thinning (=60%). Here, the scenarios allowed access to stands with lower productivity based on relaxed thinning regimes (Table 5). Aspen species volume (Appendix 5), as a percentage of total volume, ranged from 43–48%. Variation in wood quality, as measured by proxy using per acre yield (=19.5 cd ac^{-1} in the Baseline scenario), was modest and ranged from 18.8 to 20.5 cd ac^{-1}. For 2 scenarios wood quality was outside of this band: The highest wood quality was had under the Timber Stand Improvement scenario where average yield was 22 cd ac^{-1}. The lowest was found under Accelerated Thinnings (=16.8 cd ac^{-1}), which represented increased utilization of lower quality wood due to altered thinning regimes (Table 5).

The scenarios (Table 4 & 5), considering only those that altered management policies singly, with the largest effect (≈10% and greater) on harvest levels (Table 8) were No Even Flow (+0.81 mil cd yr^{-1}), Timber Stand Improvement (+0.52 mil cd yr^{-1}), State Harvest (+0.51 mil cd yr^{-1}), Silviculture (+0.43 mil cd yr^{-1}), Federal Unconstrained (+0.28 mil cd yr^{-1}), and Accelerated Thinning (+0.36 mil cd yr^{-1}). Federal Unconstrained and Silviculture were both speculative scenarios. The former, coupled with the Federal Harvest scenario (a combined +0.38 mil cd yr^{-1}

on federal lands alone, Table 8), quantified the opportunity costs of current federal management practices relative to managing federal lands primarily for timber values. The Silviculture scenario quantified the potential gain in harvest volumes assuming unlimited resources to solve silviculture challenges in forest types such as lowland ash (cf. Jacobson, 2007). However, the research investments needed are not currently in place.

Efficiency gains relative to market constraints (assuming full demand of available supply) and process inefficacies in land management were evident when contrasting the Baseline with State Harvest scenarios. The sole difference between the two was the removal of the statewide harvest cap. The additional gain in harvested roundwood can be linked to efficiency in current practices, i.e., the main tendencies of forestry in Minnesota produce exactly the 10-year average harvest value only when capped at that level. Loss of efficiency in turning existing management practices into harvested volumes occurred primarily when the amount of acres (and therefore volume) slated for harvest based on ownership-specific planning procedures is not fully harvested: treatment acres selected for management > timber sale administered acres > sold acres > harvested acres > scaled acres. The State Harvest scenario assumes that this loss of harvestable acres, and ultimately volume, was stopped; all scheduled acres were sold, harvested, and scaled within one planning period (or ideally within one year of timber permit issuance). Additional concerns related to market and process efficiency include: systematic overestimates of saleable volume from growth and yield equations, the nonreplacement of acres after on-site appraisals render these inoperable, market conditions relative to product availability, and the five-year of growth that can occur over the life of a timber permit.

Both an increase in wood quality and volume were obtained under Timber Stand Improvement. This scenario mandated that 10%, by area relative to the current harvest levels (=18,750 ac yr^{-1}), be transitioned to enhanced productivity yield tables based on precommercial entries. In contrast to this, Accelerated Thinnings reduced wood quality and provided a somewhat smaller increase in harvest volumes. However, for both scenarios the use of biomass silviculture could defray costs and, for the Accelerated Thinnings scenario, be used to channel low quality wood to biomass markets.

The effects of even flow on harvest volumes were tested using two scenarios; even flow was reduced from 5% to 10% and totally disabled. Without even flow constraints the modeled system harvested twice the long-term sustainable level of 3.69 mil cd yr^{-1} in the first planning period. This was followed by eight periods exactly at the 10-year average with, in the last planning period, 27% of all volume harvested over the full planning horizon (=13.3 mil cd yr^{-1}) removed in the last planning period alone. The initial burst in harvest activity is an artifact of removing even flow. These constraints are the primary means the modeled system insures that nonmodeled planning horizons are not compromised relative to the 50-year sustainable harvest level. Without even flow constraints the age class distributions become highly skewed (see below) and further removed from regulation (end of horizon effect).

However, the No Even Flow scenario was useful as a point in mapping the effects of management policy by scenario to ending age class distributions—unlike harvest levels these are not additive. Such distributions are especially useful for examining the implications for wildlife habitat. Importantly, movement toward age class distributions with a similar number of acres in each class suggests increasing stability in overall habitat over time. However, most age class distributions were clumped around the baseline scenario result, as a change in a single management policy did not, generally speaking, skew age class distribution. For discussion purposes five model runs will be used, including the baseline (see Figures 1–8). In all cases only even-aged types will be considered:

> *Aspen:* Initially the aspen age class distribution was bimodal with a secondary peak between minimum rotation age and MRA. In all scenarios this age class imbalance of overmature wood was eliminated (Fig. 1); remnants existed primarily to fulfill EERF targets on federal, and to a lesser extent, state lands. In the No Even Flow scenario 3 mil ac (= 52%) alone was in the youngest age class cohort after the full planning horizon; this skewness was visible in other age class distributions as well but was most pronounced for aspen.
>
> *Balsam fir:* As with aspen, the initial age class distribution was bimodal with an initial peak around stand age 20 years and the primary peak centered around minimum rotation age (Fig. 2). All scenarios, except No Even Flow, pushed the age class distribution more toward regulation. Stands with older forest characteristics were, as with aspen, maintained primarily on public lands.
>
> *Black spruce:* Unlike balsam fir or aspen the area of younger cohorts, i.e., harvest area, was clearly linked to scenario and an approach to regulation (an equal number of acres in each age class) was difficult to discern. This is tied to minimum rotation age (=90 yr), which was greater than the planning horizon (=50 yr). The initial unimodal distribution, centered at stand age 65 years, changed to a bimodal distribution centered on younger cohorts (Fig. 3) and with a larger peak at stand age 100 years.
>
> *Jack pine:* Similar to black spruce, harvest activity varied with scenario (Fig. 4). However, jack pine was the only shorter-lived type that did not see a significant trend toward regulation. In the baseline scenario the ending area with ages >MRA was greater than area with ages <MRA. This was linked to the large initial imbalance in initial age class distribution, i.e., stand ages were skewed toward inoperable stands, and relative lack of management activity in this type.
>
> *Paper birch:* The initial mode of the distribution was centered at 65 years, slightly beyond minimum rotation age. In all scenarios, except No Even Flow, a very clear trend toward regulation was evident (Fig. 5) with the largest amount of older stands, i.e., EERF on public lands, occurring under the baseline.
>
> *Red pine:* Due to this type's lifespan and minimum rotation age no trend toward age class regulation was evident. The amount of harvest activity did vary by a factor of two across all scenarios (Fig. 6) and the initial mode at age 35 years was removed.

Tamarack: No clear approach to a regulated age class distribution was evident in older aged stands. Regulation was only visible in the youngest cohorts. Otherwise, the initial multimodal age class distributions were maintained (Fig. 7).

White Spruce: The area of the youngest cohort (harvest activity) varied with scenario and ranged from 5–10 10^3 ac. All ending age class distributions had a clear mode at age 65 years with a secondary peak at 85 years. This excludes the No Even Flow scenario, which had substantially less area in older age cohorts (Fig. 8). Only in the Baseline scenario was any forest area with stand age >115 left on the landscape.

Across all types, two main trends were present: (1) The No Even Flow scenario skewed age class distributions such that regulation, i.e., a uniform age class distribution with, as applicable, some held acres beyond normal rotation to satisfy nontimber values, was not achieved, and (2) longer-lived types did not, and due to minimum rotation ages longer than the planning horizon could not, show any approach to regulation.

Caveats

While this analysis has quantified the effect of numerous management practices and demonstrated that the 5.5 mil cd yr^{-1} key recommendation is within reach, caveats must be mentioned: (1) The concept of market constraints (or market inefficiencies) can be recast as limited demand, especially given the recent economic downturn, the 2006 harvest level of 3.1 mil cd yr^{-1} and anticipated lower harvest levels for 2007–2009. This highlights the desirability of coupling wood supply with economic drivers. (2) The forest land base was undersampled and not fully quantified in terms of map format information. Only 6,331 plots across 14.7 mil ac were available. This limited any spatial interpretation and could mask feasibility issues within type. (3) The private ownership group was highly aggregated such that any distinction between industrial and nonindustrial ownership was removed. (4) The modeling of logging residue assumes that this resource is unused. However, biomass consumers exist and their number is increasing. This indicates that an unknown portion of this resource is already being utilized. (5) The analysis focused primarily on the supply side, i.e., economic considerations, apart from the involvement of the forest products industry in formulating the 5.5 mil cd yr^{-1} goal, were not considered. Additionally, social and environmental impacts were not explicitly considered, except to the extent that current and examined scenario management polices and regimes incorporate them. It is further at the discretion of each stakeholder to determine the most appropriate course of action based on overall wood supply, measures shown to increase timber productivity, and social and environmental impacts. Finally, modeling was done at a strategic level, across the entire state without considering regional differences. This is appropriate for exploring statewide sustainable harvest levels but this approach has limits in terms of choosing various strategies to increase harvest level on a regional or site-specific level. Despite these caveats, and the approximation to reality inherent in any modeling exercise, the modeled system clearly demonstrated growth potential in sustainable harvest levels in Minnesota, both relative to the 5.5 mil cd yr^{-1} goal and in general.

Need for Additional Analysis

Advisory Group recommendations for the future include maintaining and expanding capacity to do a range of statewide analyses in a timely manner. Additional analyses should be expanded and integrated to address:

- A wide range of important ecosystem services (e.g. water quality, wildlife habitat, carbon sequestration)
- Information and assumptions related to private lands timber availability
- Economics, including high valued-added products, forest management investment opportunities, transportation needs, and impacts of potential budget limitations
- Opportunities for integrating/mitigating increased biofuels production with timber production and ecosystem services
- Potential utilization and marketing opportunities and likely impacts

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Tables

Table 1. Type mappings and areal extent of timberland based on 2005 FIA data.

WE93 aggregated type	2005 FIA forest type (LOCALTYPE)[1]	2005 FIA forest type group (FORTYPE)[1]	Area (ac)
Jack pine	Jack pine (101)	White-red-jack pine (100)	362,019
Red pine	Red pine[2] (102)		395,397
White pine	White pine (103)		77,695
Balsam fir	Balsam fir (111)		392,603
Black spruce	Black spruce (112)		1,335,027
Northern white cedar	Northern white cedar (114)		571,913
Tamarack[3]	Tamarack (115), eastern red cedar (135), other forest types (198)		885,024
White spruce	White spruce[2] (116)		111,063
Oak-hickory		Oak-pine (140), oak-hickory (150)	1,545,984
Elm-ash-soft maple		Elm-ash-cottonwood (170)	1,222,258
Maple-birch		Maple-birch (180)	1,569,212
Aspen	Aspen-birch (190), aspen (191)		4,841,148
Paper birch	Paper birch (192)		969,920
Balsam poplar	Balsam poplar (194)		464,006

[1] FIA field codes from Miles and Pugh (2007).
[2] Red pine and white spruce stands with any evidence of artificial regeneration were mapped to the same aggregated types but used enhanced productivity WE93 volumes (see text).
[3] Types that could not be logically mapped to any WE93 types were placed here and amounted to <1.5% of the total area modeled.

Table 2. Ownership classes and areal extent of timberland based on 2005 FIA data.

Ownership class	2005 FIA ownership (OWNER)[1]	Area (ac)
Federal	National forest (11), bureau of land management (12), other federal agencies (14)	2,001,391
State	State (15)	3,849,425
County	County and municipal (16)	2,119,618
Private	99 (Unknown)[2]	6,772,838

[1] FIA field codes and values from the RPA shapefile (Miles and Pugh, 2007) enclosed in parenthesis.
[2] Corresponds to OWNGRP = 4, nonindustrial private land. All private land carries this same designation.

Note: Approximately 272,820 acres were erroneously classified as state rather than county land in 2005 FIA data. Figures in this study related to county and state ownerships should be adjusted accordingly.

Table 3. Cover type mappings used for logging residue (Sorenson, 2006).

WE93 aggregated type	Logging residue type[1]
Jack pine	Upland conifers
Red pine	Upland conifers
White pine	Upland conifers
Balsam fir	Upland conifers
Black spruce	Lowland conifers
Northern white cedar	Lowland conifers
Tamarack	Lowland conifers
White spruce	Upland conifers
Oak-hickory	Other hardwoods
Elm-ash-soft maple	Other hardwoods
Maple-birch	Other hardwoods
Aspen	Aspen
Paper birch	Aspen
Balsam poplar	Aspen

Table 4. Name and parameter grid for all 16 scenarios. A dashed entry indicates the absence of that constraint or management practice (see Table 5 for parameter definitions).

Scenario name	**Harvest limits**	**EERF**	Ownership cooperation	Silviculture constraints	Even flow	Accelerated thinnings	Intensive thinnings	Intensive management	Rotation ages	Private lands availability
Baseline	Overall	Both	Nil	Yes	5%	-	-	-	Baseline	90%
State harvest	Federal	Both	Nil	Yes	5%	-	-	-	Baseline	90%
Federal harvest	-	Both	Nil	Yes	5%	-	-	-	Baseline	90%
State ERF	Federal	Less State	Nil	Yes	5%	-	-	-	Baseline	90%
Federal unconstrained	-	Less Federal	Nil	Yes	5%	-	-	-	Baseline	90%
Cooperation	Federal	Both	Yes	Yes	5%	-	-	-	Baseline	90%
Silviculture	Federal	Both	Nil	-	5%	-	-	-	Baseline	90%
Relaxed even flow	Federal	Both	Nil	Yes	10%	-	-	-	Baseline	90%
No even flow	Federal	Both	Nil	Yes	-	-	-	-	Baseline	90%
Accelerated thinning	Federal	Both	Nil	Yes	5%	Yes	-	-	Baseline	90%
Intensified thinnings	Federal	Both	Nil	Yes	5%	-	Yes	-	Baseline	90%
Intensified management low	Federal	Both	Nil	Yes	5%	-	-	10%	Baseline	90%
Intensified management high	Federal	Both	Nil	Yes	5%	-	-	25%	Baseline	90%
Accelerated harvest	Federal	Both	Nil	Yes	5%	-	-	-	Accelerated	90%
Full private lands	Federal	Both	Nil	Yes	5%	-	-	-	Baseline	100%
Timber stand improvement	Federal	Both	Nil	Yes	5%	-	-	10%	Baseline	100%

Table 5. Scenario parameter key.

Constraint	Parameter		
Harvest Limits	*Overall* Harvest limits are 387,000 cd yr^{-1} on federal lands and 3.69 mil cd yr^{-1} statewide	*Federal* Harvest limits are capped at 387,000 cd yr^{-1} on federal lands only	
ERF	*Both* Effective ERF targets on state and federal lands (App. 1)	*Less State* State effective ERF targets reduced from the Baseline to the Governor's Task Force statewide planning figure of 9.4%. Note: EERF for balsam fir was unchanged; its Baseline value was less than 9.4%. Federal EERF follows App. 1	*Less Federal* Effective ERF targets on state lands; federal EERF no less than Governor's Task Force recommendation of 9.4% (App. 1)
Ownership Cooperation	*Yes* Even flow constraints on each aggregated type only. This allows the four ownership subgroups to work toward regulation in concert.	*Nil* Even flow constraints for each combination of ownership and aggregated type	
Silviculture Constraints	*Yes* Areal operability limits implemented for northern white cedar, elm – ash, and maple – birch types; tamarack species harvest limited to 70,000 cd yr^{-1}.		
Even Flow	Proxy for emphasis on age class regulation; determines the amount of between-period fluctuation of harvested volume, e.g., 5% means that the minimum period value must be ≥ 95% of the maximum value.		
Accelerated Thinnings	*Yes* Reentry intervals of 10 yr in all thinnable types; stocking thresholds reduced by 50% relative to Appendix 2. For aspen, the earliest thinnable age is lowered to 3 periods.		
Intensive Thinnings	*Yes* All thinned stands are transitioned to enhanced productivity yield tables.		
Intensive Management	A fixed percentage of clearcut stands are transitioned to enhanced productivity yield tables.[1]	For the Timber Stand Improvement scenario 10% of baseline harvest acres (= 18,750 ac yr^{-1}) linked to enhanced productivity yield tables after a timber stand improvement.[1,2]	
Rotation Ages	*Baseline* Rotation ages as given in Appendix 1	*Accelerated* All even-aged systems may be harvested one planning period earlier. This is meant to reflect an emphasis on economic vs. biological rotation ages.	
Private Lands	Percentage of private lands, by area, operable[1]		

[1] The model chooses which stands are operable or linked to enhanced productivity yield tables based on volume maximization.
[2] A precommercial timber stand improvement generates no merchantable volume and can occur in all types with stand age ≤ 40 yr.

Table 6. Volume harvested in the baseline scenario compared to published estimates.

Total volume harvested (mil cd yr^{-1})	Total aspen species[1] volume harvested (mil cd yr^{-1})	Source
3.69	1.82	Baseline scenario, annualized from full 50-yr planning horizon
3.72	2.01	Jacobson (2007), pg. 19 reporting year 2005
3.69	2.28	Jacobson (2007), pg. 19 average from reporting years 1996 – 2005 for total volume and pg. 32 from reporting years 1994 – 2005 for aspen
3.23	1.67	Removal of all live on forestland from the 2005 Minnesota FIA[2]
3.32	1.77	Average removal all live on forestland from the 2004 – 2007 Minnesota FIA

[1] Aspen species includes bigtooth aspen, quaking aspen and balsam polar.
[2] Removals reference harvested and utilized trees only. Using all live on forestland eliminates problems due to land changing from timberland to unproductive or reserved forestland through time (P. Miles, Northern Research Station USDA Forest Service, pers. comm.). FIA population estimates are from Miles (2008).

Table 7. FIA-derived estimates of growth, mortality, and maximum biological growth contrasted with ranges of prescriptive scenarios and current harvest levels. All FIA-based estimates are averages from the 2004 – 2007 Minnesota annual inventories and reference all live trees on forest land.

Growth or Harvest Level	Volume (mil cd yr^{-1})	Source
Net growth	5.00	Miles (2008)
Mortality	4.56	Miles (2008)
Gross growth	9.56	Net growth + mortality
Maximum biological growth	12.56	This study
GEIS harvest levels	4.79 – 7.00	GEIS
Thunderhawk harvest levels	3.85 – 5.24	Thunderhawk
1996-2005 annual harvest levels	3.56 – 3.82	Jacobson (2007)

Table 8. Changes in sustained timber yield by ownership relative to current practices estimated by altering selected management practices and policies singly. A dashed entry indicates no data. Statewide totals may differ due to rounding.

	Change in harvest by ownership ($1000s\ cd\ yr^{-1}$)				
Management practice	**County**	**Federal**	**Private**	**State**	**Overall**
Addressing market and process constraints	+95	+49	+184	+181	+509
Reducing ERF on state lands					
Reducing EERF from current (12%) to Governor's Task Force (9.4%) value	-1	-	-1	+19	+17
Federal lands					
Removing ASQ-based caps on harvest	+3	+68	+3	0	+68
Reducing extent of management areas that emphasize old forest characteristics	-11	+311	-24	0	+276
Cross ownership cooperation	+63	-	+61	-3	+120
Full access to private lands	-1	-	+15	0	+17
Intensive management used to restore full productivity on a fixed percentage of final harvest by area					
10%	+5	-	+10	+2	+17
25%	+9	-	+28	+4	+41
Addressing operability constraints in sensitive types	+95	-	+66	+265	+426
Reducing rotation ages in even-aged types by 5 yr	+29	-	+87	+74	+191
Precommercial timber stand improvement used to restore full productivity on 18,750 ac yr^{-1}	+117	-	+299	+104	+520
Less emphasis on age class regulation	+3	-	+22	+8	+33
No emphasis on age class regulation	+155	-	+411	+243	+808
Aggressive thinning					
"Early, often, and hard"	+65	-	+154	+143	+362
Thinned stands intensively managed	+32	-	+59	+24	+116
Logging residue					
Increased utilization of harvest residue in even-aged systems	+121	+59	+334	+127	+640

Note: Approximately 272,820 acres were erroneously classified as state rather than county land in 2005 FIA data. Figures in this study related to county and state ownerships should be adjusted accordingly.

Figures

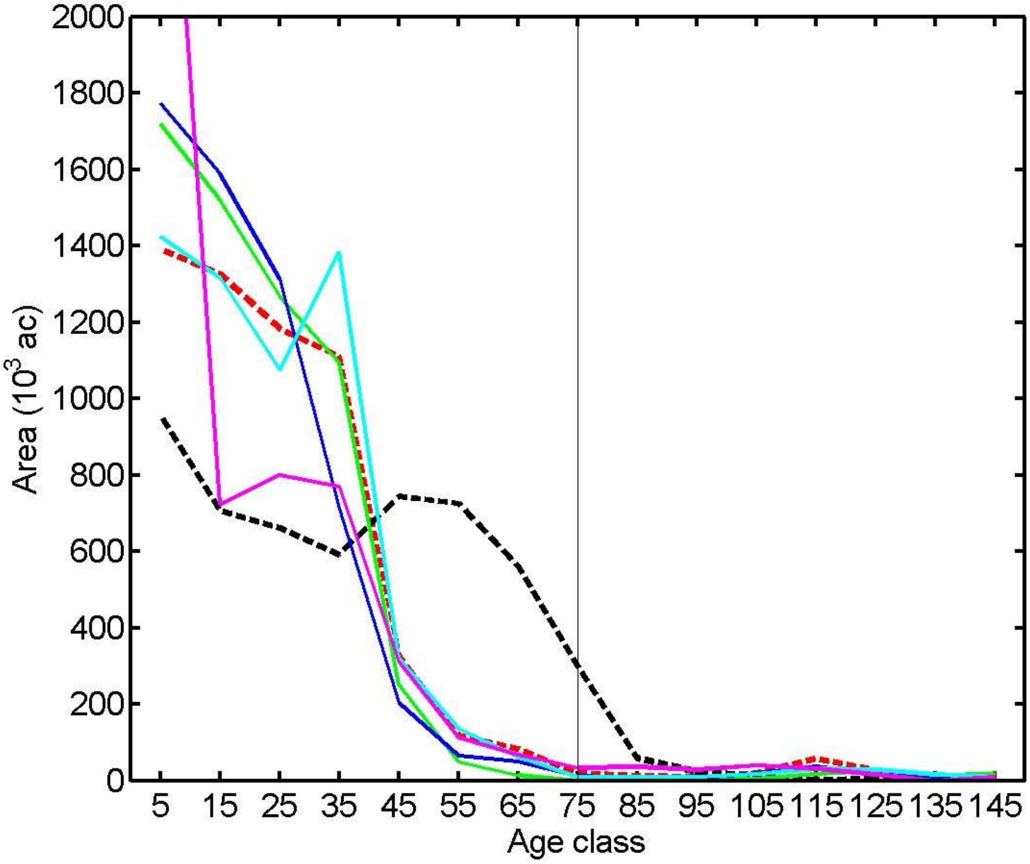

Figure 1. Age class distribution of the aspen cover type (including balsam poplar; total area = 5.3 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). Solid vertical line indicates maximum rotation age. The final age class contains all acres at or beyond the 145 yr midpoint. The youngest age class under No Even Flow has 3 mil ac at scenario end.

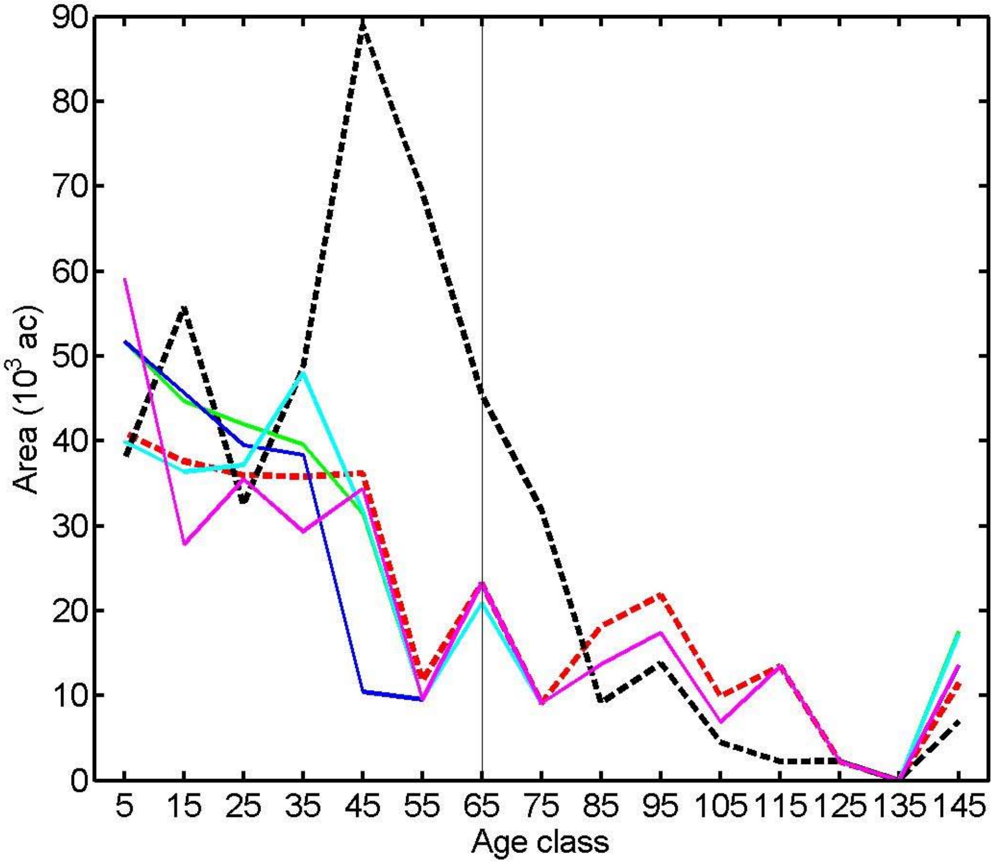

Figure 2. Age class distribution of the balsam fir cover type (total area = 0.4 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). Solid vertical line indicates maximum rotation age. The final age class contains all acres at or beyond the 145 yr midpoint.

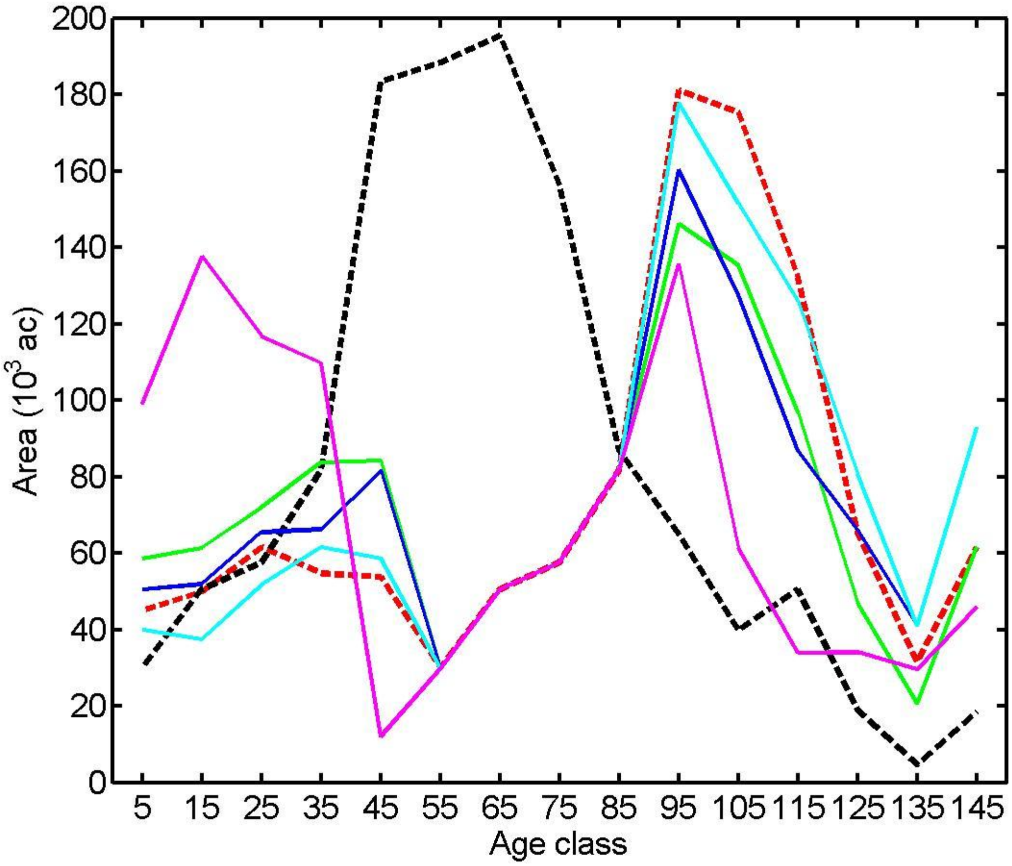

Figure 3. Age class distribution of the black spruce cover type (total area = 1.3 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). The final age class contains all acres at or beyond the 145 yr midpoint.

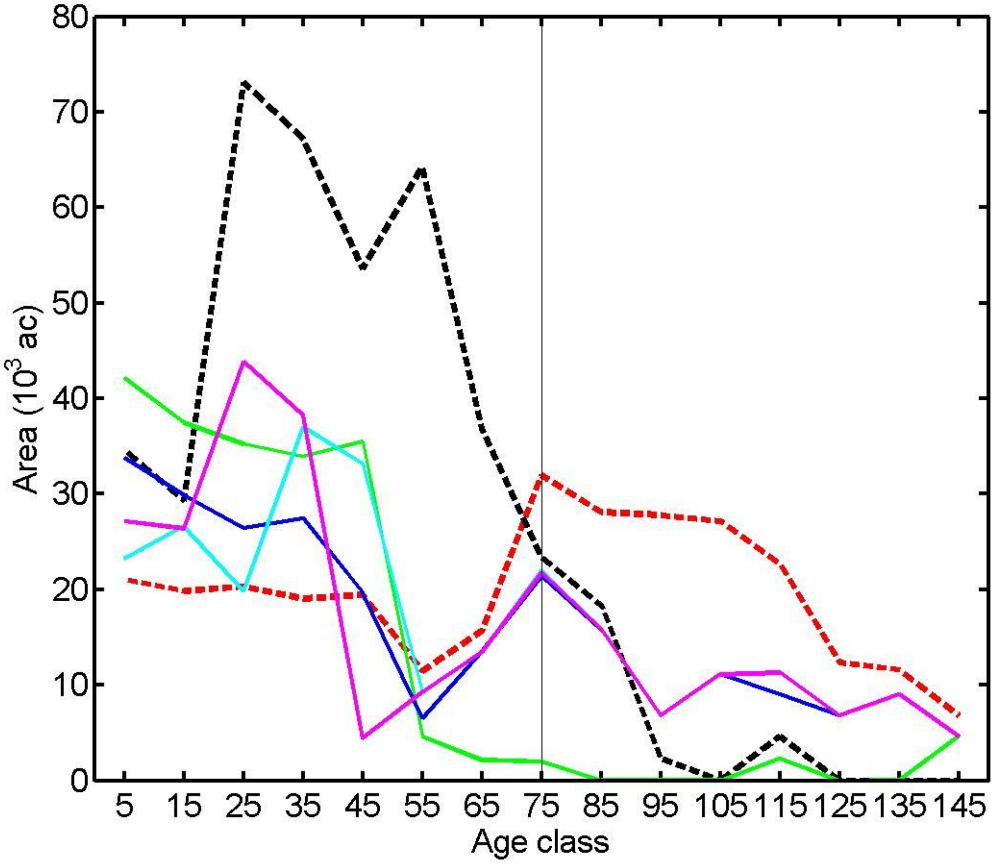

Figure 4. Age class distribution of the jack pine cover type (total area = 0.4 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). Solid vertical line indicates maximum rotation age. The final age class contains all acres at or beyond the 145 yr midpoint.

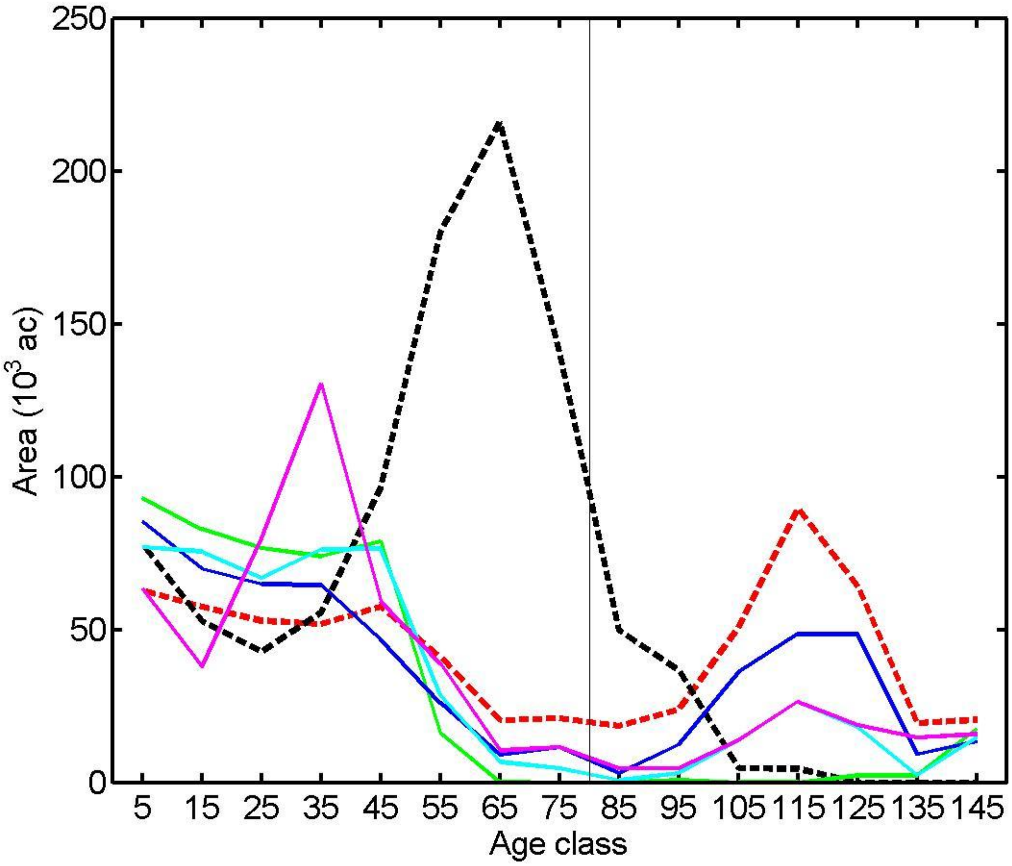

Figure 5. Age class distribution of the paper birch cover type (total area = 1 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). Solid vertical line indicates maximum rotation age. The final age class contains all acres at or beyond the 145 yr midpoint.

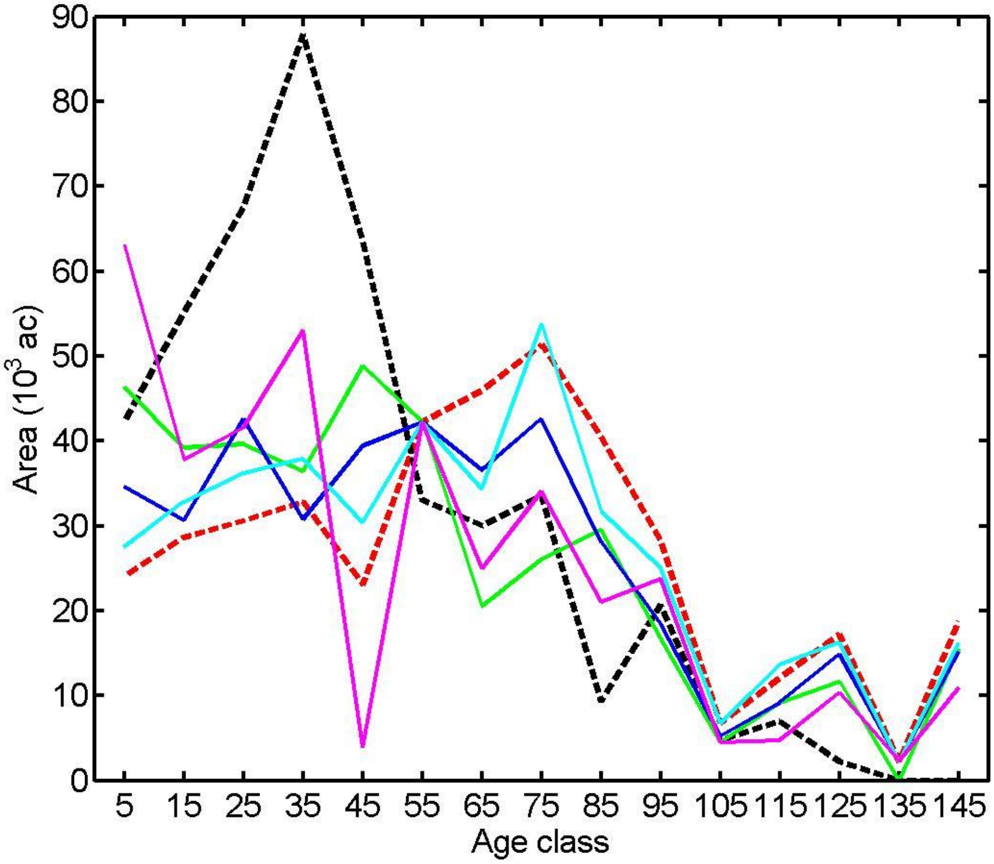

Figure 6. Age class distribution of the red pine cover type (total area = 0.4 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). The final age class contains all acres at or beyond the 145 yr midpoint.

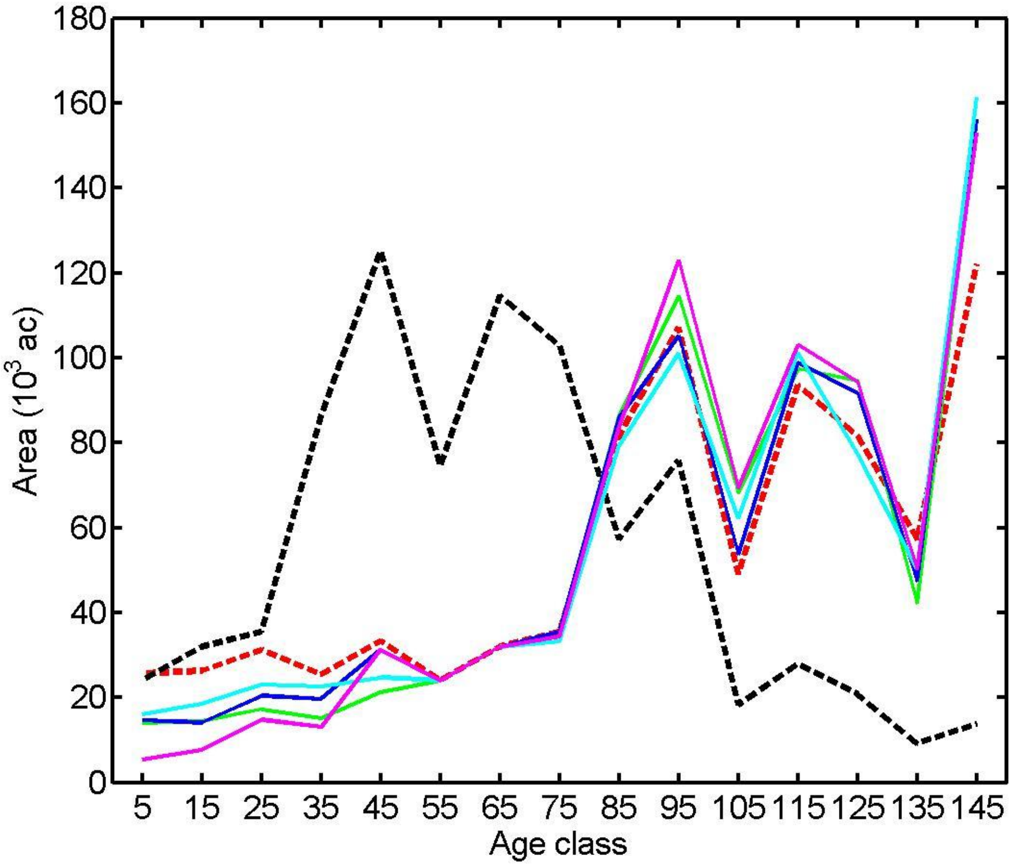

Figure 7. Age class distribution of the tamarack cover type (total area = 0.9 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). The final age class contains all acres at or beyond the 145 yr midpoint.

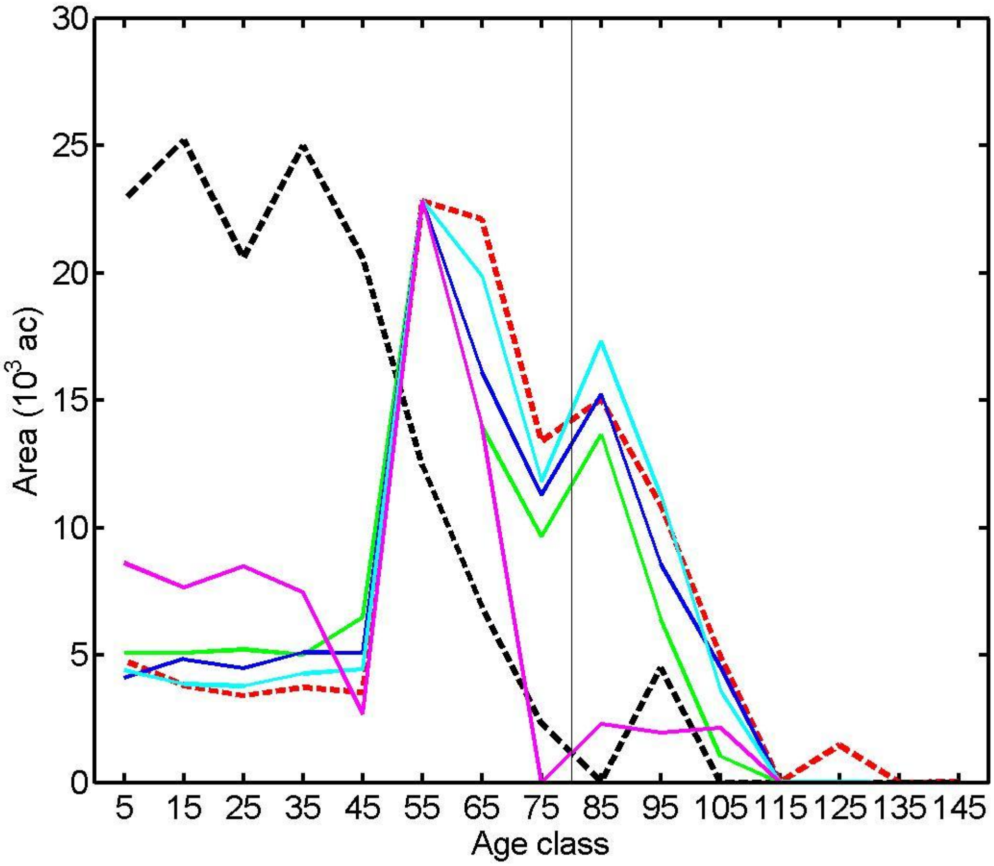

Figure 8. Age class distribution of the white spruce cover type (total area = 0.1 mil ac). Dashed line indicates initial (black) and ending (red) distributions from the Baseline scenario. Solid lines indicate ending age class distribution from 4 alternative scenarios: Federal Unconstrained (green), Accelerated Harvest (blue), Timber Stand Improvement (cyan), and No Even Flow (magenta). The final age class contains all acres at or beyond the 145 yr midpoint.

Appendix A

Appendix Table A1. Rotation ages and effective ERF percentages for even-aged types.

WE93 aggregated type	Rotation age[1,2]	State ERF (effective %)[3]	Maximum rotation age[4]
Jack pine	11 (10)	9.6%	15
Red pine	22 (12)	12.1%	38
White pine	35 (12)		39
Balsam fir	10 (8)	7.0%	13
White spruce	14 (10)		16
Black spruce	20 (18)	12.3%	30
Tamarack	14 (18)	14.2%	36
Elm – ash – soft maple	24 (18)		24
Maple – birch	24 (18)		24
Aspen	9 (8)	11.8%	15
Paper birch	11 (10)	11%	16
Balsam poplar	9 (8)	11.8%	15

[1] Rotation ages are in five-year age classes and correspond with the five-year planning periods used in the model. For example, on state lands aspen rotation is 9 age classes, which corresponds to a stand age of 41–45 yr. Stand age was the only operability criterion used for even-aged stands except for the elm-ash-soft maple and maple-birch types which also required a site index < 50.

[2] Rotation ages are for the state ownership class with the federal value in parenthesis. County and private rotation ages were always one planning period less than state rotations ages, e.g., rotation age for black spruce on county and private lands was 19 age classes. Red pine, an exception, had a rotation age of 12 age classes on county and private lands. State rotation ages were taken from Schwalm (2006). Federal values were taken from table S-TM-5 of the current Chippewa National Forest plan USDA Forest Service (2004a).

[3] Effective ERF was considered only for major forest types. The percentages refer to the amount of the forest type held beyond normal rotation on state lands only. For federal lands 29.1% of all listed types were targeted as effective ERF in the first 50 years past normal rotation with an additional 14.6% targeted after this initial 50-yr period. This corresponds to the percentage of operable acres in "Longer Rotation", "Recreation Use in a Scenic Landscape", "Semi-primitive Non-motorized Recreation", and "Semi-primitive Motorized Recreation" management areas as listed in the current management plans for the Chippewa and Superior National Forests. These management areas emphasize older rotations and/or old forest characteristics and were assumed functionally equivalent to EERF on state lands. State EERF values are from Schwalm (2006). Federal figures were estimated using current Forest Service planning documents USDA Forest Service (2004a,b).

[4] Maximum rotation ages (in five-year age classes) were used in yield table generation only and were invariant across ownership type. The types not listed here used 24 age classes as MRA.

Appendix Table A2. Operability criteria for uneven-aged types. All systems used a 20-yr reentry interval, removed 33% of standing volume, and transitioned to a regulated diameter distribution after the first management entry[1].

WE93 aggregated type	Operability criteria
Elm – ash – soft maple	Site index > 50 BA > 120ft^2 QMD > 7"
Maple – beech – birch	Site index > 50 QMD > 7"
Oak – hickory	QMD > 9"
Northern white cedar	Age of oldest cohort > 70 yr

[1] For regulated stands age-invariant volumes from Thunderhawk (H. Hoganson, Thunderhawk contributor, *pers. comm.*) were used.

Appendix Table A3. Operability criteria for types where thinnings were allowed. Reentry intervals were 1five-year for all types except for aspen, which could only be thinned once. Thinnings removed 33% of standing volume.

WE93 aggregated type	Operability criteria
Aspen	Site index > 70 Stand age 30–40
Red pine	Site index > 50 BA > 120ft^2 Stand age < 160
White pine	Site index > 50 BA > 120ft^2 Stand age < 100
Jack pine	Site index > 60 BA > 75ft^2 Stand age < 50
White spruce	Site index > 50 BA > 75ft^2 Stand age < 60

Appendix Table A4. Harvested volume by ownership and areal extent of management by treatment type for all scenarios.

	Volume harvested by ownership (1000s cd yr^{-1})					Area by treatment type (1000s ac yr^{-1})		
Scenario	**County**	**Federal**	**Private**	**State**	**Total**	**Even-aged**	**Thin**	**Uneven-aged**
Baseline	697	338	1,925	730	3,690	154	20	15
State Harvest	792	387	2,109	911	4,199	165	28	18
Federal Harvest	789	455	2,112	911	4,267	166	29	18
State ERF	791	387	2,108	930	4,216	166	29	19
Federal Unconstrained	778	766	2,087	911	4,543	180	30	19
Cooperation	855	387	2,169	908	4,319	171	29	19
Silviculture	887	387	2,175	1,176	4,625	177	28	38
Relaxed Even Flow	795	387	2,130	919	4,231	165	29	19
No Even Flow	947	387	2,518	1,154	5,006	187	32	44
Accelerated Thinning	857	387	2,263	1,054	4,561	164	90	18
Intensified Thinnings	825	387	2,168	935	4,315	164	28	18
Intensified Management Low	797	387	2,119	913	4,216	166	28	18
Intensified Management High	801	387	2,137	915	4,240	165	30	19
Accelerated Harvest	821	387	2,196	985	4,389	182	29	19
Full Private Lands	791	387	2,124	911	4,213	166	28	19
Timber Stand Improvement	909	387	2,408	1,015	4,719	166	30	19

Note 1: Current full Allowable Sale Quantity (ASQ) on federal national forest lands = 387

Note 2: Approximately 272,820 acres were erroneously classified as state rather than county land in 2005 FIA data. Figures in this study related to county and state ownerships should be adjusted accordingly.

Appendix Table A5. Harvested volume by species for all scenarios.

Scenario	Volume harvested by species[1] (1000s cd yr^{-1})															
	Aspen	Paper Birch	Red Pine	White Pine	Jack Pine	Black Spruce	White Spruce	Tamarack	Balsam Fir	Northern White Cedar	Basswood	Maple	Ash	Oak	Other	Total
Baseline	1,822	335	223	49	105	134	83	70	218	53	84	116	103	163	131	3,690
State Harvest	2,001	425	250	56	144	157	98	70	253	66	95	131	117	184	150	4,199
Federal Harvest	2,008	436	264	68	154	158	101	70	257	67	95	132	117	185	151	4,267
State ERF	2,007	426	250	57	144	164	98	70	254	66	95	132	117	184	151	4,216
Federal Unconstrained	2,082	454	316	79	176	210	110	70	270	70	98	138	124	191	157	4,543
Cooperation	2,017	435	292	60	149	161	107	70	262	68	99	134	120	188	157	4,319
Silviculture	2,011	424	251	59	144	187	99	260	263	187	103	137	139	189	169	4,625
Relaxed Even Flow	2,009	426	258	57	145	161	99	70	254	66	97	132	118	186	153	4,231
No Even Flow	2,193	450	384	70	158	238	119	70	279	71	152	160	158	271	233	5,006
Accelerated Thinning	2,090	427	412	80	174	161	120	70	265	65	97	136	119	190	154	4,561
Intensified Thinnings	2,077	433	252	58	146	159	100	70	260	67	97	135	120	189	153	4,315
Intensified Management Low	2,011	426	251	57	145	158	99	70	254	66	95	132	117	185	151	4,216
Intensified Management High	2,025	428	251	57	146	158	99	70	256	66	96	133	118	186	151	4,240
Accelerated Harvest	2,086	418	289	60	150	187	103	70	261	65	98	136	123	189	156	4,389
Full Private Lands	2,005	426	252	57	144	158	99	70	254	66	96	132	118	186	152	4,213
Timber Stand Improvement	2,312	465	259	63	169	165	108	70	290	72	102	148	129	205	162	4,719

[1] Aspen species includes bigtooth aspen, quaking aspen and balsam polar. Minor hardwood species, i.e., all hardwoods excluding paper birch and aspen were aggregated, e.g., maple includes all maple species (hard and soft). Other includes volume from hardwoods and softwoods as well as trees with unknown or missing species codes.

Appendix B: Additional Scenario

Original June 10, 2009
Last Revision June 19, 2009

The main scenarios (Tables 4-5 & 8 in the body of the report) quantify the change in harvest level relative to changing one management policy. Beyond this, one additional scenario was added at the request of several Advisory Group members to address a desire for analysis of a single harvest or timber yield level, overall and by species that would be achievable given several altered environmental and social constraints. To estimate these harvest levels an additional scenario was designed that removed "market" constraints, eased even-flow constraints on several forest types, and altered three policies or practices at once. This is not a "recommended" harvest level, but is instead an examination of timber yields and age-class impacts given the scenario parameters and constraints

This scenario is based on adjustments to the Baseline scenario and includes all of the flowing changes: (1) the upper limit on total statewide harvest volumes was disabled, (2) the upper limit on tamarack species harvest levels was disabled, (3) even flow constraints on the black spruce, elm-ash-soft maple, maple-birch, and tamarack types were disabled, (4) areal operability limits on elm-ash-soft maple and maple-birch stands of poor site quality were disabled, (5) timber stand improvement treatments (see Table 4) were performed on 18,750 acres annually, (6) accelerated thinning regimes were used (see Table 5), and (7), all thinning results in stands restored to full productivity, i.e., stands were, after treatment, indexed to the enhanced productivity yield tables.

Overall the total statewide aggregate harvest level was, annualized over the full planning horizon, 6.02 mil cd yr^{-1}. This figure is for roundwood only, i.e., excludes logging residue, and exceeds the 5.5 mil cd yr^{-1}recommendation of the 2007 Governor's Task Force on the Competitiveness of Minnesota's Primary Forest Products Industry. The aspen species group had the largest single share (= 41%) of overall volume (Table B1). Average yield was 18.5 cd ac^{-1} and the areal share of even-aged treatments was 58%. These three figures were lower than in the Baseline and reflected an increased emphasis on thinnings and greater access to stands with lower wood quality. In general, age class distributions of shorter-lived even-aged types all achieved a higher degree of regularization after the 50-yr planning period (Figure B1).

Table B1. Harvested roundwood volume by species, ownership, and overall.

Species	**Volume harvested[1] (1000s cd yr^{-1})**
Aspen	2,477
Paper Birch	490
Red Pine	431
White Pine	95
Jack Pine	223
Black Spruce	279
White Spruce	135
Tamarack	274
Balsam Fir	319
Northern White Cedar	91
Basswood	179
Maple	190
Ash	211
Oak	336
Other	289
Ownership	**Volume harvested (1000s cd yr^{-1})**
County	1,141
Federal	387
Private	3,081
State	1,410
Total	6,020

[1] Aspen species includes bigtooth aspen, quaking aspen and balsam polar. Minor hardwood species, i.e., all hardwoods excluding paper birch and aspen were aggregated, e.g., maple includes all maple species (hard and soft). Other includes volume from hardwoods and softwoods as well as trees with unknown or missing species codes.

Note: Approximately 272,820 acres were erroneously classified as state rather than county land in 2005 FIA data. Figures in this study related to county and state ownerships should be adjusted accordingly.

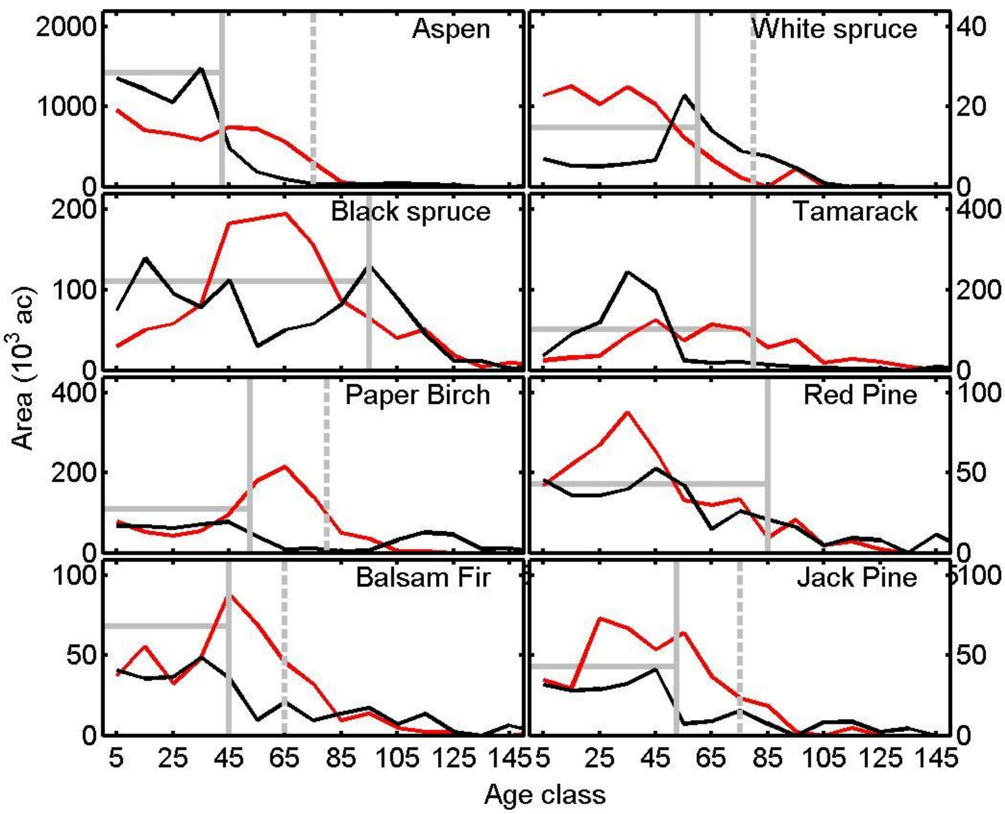

Figure B1. Area (1000's of acres) over 10-yr age class (class midpoints) with starting (red) and ending (black) age class distributions for all even-aged cover types. The age class distribution goal (horizontal gray) assumes full regularization at the average of federal and state normal rotation ages. Vertical lines indicate normal (solid gray) and maximum (dashed gray) rotation ages. Maximum rotation ages for black spruce, tamarack and red pine all exceed 145 years.

Appendix C: Summary Document

Appendix C is a stand-alone 5 page summary document to be used as a communication tool for the analysis. It was prepared at the request of the Advisory Group.

Forest Harvest Levels in Minnesota

Effects of Selected Forest Management Practices on Sustained Timber Yields

Purpose

The Statewide "Harvest Level" Analysis was done in order to:

1) Provide information to policymakers, forest managers and proposers of new industrial facilities to help assess future timber yields and forest age classes under a range of potential management and policy options that might help increase statewide harvest levels.
2) Meet a key recommendation of the *Governor's Task Force on the Competitiveness of Minnesota's Primary Forest Products Industry,* to "explore the feasibility of sustainably increasing total statewide timber production for all ownerships to 5.5 million cords per year."
3) Enable additional *future* analyses of key impacts to Minnesota's forest resources from changes in forest condition, and proposed policies.

Key findings

1) A 5.5 million cord harvest level is attainable. Two items necessary to achieve this level would be improved markets for a wide range of species and products, and increased investments in forest management practices.
2) Specific opportunities for raising harvest levels through intensified management include intensified "commercial" and "precommercial" thinning and stand treatments in several forest types such as red pine, addressing market and process constraints, and addressing regeneration challenges in forest types such as white cedar.
3) See pages 3 and 4 for a summary of harvest level impacts of the scenarios.

Key Details

- Examined estimated harvest level impacts across ownerships of changes to selected forest management practices and policies including: additional thinning, reducing rotation ages, "precommercial" stand treatments, and others.
- The analysis used state-of-the-art forest modeling techniques, is subject to key constraints and limitations, and uses baseline data from the USDA Forest Service Forest Inventory and Analysis (FIA) 2003 all-ownership forest inventory.
- A multi-stakeholder Advisory Group provided input and guidance.
- The Advisory Group made recommendations for future research, analysis and implementation work that was beyond the scope of this initial analysis.
- Quantification of potential harvest volume is one important factor that can be considered by decision makers, in addition to environmental and social benefits. Decisions on forest management policies and/or and investment levels are outside the scope of this analysis.
- The focus is largely on resource analysis, i.e., potential yields rather than social, environmental or economic, and as such the study is more limited in scope than the 1994 Generic Environmental Impact Statement on Timber Harvesting (GEIS). However, the study did incorporate the Minnesota Forest Resources Council guidelines, reserved forest areas, consideration of old growth, etc. Thus aspects of various social, economic and environmental considerations were incorporated.
- The task of assessing effects of forest management is never complete but is merely updated.

This analysis should be viewed in this same vein.

What the analysis is <u>not</u>.

- A re-do of the Generic Environmental Impact Statement (GEIS) on timber harvesting. Resources were not available for a comprehensive update of the GEIS.
- An effort to dictate how different landowners manage their forests. Harvest level impacts are only one important consideration when examining forest management and policy options and the analysis is not designed to explicitly examine the social or environmental desirability of these options.
- The final word on sustainable harvest levels. Sustainable harvest level examination is a continuing process as the forest changes, and as additional information needs and/or analysis parameters or methods are identified.

Recommendations for Future Analysis

The Advisory Group made recommendations that go beyond the scope of this initial analysis. They recommend that it is important to maintain and expand capacity to do a range of statewide analyses in a timely manner and that harvest-level analyses should be updated regularly. Additional analyses should be expanded and integrated to address:

- A wide range of vital ecosystem services (e.g. water quality, wildlife habitat, carbon sequestration, etc.)
- Information and assumptions related to private lands timber availability
- Economics, including high valued-added products, forest management investment opportunities, transportation needs, and impacts of potential budget limitations
- for integrating/mitigating increased biofuels production with timber production and "ecosystem services"
- Potential utilization and marketing opportunities and likely impacts

Harvest Level Advisory Group

An Advisory Group was formed to provide assistance in developing the analysis through peer review and input. The Advisory Group reflects a breadth of diversity in management and administration statewide, and includes representatives from state and federal government, counties, and the scientific community.

Members:

Minnesota DNR

Dave Epperly - Director, Forestry Division
Dave Schad - Director, Fish & Wildlife Division
Steve Hirsch - Director, Ecological Resources Division
Christopher Schwalm - Forest Research Scientist
Keith Jacobson - Program Supervisor

University of Minnesota College of Food, Agricultural and Natural Resources Sciences

Alan Ek - Professor and Department Head, Department of Forest Resources
Howard Hoganson – Professor, Department of Forest Resources

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Rob Harper - Supervisor, Chippewa National Forest
Mike Prouty - Field Representative, St. Paul Field Office, State & Private Forestry
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Changes in base harvest level by ownership

Estimated by altering management practices and policies.

Notes:

1. The table below contains a list of the various forest management practices and policy scenarios examined for their estimated harvest level impacts.
2. Base harvest level = 2005 Minnesota timberlands forest harvest volume, or 3.7 million cords.
3. A dashed entry indicates no data.
4. Statewide totals may differ due to rounding.
5. Harvest level impacts are one important consideration in assessing management practices and policies. Social and environmental impacts also should be considered.
6. An FIA inventory data error in assigning state/county ownership was discovered late in the process of preparing this analysis and report. Approximately 272,820 acres classified as county land in 2003 data were erroneously classified as state land in 2005 data (6/23/2009 personal communication, Pat Miles, FIA Analyst). Figures in this study related to county and state ownerships should be adjusted accordingly.

Management practice with brief description		*Change in harvest by ownership (1000s cd yr^{-1})*					*Implementation notes*
		County	**Federal**	**Private**	**State**	**Total**	
Intensified thinning ***Two scenarios as described in next column***	Stands entered sooner with shorter re-entry intervals and smaller residual basal areas. Focus solely on merchantable stock; control for insects, disease, increased competition control; stands fertilized where needed.	+97	--	+213	+167	+478	Likely to require significant additional investment in staff time to accomplish. Good potential harvest level benefits. Possible habitat benefits in some forest types such as red pine. Low political risk, in cover types such as red pine with the greatest volume impacts.
Precommercial timber stand improvement Precommercial and cultural treatments used to restore full productivity on 18,750 ac yr^{-1}. Such treatments include any action before merchantability (stand age < 40 yr) that restores full productivity. Seedbed treatment, conversion, fertilization, etc. are examples. Note also that this scenario applies only 10% , by area, of long-term (pre-downturn) harvest acreages.		+117	--	+299	+104	+520	Would require significant capital investment to achieve, but some real potential. Controversy likely to be modest for some practices such as conversion to appropriate ecological type, and higher for others such as fertilization. Future analyses should focus on developing a better understanding of direct gains from investments as compared to indirect impact of assumed future investments on current allowable cuts.
Addressing market and process constraints Example: Insuring that all planned management activities are fully operationalized, from initial administration through to scaling, within a 5-yr timeframe (ideally quicker).		+95	+49	+184	+181	+509	Would require market development, silviculture investments and perhaps shorter permit time lengths. Likely to require significant additional investment in staff time to accomplish. Also, readers should be aware that a certain percentage of sites will not result in a management activity, due to market conditions and/or inventory quality. This should go down over time as inventory improves, but will never be zero.

Management practice with brief description		*Change in harvest by ownership (1000s cd yr^{-1})* County	Federal	Private	State	Total	*Implementation notes*
Cross ownership cooperation Allowing all 4 ownerships to effectively trade-off areas to satisfy common statewide even flow goals.		+63	--	+61	-3	+120	Promote management goals that transcend ownership boundaries, e.g., ERF and/or spatial planning issues at a landscape level irrespective of ownership. Worthy of further study. Different management goals across ownerships make achieving this difficult.
Addressing regeneration constrains in difficult types Lowland black ash and white cedar are the two forest types with opportunities.		+95	--	+66	+265	+426	Would require significant capital investment in silviculture research to achieve. Finding money for a position or 2 to focus on this would be a good start. Controversy likely to be low, with potential for fairly wide stakeholder support.
Intensive management used to restore full productivity on a fixed percentage of final harvest by area Full productivity is based on full stocking with cover type matching Native Plant Community. Management actions used at final harvest to restore productivity include stand conversion, fertilization, and stocking control. ***Two scenarios, with different percentages of even-aged final harvest by area restored to full productivity.***	10% 25%	+5 +9	-- --	+10 +28	+2 +4	+17 +41	Would require significant capital investment to achieve. Controversy likely to be low for some of these activities, with potential for fairly wide stakeholder support.
Reducing minimum rotation ages in even-aged types by 5 years		+29	--	+87	+74	+191	Could implement this over time on at least a portion of lands as new management plans are completed. Potential for political sensitivity.
Age class regulation In general, the less age class regulation, the more volume, and the further away age class distribution moves from regulation. Volume gains are typically short term as age class regulation is less rewarded by the model internally and a boom-bust cycle is created.	***Two scenarios:*** Less emphasis on age class regulation	+3	--	+22	+8	+33	Potentially negative age class consequences, but there would be some opportunities to relax even flow constraints to address some age-class imbalances and still achieve desirable age class structure.
	No emphasis on age class regulation	+155	--	+411	+243	+808	Potential for very negative age class consequences without some constraints on harvest flows or forest conditions. Potentially valuable for future analyses to explore other scenarios and even-flow policies.
Reducing Extended Rotation Forests (ERF) on state lands From current levels to 30% prescribed (12% to 9.4% actual) as recommended by Governor's Task Force on Primary Forest Industry.		-1	--	-1	+19	+17	Potential for negative habitat diversity and biological diversity impacts. Likely to be contentious with stakeholders. Future analyses may be useful in identifying opportunities for better guiding ERF implementation.

Management practice with brief description		*Change in harvest by ownership (1000s cd yr^{-1})*					*Implementation notes*
		County	**Federal**	**Private**	**State**	**Total**	
Federal lands ***Two scenarios as described in next column***	Removing Allowable Sale Quantity (ASQ)-based caps on harvest	-3	+68	-3	0	+68	According to advisory group member Rob Harper, federal laws and regulations require vegetation management on the National Forests be balanced with other forest uses, and that management decisions be transparent to the public.
	Reducing extent of management areas that emphasize old forest characteristics	-11	+311	-24	0	+276	Increased timber sale quantities would require public engagement, and possibly significant analysis, therefore increases may not be realized in the short term.
Utilization of logging residue Increased utilization of harvest residue in even-aged systems. Guideline impacts are reflected in these figures.		+121	+59	+334	+127	+640	Good opportunity to provide additional volumes to some markets such as energy. Readers should note that a portion (less than 20%) of this volume is currently being utilized.
Full access to private lands All private lands are operable as opposed to 90% under the baseline scenario. Private lands availability is a critically important issue. To understand why the volume gain in this analysis of adding the final 10% of private lands are so modest, it is important to realize that the model tends to choose stand with the most volume first.		-1	--	+15	0	+17	More analysis is needed on the issue of private lands availability and management—a critical issue for Minnesota.
Additional scenario The main scenarios quantify the change in harvest level relative to changing one management policy. Beyond this, one additional scenario was added at the request of several Advisory Group members to address a desire for analysis of a single harvest or timber yield level, overall and by species that would be achievable given several altered environmental and social constraints. To estimate these harvest levels an additional scenario was designed that removed "market" constraints, eased even-flow constraints on several forest types, and altered three policies or practices at once. This scenario is based on adjustments to the Baseline scenario and includes all of the following changes: (1) upper limit on total statewide harvest volumes disabled, (2) upper limit on tamarack species harvest levels disabled, (3) even-flow constraints on black spruce, elm-ash-soft maple, maple-birch, and tamarack types disabled, (4) areal operability limits on elm-ash-soft maple and maple-birch stands of poor site quality disabled, (5) timber stand improvement treatments (see Table 4) were performed on 18,750 acres annually, (6) accelerated thinning regimes were used (see Table 5), and (7) all thinning results in stands restored to full productivity, i.e., stands were, after treatment, indexed to the enhanced productivity yield tables.		+444	+49	+1156	+680	+2329	This is not a "recommended" harvest level, but is instead an examination of timber yields and age-class impacts given the scenario parameters and constraints.