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INDIVIDUAL STAND PROJECTION UNDER DIFFERENT GOALS TO SUPPORT POLICY ANALYSIS FOR THE SIERRA NEVADA ECOSYSTEM PROJECT[1]

ABSTRACT

The Sierra Nevada Ecosystem Project (SNEP) was commissioned by Congress to assess the health of the ecosystems of the Sierra Nevada and to evaluate management strategies to maintain the health and sustainability of these ecosystems while providing resources to meet human needs. As part of this effort, a policy analysis model was developed by SNEP to analyze the ecological and economic implications of alternative strategies for managing late successional forests in the Sierra Nevada. To understand the implications of different management strategies, it was necessary to project forest characteristics, ecological effects, timber yields, and costs and revenues for each forest strata under different goals. This paper describes the methodology for managing individual stands to achieve the goals associated with the strategies. Using a growth and yield simulator for individual stand (strata) projection, a goal-oriented dynamic programming approach was developed to identify efficient prescriptions or pathways to reach alternative forest structure targets. A unique part of this effort was the inclusion of natural disturbance in the prescription generation. These prescriptions were then passed to a policy analysis model to be drawn upon to meet overall forest goals for alternative management strategies.

INTRODUCTION

The Sierra Nevada Ecosystem Project (SNEP) was commissioned by Congress to assess the health of the ecosystems of the Sierra Nevada and to evaluate "management strategies to maintain the health and sustainability of these ecosystems while providing resources to meet human needs (SNEP 1994).” The importance of late successional forests and watersheds was emphasized in numerous letters from Congress and in a bill considered by the Agriculture Committee of the House that became, in part, a model for the SNEP assignment. That bill requested "recommendations of alternative management strategies to protect and enhance each ecosystem of the Sierra Nevada forests and the resources thereof, including the watersheds and late-successional forests and their dependent and associated species, including a determination of whether late-successional reserves are necessary...” (section (5)(A) of HR 6013).” The bill also requested that ecological, timber harvest, economic, and social effects of the alternative management strategies be specified (see Appendices A through E of SNEP (1994) for more details).

Assessment of Sierra Nevada ecosystems has revealed a number of problems with achievement of health and sustainability (SNEP 1996) including: 1) decline in the amount and complexity of late-successional forest in the commercial forest types, especially mixed conifer and east-side pine, 2) declines in aquatic biodiversity and existing and potential threats to riparian-associated species, and 3) existing and potential difficulties from watershed disturbance. Also, it appears that there may be increased threat of severe fire in some forest types from the build-up in fuels and decrease in fire periodicity, although opinions vary about the degree of that increase.

Franklin and Fites-Kaufmann (1996) have proposed and evaluated the potential for a number of different conservation strategies for late-successional forests. These conservation strategies all increase the general extent and complexity of late successional

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[1] *Sierra Nevada Ecosystem Project: Final report to Congress*, vol. II. *Assessments and scientific basis for management options*. Davis: University of California. Centers for Water and Wildland Resources. 1996.

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forests in the Sierra, with varying degrees of human intervention through prescribed fire and mechanical treatment (timber harvest and road building) to accelerate development of late-successional characteristics and reduce the threat of fire. For the late-successional analysis, Franklin divided the federal lands of the Sierra Nevada into polygons (here called "LS/OG polygons") based on the characteristics of the forest. These average approximately 2500 acres in size (see Franklin and Fites-Kaufmann 1996).

Sessions, et al. (1996) have built a policy-analysis model to analyze the ecological and economic implications of strategies for late-successional forests in the fire-dominated landscapes of the Sierra Nevada. That model can also accommodate goals and strategies for riparian areas and watersheds and can accept goals for, or limits on, timber harvest and grazing and limits on budgets.

Sessions, et al. utilize the polygons of Franklin and Fites-Kaufmann as spatial building blocks in the policy simulation. Within each polygon, areas of similar overstory condition in terms of tree species, size, and density are grouped into strata following the vegetative classes developed by the Regional Office for Region 5 (USDA FS 1994b). As an example, one strata is M3G---mixed conifer, sawtimber, with a fairly dense canopy.

To understand the implications of different late-successional policies, Sessions, et al. project forest characteristics, ecological effects, timber yields, and costs and revenues for each strata within each LS/OG polygon where management of the strata is directed toward achieving the goals of the policies. As part of that analysis, they simulate large-scale fires on the landscape and the resulting effects.

This paper describes the approach taken to developing the volumetric, biometric, and ecological information (including degree of structural complexity, wildlife habitat rating, fire hazard rating, and contribution to watershed condition) associated with each strata given a specified goal, or set of goals, for the strata to achieve. After reviewing previous work that addressed similar problems, the methodology employed is explained along with an example of its use.

LITERATURE REVIEW

The methodology described in this paper has three major components: (1) projecting strata characteristics through time using a set of growth relationships, (2) linking strata conditions and activities at each point in time to ecological conditions and effects, (3) deciding the actions to undertake over time to move the strata toward specified goals. In this section, we review past work in these three areas.

Projecting Stand Development

An important choice for the Sierra Nevada Ecosystem Project is which stand simulation model to implement for forecasting the condition of forest stands over time. The input variables must be able to reflect the range of physical environments of interest, i.e. climate, soil conditions, tree list by species and diameter. The output variables from the simulation model must be able to represent the effects of the management actions to be simulated. A number of stand simulation models have been developed for forecasting the condition of forest stands over time. These models have been developed for specific geographic regions and perhaps, more importantly, for specific applications.

Individual-based gap models form one class of models. These are descendants of the JABOWA model first presented by Botkin et al. (1970). In this family of models, the primary intent is to describe the possible successional changes over long time horizons. Individual components of the model are based upon hypothesized or established physiological relationships such as the relationship between light, moisture, nutrient availability and biomass production. Two recent examples include SILVA (Kercher and Axlerod 1984) and ZELIG (Burton and Urban 1990). Important strengths of JABOWA models are the ability to project upper canopy and understory vegetation and to project stand development using physiological relationships in the absence of empirical stand response data.

Growth and yield models are a substantially different class of models. These models have traditionally been built to predict the output of commercial products (timber yield) over time. Specific examples include CACTOS (Wensel et al. 1987) and PROGNOSIS (Stage 1973). Growth and yield models are derived from regression analysis of empirical observations using a general environmental indicator (site index) and biometric variables such as species, crown closure, height, diameter, and stand density. The strength of these models is that they are fairly accurate for predicting individual tree or stand development under the range of conditions for which they have been developed. One weakness of growth and yield models is that they have not typically dealt with understory vegetation. Growth and yield models also have difficulty projecting stand development outside the range of empirical tree or stand response data on which they were built.

Ritchie (1995) has classified the distinguishing characteristics of growth and yield models and gap models (Table 1). Versions of the growth and yield models

CACTOS and PROGNOSIS (WESSIN variant) have been calibrated for the Sierra Nevada and are available; a version of the gap model ZELIG is being calibrated for the Sierra, but it is not currently available.

Over the last two decades there has been increasing interest in projecting the dead component of the stand, primarily for wildlife objectives. The two components of snag dynamics are the recruitment and fall rates. Either of the two types of stand simulation models can provide estimates for snag recruitment from mortality. Empirical studies provide estimates of the rate of snag fall rate. Raphael and Morrison (1987) provide data on the decay and dynamics of snags from the Sage Hen Creek Experimental Station near Truckee. Data is also available from the Sequoia National Park (Franklin 1996).

Ecological Linkages

Linkages of stand condition to late-successional characteristics, potential for disturbance, wildlife habitat, watershed condition, and forest health have been developed by a number of authors.

Table 1: Characteristics of Gap Models and Growth and Yield Models (Ritchie 1995)

Growth and Yield Models	Descriptive (gap) Models
Data rich, generally data come from one large planned acquisition of data to fit many component models.	Data poor, data come from a conglomeration of case studies and observed allometric relationships.
Primary models fit statistically, large data sets.	Many hypothesized relationships.
Intended to predict volume, or basal area or number of stems over time.	Intended to describe successional processes and future trends in species composition.
Features response to manipulation.	Features response to the environment.
Generally designed for short term < 100 years. e.g. FVS, CACTOS	Generally designed for long term > 100 years. e.g. ZELIG, JABOWA, FORET, SILVA
Current state of a particular stand is known and we wish to forecast future states conditional on current states.	Current state and future states of any particular stand are irrelevant. Future of specific stands is unknown. Global trends are relevant.
Successional changes are difficult to predict and are unimportant to the analysis.	Successional patterns are predictable and are integral to the analysis.
Validate by comparing with growth data from stands.	Validate by looking at trends and seeing if they match some observed or theorized trend.

The relationship between stand condition and contribution to late successional forest characteristics has been developed by Franklin and Fites-Kaufmann (1996). Their crosswalk classifies a stand into one of six ranks 0-5, with 5 signifying the largest contribution to late-successional characteristics and 0 signifying the lowest contribution. The ranking depends upon the number of large trees, total canopy and intermediate canopy closure. This approach is described further in a later section.

Linkages of stand condition to natural disturbance such as fire and disease have also been developed. Models linking the intensity of forest fires and stand condition were developed by Rothermel (1983). These models use fuel at the ground level and topographic and weather conditions to predict the flame length of the advancing fire front. Relationships have also been derived to express the probability of fire moving up into the crowns of trees as a function of flame length, height to the live crown, and foliar moisture (Alexander 1988). Stand conditions under which fire can carry through the crowns of trees have been examined by Van Wagner (1977) and Agee (1993). The probability of individual tree death as a function of flame length, expressed as scorch height, species, and tree diameter have been incorporated into the First Order Fire Effects

Model (FOFEM) developed by the USDA Forest Service (Reinhardt et al. 1995).

Linkages between disease and stand condition have most commonly been expressed as a function of species, stand density, and site index (Cochran 1994).

Wildlife relationships can be divided into spatial and nonspatial linkages. Nonspatial linkages express quality of habitat for types of wildlife based upon stand conditions such as number of species, large trees, canopy closure, and presence of snags. An important example in California is the Wildlife Habitat Relationship Index (WHR) developed by the California Division of Fish and Game (Airola 1988). A relationship between stand structure and wildlife habitat relation stage (class) has been developed for the Blodgett Experimental Forest for use in silvicultural prescriptions (Barrett and Davis 1994) and also by the Forest Service for the Sierra Nevada (USDA FS 1995).

Spatial linkages require knowledge of the size and distribution of habitat. A typical spatial model for big game is Wisdom et al. (1986). Their model requires knowledge of the distance to forage and cover in addition to nonspatial data in order to determine habitat suitability.

Linkages to watershed condition have also been spatial and nonspatial. The Equivalent Roaded Area model (ERA) developed by USDA Forest Service (1987a) is widely used in California. This model converts the results of both management activities and natural events into equivalent roaded acres as an index of disturbance. Examples of linkages between stand condition and water quantity and quality are more limited. One of the best known models is the Precipitation Runoff Modeling System (PRMS) (Leavesley et al. 1983) from the US Geological Survey. With the development of Geographic Information Systems, there has been increasing interest in developing spatial linkages combining physical science relationships with digital terrain models (Ustin et al. 1996).

Controlling Stand Development

In addition to projecting growth through time under different conditions and linking stand condition to ecological effect, we also wish to guide stand development over time toward specified goals. We wish to determine the set of activities to apply to the stand to best reach a specified set of goals.

Paraphrasing Duerr et al. (1956), ‘One of the most common decisions foresters make is which tree to cut and which to leave. Periodically the stand is entered and trees whose quality or growth rates are below par are marked for removal.’ Since these words were written many approaches have been utilized to solve the thinning intensity problem. The increased interest in mathematical programming techniques coupled with the sophistication of fast personal computing power has made possible multi-dimensional problem formulations. Focusing on the more recent solution procedures, dynamic programming and pattern search are the most prevalent in the literature. Brodie and Kao (1979) optimized thinning in Douglas-fir with a three-descriptor dynamic programming algorithm which accounted for accelerated diameter growth. The three state variables were trees per acre, basal area per acre, and time. The single control variable was trees per acre. The growth model utilized by Brodie and Kao, DFIT (Bruce et al. 1977) was better specified than previous growth models. This specification allowed stands to be simulated via the developmental variables diameter, volume, mortality, height, basal area, and number of trees. Within this formulation trees were partitioned into merchantable and unmerchantable portions.

The inclusion of a third continuous state variable, basal area, lead to an increase in the number of nodes in the dynamic programming network. Potential problems of dimensionality were overcome by Brodie and Kao (1979) by treating the network nodes as "neighborhood storage locations" for exact continuous values of the descriptors. The essential idea of the neighborhood storage locations was to combine discrete thinning with growth from the optimal nodes of the previous stage, thereby creating candidate stands in the same neighborhood. Optimization takes place over these candidates, and the highest-value alternative was stored at that neighborhood node. Future stand projections were made only from the continuous values, i.e. trees per acre and basal area, stored in each neighborhood location. The neighborhood approach efficiently used available storage to represent the continuous production-surface with a limited number of nodes.

Haight and Brodie (1985) further exploited the computational efficiency of neighborhood storage locations in the simultaneous determination of optimal timing and intensity for thinning and final rotation age for lodgepole pine management. This was the first dynamic programming algorithm applied to a single tree/distance independent stand simulator. Stand simulators of this nature allow direct manipulation of the number of trees in diameter classes. However, the computation and storage requirements for a dynamic programming algorithm in which residual numbers of trees in diameter classes are control variables was beyond the capacity of neighborhood storage location algorithms. Efficiency thus required the classification of trees into one-inch diameter classes, with each class described by the average tree diameter, height, and number of trees from the original list.

In diameter-free models, such as Brodie and Kao (1979), future growth is dependent on basal area, number of trees and age, regardless of thinning history. In an individual tree model, such as Haight and Brodie's, growth is affected by the diameter distribution as well as the stand variables. Optimization thus requires evaluation of various diameter distributions as well as thinning intensities.

Haight and Brodie constructed a four-descriptor DP algorithm for their analysis. The four state descriptors were thinning type, residual number of trees, residual basal area, and stand age. Thinning type, basal area, and residual number of trees were the control variables. The addition of thinning type to the problem formulation expanded previously defined dynamic programming networks to four dimensions, thus allowing the comparison of yields from a large number of diameter-distribution sequences.

Paredes et al. (1987) developed the PATH algorithm, an efficient solution algorithm which overcomes the computational burdens of traditional dynamic programming. The algorithm utilizes concepts from the generalized Lagrange multiplier method proposed by Everett (1963), with direct estimation of the Lagrange multiplier.

The primary difference between traditional dynamic programming and the PATH algorithm is with the nature of the objective function embedded in the recursion equation used to drive the search. With traditional dynamic programming, the cumulative return as constituted by all revenues from previous silvicultural and stocking decisions does not include any value for the standing trees, except at the final harvest node. The PATH algorithm objective function incorporates the value of the residual trees at a future time plus the return from implementing the controls. Incorporating PATH's objective function with the basic recursive equation stated by Bellman (1957), and the assumption of a monotonically increasing production function, allows the algorithm to efficiently find optimal solutions.

Paredes et al. (1987) compared the solution times for the Brodie and Kao (1979) dynamic programming formulation with the PATH algorithm and found the time savings ratio between algorithms was approximately thirty times. Also noted was the occasional minor difference in optimal thinning regimes. These differences can be attributed to artifacts of the neighborhood storage method.

Yoshimoto et al. (1988) interpreted the PATH algorithm in terms of the calculus of variations. The resulting algorithm was applied to the SPS single tree growth simulator (Arney, 1985) using a single control variable, trees per acre. Yoshimoto et al. was also able to determine exact values of the Lagrange multiplier, that is the shadow price per unit of future resource, using post optimal analysis.

Yoshimoto et al. (1990) applied the calculus of variations formulation developed by Yoshimoto et al. (1988) to the single tree/distance independent stand simulator PROGNOSIS. Solutions utilizing a minimum of 2 diameter class controls, and a maximum of 7 controls were compared. All species were grouped in the diameter classes.

Yoshimoto's economic optimization of PROGNOSIS illustrated that increasing the dimensionality of the control vector offered greater detail for the optimal thinning regime. The larger control vector was able to take advantage of the ability to manipulate individual trees in the stand, a feature of single tree/distance independent growth simulators, yielding superior thinning regimes. However, benefits from increasing the number of diameter classes were minimal for already large control vectors. To further increase the resolution of solutions, there was a need to manipulate individual trees in the growth model by developing the ability to harvest trees by species groups, as well as diameter classes.

Cousar and Brodie (1992) applied the PATH algorithm to ORGANON (Hester, et al. 1989), a single tree/distance independent growth simulator for western Oregon. The problem was formulated with 25 state variables, consisting of five species groups with four merchantable diameter classes and one unmerchantable class. This yields twenty diameter/species group control variables. The large state vector allows the algorithm to account for competitive interactions among species in the optimization process. Cousar's formulation also incorporated detailed economic input.

Research using dynamic programming has concentrated on finding optimal solutions to a single unconstrained goal. Limited work has been done using multiple objective criteria for single stand optimization. De Kluyver (1980) used multiple objective dynamic programming in a two stage procedure for developing thinning and harvesting schedules for radiata pine. The first stage of their analysis used multiple objective dynamic programming to find thinning and final harvest regimes for a given type of stand. The second stage used these regimes in a multiple objective linear programming model. The multiple objectives in their analysis focused on alternative definitions of average annual yield of a rotation and maximization of present net worth.

Haight et al. (1992) optimized timber yields subject to stand density constraints by converting a constrained maximization problem to an equivalent unconstrained problem by adding a quadratic penalty to the objective function for any violation of the target stand density constraints. They used the Hooke and Jeeves pattern search solution method with the PROGNOSIS growth and yield model (Inland Empire Version 5.2).

OUR METHODOLOGY FOR STAND PROJECTION

Given goals for a strata, we wish to find the combination of actions over time that will come closest to reaching the goals. Also, we wish to know the resulting yields, costs, revenues and ecological effects.

In this analysis, different types of activities are considered such as timber harvest and prescribed burning. To consider these activities over time, we build "prescriptions" that portray a combination of activities over time and the associated conditions, outputs, and effects. Assume that there are five time periods. Then one possible prescription might show the following pattern of activity over time:

Period	Activity
1	Timber harvest
2	Prescribed burning
3	Prescribed burning
4	No activity
5	Timber harvest

To derive prescriptions for use in the analysis of different conservation strategies for late-successional forests, a single stand optimization program, FVSPGM, has been developed. The single stand (per acre) optimization procedure used in FVSPGM combines a dynamic programming search algorithm using the PATH procedure with a goal programming objective function to minimize deviations from silvicultural and ecological goals for a single stand.

The search algorithm uses the single stand growth and yield model, FVS (formerly known as PROGNOSIS) to project stand growth. The specific variant of FVS, WESSIN, used in our simulations is the version calibrated for the west side of the Sierra Nevada. We have chosen FVS because of its availability, its recent calibration for the Sierra Nevada, and its ability to simulate growth and yield effects for the types of management actions we plan to evaluate. It may be appropriate in future studies to revisit the choice of simulation model as locally calibrated gap models become available. This is particularly true if the study interest includes forest succession under climate change, silvicultural prescriptions other than individual tree selection, and increased interest in understory development other than trees.

Thus, FSVPGM is a stand level multiple-objective optimization model which uses a set of silvicultural and ecological goals as the drivers controlling stand development. The model searches for solutions which lead to the development of stand structures most closely meeting specified silvicultural and ecological goals.

Simulated Strategies

Prescriptions are developed for each of six different management strategies. Four of the six strategies are based upon goals for the late successional old growth (LS/OG) rank of the stand; these are:

1) Matrix - Rank 2
2) Matrix - Rank 3
3) ALSE - Rank 3
4) ALSE - Rank 4.

The terms Matrix and ALSE (Areas of Late Successional Emphasis) refer to different land allocations in the policy analysis of alternative conservation strategies for late-successional forests. ALSE areas are LS/OG polygons which emphasize the maintenance and restoration of late successional forests in the Sierra under some conservation strategies.

An important goal of the ALSE strategies is the reduction of fire hazard. ALSE prescriptions permitting harvest include "biomass removals" during harvest if necessary to eliminate fuel ladders, crown density reductions to reduce the risk of crown fire, and slash treatment. Prescribed burning is also permitted to reduce fuel loadings.

Matrix areas are the remaining area outside ALSEs. "Rank" refers to the Franklin and Fites-Kaufmann (1996) classification for contribution to late successional forest structure. The matrix goals allow for the harvest of large trees surplus to the rank goals; the ALSE goals do not. In terms of the structural goals, the ALSE strategies require higher stocking of large trees and denser canopies.

The other two strategies are:

5) Minimize Fire Hazard
6) Maximize Present Net Value

The fire hazard strategy attempts to find a set of actions through time that minimize a fire hazard index considering potential flame length, stand crown closure, and basal area loss from fire. It includes "biomass" in the harvest, i.e. the harvest of small material that reduces fire hazard but ordinarily would not be removed in a commercial sawlog operation, commercial harvest and prescribed burning. The present net value strategy attempts to find a set of actions through time that maximizes the present net value of the stand, including the value of the timber harvest over time and the value of the residual stand at the end of the planning horizon.

Range of Activities Evaluated

For each strategy, one of five potential types of "activities" can take place in each period. Three are initiated by human action: prescribed fire (P), development of a defensible fuel profile zone or fuel break (B), and timber harvest through thinning and partial cutting (H). Two other "activities" are also considered: wildfire (F) and no action (N). A series of five activities (one per ten year period) defines the activity set over a planning horizon.

The stand effects of prescribed burning and wildfire on the stand are dependent on flame height, species, diameter, height to live crown, and canopy closure. For activities involving harvest, the level of the activity will be decided by FVSPGM depending upon the stand structural requirements to reach the specific goal given the sequence of "N", "P", "F", "H", and "B" activities in the activity set. Details for prescribed burns, wildfire, and the optimization routines to guide harvest levels are discussed in the following sections.

The five potential activities possible represent over 3,000 activity combinations for each strategy over the five periods (5 x 5 x 5 x 5 x 5). For example, "NNNNN" would involve no activity throughout the planning horizon, the activity set "HNHNH" involves a potential harvest in periods 1,3,5, and the activity set "FNNNN" represents an wildfire occurring under extreme fire conditions in period 1, and no activity in periods 2-5.

To reduce the number of combinations, a set of rules were developed which govern the creation of the combinations. Two examples of the rules are 1) a fuel break can only be initially developed in the first or second period; 2) harvests can occur, at most, every other period on steep slopes. A set of 17 rules was developed which lead, at most, to 324 possible activity combinations (Table 2).

Slopes less than 40% receive all combinations (324 total). Slopes greater than 40% have minimum 20 year re-entries (301 combinations). The subalpine forest type does not receive harvest leaving 73 combinations of F, P, N as the choices for this type.

FVSPGM calculates the resulting volumetric, biometric and ecological outputs which are attainable and most closely meet the silvicultural and ecological stand goals over time for each activity set.

Table 2: Summary of rules to generate possible activity combinations

Fuel Breaks	
1.	Must occur initially in periods 1 or 2
2.	If it occurs in period 2, then no action in period 1
3.	Maintain fuel break (though harvest) 20 and 40 years after initial entry
4.	No harvests in periods between fuel break maintenance
Wildfire	
1.	Can occur in any period
2.	Can not occur in a period following two consecutive previous periods that received prescribed burns
3.	Only "No action" is allowed in period after a fire
4.	Can not occur in 2 consecutive periods
Harvest	
1.	Can occur in any period
2.	Twenty year re-entry, except on slopes less than 40% where a 10-year re-entry is allowed in the first two periods
3.	No harvest the period after a wildfire (this does not refer to salvage immediately after a fire)

Table 2. (cont.)

Prescribed Burns	
1. 2. 3.	Can occur in any period A maximum of two consecutive prescribed burns (with the exception of PPPPP) No prescribed burning the period after a wildfire
No Action	
1.	Can occur in any period

Ecological Linkages and Goals

The SNEP policy group, in coordination with the SNEP work groups responsible for assessing late successional forests, wildlife diversity, watershed health, and natural disturbance in the Sierra Nevada, has adopted a set of indices for linking ecological response to vegetation change. These indices are calculated from stand structure attributes at any point in time including tree species, size and number, canopy closure, snags, and size and number and the height to the live crown by diameter class and species. The specific ecological and watershed health indices are late successional-old growth (LS/OG) rank, Wildlife Habitat Relationship (WHR) class, contribution to equivalent roaded acres (ERA), and fire hazard.

Progress towards a silvicultural/ecological strategy is measured through nine modeling goals which describe stand structure: 1) large trees, 2) total canopy closure, 3) intermediate canopy closure, 4) snags, 5) down wood, 6) fire potential, 7) basal area, 8) Wildlife Habitat Relation (WHR) size class, and 9) late successional rank. These were chosen after analysis of the information needed to portray movement toward the overall goals, e.g. ALSE - 4, for each of the six strategies mentioned in previous sections.

Target levels of the modeling goals are established for each strategy. Measurement of the attainment of a specific structure goal is determined within discrete intervals defined by the goal width. Basically, the goal width allows flexibility in meeting the goal target. For example, the large trees per acre has a neighborhood (width) of one tree per acre. Thus if the target is four large trees, 4.15 trees equally attains the target as 4.75 trees. The application of neighborhoods always occur above the target. Thus, the target is a “floor”. The neighborhoods (widths) for each goal are listed in Table 3, and described in more detail in the following section.

Table 3. Goal/metric widths and descriptions for use in stand optimization routines

Goal/Metric #	Goal/Metric Width	Goal/Metric Description
1.	1 tree	Large Trees Per Acre
2.	5%	Total Canopy Closure
3.	5%	Intermediate Canopy Closure
4.	1 snag	Snags Per Acre
5.	1 chunk	Down Wood Per Acre (Chunks)
6.	5 units	Fire Potential Index
7.	5 sq.ft.	Basal Area Per Acre
8.	N/A	WHR Size Class
9.	N/A	LS/OG Rank

A simulation run, i.e. prescription, is developed by first specifying the desired magnitude (target) of each of the above goals in the target stand, e.g., 12 tpa >30" dbh and an LS/OG rank of 4. Two additional data are input along with the target: relative importance of each goal (i.e., a weight) and a numeric penalty (a multiplier) for not meeting the target. Franklin and Fites-Kaufmann (1996) provided the target levels for the large tree, canopy closure, and snag structure targets for the matrix and ALSE management options. We developed the target levels for the remaining management options. All targets, metric weights and penalties are shown in Appendix Table A1.

Solving For The Harvest Intensity In A Period

One of the five activities discussed above is partial harvesting. The harvesting activity allows for the option of removing trees, by species group and diameter class, when so doing moves the stand's future structure towards a structure which more closely resembles the desired management goal.

FVSPGM determines the periodic harvest intensity, i.e. which trees to cut by species and dbh class, by evaluating a large number of potential solutions. These potential solutions are evaluated in two steps. The first step determines a family of solutions which equally minimize the difference between the structure resulting from the solution and the target stand structure through time (based on the goal class width). The second step evaluates this family of solutions to identify the solution which has the highest economic value, i.e. highest present net value of the stand through time including the ending inventory.

The first step is solved using the objective function:

$$Minimize\ \ Z = \sum_i weight_i * D_i^{penalty_i}\ \ over\ all\ structure\ metrics$$

Where D_i = absolute value of the difference between the current value of metric *i* and the target level of metric *i*.

Structuring the algorithm with discrete classes, e.g., 1.0 tpa classes, allows multiple solutions, i.e. harvest intensities, for a single value of Z. The metric input also allows the specification of whether a target must be met exactly, or whether a penalty occurs from exceeding the target or being under the target.

During the evaluation of potential moves at each time period, all structural modeling goals, except fire, are evaluated at a point 30 years into the future. This time frame more completely captures the effects of any harvesting activities. The fire potential index is evaluated at a point 10 years into the future.

The second step evaluates the economics of the set of solutions which minimized Z. From this set, the solution which gives the highest economic value of the stand is selected as the harvest intensity. This solution is simulated, the residual stand grown forward ten years, and the process repeated for each period of the planning horizon.

For example, FVSGM may generate over 600 different harvest intensities for a single period. These intensities vary by the number of stems removed and the species and size classes of the removals. Within these 600 intensities, possibly 20 or more may equally meet the stand structure targets; i.e. one solution may have less large trees than another, but compensates with a higher canopy density. For each of the 20 or more harvest intensities which meet the targets, the economic value is calculated and the intensity with the highest present net value is selected. In the case that all candidate intensities are negative, the candidate with the lowest negative value is chosen. It is important to note that although the intensity with the highest present net value is being chosen, the present net value criteria is being used as a way of finding the most efficient way to reach a management goal given that more than one way exists to reach the structural targets representing the goal.

The use of the present net value selection among harvest intensities to meet a management goal such as ALSE-4 or Matrix-3 should not be confused with the maximize present net value management goal which does not have stand structural goals. Under the maximize present net value management goal the resulting stand structure is a residual of the analysis rather than the driver of the analysis.

Typically, the optimization algorithm is able to more closely reach the desired structure targets as the number of non-zero goal levels increase; i.e. by specifying target levels for seven of the nine metrics vs. two of the nine. This is a function of how sensitive a structure metric is to a neighborhood of solutions. The more sensitive the metric, such as canopy, the more effect the metric has on the solution. Also, there are strong relationships between metrics, such as between large trees, canopy closure, and rank. Thus, if the management decision is to increase the rank of a stand, specifying target levels for all three will yield better results than just specifying a target for the rank goal alone.

As an example, the ”minimize fire” strategy has the following non-zero goal levels: Large trees = 8; Total Canopy = 20%; Fire Hazard = 10 (out of 100); Basal Area <= 200; WHR Size Class = 5. Over achieving the large tree and WHR size class is not penalized; under achieving the fire hazard target (of 10) is also not penalized. With the basal area and canopy closure structure targets, however, deviations in either direction are penalized. These structural targets for the “minimize fire” strategy generally result in a stand with a relatively high average diameter and little intermediate understory--a stand highly resistant to crown fire.

Constraints on the Search for the Best Harvest Intensity

The harvest search procedure, and thus the solutions, are constrained by two parameters: 1) a minimum net board foot harvest which varies by slope (2,800 bf on slopes less than 40%, 5,000 bf on slopes greater than 40%) and 2) a minimum residual basal area of 75 sq. ft. per acre. These limits help insure that the harvests will pay for themselves (to a degree--see below for the costs that are included) and that the analysis will not select “nonsense” solutions, such as very low harvests and very low basal areas, that are outside the capability of the simulation to accurately represent. The only exception to minimum levels of harvest involve the biomass harvest activity. If ladder fuels exist under canopy conditions which could result in crown fire, the ladder fuels are removed regardless of the minimum volume target during the first two periods of an ALSE management goal strategy which permits harvest or in the minimize fire hazard management goal even if the revenues will be negative.

Making Moves

The solution procedure evaluates a series of “moves”. The moves, also referred to above as solutions, guide FVSPGM along the production surface of the stand. Each move is made by harvesting a predetermined number of trees per acre in a particular decision variable. The specific search algorithm is referred to as a region limiting strategy (Pierre, 1986).

The decision variables are defined by seven species groups and seven diameter classes as:

Species Groups

1. sugar pine
2. ponderosa and jeffrey pine
3. Douglas-fir
4. true fir (red and white)
5. cedar
6. other conifer
7. hardwoods

DBH Classes

1. 0-5.5”
2. 5.6” - 11.5”
3. 11.6” - 17.5”
4. 17.6” - 23.5”
5. 23.6” - 29.5”
6. 29.6” - 35.5”
7. 35.6”+

Projecting Growth

Implicit in the solution method implemented by FVSPGM is the need to project stand structure through time, 50 years in this case evaluated in five ten-year periods. The existing stand structure is described by a tree list which has been derived from FIA plot data using the plot groupings (California vegetative type) from the FIA analysis (USDA FS 1994). The Forest Vegetation Simulator (FVS), WESSIN variant (Dixon 1994), is used to project single tree growth (species and diameter class) as a function of slope, aspect, elevation, stand density, site quality and National Forest. For each strategy and vegetative type, prescriptions are derived and growth projected for two slope classes (0-40% and >40%) and two azimuths (southwest and northeast) to provide needed information for the land strata of policy simulation model. Average elevation and site index from the FIA plots are also used in the growth estimation. Additional details on growth projections using FVS can be found in Stage (1973), Dixon (1994) and Ritchie (1995).

Exogenously to the growth routines, growth rates for the ponderosa pine forest type calculated by FVS are adjusted downward to account for insect-related mortality. The adjustment occurs when the basal area of the stand is greater than 95% of a normally stocked (Meyer, 1938) stand at 60 years of age, as a function of Dunning site class.

Initial Inventory

The simulation inventory was developed from the FIA databases for each national forest. The inventories were stratified by California vegetative type; i.e. M3G, P3N, and stratified by two slope and two aspect classes.

The vegetation data in FVSPGM is input and grown in FVS by species, dbh, crown ratio, total height, and trees per acre. FVS is able to calculate the height and crown ratio for input data which lacks this detail. The inventory data coming from the FIA databases is aggregated by dbh and species. Dbh's are input into FVSPGM in 2" dbh classes. The average dbh, height, and crown ratio for that class are input into the model. Eleven species are recognized in the growth model:

1) sugar pine
2) ponderosa pine
3) jeffrey pine
4) Douglas-fir
5) white fir
6) red fir
7) incense cedar
8) giant sequoia
9) other conifers
10) black oak
11) other hardwoods

Modeling Snag Dynamics

FVSPGM tracks snags greater than 24", and pieces of down wood greater than 24", each by species groups. This is done in routines outside of FVS as FVS does not track dead components of the stand. The initial snag and down wood inventory is derived from the FIA inventory. FVSPGM tracks snag recruitment into the 24"+ snag class. This recruitment is from tree mortality coming out of FVS. Once the tree becomes a snag, FVSPGM tracks its deterioration and likelihood of falling over and becoming down woody debris. Snag dynamics are modeled with 3 species classes [pines; true firs; and other conifer and hardwoods combined as the last group] and 5 degeneration classes, from recent dead to a decayed broken stem. The number of stems in each class through time is estimated using a Leslie matrix with transition probabilities derived from data from the UC Berkeley Sage Hen Creek Field Station and Raphael and Morrison, (1987).

The variant of FVS that we used in our growth projections calculates tree mortality based on a maximum stand density index for each species. Thus mortality is determined by competitive stress. Periodic surges of mortality, such as from drought and associated insect attack, most probably are only partially accounted for in this approach.

Recent mortality on the Sierra Forests for large trees (over 24"), as estimated though plot information, occurred at considerably higher rates than that estimated in FVS. Mortality was especially elevated for large red fir and white fir. These plots were taken at the tail-end of a prolonged drought which appeared to cause one of the periodic surges in mortality mentioned above.

Thus, we feel that the mortality estimates from FVS may understate the death rate of large trees. If we are underestimating large tree mortality, we, in turn, are underestimating snags and overestimating the number of large live trees in the stands. It should be noted, however, there are other sources of mortality in the analysis, such as logging damage, in addition to the endemic mortality provided by the FVS.

Down wood degeneration is traced in a manner similar to mortality. The probabilities are based on a degeneration class and age relationship outlined in the USDA Forest Service FIA handbook (1994).

LS/OG Rank

The rank is derived from tables which relate quantitative forest structure data to LS/OG rank. These tables were developed by Franklin and Fites-Kaufmann with some further modification by the authors and use the normalized rank classification (Franklin and Fites-Kaufmann 1996).

The rank classifications are based on three structure components:

1) number of large trees per acre
2) total canopy closure
3) intermediate canopy closure

FVSPGM first checks the large tree component of a stand, tallying the number of trees by the following dbh breaks: 40"+, 30"+, 24"+, 18"+, and 16"+. The trees per acre in each of these breaks is compared to the structural requirements. If a match is found, the remaining structure components are then checked to further define stand rank. Appendix Table A2 lists the minimum criteria for each rank. Because of our uncertainty in modeling of big tree mortality and snag falldown, rank determinations consider only large trees, total canopy closure and intermediate canopy closure.

Wildlife Habitat Relations (WHR)

WHR is comprised of three components: habitat type, size class, and canopy cover. The WHR habitat type call keys on the species with the majority of canopy in the stand, typically greater than 50% of the total canopy. In some cases due to the lack of specificity of minor species in the growth model, the habitat call is based on the forest type; for example, all juniper strata are labeled with the juniper habitat type. Excluding non-stocked areas, eleven habitat types are represented; juniper, lodgepole, eastside pine, subalpine, foot hills pine, red fir, white fir, ponderosa pine, jeffrey pine, mixed conifer, and hardwood.

Size class is based on the quadratic mean diameter QMD of all trees greater than 5". If the stand has no stems greater than 5", then the QMD is based on all stems.

The canopy class is based on the crown closure of the codominant and dominant trees, i.e., the canopy of all trees in the WHR size class call and greater. Canopy is calculated through a series of equations developed by Warbington and Levitan (1992) which calculate crown area as a function of dbh. FVSPGM sums canopy by species, and then adjusts the species totals for overlapping canopy based on the gap theory formula (USDA Forest Service 1994b): non-overlapping canopy percent equals (1-exp(-overlapping canopy percent)).

The steps in the determination of the WHR are:

1. Calculate crown area by the 11 FVSPGM species groups
2. Calculate crown area by WHR dbh classes (Table 4). These values are used to determine if the stand is multi-layered.
3. Adjust crown area in species and dbh classes from overlapping to non-overlapping percent.
4. Determine habitat type. (In the following, other conifer refers to any conifer species except Douglas-fir, white and red fir, jeffrey, sugar, lodgepole, ponderosa, incense cedar)
   - a. if forest type = juniper; habitat type = juniper
   - b if forest type = lodgepole; habitat type = lodgepole
   - c if forest type = eastside pine; habitat type = eastside pine
   - d. if forest type is non-stocked or barren; habitat type = forest type
   - e. if the crown area of all conifer species is less than 40% of the total crown area, habitat type=hardwoods
   - f. if the crown area of other conifers is greater than 25% of the total crown area;
     - i.) if the forest type is subalpine, redfir, or mountain hemlock, habitat type=subalpine
     - ii.) if the forest type is not any of the above; habitat type = foot hills pine
   - h. if the crown area of red fir is greater than 50% of the total crown area; habitat type=red fir
   - i. if the crown area of ponderosa pine is greater than 50% of the total crown area; habitat type= ponderosa pine
   - j. if the crown area of jeffrey pine is greater than 50% of the total crown area; habitat type= jeffrey pine.
   - k. if none of the above criteria are met; habitat type= mixed conifer

Table 4: Definition of WHR size classes.

Size Class	WHR Code	QMD Range
Seedling Tree	1	<1"
Sapling Tree	2	1" - 5.9"
Pole Tree	3	6" - 10.9"
Small Tree	4	11" - 23.9"
Medium/Large Tree	5	>24"
Multi-layered	6	>24" has >25% canopy closure 6" - 23.9" has >25% canopy >6" has 60% canopy

5. Determine Size Class. The WHR size classes are based on quadratic mean diameter (QMD) (Table 4).
   The procedure used to calculate QMD is:
   a0 Calculate QMD of stems greater than 5". If no stems are greater than 5", calculate the QMD of all stems.
   b0 Determine if the stand is multi-storied. If the crown closure of stems greater than 24" is greater than 25%; and the crown closure of stems 6" to 24" is greater than 25%; and the crown closure of stems greater than 6" is greater than 60%; then the stand is multi-storied.
   c0 Given the QMD, the corresponding WHR code can be read off of the chart given above, i.e., a QMD of 14" matches to a WHR size class of four.
6. Determine Canopy Class.
   Canopy class is based on the canopy closure of the codominants and dominants (Table 5). These stems are defined in the algorithm to be the stems in the WHR size class and above, i.e. for a stand of size class four, the canopy is summed for all stems greater than 11".

Table 5: Definition of WHR canopy classes.

Canopy Class:	WHR Code	Canopy Closure
Non-Stocked	X	< 10%
Sparse	S	10% - 24%
Open	P	25% - 39%
Moderate	M	40% - 59%
Dense	D	60% - 100%

Fire Hazard Index

One of goals in the stand level simulations is to reduce the likelihood of stand terminating fires. Stand terminating fires are most likely to result when several conditions are present:
1) high fuel loadings leading to high flame lengths and high scorch heights,
2) small diameter trees which are more susceptible to mortality from flame scorch,
3) crowns extending to near the ground surface which create pathways for a fire to reach the crowns of adjacent trees (ladder fuels),
4) high crown densities which would carry fire should it reach the tree crown level.

In order to guide stand simulations toward structures which would reduce the likelihood of stand terminating fires we developed a fire hazard rating or index which incorporates both prefire fire conditions and postfire effects. The “fire hazard” rating is calculated based on three factors:
1) percent of basal area a fire would kill if a fire occurred post-treatment,
2) difference between the pretreatment flame length and post-treatment flame length and
3) post-treatment percent canopy closure.

The percent basal area killed is based on the predicted flame length. The predicted flame length is used to derive the scorch height from which the probability of a tree of given species and diameter dying due to fire can be estimated. The flame length is based on the current forest structure condition aggregated by vegetation type, and the silvicultural activities through time. Each factor is weighted as follows:

Fire Hazard = 10* % basal area mortality - 2 *change in flame length + 20 * % canopy closure

where the canopy and basal area mortality are expressed as decimal percent and the change in flame length is in feet. For example, if the post-treatment % basal area which would burn=40, the pre-treatment flame length was 6.0 ft. and the post-treatment flame length was 3.0 ft. and the post-treatment % canopy =50, the fire hazard index would be 10*.4 - 2*3 + 20 * .5 or 8.

The coefficients were developed through an iterative process which monitored forest structure relative to the probabilities of stem death and the minimization of fire-related death. No activity results in an increase in flame length; all activities other than wildfire result in a decrease in flame length. The SNEP fire disturbance group developed the flame length/activity and mortality relationships (Table 6 and Appendix 5).

Two special hazard index ratings, 99 and 95 are assigned for stand conditions which we assume would lead to a stand terminating event. The fire hazard index=99 is assigned when the canopy density is greater than 70% and the flame length is greater than 6.0 ft. The fire hazard index=95 is assigned when the canopy index is greater than 70%, the flame length is lower than 6.0 ft, but some live crowns are close enough to the ground to create pathways for fire to reach the crowns of adjacent trees (fuel ladders).

Flame Length

Flame length is assumed to vary with fuel loading, wind, aspect, and slope. A set of standard extreme weather conditions were established for each administrative unit by the SNEP fire disturbance group (Bahro 1996). For each administrative unit, flame lengths for the existing stand were established for each vegetation strata, slope, and aspect. Using rules developed by Bahro (1996), flame lengths changed over time depending upon management actions, stand development, and slope and aspect (Table 6).

Table 6: Assumed change of flame length (ft) per decade as a function of management activity and stand development.

Action	North		South	
	Steep	Gentle	Steep	Gentle
Precommercial Thin	-2	-2	-2	-2
Prescribed Burn	-2	-2	-2	-2
Harvest and Slash Treatment	-1	-3	-1	-3
Fuel break	-4	-4	-4	-4
No Action	1	1	2	1

Ingrowth

Ingrowth is the number of “small” trees incorporated into the simulation at each time step. It is based on the average number of small trees per acre in the inventory. The definition of “small” is based on dbh, and varies by forest type as follows:

Forest type	dbh
A	0"-3"
F	0"-4"
H	0"-3"
M	0"-5"
P	0"-5"
R	0"-4"

The dbh classes are based on the relative growing potential and stocking of the strata. For example, the mixed conifer strata is more likely to have larger submerchantable trees than the alpine strata for similar ages.

The number of small trees (SMALL TPA) is an estimate of typical stocking by forest type, rather than an estimate of what grows into a particular stand. SMALL TPA is defined as the mean number of tpa plus or minus a random deviation. The random deviation is plus or minus one standard deviation, based on observations of small tpa by strata in the FIA inventory. The mean and standard deviation are based on observations of small tpa by strata in the FIA inventory.

FVSPGM compares the actual number of small trees in the stand being simulated with SMALL TPA to determine if additional small trees should be added to the simulation. Essentially this strategy makes sure the simulation always approximates the observed number of small trees. Ingrowth is calculated 10 years after the activity and is the first calculation at the beginning of the period. Thus no ingrowth occurs in the first period of the planning horizon.

Calculating Small Trees Per Acre

The ingrowth function first determines the activity that occurred in the previous period. If the stand was thinned or had a non-crown fire, the typical tpa is based on the mean and standard deviation for the forest type. The introduction of a random deviation is to account for the range of variability in the FIA inventory. The random number for the deviation comes from a uniform distribution.

If the stand had a crown fire, the typical tpa introduced into the simulation is preset. In Wilderness and national parks, 25 tpa, 0.8" dbh are added, non-Wilderness ALSEs get 100 tpa, non-ALSE lands are planted with 250 tpa.

Determining If The Stand Is Understocked

Once the typical number of small trees is calculated (stocking level 2), the number of small trees currently on the site is calculated (stocking level 1). These levels are compared and if stocking level 1 is greater than eighty percent of stocking 2 there is a 20% probability the model will add more small trees. If stocking level 1 is less than eighty percent of stocking 2 there is a 50% probability the stand is understocked and more small trees will be added.

Adding Tree Records

Tree records are added to the tree list until the total number of small trees per acre equals stocking level 2. The species composition of the additional trees is approximated by the current species composition (as a function of basal area). If the stand had a stand terminating fire the previous period, the pre-burn species composition is used. The additional trees are a minimum of 1" dbh plus a random increment between 0 and the maximum dbh for the forest type. If a stand burned in the previous period, an exception to this rule is made and all additional small trees will be 0.8" dbh at ten years.

Revenues and Costs

Log revenues and costs are based on tree dbh and total cubic feet removed respectively. Log revenues are computed by \$/mbf values based on two-inch dbh classes up to 50 inches dbh (Appendix Table A3). Log revenues by species and diameter class were derived from USDA Forest Service mill studies and lumber values for second growth timber updated to 1992 (USDA Forest Service 1992). Lumber prices by diameter class were converted to log scale using mill study overrun factors. The log values were used to develop values per tree using species, tree height, and breast height diameter. The tree values are compiled into a lookup table which FVSPGM accesses at each possible move to determine stand value.

Similarly, a harvesting cost lookup table was developed (Appendix Table A4). Logging costs include stump to mill, profit and risk, road maintenance and construction. Other costs considered include slash treatment costs, sale preparation costs, sale administration costs, and NEPA costs (Appendix Table A4). Logging, road construction, road maintenance and slash disposal costs were differentiated by ground slope. Costs are differentiated between flat (less than or equal to 40 percent ground slope) and steep ground (greater than 40 percent ground slope), and volume per acre removed. Ground based systems are used on the flat slopes while skyline logging is assumed on the steep slopes. Site preparation on the flatter slopes assumes mechanization is possible with more intensive preparation, while manual methods and less intensive preparation are assumed on the steeper slopes. Transportation distance was assumed to be 120 miles round trip. Environmental Analysis costs were estimated at \$23/mbf (\$115/mcf) following a study by Campbell (1995). Sale preparation and administration costs were based on estimated average sale costs on the Eldorado National Forest (Bodenhausen, 1995).

Volumes

Gross inventory volumes and harvest volumes are calculated from equations developed by Wensel and Olson (1993). Net volume, (net of visual defect only) is calculated from equations developed by Levitan (1995) where net volume is a function of gross volume.

Logging Damage

FVSPGM anticipates that logging damage will occur when a stand is entered for harvest. The sources of mortality are assumed to be tree breakage from felling and equipment related damage from subsequent skidding and yarding. Damage is concentrated in trees 10-20 feet tall. Mortality from felling is assumed to be a function of the canopy area of trees harvested. The felling mortality rate for the trees 10-20 feet tall is estimated as 65% multiplied by the percent of canopy removed. Mortality from skidding or yarding is assumed constant at a mortality rate of 3.5% of the trees in the 10-20 foot height class due to equipment either running over the trees or lines pulling the trees over. As an example, if 30 percent of the canopy is removed during harvest, the percent of the small trees killed during logging is equal to .65 x .30 + .035 = .23 or 23 percent.

Modeling Fire at the Stand Level

FVSPGM takes into account two kinds of fire: wildfire, and prescribed fire. Wildfire is assumed to occur under a specific set of extreme weather conditions which are established for each administrative area by the SNEP fire disturbance group. Prescribed fire is assumed to occur under less severe weather conditions. This section describes the methodology for estimating mortality from wildfire and prescribed fire and the rules for changing flame length as a function of management activity.

Wildfire

FVSPGM estimates stem mortality due to wildfire given the flame length, species, diameter, height to the live crown, canopy closure, and topography. The initial flame lengths are input into FVSPGM by forest type, slope, and aspect. The flame length increases if no activity occurs in a stand, and decreases as a function of type of activity (prescribed burning, fuel break installation/maintenance, or thinning and partial harvest). A harvest which cuts trees for which 80% or more of the harvested basal area comes from trees less than 11” dbh is defined as a precommercial thinning and has a different flame length response than a selective harvest of larger trees.

Stem mortality is calculated based on a table of fire effects probabilities for non-crown fires derived by Bahro (1995) using the USDA First Order Fire Effects Model (Appendix Table A5). These probabilities are by 2-inch dbh classes for 3 species groups [other conifer, red fir, cedar, hardwoods; sugar and ponderosa pine; Douglas-fir], and are referenced by scorch height. FVSPGM sums the fire effects probabilities for all dbh/species groups in the stand. The summed probabilities are then multiplied by the standing basal area in each dbh/species group to determine the percent of basal area killed in the stand. These probabilities are also multiplied by standing trees per acre to determine trees per acre killed by the fire.

Stand replacement fires are modeled as killing all stems in the stand, i.e., stand terminating. Tree or stem mortality occurs when the flame length is greater than 6 ft. and the canopy closure is greater than 70%; or when there is a presence of ladder fuels (dbh < 8”) and the flame length is long enough to get into these crowns (and canopy closure is greater than 70%). Ladder fuels are present and susceptible to carrying fire when the average height to the live crown base of these stems is less than the 4.5 times the flame length, less 7.5 feet.

Snags burn at the rate (0.6389*log(flame length)-0.5989) percent in non-crown fires. All snags burn in a crown fire. All large woody debris burns completely regardless of fire intensity.

The level of salvage is a function of the strategy. Strategies for the matrix lands, such as Matrix-Rank 3, or Max NPV allow salvage of 66% of the volume, except for the three largest snags created by the fire. The ALSE goal sets leave all burned stems greater than 24” as snags and salvage 66% of the stems 12-24” dbh.

Prescribed Fire

Prescribed burning is modeled by removing trees from the stand based on predefined mortality probabilities, supplied by the SNEP fire disturbance group (Table 7). Stems greater in size than the minimum snag diameter, 24", are recruited into the stand snag list. No volume is salvaged from prescribed burns.

Table 7: Mortality from prescribed fire by DBH class

DBH Class	Mortality from Prescribed Fire (%)
0.0 - 5.5"	70
5.6"- 11.5"	23
116"- 17.5"	10
176"- 23.5"	5
236"- 29.5"	5
290"- 35.5"	4
36+	4

Defensible Fuel Profile Zones (Fuel Breaks)

The “fuel break” activity has been defined to permit examination of issues in the policy analysis model. The objective of the fuel break is to establish forest conditions under which it is likely that suppression forces could stop the spread of a wildfire. These forest conditions are expressed as a combination of flame length which affects the resistance to control at the ground level and canopy closure which reflects the opportunity for fire to spread through the crowns.

The establishment of a fuel break is modeled as a harvest which brings the residual canopy closure down to 30%. This canopy reduction is reached through a two-step harvesting process which removes small to large trees. The first step brings the canopy down to 40%, the second step brings the canopy to 30%.

The two steps are differentiated by the proportion of hardwoods which are harvested relative to the conifer harvest, and the minimum dbh harvested. The first stage cuts hardwoods at 50% of the conifer rate, and cuts in all the dbh classes (biomass) including saplings. After the canopy has been reduced to 40% (stage one), the net revenues of the harvest are calculated. If the revenues are positive, step two removes trees greater than 5.5" dbh in the same proportion of conifer to hardwoods as step one.

However, if the revenues at this point are negative, step two will only harvest conifers, and the minimum dbh harvested is 17.5" to maintain positive cash flow. Step two continues until the canopy is less than 30% closure.

The harvest in each step is an iterative process (Table 8). The first iteration in step one harvests a pre-specified percentage of all trees in a dbh class, i.e. the initial harvest percent. If this first pass fails to bring the canopy down to 40%, the second iteration removes an additional 25% of the initial harvest percentage; (if the initial % is 20%, the second iteration will remove an additional 5%, 0.20 * 0.25 = 0.05). The iterations continue until the canopy goal is met, or a maximum percentage of the stems in a dbh class are removed. The second step continues with the ending harvest percent from step one.

Table 8: Harvest percents by diameter class in the harvest steps

DBH CLASS	Initial Harvest %	Maximum Harvest %	Harvest Increase %
0.0 - 5.5"	60%	95%	25%
5.6" - 11.5"	20%	95%	25%
11.6" - 17.5"	10%	90%	25%
17.6" - 23.5"	5%	85%	25%
23.6" - 29.5"	2%	85%	25%
29.0" - 35.5"	0.5%	80%	25%
36+	0.5%	80%	25%

If a fuel break installation activity ("B" activity) has been specified, the fuel break algorithm will begin if the stand currently has more than 40% canopy closure. If the stand does not have more than 40% canopy closure, no activity is undertaken.

The fire breaks must be installed in either the first or second period. They are maintained, i.e. the canopy is reduced to below 30%, every 20 years. Observations of growth indicate the canopy typically reaches about 50% closure approximately 20 years after it has been thinned back to 30% crown closure.

Equivalent Roaded Acres (ERA)

The Equivalent Roaded Acres (ERA) method is being used in the regional simulations to estimate cumulative watershed impacts of harvest, site preparation, wildfire, and grazing. The ERA method is based upon relating the amount of ground cover in terms of that which would exist for an area without cover, i.e., a road. Revegetation (recovery) after disturbance is time and impact related. The ERA coefficients used in this study (Table 9) are derived from the Eldorado National Forest publication "Cumulative Off-Site Watershed Effects (CWE) Analysis Process" (Eldorado National Forest, 1995). Further discussion can be found in Menning et al. (1996).

For each activity, an ERA factor is calculated using the coefficients in Table 9 with the following exceptions for selection harvst and wildfire. Since all harvesting activities involve some level of selection harvest the ERA coefficients has been modified to differentiate between levels of harvest activity by the relationship

ADDENDUM

Table 9: Eldorado ERA coefficients (Eldorado National Forest, 1995).

Activity or Impact	Years since impact 1	2	5	10	20	50
I. Transportation system	*(multiply road coefficients by 1.5 when slope is >40%)**					
A. System & non-system roads and landings						
1. good drainage	1.0	1.0	1.0	1.0	1.0	1.0
2. poor drainage	1.5	Fixing road during problems associated with ditches, culverts, etc.: coefficients return to 1.0				
3. diversion potential	2.0	Same comment as above				
B. Abandoned roads and landings	1.0	0.9	0.9	0.8	0.8	0.8
C. Trails (recreational)	1.0	1.0	1.0	1.0	1.0	1.0
D. Ripped and obliterated roads and landings	0.4	0.3	0.3	0.2	0.1	0.1
II. Silvicultural system						
A. Tractor (includes impact due to skid trails)						
1. Clearcut and seed tree	0.25	0.24	0.20	0.15	0.10	0.08
2. Shelterwood	0.22	0.20	0.15	0.10	0.10	0.08
3. Overstory removal	0.20	0.16	0.12	0.10	0.10	0.08
4. Sanitation/Salvage	0.15	0.10	0.08	0.05	0.05	0.04
5. Selection/Thinning	0.15	0.12	0.10	0.08	0.08	0.08
B. Cable						
1. Clearcut	0.15	0.14	0.10	0.05	0	0
2. Overstory Removal	0.10	0.06	0.02	0	0	0
C. Helicopter						
1. Clearcut & seed tree	0.10	0.09	0.05	0.02	0	0
2. Overstory removal	0.05	0.05	0.05	0	0	0
3. Sanitation/Salvage	0.02	0	0	0	0	0
4. Selection/Thinning	0.05	0.02	0.01	0	0	0

Table 9. (cont.) Eldorado ERA coefficients (Eldorado National Forest, 1995)

III. Site preparation method						
A. Mechanized						
1. Pile & Burn	0.15	0.12	0.10	0.05	0.05	0.05
2. YSM Tractor	0.10	0.08	0.05	0.03	0.03	0.03
3. YSM cable	0.05	0.02	0	0	0	0
4. Crush & Chip	0.04	0.02	0.02	0.02	0.02	0.02
B. Non-mechanized						
1. Broadcast burning L-M	0.08	0.05	0.02	0	0	0
2. Hand pile & burn	0.05	0.02	0	0	0	0
3. Lop & scatter slash	0	0	0	0	0	0
C. Herbicides	0	0.05	0	0	0	0
D. Rip/obliterate skid trails	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
E. Hand grubbing	0.10	0.05	0	0	0	0
F. Disc (not plowed)	0.07	0.05	0.02	0	0	0
VI. Wildfire	*(multiply fire coefficients by 1.5 when slope is >40%)**					
A. Crown (0-10% CC)	0.30	0.30	0.20	0.10	0.05	0
B. High intensity (10-40% CC)	0.18	0.15	0.10	0.05	0	0
C. Moderate intensity (40-60% CC)	0.05	0	0	0	0	0
D. Low intensityy (60+% CC)	0	0	0	0	0	0
*V. Grazing in flat riparian areas**	*0.0135*	*0*	*0*	*0*	*0*	*0*

*All the items in *italics*--grazing coefficients and corrections for slopes over 40% -- are modifications to the Eldorado method based on meetings of cumulative watershed specialists convened by the Sierra Nevada Ecosystem Project in May, 1995.

$$\mathrm{ERA} = \max\,(.01 * \text{mbf removed}, .08) \le 0.20.$$

For wildfire, the ground cover is being related to fire severity through flame height where

Flame Height	Average ERA for decades after fire			
(ft)	1	2	3	4
>12	0.20	0.075	0.025	0
8-12	0.102	0.025	0	0
4-8	0.005	0	0	0

ERA factors over time are not additive. At each point in time the assumed ERA impact is the maximum of either the impact resulting from the current activity or the residual impact of the past activity.

The activities being generated during the individual stand projection are generalized and non-spatial, that is, they reflect management treatment or fire activity by forest type, condition, slope and aspect. ERA contributions due to previous harvesting, fire, and road construction are added during the regional simulations as are ERA contributions of future road construction and grazing. During the regional simulations, the allocation of activities is constrained by the cumulative ERA over contiguous areas approximately 3000 to 7000 acres in size. The allowable ERA limits are a policy variable and vary by management zone and scenario.

EXAMPLES OF FVSPGM OUTPUT

An example of the FVSPGM yield streams for five different strategies has been constructed for the vegetation strata M3G (mixed conifer, size class three, heavy canopy closure) on site one, southwest aspect, ground slope less than 40 percent. The five strategy examples are:

1. ALSE - Rank 4
2. Matrix - Rank 3
3. Matrix - Rank 2
4. Maximize Present Net Value
5. Minimize Fire Hazard

In this analysis for those prescriptions which permit harvesting, we used the prescription "HHHHH" which potentially permits a harvest each period. Whether a harvest actually takes place each period will depend upon the contribution of a potential harvest to the goal.

We also illustrate two other prescriptions which might be used to reach goals when harvest is not allowed: 1) "NNNNN" (no action) and 2) "PPPPP" (prescribed burn each decade) to show effects where harvest is not allowed. A third prescription, Fuel Break, which illustrates establishing a defensible fuel profile zone is also shown.

The first time period begins in 1996 so the midpoint is the year 2001. The number of harvest entries, level of harvest removals, effect on LS/OG rank, mean stand diameter, canopy closure, fire hazard and residual stand value are compared (Table 10, Appendix Table A6, and Figure 1).

Activities are permitted for the first five 10-year periods, but we have shown the simulation for ten 10-year periods to illustrate the longer run effects. Except where noted, the discussion below refers to the first five periods (50 years). Detailed output is shown in Appendix Table A6.

No Action

Under "NO ACTION", NNNNN, the LS/OG rank increases from 3 to 4 over the five periods, the quadratic mean diameter grows from 12.7 to 16.0 inches, and the canopy closure increases from 87% to 129%. Canopy closure can exceed 100 percent due to summing the canopies of all trees and overlapping canopies occurring. The number of trees per acre greater than 30 inches in diameter increase from almost 10 to a little over 23 over the 50 years. The initial fire hazard, 99, indicates that all trees would probably die should a fire originate in or reach this stand.

Prescribed Fire

Under the prescribed fire activity set, PPPPP, LS/OG rank also reaches 4, but the residual canopy is steadily reduced to 63% after 50 years, resulting in an ending fire hazard of 14, although the fire hazard for the first 25 years would still probably result in a stand terminating event. The number of trees greater than 30 inches is about 13 percent lower than under the NO ACTION after 50 years due to fire induced mortality from prescribed burning. The ending quadratic mean diameter is much larger than under NO ACTION due to the removal of the smaller stems through a repeated program of prescribed fire. The present net value is the lowest of all the prescriptions due to cost of the prescribed fire program.

ALSE Rank 4

Under the goal of ALSE RANK 4, harvest occurs in the first four periods removing a total of 20.0 thousand board feet. Harvest in the first two periods is oriented toward reducing fire hazard by removing ladder fuels and slash treatment with biomass recovery. Harvest in the remaining periods is oriented toward reaching structural goals of large trees while maintaining low fire hazard through density control. The fire hazard after treatment in the first period is reduced from 99 to 10 and is held in the range 7 to 14 over the 50 years. LS/OG rank 4 is reached by the second period and the number of trees greater than 30 inches is about 6 percent lower than under NO ACTION at the end of 50 years. The ending quadratic mean diameter is about 25 percent larger than under NO ACTION due to the removal of ladder fuels.

Matrix Rank 3

Under the goal MATRIX RANK 3, harvest occurs in four of the five periods removing 30 mbf. The LS/OG rank stays between 3 and 4 over the planning horizon. The ending quadratic mean diameter is about 10 percent larger than under NO ACTION. The canopy closure is reduced

Table 10: Summary comparison of simulation example results under different goals.

Goal	Ending Rank Beg. = 3	Ending Trees >30 in. TPA Beg. = 9.6	Ending Trees >40 in. TPA Beg. = 2.0	Ending Canopy Closure % Beg. = 87	Ending Mean Diameter[1] (in.) Beg. = 12.7	Ending Basal Area Beg. = 244	Ending Inventory MBF Beg. = 35.7	Ending WHR Beg. = M4M	Harvest Volume MBF	Present Net Value	End Fire Hazard Index Beg. = 99	Average ERA[2]	Number of Harvest Entries[3]
1. No Action	4	23.2	9.2	129	16.0	358	68.0	M6D	0.0	$409	99	0/0.08	0
2. ALSE Rank 4	4	21.7	8.9	56	20.7	252	59.2	M4M	20.0	$1,878	13	0.18	4
3. Matrix Rank 3	4	15.7	6.8	49	18.7	189	47.8	P4M	30.0	$3,980	10	0.18	4
4. Matrix Rank 2	2	13.6	5.5	37	19.7	146	32.1	M4P	39.8	$5,660	11	0.19	4
5. Maximize PNV	3	6.3	0.8	68	13.4	219	32.8	M6M	53.1	$7,401	17	0.22	5
6. Min. Fire Hazard	4	14.6	6.7	45	22.8	212	42.7	M5M	30.4	$4,148	13	0.18	4
7. Prescribed Fire	4	20.3	8.4	63	24.7	262	55.6	M5M	0	$199	14	0/0.08	0
8. Fuel Break	3	11.8	6.8	30	28.4	137	34.6	M5P	21.1	$3,767	7	0.19	5

NOTE: Except PNV, all ending outputs are for the end of the fifth period. PNV is calculated using outputs of the first five periods plus residual inventory value projected at the tenth period.

[1] Mean diameter is Quadratic Mean Diameter (QMD).

[2] ERA is averaged over the first five periods. Units are equivalent roaded acres per acre. If area is previously unroaded, ERA = 0. Otherwise we assume at least a salvage harvest has occurred in the past with cumulative ERA = 0.08.

[3] Harvest entries are over the first five periods.

ADDENDUM

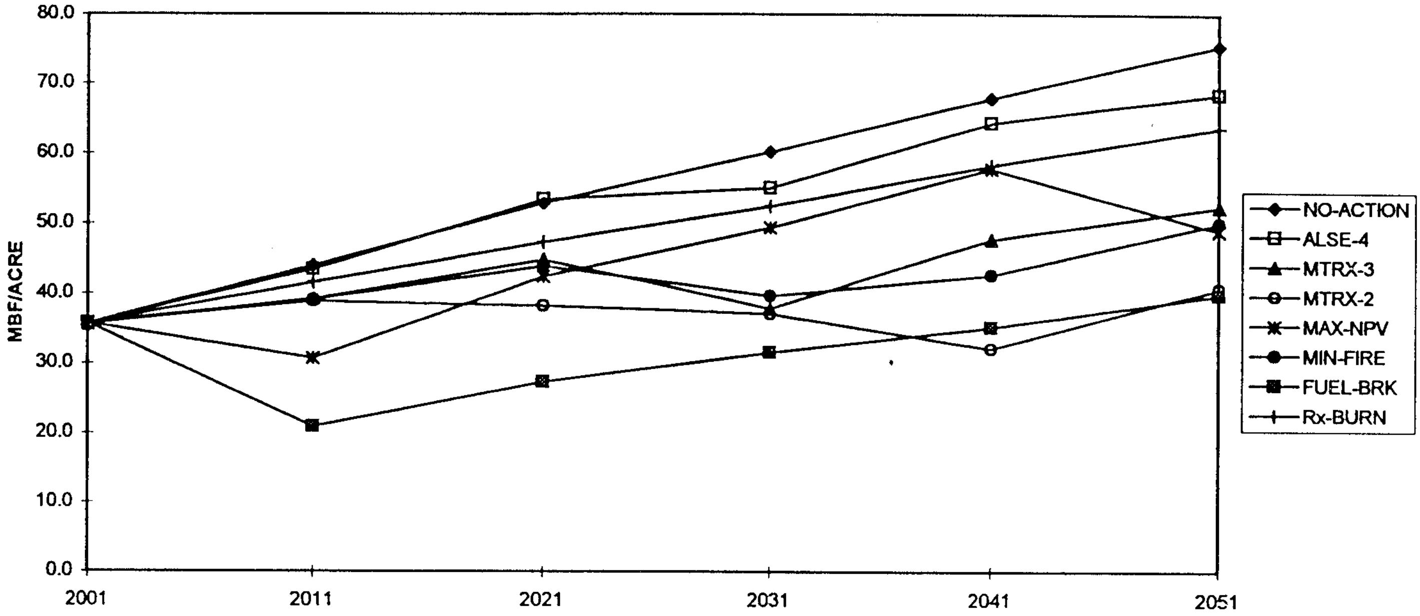

Figure 1a. Inventory before harvest from simulation examples under different goals.

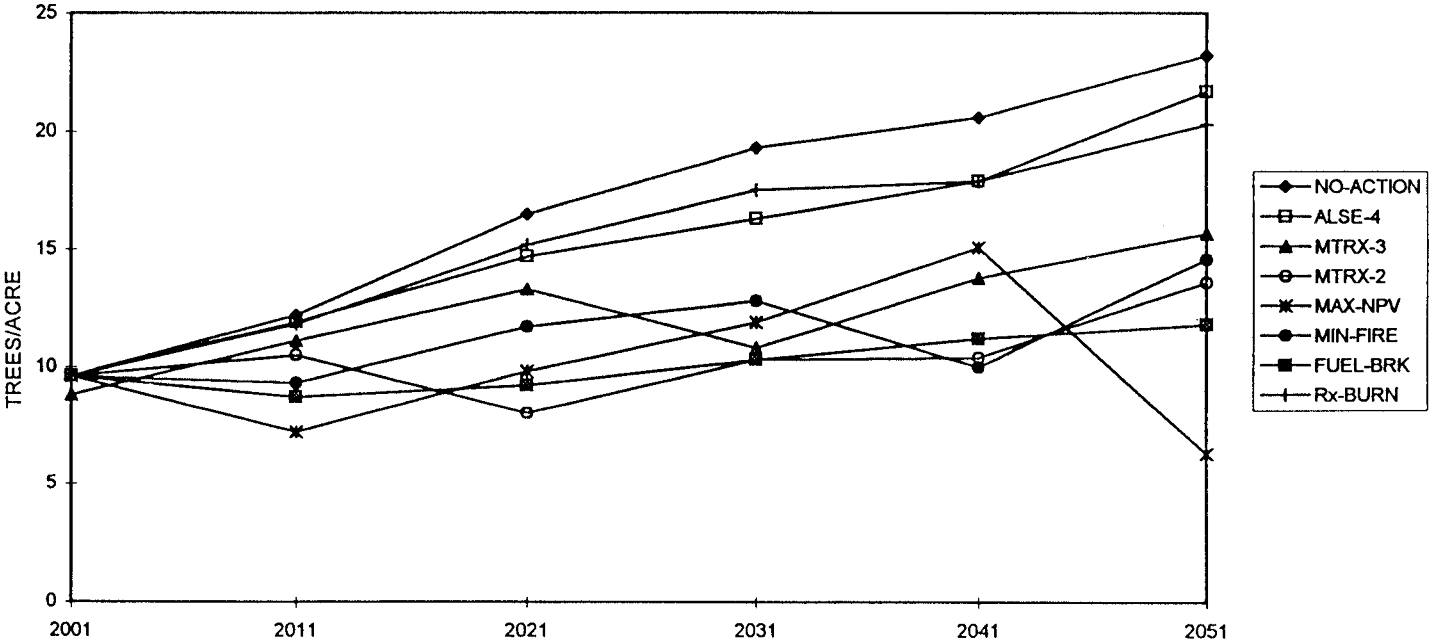

Figure 1b. Trees per acre over 30" diameter before harvest from simulation examples under different goals.

from 87% to 49% over the planning horizon. The number of trees greater than 30 inches in diameter increases from 10 to about 16 over the five periods. The initial fire hazard is 99, but is brought to 9 after harvest in the second period. The ending value of the stand is about 6 percent less than under NO ACTION, but the present net value is almost 14 times that under NO ACTION.

Matrix Rank 2

Under the goal MATRIX RANK 2, harvest occurs in four of the five periods removing almost 40 mbf. The LS/OG rank stays between 2 and 4 over the planning horizon. The ending quadratic mean diameter is about 23 percent larger than under NO ACTION. The canopy closure is reduced from 87% to 37% over the planning horizon. The number of trees greater than 30 inches in diameter increases from 10 to about 14 over the five periods. The initial fire hazard is 99, but is brought to 10 after harvest in the first period. The ending value of the stand is about 11 percent less than under NO ACTION, but the present net value is almost 10 times that under NO ACTION.

Max PNV

Under the goal of MAX PNV harvest occurs in all periods removing 53 mbf. LS/OG rank varies between 2 and 4. Ending quadratic mean diameter is smaller than under NO ACTION due to heavy removals in the larger diameter classes. Canopy closure reduced from 87% to 68% over the planning horizon, but is above 90% in some periods. Trees greater than 30 inches fall from about 10 to 6 and trees greater than 40 inches are almost eliminated. Fire hazard is reduced to 13 after harvest in the second period and remains low. As expected, this simulation has the highest present net value.

Min Fire Hazard

Under the goal of MIN FIRE HAZARD harvest occurs in the first four periods and a positive net revenue is produced in all cases. After treatment in the first period, fire hazard is reduced to a very low level and stays there for the remaining periods in the 50-year planning horizon. Quadratic mean diameter at 50 years is much higher than under NO ACTION due to heavy removals in the smaller diameter classes. Canopy closure is also greatly reduced. LS/OG rank stays between 2 and 4. The ending value of the stand is less than under NO ACTION, but the present net worth is more than 10 times that of NO ACTION.

Fuel Break

Under the FUEL BREAK activity, harvest occurs in each of the five periods removing about 21 mbf. The initial entry revenue is positive and strong, but maintenance entries in the second through fourth periods are slightly negative and period five is slightly positive. Under this activity fire hazard is brought to a very low level after treatment in the first period through removal of fuel ladders and crown density reduction and maintained at a low level. LS/OG rank is initially reduced to 2, but climbs over the 5 periods to end at rank 4. The number of trees larger than 30 inches is reduced from 10 to about 8 during the first period and then increases to about 12 by the end of 50 years. The number of trees larger than 40 inches increases from 2 to about 7 over the 50 years. The ending value of the stand is about 20 percent lower than under NO ACTION, but the present net worth is more than 9 times that of NO ACTION.

OUTPUT FOR POLICY SIMULATION

A file of abbreviated information from the FVSPGM prescriptions containing the harvest per period, rank, WHR, flame length, hazard index, and basal area which would be killed if a fire occurred under extreme weather conditions is prepared for export to the policy analysis model. A prescription is produced for each combination of strategy, forest type, activity, slope, and aspect. The prescriptions for a typical forest run include prescriptions for each of 6 strategies x 50 vegetation strata x 324 activities x 2 slopes x 2 aspects or approximately 390,000 prescriptions. These prescriptions then become the pool of activities from which the policy simulation model can draw from to achieve the objectives for each administrative unit (national forest or national park). A separate pool of prescriptions is prepared for each administrative unit.

CONCLUDING REMARKS

The use of single stand dynamic programming algorithms to provide input for subsequent regional optimization models is not new. For example, DPDFSIM (Johnson and Sleavin 1984), the dynamic programming-based optimizer for the Douglas-fir growth model DFSIM (Curtis et al. 1981) has been widely used by the USDA Forest Service since the early

1980's to develop prescriptions for forest scheduling using linear programming.

The distinguishing differences between FVSPGM and other single stand optimization algorithms are the detailed specification of the state space, i.e., the seven species groups and seven dbh classes, and the use of the ecological objective function to minimize deviations from silvicultural and ecological goals. The objective function guides the dynamic program to achieve solutions as close to the goals as possible.

The exponential weighting of the deviations of the goals penalizes larger deviations more than smaller deviations. This form of goal programming has been criticized by some analysts because it requires the knowledge of both the goals and relative tradeoffs between goals to establish the weights (penalties). For this problem, where the ecological goals are specified, the use of preset goals with exponential deviations seems a reasonable approach.

Beyond the use of FSVPGM as a multi-goal driven dynamic program is a third difference between this approach and other single stand optimization models. Embedded within the dynamic programming algorithm is the best path for stand development given the current state. In our problem, all of the strategies being considered include the possibility of wildfire occurring during the planning horizon. This possibility could be considered a meta-state so that for each strategy, a prescription is developed for the possibility that a wildfire occurs one or more times during the planning horizon. These "best" paths (prescriptions) given a fire occurs are then passed to the policy simulator which simulates the stochastic occurrence of wildfire and management's reaction to it. Although our examples of FVSPGM did not illustrate the occurrence of fire in the "NNNNN" and "HHHHH" goal sets due to manuscript space limitations, the additional yield streams with fire provide management with not only an estimate of the fire effects which would occur, but also what management actions could be taken to maintain progress to the original goal given that the fire does occur.

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ADDENDUM

Appendix Table A1. Summary of Target Levels, Weights and Penalties by Goal and Aspect.

TRIX RANK 2
L ASPECTS **k Ahead = 20 years**

tric	Target	Weight	Penalty	Achieve
Trees	3	8	2	exactly
opy	30%	4	1	exactly
anopy	n/a	n/a	n/a	n/a
gs	2	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	10	7	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	2	5	3	exactly

TRIX RANK 3
L ASPECTS **k Ahead = 20 years**

Metric	Target	Weight	Penalty	Achieve
Trees	6	8	2	exactly
opy	50%	4	1	exactly
anopy	n/a	n/a	n/a	n/a
gs	2	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	10	7	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	3	5	3	exactly

SE RANK 3
RTHEAST **k Ahead = 30 years**

tric	Target	Weight	Penalty	Achieve
Trees	10	8	2	at least
opy	65%	4	1	exactly
anopy	n/a	n/a	n/a	n/a
gs	4	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	15	7	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	4	5	3	at least

SE RANK 3
UTHWEST **k Ahead = 30 years**

Metric	Target	Weight	Penalty	Achieve
Trees	8	8	2	at least
opy	50%	4	1	exactly
anopy	n/a	n/a	n/a	n/a
gs	4	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	15	7	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	4	5	3	at least

SE RANK 4
RTHEAST **k Ahead = 30 years**

tric	Target	Weight	Penalty	Achieve
Trees	16	8	2	at least
opy	65%	4	1	exactly
anopy	20%	1	1	at least
gs	6	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	10	1	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	5	5	3	at least

SE RANK 4
UTHWEST **k Ahead = 30 years**

Metric	Target	Weight	Penalty	Achieve
Trees	12	8	2	at least
opy	50%	4	1	exactly
anopy	20%	1	1	at least
gs	4	1	1	at least
n_Wood	n/a	n/a	n/a	n/a
_Hazard	15	1	2	at most
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	5	5	3	at least

NIMIZE FIRE
L ASPECTS **k Ahead = 10 years**

tric	Target	Weight	Penalty	Achieve
Trees	8	5	2	at least
opy	20%	3	2	at least
anopy	n/a	n/a	n/a	n/a
gs	n/a	n/a	n/a	n/a
n_Wood	n/a	n/a	n/a	n/a
_Hazard	10	9	2	at most
cts	200	1	1	at most
R_Size	5	5	3	at least
OG_Rank	n/a	n/a	n/a	n/a

X NPV
L ASPECTS **k Ahead = 10 years**

Metric	Target	Weight	Penalty	Achieve
Trees	n/a	n/a	n/a	n/a
opy	n/a	n/a	n/a	n/a
anopy	n/a	n/a	n/a	n/a
gs	n/a	n/a	n/a	n/a
n_Wood	n/a	n/a	n/a	n/a
_Hazard	n/a	n/a	n/a	n/a
cts	n/a	n/a	n/a	n/a
R_Size	n/a	n/a	n/a	n/a
OG_Rank	n/a	n/a	n/a	n/a

Appendix Table A2. Summary of Criteria to Determine Rank

OG Rank	ge Tree DBH	n # TPA	nopy Closure	ermediate Canopy	ags/Acre
estside and Eastside Mixed Conifer, Ponderosa Pine					
5	40	10	55%	10%	2.0
4	40	6	40%	0%	2.0
4	40	2	55%	10%	2.0
4	30	12	55%	0%	0.5
3	40	6	20%	0%	0.5
3	40	2	40%	0%	0.5
3	30	6	40%	0%	0.5
2	40	2	20%	0%	0.0
2	30	2	20%	0%	0.0
2	24	20	40%	0%	0.0
1	30	0.5	10%	0%	0.0
b-Alpine					
5	30	10	40%	0%	0.5
4	30	6	20%	0%	0.5
4	24	10	40%	10%	2.0
3	30	2	10%	0%	0.0
3	24	2	20%	0%	0.5
2	30	0.5	10%	0%	0.0
	24	0.5	10%	0%	0.0
ite Fir					
5	40	10	60%	10%	2.0
5	40	10	60%	0%	2.0
4	40	6	40%	0%	2.0
4	30	10	40%	0%	2.0
3	30	6	40%	0%	2.0
3	40	2	40%	0%	0.0
2	30	2	20%	0%	0.0
2	24	20	40%	0%	0.0
Red Fir					
5	40	10	55%	10%	4.0
5	40	10	55%	0%	4.0
4	40	6	40%	0%	2.0
4	30	10	10%	0%	2.0
4	30	6	40%	0%	0.5
3	30	2	20%	0%	0.5
2	30	0.5	10%	0%	0.0
2	24	20	40%	0%	0.0
1	24	10	10%	0%	0.0
1	16	20	40%	0%	0.0

Appendix Table A2. Summary of Criteria to Determine Rank (cont.)

OG Rank	ge Tree DBH	n # TPA	nopy Closure	ermediate Canopy	ags/Acre
Hardwoods					
5	24	15	40%	10%	2.0
4	24	6	40%	10%	0.5
4	18	15	40%	10%	0.5
3	18	6	40%	10%	0.5
2	18	2	20%	0%	0.0
Juniper					
5	30	10	40%	0%	2.0
4	30	4	20%	0%	2.0
3	30	2	10%	0%	2.0
3	30	0.5	40%	0%	0.0
2	24	20	20%	0%	0.0
1	24	5	40%	0%	0.0

Appendix Table A3. Log Prices Used in FVSPGM by Species and Diameter, $/mbf Scribner Decimal C Log Scale, 16-ft Basis.

dib (in)	Doug. Fir	White Fir	Red Fir	Sugar Pine	Pond. Pine	Inc. Cedar
6	269	329	329	363	345	500
7	269	329	329	363	345	477
8	269	329	329	363	345	454
9	269	329	329	363	345	431
10	269	329	329	363	345	408
11	269	329	329	363	345	385
12	269	329	329	363	345	379
13	284	331	331	361	345	373
14	302	333	333	360	344	367
15	317	330	330	360	344	361
16	331	328	328	360	345	358
17	343	318	318	363	348	357
18	356	307	307	366	352	357
19	366	297	297	368	355	357
20	375	287	287	370	357	361
21	381	281	281	373	360	365
22	388	275	275	375	363	369
23	392	273	273	378	366	373
24	396	271	271	382	370	378
25	396	261	261	385	374	383
26	396	252	252	389	378	388
27	393	255	255	393	382	394
28	391	257	257	397	386	399
29	385	252	252	400	390	404
30	378	248	248	404	394	409
31	368	247	247	409	398	414
32	357	246	246	413	402	419
33	343	246	246	417	406	422
34	330	246	246	421	410	422
35	312	246	246	426	415	422
36	293	246	246	432	421	422
37	293	245	245	439	428	422
38	293	245	245	447	435	422
39	293	245	245	456	444	422
40	293	245	245	465	453	422
41	293	245	245	475	463	422
42	293	245	245	485	472	422
43	293	245	245	495	482	422
44	293	245	245	505	492	422
45	293	245	245	515	501	422
46	293	245	245	525	510	422
47	293	245	245	535	520	422
48	293	245	245	545	530	422
49	293	245	245	555	540	422
50	293	245	245	565	550	422

ADDENDUM

Appendix Table A4. Harvesting Costs Used in FVSPGM (with profit and risk, roads, slash, NEPA costs, sale preparation and administration for slopes <40%). MCF = thousand cubic feet.

Ground based logging costs $/MCF

Stand	Stand MCF per acre					
Avg DBH	0.5	1	2	3	4	5
3	$2,829	$2,624	$2,468	$2,346	$2,296	$2,228
4	$1,880	$1,718	$1,606	$1,527	$1,494	$1,452
5	$1,542	$1,395	$1,298	$1,235	$1,208	$1,175
6	$1,406	$1,265	$1,175	$1,117	$1,093	$1,064
7	$1,331	$1,194	$1,107	$1,053	$1,030	$1,003
8	$1,284	$1,149	$1,064	$1,012	$990	$964
9	$1,250	$1,116	$1,033	$983	$961	$936
10	$1,224	$1,092	$1,010	$960	$940	$915
11	$1,204	$1,072	$991	$943	$922	$898
12	$1,187	$1,056	$976	$928	$908	$885
13	$1,172	$1,042	$963	$916	$896	$873
14	$1,160	$1,031	$951	$905	$885	$863
15	$1,149	$1,020	$941	$895	$876	$853
16	$1,139	$1,010	$932	$887	$867	$845
17	$1,135	$1,007	$929	$883	$864	$842
18	$1,133	$1,005	$927	$882	$862	$840
19	$1,130	$1,002	$924	$879	$860	$838
20	$1,128	$1,000	$922	$877	$858	$836
21	$1,127	$999	$921	$877	$857	$836
22	$1,127	$999	$921	$877	$857	$836
23	$1,126	$999	$921	$876	$857	$835
24	$1,127	$999	$921	$876	$857	$836
25	$1,127	$999	$921	$876	$857	$836
26	$1.127	$999	$921	$876	$857	$836
27	$1,127	$999	$921	$876	$857	$836
28	$1,127	$999	$921	$876	$857	$836
29	$1,127	$999	$921	$876	$857	$836
30	$1,127	$999	$921	$876	$857	$836
31	$1,127	$999	$921	$876	$857	$836
32	$1,127	$999	$921	$876	$857	$836
33	$1,127	$999	$921	$876	$857	$836
34	$1,127	$999	$921	$876	$857	$836
35	$1,127	$999	$921	$876	$857	$836
36	$1,127	$999	$921	$876	$857	$836
37	$1,127	$999	$921	$876	$857	$836
38	$1,127	$999	$921	$876	$857	$836
39	$1,127	$999	$921	$876	$857	$836
40	$1,127	$999	$921	$876	$857	$836
41	$1,127	$999	$921	$876	$857	$836
42	$1,127	$999	$921	$876	$857	$836
43	$1,127	$999	$921	$876	$857	$836
44	$1,127	$999	$921	$876	$857	$836
45	$1,127	$999	$921	$876	$857	$836
46	$1,127	$999	$921	$876	$857	$836
47	$1,127	$999	$921	$876	$857	$836
48	$1,127	$999	$921	$876	$857	$836
49	$1,127	$999	$921	$876	$857	$836
50	$1,127	$999	$921	$876	$857	$836

Transportation = $200/MCF trucking (120 mile round trip)

	<40%		
Road Maint & Const ($/MCF)	$75.00	Environmental Analysis (NEPA)	$115/MCF
Slash Disposal ($/acre)	$100.00	Sale Preparation	$125/MCF
		Sale Administration	$75/MCF

Appendix Table A4 (cont). Harvesting Costs Used in FVSPGM (with profit and risk, roads, slash, NEPA costs, sale preparation and administration for slopes >40%). MCF = thousand cubic feet.

Cable logging costs $/MCF

Stand	Stand MCF per acre					
Avg DBH	0.5	1	2	3	4	5
3	----	----	----	----	----	----
4	----	----	----	----	----	----
5	----	----	----	----	----	----
6	$2,180	$1,904	$1,757	$1,669	$1,639	$1,602
7	$2,073	$1,799	$1,655	$1,572	$1,542	$1,507
8	$1,983	$1,711	$1,568	$1,489	$1,460	$1,428
9	$1,905	$1,635	$1,493	$1,418	$1,390	$1,359
10	$1,837	$1,568	$1,428	$1,356	$1,328	$1,299
11	$1,777	$1,509	$1,370	$1,301	$1,274	$1,247
12	$1,723	$1,457	$1,319	$1,253	$1,226	$1,200
13	$1,675	$1,410	$1,274	$1,209	$1,183	$1,158
14	$1,633	$1,369	$1,233	$1,171	$1,145	$1,121
15	$1,596	$1,332	$1,197	$1,137	$1,111	$1,088
16	$1,563	$1,300	$1,166	$1,107	$1,082	$1,060
17	$1,534	$1,272	$1,138	$1,081	$1,056	$1,035
18	$1,510	$1,248	$1,115	$1,059	$1,034	$1,013
19	$1,489	$1,228	$1,096	$1,040	$1,015	$995
20	$1,473	$1,212	$1,080	$1,025	$1,001	$981
21	$1,460	$1,200	$1,067	$1,013	$989	$970
22	$1,451	$1,191	$1,059	$1,005	$981	$961
23	$1,446	$1,185	$1,053	$1,000	$976	$957
24	$1,444	$1,184	$1,051	$998	$974	$955
25	$1,444	$1,184	$1,051	$998	$974	$955
26	$1,444	$1,184	$1,051	$998	$974	$955
27	$1,444	$1,184	$1,051	$998	$974	$955
28	$1,444	$1,184	$1,051	$998	$974	$955
29	$1,444	$1,184	$1,051	$998	$974	$955
30	$1,444	$1,184	$1,051	$998	$974	$955
31	$1,444	$1,184	$1,051	$998	$974	$955
32	$1,444	$1,184	$1,051	$998	$974	$955
33	$1,444	$1,184	$1,051	$998	$974	$955
34	$1,444	$1,184	$1,051	$998	$974	$955
35	$1,444	$1,184	$1,051	$998	$974	$955
36	$1,444	$1,184	$1,051	$998	$974	$955
37	$1,444	$1,184	$1,051	$998	$974	$955
38	$1,444	$1,184	$1,051	$998	$974	$955
39	$1,444	$1,184	$1,051	$998	$974	$955
40	$1,444	$1,184	$1,051	$998	$974	$955
41	$1,444	$1,184	$1,051	$998	$974	$955
42	$1,444	$1,184	$1,051	$998	$974	$955
43	$1,444	$1,184	$1,051	$998	$974	$955
44	$1,444	$1,184	$1,051	$998	$974	$955
45	$1,444	$1,184	$1,051	$998	$974	$955
46	$1,444	$1,184	$1,051	$998	$974	$955
47	$1,444	$1,184	$1,051	$998	$974	$955
48	$1,444	$1,184	$1,051	$998	$974	$955
49	$1,444	$1,184	$1,051	$998	$974	$955
50	$1,444	$1,184	$1,051	$998	$974	$955

Transportation = $200/MCF trucking (120 mile round trip)

	>40%		
Road Maint & Const ($/MCF)	$100.00	Environmental Analysis (NEPA)	$115/MCF
Slash Disposal ($/acre)	$225.00	Sale Preparation	$125/MCF
		Sale Administration	$75/MCF

Appendix Table 5a. Fire Mortality Rates Used in FVSPGM by Species, Diameter and Scorch Height (from Bahro, 1995).

PONDEROSA PINE

AVERAGE PROBABLITIES OF MORTALITY IN PONDEROSA PINE FOR 5 FOOT SCORCH HEIGHT INTERVALS BY DIAMETER

SCORCH HEIGHTS (FEET)

	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
2	0.56	0.65	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
4	0.50	0.50	0.50	0.61	0.65	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
6	0.35	0.35	0.35	0.35	0.36	0.52	0.56	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
8	0.24	0.24	0.24	0.24	0.24	0.24	0.37	0.50	0.52	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
10	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.28	0.45	0.51	0.52	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.21	0.38	0.47	0.50	0.56	0.71	0.71	0.71	0.71	0.71	0.71	0.71
14	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.17	0.33	0.45	0.49	0.55	0.71	0.71	0.71	0.71	0.71	0.71
16	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.15	0.30	0.42	0.48	0.49	0.71	0.71	0.71	0.71	0.71
18	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.14	0.28	0.41	0.47	0.49	0.70	0.70	0.70	0.70
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.14	0.27	0.39	0.45	0.48	0.54	0.70	0.70
22	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.07	0.14	0.27	0.38	0.45	0.47	0.53	0.69
24	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.08	0.15	0.27	0.38	0.44	0.47	0.53
26	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.08	0.16	0.28	0.38	0.43	0.46
28	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.09	0.18	0.29	0.38	0.43
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.06	0.11	0.20	0.30	0.38
32	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.07	0.12	0.22	0.31
34	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.08	0.14	0.24
36	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.09	0.17
38	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.11
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.08
S.	0.13	0.13	0.15	0.15	0.16	0.18	0.19	0.22	0.23	0.26	0.28	0.32	0.34	0.37	0.40	0.44	0.47	0.50	0.54	0.57

SUGAR PINE

AVERAGE PROBABLITIES OF MORTALITY IN SUGAR PINE FOR 5 FOOT SCORCH HEIGHT INTERVALS BY DIAMETER

SCORCH HEIGHTS (FEET)

Tree DBH	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
2	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	0.74	0.74	0.74	0.89	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	0.68	0.68	0.68	0.68	0.70	0.87	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	0.63	0.63	0.63	0.63	0.63	0.63	0.72	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.61	0.77	0.90	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.54	0.67	0.82	0.92	0.97	0.99	0.99	1.00	1.00	1.00	1.00	1.00
14	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.48	0.59	0.74	0.87	0.94	0.97	0.99	0.99	0.99	0.99	0.99
16	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.43	0.53	0.67	0.81	0.91	0.95	0.98	0.99	0.99	0.99
18	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.39	0.47	0.61	0.75	0.86	0.93	0.96	0.98	0.99
20	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.35	0.43	0.56	0.70	0.82	0.90	0.94	0.97
22	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.32	0.39	0.51	0.65	0.78	0.87	0.92
24	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.29	0.36	0.47	0.61	0.74	0.84
26	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.23	0.27	0.34	0.44	0.57	0.70
28	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.25	0.32	0.42	0.54
30	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.23	0.30	0.40
32	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.18	0.22	0.29
34	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.17	0.21
36	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.16
38	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.13
40	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
AVGS.	0.36	0.37	0.37	0.38	0.39	0.40	0.40	0.42	0.43	0.45	0.46	0.48	0.50	0.53	0.56	0.58	0.61	0.64	0.68	0.71

Appendix Table 5b. Fire Mortality Rates Used in FVSPGM by Species, Diameter and Scorch Height (from Bahro, 1995) (cont.).

DOUGLAS FIR

AVERAGE PROBABLITIES OF MORTALITY IN DOUGLAS FIR FOR 5 FOOT SCORCH HEIGHT INTERVALS BY DIAMETER

Tree DBH	SCORCH HEIGHTS (FEET 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
2	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	0.62	0.66	0.90	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	0.48	0.48	0.53	0.77	0.93	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
8	0.35	0.35	0.35	0.44	0.67	0.86	0.95	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
10	0.25	0.25	0.25	0.27	0.38	0.59	0.79	0.91	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
12	0.19	0.19	0.19	0.19	0.22	0.34	0.53	0.73	0.87	0.93	0.96	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
14	0.14	0.14	0.14	0.14	0.15	0.20	0.32	0.50	0.69	0.83	0.91	0.95	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97
16	0.11	0.11	0.11	0.11	0.11	0.13	0.19	0.31	0.48	0.65	0.79	0.88	0.93	0.95	0.96	0.96	0.96	0.96	0.96	0.96
18	0.08	0.08	0.08	0.08	0.08	0.09	0.12	0.19	0.30	0.46	0.63	0.77	0.86	0.91	0.93	0.95	0.95	0.95	0.95	0.95
20	0.07	0.07	0.07	0.07	0.07	0.07	0.09	0.12	0.20	0.31	0.46	0.62	0.75	0.83	0.89	0.92	0.93	0.94	0.94	0.94
22	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.09	0.13	0.21	0.32	0.46	0.61	0.73	0.82	0.87	0.90	0.92	0.92	0.92
24	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.09	0.14	0.22	0.33	0.47	0.61	0.72	0.80	0.85	0.89	0.90	0.91
26	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.07	0.10	0.15	0.24	0.35	0.48	0.61	0.72	0.79	0.84	0.87	0.89
28	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.07	0.11	0.17	0.26	0.37	0.50	0.62	0.71	0.78	0.83	0.86
30	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.06	0.08	0.13	0.19	0.28	0.40	0.52	0.63	0.71	0.78	0.82
32	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.06	0.10	0.15	0.22	0.31	0.42	0.54	0.64	0.72	0.77
34	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.07	0.11	0.17	0.24	0.34	0.45	0.56	0.65	0.72
36	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.06	0.09	0.13	0.19	0.28	0.37	0.48	0.58	0.66
38	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.05	0.07	0.10	0.15	0.22	0.31	0.41	0.51	0.60
40	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.06	0.08	0.12	0.18	0.25	0.34	0.44	0.53
AVGS.	0.17	0.18	0.20	0.22	0.25	0.28	0.32	0.36	0.40	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.78	0.82	0.85	0.87

WHITE FIR

AVERAGE PROBABLITIES OF MORTALITY IN WHITE FIR FOR 5 FOOT SCORCH HEIGHT INTERVALS BY DIAMETER

Tree DBH	SCORCH HEIGHTS (FEET 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
2	0.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	0.72	0.72	0.87	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	0.62	0.62	0.63	0.74	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	0.53	0.53	0.53	0.53	0.63	0.79	0.90	0.96	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.43	0.43	0.43	0.43	0.45	0.55	0.69	0.83	0.91	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
12	0.35	0.35	0.35	0.35	0.35	0.38	0.48	0.61	0.75	0.86	0.92	0.96	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99
14	0.29	0.29	0.29	0.29	0.29	0.29	0.33	0.42	0.54	0.67	0.79	0.88	0.93	0.96	0.97	0.98	0.99	0.99	0.99	0.99
16	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.29	0.37	0.48	0.61	0.73	0.83	0.89	0.93	0.96	0.97	0.98	0.98	0.98
18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.21	0.25	0.33	0.43	0.55	0.67	0.78	0.85	0.90	0.94	0.96	0.97	0.97
20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.18	0.23	0.30	0.39	0.50	0.62	0.73	0.81	0.87	0.91	0.94	0.95
22	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.16	0.21	0.27	0.36	0.46	0.57	0.68	0.77	0.84	0.88	0.92
24	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.15	0.19	0.25	0.33	0.43	0.53	0.64	0.73	0.80	0.86
26	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.14	0.18	0.24	0.31	0.40	0.50	0.60	0.69	0.77
28	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.11	0.13	0.17	0.22	0.29	0.38	0.47	0.57	0.66
30	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.10	0.13	0.16	0.22	0.28	0.36	0.45	0.54
32	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.08	0.10	0.12	0.16	0.21	0.27	0.35	0.43
34	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.08	0.10	0.12	0.16	0.20	0.26	0.33
36	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.08	0.09	0.12	0.16	0.20	0.26
38	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.06	0.08	0.10	0.12	0.16	0.20
40	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.08	0.10	0.12	0.16
AVGS.	0.26	0.26	0.27	0.28	0.29	0.31	0.33	0.36	0.39	0.41	0.44	0.48	0.51	0.54	0.58	0.61	0.65	0.68	0.72	0.75

Appendix Table A6.1. Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: NO ACTION ***Present Net Value*** ***$409***

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	0	276	0	244	0	244	0	35.7	0.0	35.7	0.0	12.7	0.0	12.7
2011	426	0	426	150	283	0	283	38	44.0	0.0	44.0	8.2	11.0	0.0	11.0
2021	384	0	384	-42	322	0	322	40	52.9	0.0	52.9	9.0	12.4	0.0	12.4
2031	313	0	313	-71	340	0	340	18	60.3	0.0	60.3	7.4	14.1	0.0	14.1
2041	257	0	257	-55	358	0	358	17	68.0	0.0	68.0	7.7	16.0	0.0	16.0
2051	548	0	548	291	395	0	395	38	75.6	0.0	75.6	7.6	11.5	0.0	11.5
2061	451	0	451	-97	420	0	420	25	83.1	0.0	83.1	7.5	13.1	0.0	13.1
2071	387	0	387	-64	441	0	441	21	90.9	0.0	90.9	7.8	14.5	0.0	14.5
2081	566	0	566	179	473	0	473	32	98.6	0.0	98.6	7.7	12.4	0.0	12.4
2091	487	0	487	-80	495	0	495	23	105.3	0.0	105.3	6.7	13.7	0.0	13.7
2101	425	0	0	-61	518	0	0	23	113.0	0.0	0.0	7.7	14.9	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	87%	23%	23%	99.0	99.0	9.6	9.6	2	2	3.5	3.2	$0
2011	4	4	M6M	M6M	101%	101%	27%	27%	99.0	99.0	12.2	12.2	2.4	2.4	3.0	4.3	$0
2021	4	4	M6D	M6D	111%	111%	31%	31%	99.0	99.0	16.5	16.5	3.9	3.9	2.8	5.2	$0
2031	4	4	M6D	M6D	108%	108%	28%	28%	99.0	99.0	19.3	19.3	5.2	5.2	3.3	6.1	$0
2041	4	4	M6D	M6D	104%	104%	26%	26%	99.0	99.0	20.6	20.6	6.3	6.3	4.1	7.1	$0
2051	4	4	M6D	M6D	129%	129%	33%	33%	99.0	99.0	23.2	23.2	9.2	9.2	4.8	8.2	$0
2061	5	5	M6D	M6D	129%	129%	35%	35%	99.0	99.0	25.2	25.2	10.9	10.9	5.4	9.3	$0
2071	5	5	M6D	M6D	128%	128%	33%	33%	99.0	99.0	26.4	26.4	11.4	11.4	5.6	10.4	$0
2081	5	5	M6D	M6D	143%	143%	33%	33%	99.0	99.0	28.7	28.7	12.9	12.9	5.7	11.2	$0
2091	5	5	M6D	M6D	143%	143%	37%	37%	99.0	99.0	29.8	29.8	14.9	14.9	6.1	12.0	$0
2101	5	0	M6D		143%	0%	38%	0%	99.0	0.0	30.4	0.0	15.3	0.0	6.0	12.7	$27,169

Appendix Table A6.2 Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: ALSE - RANK 4 ***Present Net Value*** **$1,878**

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	161	115	0	244	28	217	0	35.7	0.7	35	0	12.7	5.6	18.6
2011	384	288	96	269	264	24	240	47	43.4	1.2	42.3	8.4	11.2	3.9	21.4
2021	163	10	149	67	284	42	242	44	53.4	9.1	44.4	11.1	17.9	27.6	17.3
2031	138	11	127	-11	270	22	248	28	55.1	3.8	51.4	10.8	18.9	19.4	18.9
2041	120	13	108	-7	280	27	252	31	64.4	5.2	59.2	13	20.6	19.8	20.7
2051	104	0	104	-4	280	0	280	27	68.6	0	68.6	9.4	22.2	0	22.2
2061	94	0	94	-9	297	0	297	17	75.3	0	75.3	6.7	24	0	24
2071	84	0	84	-10	310	0	310	13	81	0	81	5.8	26	0	26
2081	432	0	432	348	333	0	333	23	85.6	0	85.6	4.5	11.9	0	11.9
2091	364	0	364	-68	350	0	350	18	88.2	0	88.2	2.6	13.3	0	13.3
2101	314	0	0	-50	367	0	0	17	93.3	0	0	5.2	14.6	0	0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	64%	23%	22%	99.0	10.0	9.6	9.6	2.0	2.0	3.5	3.2	($215)
2011	4	4	M4M	M4M	80%	59%	23%	20%	95.0	7.0	11.9	11.9	2.9	2.9	2.6	4.2	$225
2021	4	4	M6D	M4M	71%	62%	25%	21%	16.0	14.0	14.7	13.2	3.4	3.4	2.1	4.8	$2,654
2031	4	4	M4M	M4M	64%	58%	17%	13%	15.0	13.0	16.3	14.5	5.0	5.0	2.1	5.2	$1,306
2041	4	4	M4M	M5M	62%	56%	17%	15%	14.0	13.0	17.9	17.9	6.6	6.6	2.2	5.6	$1,772
2051	4	4	M4M	M4M	61%	61%	16%	16%	14.0	16.0	21.7	21.7	8.9	8.9	2.0	6.0	$0
2061	5	5	M5M	M5M	63%	63%	17%	17%	14.0	16.0	22.0	22.0	11.8	11.8	2.3	6.4	$0
2071	5	5	M5M	M5M	63%	63%	16%	16%	14.0	16.0	21.2	21.2	14.1	14.1	2.9	7.1	$0
2081	5	5	M5M	M5M	84%	84%	12%	12%	95.0	99.0	20.4	20.4	15.2	15.2	3.6	8.1	$0
2091	5	5	M4M	M4M	92%	92%	11%	11%	99.0	99.0	20.8	20.8	14.6	14.6	4.2	9.2	$0
2101	4	0	M4M		93%	0%	9%	0%	99.0	0.0	20.8	0.0	15.8	0.0	4.1	10.2	$27,865

Appendix Table A6.3 Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: MATRIX - RANK 3 ***Present Net Value*** **$3,980**

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	63	200	0	244	46	198	0	35.6	4.6	31.0	0.0	12.7	11.6	13.5
2011	367	35	318	168	240	38	202	43	39.3	6.0	33.3	8.3	10.9	13.9	10.8
2021	287	84	192	-31	243	86	156	40	44.8	14.4	30.4	11.5	12.4	13.7	12.2
2031	189	0	189	-3	192	0	192	35	37.9	0.0	37.9	7.5	13.6	0.0	13.6
2041	182	82	100	-7	226	37	189	34	47.8	5.0	42.8	9.9	15.1	9.0	18.7
2051	472	0	472	373	254	0	254	65	52.4	0.0	52.4	9.6	9.9	0.0	9.9
2061	408	0	408	-64	291	0	291	37	57.3	0.0	57.3	4.9	11.4	0.0	11.4
2071	336	0	336	-72	305	0	305	14	63.0	0.0	63.0	5.6	12.9	0.0	12.9
2081	453	0	453	117	331	0	331	26	70.1	0.0	70.1	7.1	11.6	0.0	11.6
2091	379	0	379	-74	349	0	349	19	76.3	0.0	76.3	6.2	13.0	0.0	13.0
2101	325	0	0	-54	368	0	0	18	83.6	0.0	0	7.3	14.4	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	67%	25%	20%	99.0	10.0	8.8	8.3	2.0	2.0	3.5	3.2	$1,286
2011	4	4	M4M	M4M	81%	69%	24%	22%	95.0	10.0	11.1	10.0	3.1	3.1	2.7	4.2	$1,949
2021	4	3	M4M	M4P	76%	49%	17%	7%	17.0	10.0	13.3	8.7	3.7	3.7	2.5	5.0	$3,985
2031	3	3	M4P	M4P	57%	57%	9%	9%	14.0	16.0	10.8	10.8	5.2	5.2	2.0	5.4	$0
2041	4	4	M4P	M4P	63%	49%	17%	17%	15.0	10.0	13.8	11.5	7.2	6.2	1.8	5.6	$1,606
2051	4	4	P4M	P4M	80%	80%	22%	22%	19.0	95.0	15.7	15.7	6.8	6.8	1.5	5.6	$0
2061	4	4	P6M	P6M	88%	88%	19%	19%	20.0	23.0	15.7	15.7	6.7	6.7	1.8	5.8	$0
2071	4	4	M6M	M6M	87%	87%	16%	16%	20.0	23.0	16.3	16.3	7.2	7.2	2.3	6.2	$0
2081	4	4	M6M	M6M	97%	97%	19%	19%	95.0	99.0	19.8	19.8	7.5	7.5	2.5	6.7	$0
2091	4	4	M6M	M6M	99%	99%	19%	19%	99.0	99.0	21.2	21.2	8.7	8.7	2.7	7.2	$0
2101	4	0	M6M		99%	0%	23%	0%	99.0	0.0	20.8	0.0	9.1	0.0	2.8	7.7	$24,298

Appendix Table A6.4   Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: MATRIX - RANK 2 ***Present Net Value*** **$5,660**

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	49	216	0	244	38	206	0	35.7	5.1	30.6	0.0	12.7	12.0	13.2
2011	399	23	300	183	247	60	185	42	38.9	11.9	27.0	8.3	10.7	21.7	10.6
2021	272	63	200	-27	231	74	157	46	38.2	11.8	26.5	11.2	12.5	14.6	12
2031	197	127	70	-3	201	80	121	45	37.1	11.0	26.2	10.7	13.7	10.8	17.8
2041	69	0	69	-1	146	0	146	25	32.1	0.0	32.1	6.0	19.7	0.0	19.7
2051	448	0	448	379	203	0	203	57	40.7	0.0	40.7	8.6	9.1	0.0	9.1
2061	577	0	577	129	259	0	259	56	49.2	0.0	49.2	8.5	9.1	0.0	9.1
2071	455	0	455	-123	305	0	305	46	57.9	0.0	57.9	8.7	11.1	0.0	11.1
2081	328	0	328	-127	331	0	331	26	66.9	0.0	66.9	9.0	13.6	0.0	13.6
2091	252	0	252	-76	355	0	355	24	76.8	0.0	76.8	9.9	16.1	0.0	16.1
2101	199	0	0	-53	377	0	0	22	86.9	0.0	0	10.1	18.6	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	70%	23%	23%	99.0	95.0	9.6	7.2	2.0	2.0	3.5	3.2	$1,397
2011	4	4	M6M	M4P	89%	65%	30%	22%	95.0	9.0	10.5	6.1	2.6	2.2	2.9	4.3	$4,274
2021	4	3	M4M	M4P	81%	58%	22%	9%	19.0	14.0	8.0	7.6	2.4	2.0	2.4	5.0	$3,551
2031	4	2	M4P	M4P	66%	35%	17%	11%	15.0	9.0	10.3	8.9	2.4	2.0	2.0	5.4	$3,373
2041	2	2	M4P	M4P	37%	37%	8%	8%	9.0	11.0	10.4	10.4	2.6	2.6	1.8	5.6	$0
2051	4	4	M4P	M4P	73%	73%	14%	14%	95.0	95.0	13.6	13.6	5.5	5.5	1.6	5.6	$0
2061	4	4	M6M	M6M	89%	89%	13%	13%	95.0	95.0	15.1	15.1	6.4	6.4	1.7	5.8	$0
2071	4	4	M6M	M6M	95%	95%	11%	11%	23.0	99.0	14.5	14.5	6.8	6.8	2.1	6.1	$0
2081	4	4	M6D	M6D	90%	90%	33%	33%	99.0	99.0	15.1	15.1	8.1	8.1	2.7	6.8	$0
2091	4	4	M6D	M6D	86%	86%	35%	35%	99.0	99.0	15.3	15.3	7.8	7.8	3.4	7.7	$0
2101	5	0	M6D		83%	0%	30%	0%	99.0	0.0	15.6	0.0	10	0.0	3.6	8.6	$25,440

Appendix Table A6.5 Output Exmples for Stand Simulation under Different Goals (M3G Strata).

GOAL: MAXIMIZE PRESENT NET VALUE ***Present Net Value*** **$7,401**

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	11	253	0	244	56	188	0	35.7	13.8	21.9	0.0	12.7	30.9	11.7
2011	439	3	429	186	243	16	227	55	30.7	3.6	27.2	8.8	10.1	33.6	9.8
2021	371	3	366	-58	281	22	258	54	42.4	5.8	36.6	15.2	11.8	34.8	11.4
2031	322	8	313	-44	309	26	284	51	49.4	4.8	44.5	12.8	13.3	24.2	12.9
2041	276	52	224	-37	333	114	219	49	57.9	25.1	32.8	13.4	14.9	20.0	13.4
2051	574	0	574	350	302	0	302	83	49.0	0.0	49.0	16.2	9.8	0.0	9.8
2061	424	0	424	-150	330	0	330	27	57.6	0.0	57.6	8.6	11.9	0.0	11.9
2071	332	0	332	-92	355	0	355	26	68.0	0.0	68.0	10.4	14.0	0.0	14.0
2081	440	0	440	108	389	0	389	34	78.3	0.0	78.3	10.3	12.7	0.0	12.7
2091	349	0	349	-91	417	0	417	28	88.8	0.0	88.8	10.5	14.8	0.0	14.8
2101	291	0	0	-58	441	0	0	24	99.0	0.0	0.0	10.2	16.7	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	2	M4M	M4M	87%	74%	23%	22%	99.0	95.0	9.6	4.2	2.0	0.7	3.5	3.2	$4,833
2011	3	2	M4M	M4M	84%	80%	18%	18%	95.0	13.0	7.2	4.5	0.8	0.8	2.6	4.2	$1,355
2021	3	3	M4M	M4M	92%	89%	30%	29%	21.0	21.0	9.8	7.0	1.4	1.1	2.3	4.8	$1,512
2031	3	3	M6D	M4M	97%	91%	29%	28%	22.0	21.0	11.9	8.5	2.0	2	2.2	5.3	$2,096
2041	4	2	M6D	M4M	96%	68%	30%	31%	22.0	17.0	15.1	3.1	2.0	0.6	2.2	5.7	$9,805
2051	3	3	M6M	M6M	110%	110%	29%	29%	26.0	95.0	6.3	6.3	0.8	0.8	2.2	6	$0
2061	4	4	M6D	M6D	108%	108%	25%	25%	25.0	27.0	13.6	13.6	1.3	1.3	2.6	6.5	$0
2071	4	4	M6D	M6D	105%	105%	20%	20%	24.0	27.0	22.6	22.6	1.4	1.4	3.1	7.2	$0
2081	4	4	M6D	M6D	111%	111%	30%	30%	95.0	99.0	23.7	23.7	2.6	2.6	4.2	8.6	$0
2091	4	4	M6D	M6D	111%	111%	38%	38%	99.0	99.0	24.5	24.5	4	4	5	10.2	$0
2101	4	0	M6D		111%	0%	37%	0%	99.0	0.0	23.8	0.0	6.2	0.0	5.2	11.8	$30,890

Appendix Table A6.6 Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: MINIMIZE FIRE HAZARD ***Present Net Value*** **$4,148**

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	160	116	0	244	40	205	0	35.7	4.5	31.2	0.0	12.7	6.8	18.0
2011	377	312	65	261	245	64	181	40	39.2	7.0	32.1	8.0	10.9	6.1	22.7
2021	135	32	93	70	216	70	146	35	43.9	14.0	29.9	11.8	17.1	20.2	17.0
2031	92	15	77	-1	178	20	158	33	39.7	4.9	34.8	9.8	18.9	15.9	19.4
2041	76	0	76	-1	185	0	185	27	42.7	0.0	42.7	7.9	21.1	0.0	21.1
2051	75	0	75	-1	212	0	212	27	50.1	0.0	50.1	7.5	22.8	0.0	22.8
2061	74	0	74	-1	239	0	239	27	58.5	0.0	58.5	8.4	24.4	0.0	24.4
2071	72	0	72	-2	267	0	267	27	67.4	0.0	67.4	9.0	26.1	0.0	26.1
2081	408	0	408	336	304	0	304	37	76.1	0.0	76.1	8.6	11.7	0.0	11.7
2091	322	0	322	-86	312	0	312	9	77.5	0.0	77.5	1.4	13.3	0.0	13.3
2101	273	0	0	-50	327	0	0	14	81.8	0.0	0.0	4.2	14.8	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	61%	23%	22%	99.0	9.0	9.6	6.9	2.0	1.9	3.5	3.2	$1,101
2011	4	3	M4M	M4M	79%	45%	26%	17%	95.0	4.0	9.3	8.0	2.8	2.8	2.6	4.2	$1,706
2021	4	2	M5M	M5P	55%	38%	15%	13%	13.0	9.0	11.7	9.3	3.6	3.6	2.0	4.7	$4,815
2031	3	3	M5P	M5P	46%	41%	13%	13%	11.0	10.0	12.8	9.5	4.9	4.9	1.6	5.0	$1,605
2041	4	4	M4P	M4P	45%	45%	12%	12%	11.0	13.0	10.0	10.0	6.1	6.1	1.4	5.1	$0
2051	4	4	M5M	M5M	49%	49%	14%	14%	12.0	14.0	14.6	14.6	6.7	6.7	1.3	5.1	$0
2061	4	4	M5M	M5M	54%	54%	7%	7%	12.0	15.0	15.0	15.0	9	9	1.2	5.1	$0
2071	4	4	M5M	M5M	57%	57%	9%	9%	13.0	15.0	15.4	15.4	9	9	1.1	5.0	$0
2081	4	4	M5M	M5M	80%	80%	13%	13%	99.0	99.0	19.7	19.7	9.3	9.3	1.6	5.2	$0
2091	4	4	M5M	M5M	84%	84%	11%	11%	99.0	99.0	23.7	23.7	9.4	9.4	3.8	6.6	$0
2101	4	4	M5M	M5M	87%	0%	6%	6%	99.0	99.0	24.0	24.0	9.8	9.8	4.0	8.2	$25,906

Appendix Table A6.7. Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: PRESCRIBED BURN ***Present Net Value*** ***$199***

PER	Begining TPA	Burned TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Burned SBA	Residual SBA	Growth SBA	Begining MBF	Burned MBF	Residual MBF	Growth MBF	Begining QMD	Burned QMD	Residual QMD
2001	276	106	170	0	244	26	218	0	35.7	2.1	33.7	0.0	12.7	6.7	15.3
2011	400	203	196	230	257	26	232	39	41.6	2.2	39.4	7.9	10.9	4.8	14.7
2021	181	58	122	-16	262	20	242	31	47.3	2.4	45.0	8.0	16.3	8.0	19.0
2031	113	19	93	-10	267	16	250	24	52.5	2.5	50.0	7.5	20.8	12.4	22.2
2041	88	9	79	-5	277	15	262	27	58.3	2.7	55.6	8.4	24.0	17.0	24.7
2051	442	0	442	363	310	0	310	48	63.8	0.0	63.8	8.2	11.3	0.0	11.3
2061	360	0	360	-82	330	0	330	20	68.7	0.0	68.7	4.9	13.0	0.0	13.0
2071	304	0	304	-56	346	0	346	16	74.8	0.0	74.8	6.1	14.5	0.0	14.5
2081	553	0	553	250	375	0	375	29	80.3	0.0	80.3	5.6	11.1	0.0	11.1
2091	460	0	460	-93	397	0	397	22	85.6	0.0	85.6	5.2	12.6	0.0	12.6
2101	394	0	0	-66	417	0	0	20	92.0	0.0	0.0	6.4	13.9	0.0	0.0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	3	M4M	M4M	87%	71%	23%	21%	99	99	9.6	9.2	2.0	1.9	3.5	3.2	($75)
2011	4	4	M6M	M6M	91%	71%	25%	23%	99	95	11.8	11.3	2.3	2.2	4.2	4.9	($75)
2021	4	4	M6M	M4M	77%	67%	27%	25%	95	11	15.2	14.6	3.6	3.5	4.9	6.8	($75)
2031	4	4	M6M	M4M	70%	64%	23%	21%	15	14	17.5	16.8	4.5	4.4	5.8	8.7	($75)
2041	4	4	M5M	M5M	67%	63%	21%	19%	15	14	17.9	17.2	5.9	5.7	6.6	10.8	($75)
2051	4	4	M5M	M5M	98%	98%	19%	19%	21	95	20.3	20.3	8.4	8.4	7.6	12.9	$0
2061	4	4	M4M	M4M	101%	101%	17%	17%	22	24	20.6	20.6	9.0	9.0	7.8	14.8	$0
2071	4	4	M6M	M6M	100%	100%	15%	15%	22	24	24.2	24.2	9.3	9.3	7.5	16.1	$0
2081	5	5	M6M	M6M	119%	119%	17%	17%	95	99	24.0	24.0	12.3	12.3	7.6	17.1	$0
2091	5	5	M6M	M6M	120%	120%	23%	23%	99	99	25.9	25.9	13.7	13.7	7.7	17.9	$0
2101	5	0	M6D		120%	0%	33%	0%	99	0.0	26.0	0.0	13.9	0.0	7.7	18.5	$23,273

Appendix Table A6.8 Output Examples for Stand Simulation under Different Goals (M3G Strata).

GOAL: FUELBREAK ***Present Net Value*** ***$3,767***

PER	Begining TPA	Harvest TPA	Residual TPA	Ingrowth/ Mortality	Begining SBA	Harvest SBA	Residual SBA	Growth SBA	Begining MBF	Harvest MBF	Residual MBF	Growth MBF	Begining QMD	Harvest QMD	Residual QMD
2001	276	240	32	0	244	153	91	0	35.7	17.8	17.9	0	12.7	10.8	22.8
2011	301	193	108	269	113	13	100	23	20.9	0.9	20	3	8.3	3.5	13.1
2021	107	59	48	-1	122	8	114	22	27.3	0.4	26.9	7.3	14.5	5	20.9
2031	47	7	40	-1	132	7	124	18	31.6	1.4	30.2	4.7	22.6	13.3	23.9
2041	39	8	31	-1	142	5	137	17	35.2	0.6	34.6	5	25.8	10.7	28.4
2051	405	0	405	374	179	0	179	43	39.8	0	39.8	5.2	9	0	9
2061	370	0	370	-35	213	0	213	33	45.1	0	45.1	5.4	10.3	0	10.3
2071	326	0	326	-44	251	0	251	38	52.5	0	52.5	7.4	11.9	0	11.9
2081	371	0	371	45	292	0	292	41	60.3	0	60.3	7.8	12	0	12
2091	317	0	317	-54	330	0	330	38	69.5	0	69.5	9.1	13.8	0	13.8
2101	240	0	0	-77	351	0	0	21	78.4	0	0	8.9	16.4	0	0

PER	Begining Rank	Residual Rank	Begining WHR	Residual WHR	Begining Canopy	Residual Canopy	Begining Intr. Can	Residual Intr. Can	Begining Fire Haz	Residual Fire Haz	Begining 30"+ tpa	Residual 30"+ tpa	Begining 40"+ tpa	Residual 40"+ tpa	Begining Snags	Begining LWD	Harvest Revenues
2001	3	2	M4M	M5S	87%	28%	23%	7%	99.0	0.0	9.6	7.6	2.0	2.0	3.5	3.2	$4,597
2011	3	2	M5S	M5S	48%	30%	4%	4%	12.0	3.0	8.7	8.3	2.6	2.5	3.1	7.8	($75)
2021	2	2	M4S	M4S	37%	29%	5%	4%	9.0	7.0	9.2	9.2	3.2	3.2	3.0	8.8	($89)
2031	2	2	M4P	M4S	31%	29%	5%	5%	8.0	7.0	10.3	9.8	5.3	5.1	0.2	11.5	($75)
2041	3	3	M5P	M5P	32%	30%	7%	7%	8.0	7.0	11.2	11.1	6.2	6.1	0.9	11.5	$164
2051	4	4	M5P	M5P	63%	63%	6%	6%	15.0	17.0	11.8	11.8	6.8	6.8	0.2	11.8	$0
2061	4	4	M4P	M4P	73%	73%	6%	6%	17.0	20.0	12.2	12.2	7.5	7.5	0.5	11.3	$0
2071	4	4	M6M	M6M	78%	78%	17%	17%	19.0	95.0	13.4	13.4	8.2	8.2	0.8	10.9	$0
2081	4	4	M6M	M6M	88%	88%	20%	20%	95.0	99.0	13.3	13.3	8.9	8.9	1.0	10.5	$0
2091	4	4	M6M	M6M	92%	92%	41%	41%	99.0	99.0	14.2	14.2	8.7	8.7	1.3	10.2	$0
2101	4	0	M6D		88%	0%	27%	0%	99.0	0.0	14.3	0.0	9.5	0.0	2.0	10.2	$22,266