AN EVALUATION OF TWO TIMBER SUPPLY MODELS FOR STATE ASSESSMENTS

by

Thomas William Sutfin

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INTRODUCTION

Problem Statement

As a result of growing concerns for future timber supplies, forestry decision makers intensified state resource planning and forestry program development in the 1970's. In the last 15 years several states have conducted timber supply analyses which examined long-run trends in stumpage supply. Opportunities for influencing the course of those trends through management of the forest resource were identified. These efforts have come to rely heavily on computer-based models to analyze the large data bases associated with this work. Many new timber supply models have been developed, with a trend toward increased capability and complexity.

Although these models can be powerful forest planning tools, their complexity may present several serious problems. They can be expensive to install and operate. Their use often requires highly skilled and specialized personnel whose expertise includes both computer systems and forestry. Furthermore, the interpretation of the output of such models relies on a thorough understanding of the models' information requirements, their operational structure, and their underlying assumptions.

The timber supply models that are currently available differ substantially from each other in data requirements, costs, and outputs. Each was designed to meet the needs of a particular organization, and thus reflects the managerial objectives and concerns of that organization. When another organization considers adopting an existing model, it must investigate the model's capability for producing the information it desires and determine how complicated and costly the model is to operate. A thorough knowledge of the proposed model will allow the adopting organization to determine if the model is suitable for its needs or can be modified to be so.

Two models that have been suggested for state timber supply assessments are SHRUB (Barber, 1985) and RMS80 (Resource Maturity and General Management Simulation System, Allison, 1978). SHRUB is a computer program developed by Dr. Richard Barber for solutions to operational harvest scheduling problems. It is noted for its ease and low cost of operation. RMS80 is a planning model developed in New Zealand to improve the management of forests owned by N.Z. Forest Products Limited. This model incorporates new measurement concepts which reflect characteristics of forest maturity, dynamics of timber flows and forest value. Both models can be utilized to identify the effect on forest maturity and long term flow potential of alternative conditions and management options.

Study Objective

The objectives of this paper are to: (1) describe the structure and output of SHRUB and RMS80, (2) evaluate their respective ability to satisfy the needs of a state level timber assessment, and (3) demonstrate their application to forest planning using the state of California as the focus of a case study. The results of the SHRUB runs made for this analysis were compared to the results of previous research on the same regions conducted with the RMS80 model (McLean, 1981). Both sets of runs utilized the same data base and management assumptions.

In the process of evaluating SHRUB and RMS80, this paper addresses assessment objectives and approaches, as well as types of computer-based models. To put SHRUB and RMS80 and the type of analysis that follows into perspective, the next chapter presents some background information on timber supply analysis objectives and models.

BACKGROUND ON TIMBER SUPPLY ANALYSIS OBJECTIVES AND MODELS

A Discussion of Study Objectives and Approaches

Timber supply analyses have been conducted for a variety of purposes. The objectives of a particular timber supply study dictate the specific analytical methods used. As a starting point, the "physical supply" of timber in a particular area could be considered (Alig et al., 1984). A physical supply analysis considers only the interactions of timber growth, mortality, and removals in regional timber inventories over time. It does not address the demand for timber, the effects of changes in timber prices, nor economic conditions. Thus it is not a prediction of how much timber will be harvested by forest landowners in the future. Instead, the objectives are usually to: (1) determine if current harvest rates can be maintained, (2) determine the long term production potential, (3) develop a range of possible harvest levels based on alternative management and policy assumptions, and (4) identify potential timber supply problems and opportunities. While both RMS80 and SHRUB perform present net worth analyses, they do not dynamically estimate prices; they iterate with physical attributes and hence are characterized here as "physical supply models."

Alternatively, the focus of a timber assessment might be economic timber supply, a broader concept based on the economic feasibility of growing and harvesting timber. Economists define economic timber supply as a schedule of amounts of stumpage that producers are willing to offer at various prices. It reflects the idea that as stumpage prices rise, more timber becomes economically accessible and timber growers are willing to sell more. Thus the objective of an economic timber supply analysis is to predict how much timber will be produced given projected economic conditions.

Economic supply analyses are more complicated than physical supply analyses; models are generally more sophisticated and data requirements are substantially greater. Often the needed production/price relationships and timber demand information are very difficult to obtain. This partly explains why most of the past timber assessments have examined physical supply. Another reason is that resource analysts have frequently chosen first to determine if physical production will be limiting, and later to assess economic supply and its impacts on employment and local economies.

Given a specific assessment objective, one can go about achieving it using a variety of approaches. The problem can be formulated from different perspectives and models can be utilized in many ways. For example, if the objective is to perform a physical timber supply analysis, the approach can be formulated using either a positive or normative perspective (Beuter, 1978). A positive approach would describe things as they are, and as they are likely to be (e.g., the projection of timber availability based on a continuation of past trends and interactions). A normative approach is designed to show what ought to be, given specified conditions and assumptions (e.g., a harvest schedule that maximizes physical output). Many analysts believe that the positive approach is more useful in program and policy development because it better identifies the scope and nature of future supply problems. However, both of these approaches provide useful information and analyses often employ a combination of the two.

The analysis approach also includes how models are put to use. One model can be used as the sole analytical tool for a study or several models can be linked together such that the output of one is used as the input of another. Thus the approach need not be limited by the model. Constraints can arise in practice, however, if funds are limiting or if analysts become "locked in" to a particular model.

Additionally, a series of models can be used to refine the analysis of a single resource. For example, both physical and economic timber supply models may be used. Or the output of several single-resource models can be fed into a multi-resource model to examine the interactions among resources. Using several models also can serve to break up the analysis into more manageable phases instead of taking on an enormously complicated assessment problem *en masse*.

Computer-based Timber Supply Models

If ample time and financial resources are available, a new model can be developed to perform the desired analysis. Alternatively, an existing model can be used to do the job.

Of course either way, the model(s) used must be consistent with analysis objectives and approach. Put simply, they must be able to supply appropriate answers to questions of interest. Modelling of harvest flows has generally been addressed through two broad analytical approaches: simulation and optimization (Alig et al., 1984). Simulation models calculate the outcome or ending resource condition of a preselected management program and harvest schedule. The analyst specifies the entire treatment/harvest plan and the model provides the results of this prescription. A sensitivity analysis is conducted by studying the effects of changes in the treatments and/or data assumptions on the resulting resource condition.

Optimization models select the best harvest and management program for a given objective, under stated constraints. The objective may be, for instance, to maximize harvest. With this approach, sensitivity analysis involves altering the problem specification (e.g., the constraints) to observe alterations in optimal output. Optimization techniques are generally associated with the normative approach and simulation techniques are often used in positive analyses.

Of course, not all timber supply models fit neatly into one of these approaches. Some models incorporate both or use another method known as binary search. This technique iteratively searches for an optimal solution by applying a set of decision rules (Hann and Brodie, 1980). Both SHRUB and RMS80 are simulation models that employ binary search techniques.

MODEL DESCRIPTIONS

Introduction

Models are simplified representations of reality. They are used to improve our understanding of real systems and to influence their behavior. Models are attractive because they can efficiently predict the results of different alternatives and can be used to answer questions. Model building is basically a process of deciding which components of a complex real-world system are to be chosen for analysis and at what level of detail. This process establishes what will be determined inside the model (endogenously) and what will be determined outside the model (exogenously). The central issue is to find a satisfactory trade-off between precision and simplicity consistent with analysis objectives (Duerr et al., 1979).

Computer-based physical timber supply models, including RMS80 and SHRUB, are basically sets of mathematical equations designed to represent the essential interactions of timber growth and removals on forest inventory over time. Data on the current condition of the timber resource are combined with a series of assumptions about growth, mortality, removals, utilization efficiencies and economic factors. These data and assumptions are entered into the computerized calculation procedure which projects the impacts of these assumptions on resource conditions over time. The outputs provided by these models are projections of the forest structure (i.e., age class distribution) at particular years in the future, and summaries of harvest, costs, and revenues (Marty, 1973).

Individual models vary in the nature and detail of resource description, projection methods, flexibility allowed in the assumed course of future events, and underlying objectives of the projection (i.e., simulation or optimization). These differences result in significant variations in operational structure, data requirements, and outputs. These items are discussed in the following description of SHRUB and RMS80, based on the model documentation currently available.

SHRUB

Development Perspective

SHRUB was developed for inexpensive solutions to operational harvest scheduling problems. To create SHRUB, Barber expanded the capabilities of HARVEST, a harvest scheduling model developed earlier for use in forest management instruction (Barber, 1983). Among the features added were the ability to simulate thinnings, change timberland area over time, and include quality premiums in stumpage prices.

Model Structure

The program is designed to represent an even-aged forest consisting of a single species on a homogeneous site.

The initial forest is described by the area and yield (volume per unit area) in user-specified timber age classes. The model simulates growth by moving the acreage in one age class to the next older class at the end of each period and increasing the timber volume on that area accordingly. For a final harvest, the acreage in each age class from which timber is removed is reclassified to the age 0 class and the timber yield is recorded. The program moves from period to period for the duration of the simulation interval, reassigning areas of the forest to different age classes to account for growth and harvest, and performing an extensive bookkeeping process. The end result is a description of the forest structure consisting of acres by age class and the volumes harvested for each period. By entering information on stumpage price, logging and management costs, and a discount rate, summaries of present net revenues by period for each harvest schedule are also calculated.

Operating-Procedures

SHRUB is run interactively on most types of computer terminals having printing capability. When the program is called up, it offers the user a brief description of its capabilities and then requests the necessary data and management alternatives. First, the user specifies the age class interval and period length, with typical values for both being 5, 10, or 20 years. The program has a limit of 30 age classes and 30 periods of time, but it can be modified to any dimension. Next, the user enters the number of acres for each timber age class and two yield tables, one for the existing forest and a second for all regenerated stands. The program continues to query the user for data as outlined below. This information may be used to calculate any number of harvest schedules and may be saved by the program for future use. Once all the desired information is entered, the user specifies the type of harvest schedule to be calculated and the program prints the results.

The user can either specify the harvest level (a volume-control harvest schedule), or have the model determine the harvest schedule based on area-control, maximum even-flow or present net worth. If the user-specified harvest level is too great for the forest to sustain for the assigned simulation period, the program prints a warning that the forest has been exhausted. In this case, the user may rerun the model with a revised harvest estimate.

Data Requirements

The following is a list of data requirements of SHRUB in the order in which they are requested by the program. To run a particular harvest schedule all of this information need not be entered. For example, only the economic optimization option requires information on timber demand schedules. Furthermore, if information on the costs and revenues of timber harvesting is not desired, then financial data need not be entered. For a detailed description of these items see the SHRUB user's manual (Barber, 1985).

Timber classes:

Age class interval

Minimum harvest age

Maximum age timber can reach

Acreage shifts:

Number of periods of acreage change

Acreage change by period

Timber yields:

Units of volume (MBF or MCF)

Type of yield tables to be used:

(1) existing

(2) nonstandard acres in the initial forest

(3) regeneration

Acreage and yield data by age class for each type of yield table used. (yield = residual + thinning volume)

Financial data:

Annual interest rate

Stumpage demand function (period, intercept, and slope)

Cost per unit harvest (thinning and final harvest)

Costs per acre - thinning, final harvest, regeneration, annual management cost, cultural treatment costs by age class

SHRUB Outputs

SHRUB will calculate harvest schedules based on area, volume, and economic optimization. When using the area-based harvest schedule, the forest is regulated on a user-specified rotation age with equal acreage harvested each period. Area control stabilizes the area harvested during the conversion period, but the volume harvested will fluctuate, depending on the initial age-class distribution.

For volume-based harvest schedules, either a user-specified volume is harvested each period or a maximum harvest volume in each period is determined on the basis of a variety of user-specified conditions. These conditions determine three basic types of even-flow schedules: standard even-flow, sequential constant look-ahead, and sequential changing look-ahead.

In all three, the maximum volume is determined by a binary search technique which starts with a user-specified trial cut. If this harvest level can be sustained, it is increased in ten percent increments until a result that is too high is obtained. This establishes an upper bound for the solution. Likewise, an upper bound would be obtained if the initial trial cut could not be sustained. The lower bound is the last lower trial used, or ten percent below the first trial if it exhausts the timber resource. The program repeatedly uses the midpoint between the last upper and lower bounds for the next iteration, with the result establishing a new high or low boundary. This successive halving is repeated until a set tolerance (0.01 percent) between these bounds is met, yielding the solution.

The standard even-flow option determines the highest harvest level that can be sustained for the entire analysis period. The harvest level is the same for all periods, and is equivalent to the maximum volume-control cut. The area harvested, however, will vary between periods depending on the initial forest structure. This is the most constraining even-flow schedule.

In the sequential constant look-ahead even-flow option, a "look-ahead" period that is shorter than the overall analysis period is set. For example, a look-ahead of 50 years and an analysis period of 200 years could be used. The maximum even-flow harvest which can be sustained over this look-ahead determines the cut in the first decade. The cut for the second decade is again the maximum even-flow harvest that can be sustained over the look-ahead, but this time the look-ahead includes the second through sixth decades. This process is repeated until harvest levels have been determined for each period of the analysis. This solution differs from standard even-flow in that different harvest levels usually occur in each period of the analysis and may increase or decrease depending on the initial age-class distribution.

The third type of even-flow schedule available is the sequential changing look-ahead option. Here the look-ahead is changed each period by a fixed user-specified amount. For example, the initial look-ahead can be equal to the number of years of the analysis, say 200 years, and decrease 10 years each period. This would simulate a nondeclining even-flow harvest schedule, where the cut remains constant, or increases over time, but is never allowed to decrease.

The fourth type of harvest schedule available on SHRUB is Economic Harvest Optimization (ECHO). This harvest schedule is calculated using binary search techniques that determine a harvest sequence that maximizes present net worth. It assumes an ownership with holdings large enough that the volume harvested will affect the market price received for stumpage (i.e., the ownership faces a downward-sloping demand function). This situation might occur for large corporate or federal holdings in some areas in California.

SHRUB also permits the combination of portions of area control, volume control, and even-flow harvest schedules while maintaining the continuity of the inventory. Each individual piece is a short harvest schedule of the type requested, beginning with the ending inventory of the preceding piece. This is called a spliced harvest schedule.

RMS80 (RESOURCE MATURITY AND GENERAL MANAGEMENT SIMULATION SYSTEM)

Development Perspective

The measurement techniques contained in RMS80 were developed by Brian J. Allison (1978) to improve the planning and management of forest owned by N.Z. Forest Products Ltd.

(a private firm in New Zealand). Allison felt that the traditional unit measures of forests such as growing stock volume and volume increment gave inadequate insight into how the quantity and average age of forests changed with management inputs and land acquisitions. Thus he developed new measurement units which he refers to as "forest mass measures," because they represent the general quantity of forests. These new measures are calculated for a forest by RMS80 from information on standing inventory, growth rates, and assumptions regarding future management. Hence, RMS80 is not a harvest scheduling model, but a measurement model. It provides a standard of comparison, with which to analyze the effects of various conditions and investments on long term timber flows and forest value.

Model Structure

Like SHRUB, RMS80 simulates even-aged forests consisting of one species growing on a homogeneous site. Stands are described by the area and yield in timber age classes. Although one-year age classes are usually used, age classes can be set to any number of years by command. Individual stands may be kept separate to simulate different initial structures, stocking levels, or ownerships, but when harvested, all stands or "crop types" are regenerated using the same user-specified yield function. RMS80 simulates the growth and harvest of the forest over time in a manner generally similar to SHRUB (i.e., using a yield-table growth projection system with harvest priority by oldest age). It calculates the forest mass measures using binary search techniques. Costs and revenues of management activities can be used by RMS80 to determine additional forest value measures and detailed accounting reports.

Operating Procedures

RMS80 is run using a series of job instructions specified by the user (i.e., commands and read statements). The order of the commands determines the simulation sequence performed by the model. Each command causes the RMS80 program to carry out a routine. As RMS80 will follow exactly what it is instructed to do, commands must be correctly specified and be in proper order. Users can insert comments to describe the purpose and method of a job and document the data used. The job instructions and comments are read from cards or computer files.

Some commands require additional data for the routine to function; for example, when using the commands that create a crop type, age class, area, and yield information must be also entered. Other commands, such as the instruction which causes the simulation run to end, require no additional information. In general, a simulation begins by entering the commands and associated data that describe the forest, followed by a specification of how the forest is to be managed over time (e.g., regeneration, thinning, harvest priority). The simulation sequence is finished by instructing the program as to which measures to calculate and what is to be printed. Details regarding the commands and specific operating procedures are described in the RMS80 Job Instructions (N.Z. Forest Products Ltd., 1984).

Data Requirements

An individual RMS80 simulation run may be quite simple, involving a single stand and few management activities. This type of run will require relatively little information. Alternatively, runs with many crop types, management functions, land area shifts, and an array of measures to be calculated require much more information. The following list covers the data that may be needed when using RMS80.

Forest Description:

- Area and yield data by age class for each existing crop type
- Composite yield function by which all crop types will be regenerated
- Age class interval
- Attrition factor (mortality rate)

Management Options:

- Regeneration lag
- Logging plan (stand harvest priority, if other than oldest age first)
- Thinning (crop type, age, yield, costs)

Regeneration plan (crop type, area, years)

Planting plan (restocking bare land - crop type, area, years)

Sorting (yield quality specification)

Crop type merging

Financial data:

Discount factors

Inflation rate

Age dependent costs

Stumpage price by crop type and age class

Land value

Operation costs (management activities)

Annual costs

Transport distances and costs

Logging costs

Tax rates

RMS80 Outputs

Introduction. In the early 1970's, Allison became increasingly aware of what he considered the inadequacies of existing forest measures. For example, his company had recently developed large areas of young plantations and it was not readily apparent using traditional measures, such as area and average age, how much additional forest had been obtained from these efforts (McLean, 1981).

Today, as in those times, Allison feels that no individual traditional measure or group of measures adequately meets his planning needs (Allison, 1978). For instance, Allison says that while area, as a forest measure, is widely used and easily determined, it contains no information on maturity and two forests of the same area may have very different quantities of forest. Furthermore, he maintains that considering area and average age together is an improvement and is also fairly easily determined, but it does not take into account differences in forests that result from dissimilar species and site. Allison rejects growing stock, unless you are interested in liquidating a forest, because only a small portion of it is ever cut in a short time period. He suggests that in planned and managed forests it is the flow, not the standing volume, that is of interest. Allison points out, however, that volume increment is an inadequate indicator of long term potential flow unless the forest is fully regulated.

Consequently, Allison attempted to integrate the information contained in the measures of growing stock, increment, and average age, into a general forest measure. Specifically, he sought an "objective measure" which would reflect the effects of a change in forest structure on both sustainable yield and forest maturity. Allison was interested in forest maturity (particularly in the age at which trees are harvested), in addition to sustainable yield, because it significantly influences many costs and returns in the forest utilization system. Costs of logging, transportation, and log handling are dependent, to a considerable extent, upon volume per tree. For intensively managed even-aged forests, this tends to be closely related to tree age. Also, lumber grade and volume recovery increase with log size. All this led Allison to the consideration of the fully regulated or "normal" forest as a measure.

The Normal Forest. In a normal forest the quantity and quality of yield is the same each year. In the simplest case, the number of age classes in the normal forest is equal to the rotation age, and there is an equal area of forest in each age class. Therefore, one area matures each year. The sustainable harvest or "normal cut" is equal to forest-wide growth which is also equivalent to the volume in the oldest age class. When this mature timber is harvested each year, the land is assumed to be immediately restocked, thus completing the harvest cycle and ensuring a constant sustainable yield in perpetuity. The normal forest is in a steady state; its age class distribution does not change over time.

These attributes of a regulated forest have made it a traditional management goal. Once obtained, the normal forest is relatively straightforward to manage. The same treatments are performed each year and there is a steady, sustained annual harvest. Planning is simplified and no more growing stock is carried than is necessary (Davis, 1966).

There are problems, however, with this goal. In practice a fully regulated forest is difficult, if not impossible, to obtain. Changes in growth rates, and losses resulting from insects or disease attack, and fire make it hard to achieve and maintain a regulated condition. The conversion process from the abnormal condition to the fully regulated state imposes an economic cost on the landowner, and the goal of a constant harvest rate is in conflict with the need to take advantage of favorable market conditions. Furthermore, wood product markets change over time, and the type and quantity of products implied by a certain rotation age may be inappropriate for future markets.

As a result of these problems, the rigid concept of full regulation is rarely employed as a management objective. Sustainable harvest levels are still desirable and target rotation ages or log sizes and quality are used. Yet, concern to maintain flexibility and avoid significant short term sacrifice plays a more dominant role than the traditional normal forest concept would permit (McLean, 1981).

The Equivalent Normal Forest. Instead of using the fully regulated forest as a management goal, Allison uses it as a scale of maturity of the existing forest. The approach to forest measurement that he proposed involves the identification of a normal forest which is "equivalent" to the actual forest being measured. The actual forest is equivalent to the normal forest in terms of total area, sustainable harvest level, regeneration yield function and average age (following simulation). To understand how this is done, it is necessary to review the pattern of stand and forest growth over time and how a forest behaves under a constant cut.

Figure 1 shows how mean annual increment (MAI) of an acre of forestland rapidly increases in the initial years of growth, culminates at that age where annual increment equals MAI, and then gradually declines. This is true for all timber species on all sites when grown in even-aged stands, although the slope of the curve, maximum MAI, and age at which it occurs may be highly variable.

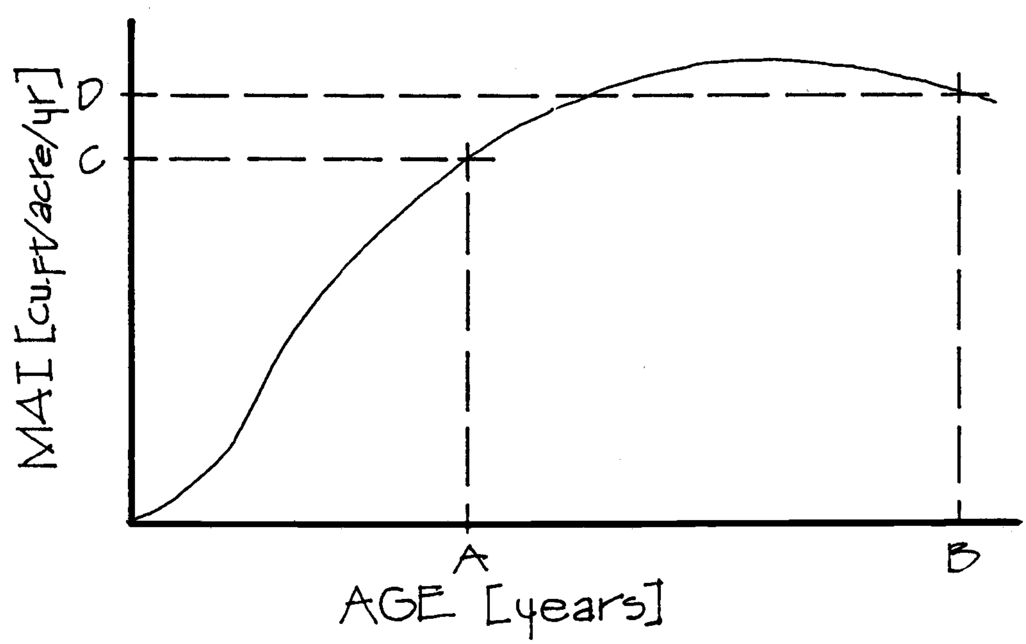

Figure 1: Mean Annual Increment (MAI) of Forest Growth

We know that a normal forest will remain fully regulated if the normal cut is harvested from the oldest age class, and all stands within the forest grow according to the same yield function. But what happens when a constant cut other than the normal cut is applied? Suppose that a normal forest is growing according to the yield curve shown in Figure 1 and has a rotation of A (above). If more than the normal cut was harvested, the cut would be more than growth (MAI) and there would be a decrease in growing stock. The average age would decrease (because more than just the oldest age class would be cut), and the rotation would fall along the MAI curve, causing the cut to exceed growth by even greater amounts. Finally, the forest would be completely cut.

If a cut was applied to this normal forest that was less than the normal cut, the growing stock would increase over time. The average age would also increase because only part of the oldest age class would be harvested. Hence, growth would increase as the rotation moved to the right along the MAI curve. Growing stock would continue to accumulate and the rotation would eventually, over a long period of time, increase beyond the age of culmination of mean annual increment. MAI would then gradually decline to the level of the cut and the forest would reach a new steady state.

Now let us consider a normal forest with the same regeneration function but with a rotation age of B (Figure 1). In this case, if less than the normal cut was harvested, the cut would be less than growth and the growing stock would build up. As this occurred the age class distribution would increase to the right along the MAI curve, and as it did so, growth would fall. Over time, the MAI would fall until the new constant cut level was reached and the forest would again be fully regulated at a new rotation.

The same sort of argument works in the opposite direction. With a constant harvest level greater than the normal cut, the oldest stands would be cut out. This would occur, for instance, if a harvest level equal to the culmination of mean annual increment were used. If this constant cut is continued, the average age will fall and in the process the growth will increase. Eventually, the growth will equal the cut and at that time the forest would have reachieved full regulation.

Finally, consider a constant cut greater than the culmination of MAI. Of course, since the culmination of MAI is the maximum rate at which a forest can grow, a cut above this will ultimately exhaust any forest.

Thus, there is a very different response in a normal forest depending on how its rotation age compares to the age of culmination of MAI. Allison describes this by a measure he calls the Relative Rotation (RR). It is the ratio of the rotation of a normal forest to the age of maximum MAI of the regeneration yield curve. A fully regulated forest with a rotation less than the age of maximum MAI has a relative rotation of less then 1.0 (i.e., $RR < 1$). Correspondingly, a normal forest with a rotation age greater than the age of maximum MAI has a relative rotation of greater than 1.0

(i.e., RR > 1). The third possible condition is when the rotation age and the age of culmination of MAI are equivalent. In this case, the relative rotation is equal to 1.0 (i.e., RR = 1). The response of normal forests to constant cuts other than the normal cut (NC) are summarized in the following tabulation:

	RR < 1	RR > 1
Cut < NC	Ave. age increases. Growth increases, then decreases. New rotation: RR > 1	Ave. age increases Growth decreases New rotation: greater
NC < Cut < Max MAI	Exhausts	Ave. age decreases Growth increases. New rotation: approaches rotation of maximum MAI

Source: Dr. Ken Fowler, personal communication

Allison applied these conclusions to unregulated forests using the volume-control method of forest regulation. Assuming that the oldest trees are harvested first and that all acres are regenerated using the same growth function, an unregulated forest under a constant harvest will eventually either become fully regulated or it will be completely cut. The result depends on how the level of harvest compares to the forest's rate of growth and degree of maturity. Therefore, an unregulated forest can be regulated over a broad range of harvest levels determined by the regeneration function.

Allison has used this idea to develop his new forest measure. RMS80 uses any forest age class distribution and simulates a series of feasible constant cuts. These produce a range of regulated forests, all resulting from the initial forest. Each of these forests is grown with the same yield function and has the same total area, but has a different rotation age and average age. Using binary search techniques, the program selects the normal forest which is equivalent to the actual forest in terms of sustainable harvest volume and steady state average age. This regulated forest is called the Equivalent Normal Forest (ENF) and the measurement unit that describes it is rotation age. For example, a representative ENF for a forest might be 67.34 years.

The yield associated with this ENF is called the normal cut. For forests with a relative rotation less than 1.0, the normal cut is equivalent to the maximum volume-control harvest level. For a forest with a relative rotation greater than 1.0, the normal cut is equal to the constant cut that results in no change in the long term stocking level.

It is important to note that although Allison uses the normal forest and a constant annual cut as a condition of measurement, he does not suggest that we should manage to attain this fully regulated condition. The ENF is a measure of the maturity of existing forests and is used for comparison purposes. For example, two forests with quite different age class distributions, but the same ENF, have equivalent long term potential timber flows. The following excerpt from Allison's Some Aspects of Forest Planning (1978) further discusses this distinction between the normal forest as a scale of measurement versus an object of management.

> "The ENF model resolves the interaction between growing stock and growth, under standard conditions, to furnish a measurement. As with any other measurement system, there are no implications that the standards adopted represent managerial intentions. We do not make objects with dimensions of 1 metre simply because we adopt the metre as a standard of measurement. A system of measurement analogous to the ENF is that of gauging the flow of a stream. Water first enters a pond in which most of the turbulence is dampened out, similarly simulation in the ENF measurement smooths out the abnormalities in the forest. The water is known to accelerate under the constant force of gravity. This corresponds to the regeneration curve, a standard curve representing the force of growth in the forest. The water then flows over a weir of known cross section, from the depth of water over the weir we can deduce the flow in the stream. Rotation is analogous to the cross section of the weir and the amount of the constant cut to the depth of the water. As a standard of condition of measurement, ponding or normality has no connotation of management objective. The procedure for gauging a stream flow is the same whether the water is to be utilized in a brewery or lost in a desert. The flow is not determined with the object of making it even but of comparing it to some use or effect the water may have in an ends-means scheme. The flow is a measure of one element of a system which then has to be combined with measures of other elements such as the water requirements of a brewery or the downstream capacity to absorb the flow without flood damage. The ENF is similarly a measure of one element in the forest planning system."

The Normal Exchange Value and the Relative Value Index. RMS80 calculates two additional new forest measures based on the ENF. The first is a measure of total forest value called the Normal Exchange Value (NEV). It is essentially equivalent to the present net worth (PNW) of the actual forest. Both represent the discounted present value of the perpetual series of revenues and costs arising in the actual forest under a periodic harvest equal to the normal cut of the equivalent normal forest (McLean, 1981). The actual calculation procedures are different, however, with the NEV calculated using the net revenues from a fully regulated forest. These are then adjusted for abnormal costs and revenues which occur during the conversion to normality.

The second forest value measure is called the Relative Value Index (RVI). It is the sum of the present value of these differences in costs and revenues between the actual forest during the conversion period and the equivalent normal forest. That is, the RVI equals the present value of the actual net revenues minus the normal net revenues. Thus, a positive RVI represents the amount by which the actual forest is of less value than its ENF. Conversely, a negative RVI is the amount the actual forest is of more value that its ENF. Allison calls the RVI a measure of abnormality of an actual forest in comparison to its fully regulated equivalent normal forest.

Other outputs. In addition to the new forest measures ENF, NEV, and RVI, RMS80 calculates the yield, area, growing stock, increment, and structure of each crop type by period. Once each crop type is fully regulated, these parameters will remain constant over time unless changes are made in the assumed management intensity or forestland area. RMS80 calculates several additional financial values including the marginal cost and replacement cost of wood. It also provides an estimate of discounted cash flows.

MODEL EVALUATION FOR STATE TIMBER ASSESSMENTS

A Discussion of Evaluation Criteria

Introduction

Since our goal is to compare models and clearly delineate their limitations, it is necessary to develop evaluative criteria. These must relate to the specific analyses which are to be made. The focus of this evaluation is on the ability of SHRUB and RMS80 to provide the necessary information for a state physical timber supply assessment. The criteria listed below will be used as the basis of this evaluation. They address not only the model's capabilities, but its ease and cost of use. These criteria are discussed in the remainder of this section.

1. Model Capabilities and Flexibility
2. Ease of Installation and Operation, Data Requirements, and Associated Costs
3. Accessibility of Technical Support
4. Model Limitations and Assumptions
5. Applicability to State Physical Timber Supply Assessments

Model Capabilities and Flexibility

For maximum usefulness, the model should be capable of simulating different types of harvest schedules and projecting the resulting inventory and increment by timber type and ownership group. This would include the ability to portray various forest structures and management schemes. For example, the model should allow for different stocking levels and yields, and even-age and uneven-age management. It should have the capacity to handle different levels of aggregation, such as counties, timbersheds, and states. Program options should allow considerable flexibility as to the assumed course of future events. This allows the model to be used to evaluate the effects of changes in management intensity and government policy on projected timber availability and forest conditions.

Ease of Installation and Operation, Data Requirements, and Associated Costs

While it is essential to evaluate a model's capability to produce desired outputs, it is also important to consider what it takes to achieve these results. For example, the installation of a model may be complicated by a program that was written in a nonstandard language or for a specific type or size of computer. A computer programmer may be needed to adapt the model to your computer system.

Ease of operation of a model is often related to the range of options available in the program. All purpose models tend to be complex, and the greater the complexity, the more training and documentation are required for successful implementation. Also related to ease of use is the ability to change or add to the program structure to accommodate analysis needs. The model should be documented to the extent that it can be readily modified by a skilled computer programmer employed outside the group responsible for development of the program.

The model should be compatible with the type of data available. For state level assessments, where several timbersheds and ownerships are analyzed separately, the program must have the ability to accommodate large data sets. Furthermore, it is worthwhile to know whether the model requires information that is not available. If it does, will this information be difficult or expensive to collect?

All of the above factors will influence the cost of using computer-based models. In general, the more sophisticated the model, the more expensive it will be to operate. This is because user training time increases, the cost of each run is greater, and a programmer analyst may be needed to install and/or maintain the program. The level of expenditure is also dependent on the size of the data base required. Large, detailed data sets take substantial time to prepare and input for processing. Additionally, the computer costs of individual runs can be great. High operating costs could significantly influence one's capacity to explore alternative assumptions regarding data and management policies. Some models may be so large and complex that extensive sensitivity analysis is prohibitively expensive. Thus, the model should process data efficiently in order to reduce costs.

Accessibility of Technical Support

The model should have user manuals of sufficient detail and clarity to allow implementation by new users. Documentation should include concise but easy-to-understand descriptions of installation and operating procedures, data requirements, and the proper interpretation of model outputs. Any assumptions that are built into the model should be noted and a well documented program listing should be available. If training and documentation resources are not adequate, it is likely that either the program will be misused or not fully utilized. It is also desirable to have access to support from model developers and users to avoid serious implementation problems.

Model Limitations and Assumptions

The following model evaluation will include a discussion of program limitations as they relate to a state timber supply assessment. Significant assumptions built into the program structure also will be described.

Applicability to State Physical Timber Supply Assessments

State physical timber supply assessments have addressed a range of questions that can be summarized by the following: (1) What is the current forest condition?, (2) What is the future likely to be with present trends?, (3) Where would we like to be in the future?, and (4) What is the best way to get there? A model that can address all of these questions would be the most appropriate for this type of analysis.

An evaluation of the current forest condition has traditionally relied on information on timberland area, ownership, timber types, stocking levels, increment and harvest. These data are gathered from extensive inventories and form the basic input to models for further analysis.

To determine whether or not the existing condition of the timber resource is (or is likely to be) a limiting factor, a positive approach to projecting timber availability is used. This approach assumes that current interactions among the variables which influence supply will continue in the future. The scope and nature of potential physical supply is examined by varying assumptions regarding management intensities, harvest levels, land-use changes, and utilization efficiencies. These projections are indicators of what may happen. The amount of timber actually harvested depends not only on the physical production, but on the prices established in local stumpage markets and the extent to which timber owners enter these markets.

Estimates of future timber availability may not compare favorably to desired levels of production. In this case, analyses can be conducted which evaluate the effectiveness of different rates of government taxation, levels of regulation, and subsidy programs.

An Evaluation of SHRUB

Model Capabilities and Flexibility

SHRUB has a fairly complete range of harvest scheduling capabilities. As described in the previous chapter, SHRUB can simulate four basic types of harvest schedules: area control, volume control, even-flow, and Economic Harvest Optimization (ECHO). Area control, volume control, and even-flow harvest schedules can be spliced together. It can also evaluate the costs and revenues of these schedules over time and the effect of changes in timberland area. Two yield tables are used: one for the existing forest, and a second for all regenerated stands. This capability allows simulation of a natural forest's conversion to a managed forest, or a one-time change in management intensity. Additionally, the program permits the simulation of thinnings, and the specification of nonstandard age classes in the initial forest which are growing at a different rate than the rest of the forest.

Ease of Installation and Operation, Data Requirements, and Associated Costs

One of the primary attractions of the SHRUB model from a user perspective is its ease of operation. The user's manual clearly describes each program option and the interactive program guides you through model operation from data input to harvest schedule output. Someone familiar with basic harvest scheduling methods should be able to study the user's manual and in a matter of a few hours generate usable outputs. Once the user is familiar with SHRUB's operating procedures, entering the data and specifying the problem may take 10 to 30 minutes, depending on the run's complexity. Once entered, the data may be used to calculate any number of harvest schedules. The tables produced by the program are clearly labeled and straightforward to read.

The source program is written in FORTRAN version five (ANSI standard), and should be easily adapted to most computer systems. It is currently being used on Control Data Corporation and IBM mainframe computers, and has no known machine dependencies (Barber, 1985). It is also available in a format for use on IBM compatible microcomputers.

The source program has a modular construction and is adequately documented. If one or more harvest schedule options are not needed, appropriate subroutines could be eliminated without affecting the operation of the remaining portions of the program.

Data requirements of SHRUB are neither unusual nor particularly complex. As described above, input requirements consist of inventory data that describe a forest of any size by acres and volumes of standing timber by age class. A regeneration yield table (including thinning volumes) is specified and costs and revenues of management inputs by age can be used. Also required are instructions to the model regarding length of the age class interval and possible shifts of acreage in or out of timber management.

Of course, the data requirements of a statewide timber assessment are significantly greater. The state would be divided into several timbersheds, each composed of three or more ownership groups. Furthermore, each timbershed/ownership group could be broken down by land quality (site class) and tree species. Analyzing the resulting large data base with SHRUB may take hundreds of runs because each timbershed/ownership group (and subunit) would have to be run separately. This will be further discussed in the section on model limitations.

SHRUB is inexpensive to acquire and operate. It can be purchased for $500 from the Forest Resources Institute, Courtview Towers, Suite 24, 201 N. Pine Street, Florence, Alabama 35630. While operating and program storage costs will vary with particular rate schedules, they will generally be quite low. The simulation program, which contains over 1000 lines, calculates solutions efficiently; usually less than 10 computer processing seconds are required. Thus, even if hundreds of runs were performed for an analysis, the total cost would still be low. Total storage requirements are approximately 12,000 octal words.

Accessibility of Technical Support

The SHRUB user's manual is concise and clearly written. Each step of the program is shown in the manual as it is displayed to the user and examples of the tables generated by each harvest scheduling option are included. The manual is also an introduction to harvest scheduling and thus contains descriptions of specific types of harvest schedules including the assumptions and implications of these techniques.

Richard Barber is available to assist new users with technical problems, and a network of users is developing. SHRUB is currently being used at Humboldt State University, (Arcata, CA), Oregon State University, (Corvallis, OR), and the University of Florida, (Gainesville, FL). Hence, the user's manual in combination with support from the model developer and users should be adequate to achieve implementation of SHRUB.

Model Limitations and Assumptions

SHRUB simulates the growth of single-species, even-aged forests. Yields from mixed-species and/or uneven-aged forests must be approximated, and some reliability is sacrificed. Harvest priority is limited to oldest age first.

The number of treatments that can be specified in SHRUB is limited. These options are thinnings, planting nonstocked acreage, and shifts in timberland area over time. Other changes in the level of management intensity are simulated in aggregate form by modifying the values of the regeneration yield function.

Of greater significance is the model's lack of a hierarchical aggregation system which permits the evaluation of several levels of inventory detail in one computer run. SHRUB can only consider one "forest" at a time. The many forest subdivisions of a detailed state assessment would have to be analyzed separately with the results of each run totaled outside the model to get state summaries. Although this would be feasible, the process would be cumbersome. The analysis could be simplified by dividing the state into only a few timbersheds with input data consisting of broad averages. This reduces the number of SHRUB runs, but yields considerably less information and prohibits the disaggregation of results to specific areas.

The model determines harvest priority without considering location. All acres within an age class that are entered into SHRUB are considered equally accessible and interchangeable. This may be inappropriate if a large geographic area is being analyzed at one time. For instance, the acres in one age class may actually originate from different ends of a state. The model would behave as if there is no cost to the industry or the economy in general of shifting the harvest from northern California in one decade to the southern Sierra region in the next decade. Therefore, the larger the forest unit analyzed, the less realistic the results.

Applicability to State Physical Timber Supply Assessments

SHRUB's primary advantages are that it is easy and inexpensive to use. Additionally, it provides a range of quick, readily interpreted harvest schedules of moderate complexity. However, because it was designed to be simple to operate, it cannot accommodate large data sets consisting of several subunits - like those common to state level assessments.

Yet this does not mean that SHRUB could not have a useful role in a state physical timber supply analysis. SHRUB could be used effectively as a screening device of input data and assumptions, making trial runs on it prior to using a larger and more complex model. These runs could test the sensitivity of harvest potentials to various management assumptions and could determine trial harvest levels for larger models. SHRUB can also validate the results of other models and evaluate policy options by entering summarized data. This model's range of harvest scheduling options is sufficient to evaluate, in generalized form, the likely consequences of the continuation of present and alternative harvest levels. Therefore, while one would probably rely on a larger, more sophisticated model capable of analyzing a very complex data base for one's final projections, SHRUB can be an important complementary analytical tool used to expedite the analysis and to produce cost savings.

An Evaluation of RMS80

Model Capabilities and Flexibility

RMS80 approaches forest planning from a new perspective, providing an alternative framework for evaluating potential forest production and value. The Equivalent Normal Forest (ENF) and normal cut measure the current forest condition and reflect the dynamic nature of forests.

RMS80 evaluates a forest with the following measures: ENF, normal cut, relative rotation, and Normal Exchange Value (NEV). As described in the previous chapter, the ENF and normal cut are indicators of forest maturity and timber flow potential, respectively. The relative rotation of the forest indicates the effect of harvest levels, when they differ from the normal cut, on the average forest age and level of growing stock. The NEV is the current value of future net revenues. The program also determines the total growing stock and increment over time. Various forest subdivisions can be monitored separately by entering them as different crop types (up to 30). Each crop type can be assigned a unique yield table to describe existing stands, but all crop types are regenerated using a common regeneration yield table.

Following an initial resource description, RMS80 can perform sensitivity analyses on the data, as well as for management and yield assumptions. Those data which are determined to have the greatest impact on the results could be given higher priorities in future inventories. RMS80 can also evaluate the cost effectiveness of different management alternatives. This is accomplished by comparing the cost of an investment to the change it produces in the NEV.

The program permits the specification of a wide range of management inputs and variables. These include thinning, regenerating nonstocked land, regeneration lag, mortality rate, and stand harvest priority - if other than oldest age first. Additionally, several management costs can be specified for accounting purposes. Examples include the costs of planting, logging, trucking, inflation, and purchasing timberland.

Ease of Installation and Operation, Data Requirements, and Associated Costs

RMS80, with about 20,000 lines of FORTRAN code, is designed to run on a mainframe computer. It has been installed on several computer systems and does not appear to have any significant machine dependencies (Allison, personal communication).

RMS80 is a moderately complex system to use, and it may take a day or more to generate original, useable outputs. A more thorough understanding of the program's options may take several days. There are over 140 commands available to describe a forest and perform simulation and analysis. Commands chosen for a job are summarized in a simulation control table which is printed at the beginning of each output. All tables produced by the program are well labelled, and users can include comments in the output that describe each step of the analysis.

The system has exacting requirements for correct job formulation. If all the read statements, data, and commands are not properly sequenced and specified, the program will not execute, or it will produce unintended results. For each RMS80 run, however, a complete validation check is done to minimize the chance that inadvertent errors will invalidate the run. Nonetheless, the user's manual recommends starting with very simple runs, and then building to full forest simulations in a step by step process. Careful checking of the output after each job is essential.

In addition to learning the technical aspects of operating the model, new users must familiarize themselves with the meaning and uses of the program outputs. The traditional measures of forest quantity and value generated by RMS80 will be more readily understood and accepted than the new measures such as the ENF and normal cut.

RMS80 was designed from the beginning with the expectation of expansion and modification. It should not be difficult to change the system if one's requirements are not met by the standard routines available. For example, the maximum number of age classes can be easily changed because all array dimensions are programmed as named variables.

As described in the previous chapter, RMS80's detailed system of forest and cost accounting results in potentially high data requirements. Of particular note is the need for age-dependent cost information to determine the financial measures. These costs are associated with the management, harvesting, and processing of trees of a particular age. Use of the program's financial functions, however, is optional.

The cost of acquiring and using the model is moderate for such a system. RMS80 can be purchased for $10,000 (US) from N.Z. Forest Products Limited, Kinleith Mills, Private Bag, Tokoroa, New Zealand. This fee includes a full program listing, complete system documentation, and free access to new versions of the model as they are developed by N.Z. Forest Products Limited. Prospective purchasers should contact Brian J. Allison, Manager, Forest Planning and Services, at the above address for additional information.

The program processes data in a generally efficient manner. With the automatic command validation check and the ability to tailor each run to the task at hand, computer costs can be kept to a minimum. Depending on the computer rate schedule, a 50 year simulation of 30 crop types and 60 age classes will cost about $50 (Allison, personal communication).

Accessibility of Technical Support

Obtaining adequate technical support to effectively operate RMS80 is a potential problem. First, the sheer distance of users in the United States from the model developers in New Zealand creates a barrier to communication. Second, while the system is extensively documented with training manuals and sample runs, the job instructions and output descriptions are sometimes wordy or hard to follow. New users will likely have questions on the model's operation. Finally, only limited service is available directly from N.Z. Forest Products.

This situation should improve as the model gains wider acceptance and a support system of users develops. The system is in use at the School of Forestry, University of Canterbury, and at Fletcher Challenge Corporation of New Zealand. The standard yield forecasts, based on the ENF, are likely to be adopted for use by the New Zealand National Forest description system. Also, a computer bureau service which was formed in New Zealand in 1984 should now have technical information on RMS80 available.

Model Limitations and Assumptions

RMS80 has many of the same limitations as SHRUB. It is designed to simulate only even-aged, single-species forests. The standard routine determines harvest priority without regard to location. And there is no hierarchical aggregation system which enables different levels of inventory detail to be considered simultaneously.

Although the program has the ability to distinguish different crop types, the value of this feature for statewide timber assessments is largely negated. This is due to the model's assumption that all crop types are regenerated using a single, composite yield function. This is crucial for determining the ENF, and eliminates variations in yield due to different sites, species, and management intensities after the initial growing stock is harvested. One regeneration function is necessary because it provides a scale of measurement with which to compare the actual forest to a range of normal forests.

More importantly, RMS80 is able to simulate only one type of harvest schedule, the normal cut (i.e., the maximum volume control harvest). It is not possible to examine the effects of other cutting levels, such as maximum present net worth or even-flow, with this measurement model.

<u>Applicability to State Physical Timber Supply Assessments</u>

RMS80's primary role in state timber analysis would be to address the first basic assessment question: What is the current forest condition? The model's measurement techniques provide a standard method of describing the condition of the existing forest. It also has an analytical framework which allows it to assess timber quality and long term potential timber availability.

A broad assessment could be achieved by simulating the state's timber resources as one large forest. One could also assess timbersheds by ownership group and add the normal cuts determined for each unit to arrive at regional tallies. (The ENFs could not be averaged.) This type of analysis is performed in the following chapter.

The normal cuts could be compared to recent harvest levels for each analysis area. This would allow one to determine what effect the current harvest will have on the forest sustainability and average age if continued indefinitely. This comparison would give one some idea of what the future is likely to be, given present trends (the second basic assessment question).

Assumptions regarding management intensities and timberland availability could be varied to determine their effect on the forest mass and value measures. This type of analysis would provide useful insights into the forest condition and the sensitivity of the RMS80 measures to changes in assumptions. It would not address, however, many fundamental assessment questions. Without the ability to simulate different types of harvest schedules, one could not adequately investigate likely alternative futures, nor thoroughly analyze government policies and programs. Thus, RMS80's ability to provide a standard of comparison and a measure of long term timber flow potential would be useful in a state timber supply analysis, but it could not provide all analysis needs.

A DEMONSTRATION OF SHRUB AND RMS80

Scope of the Study

The objective of this study is to demonstrate the use of SHRUB and RMS80 for state physical timber supply assessments. Statewide and regional volume control and even-flow harvest schedules determined by SHRUB are compared to the ENFs and associated normal cuts determined by RMS80. These results are interpreted and their implications for forest policy in California are discussed. Assumptions regarding timberland availability and potential yield are also examined. The RMS80 runs were made by Devon McLean as part of his earlier research on timber resource planning in California (McLean, 1981).

California was divided into six regions (see figure 2), with three ownership categories: National Forest, Forest Industry, and Other. The same data base and management assumptions were used for all runs. It should be noted that the crudeness of the data used permits only a very rough estimate of the long term sustained yield potential of California's timberland. Furthermore, this study is intended as an introductory demonstration of these two models, and not as an in-depth analysis of their capabilities. Consequently, no financial analysis is included.

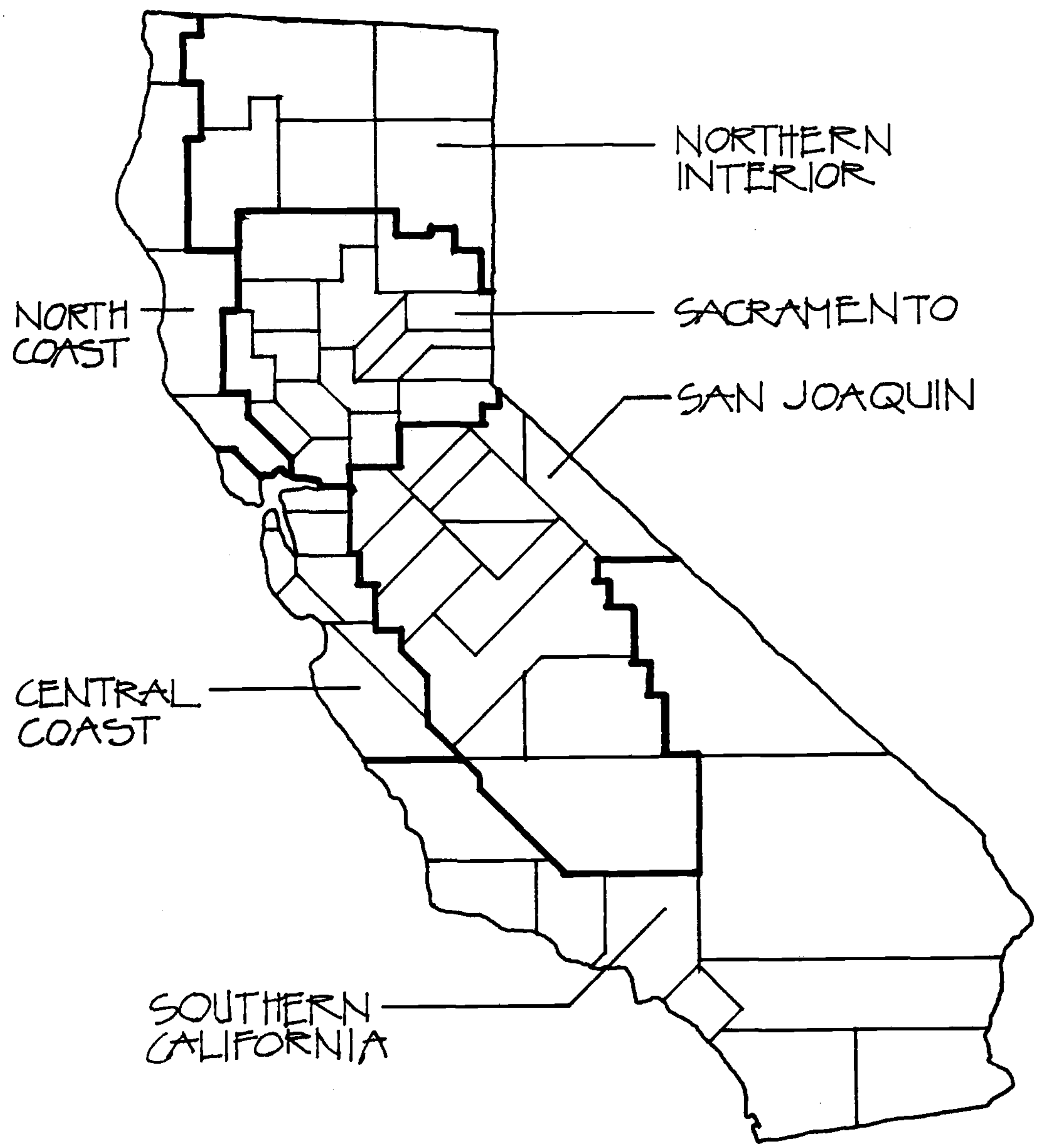

Figure 2: Counties and Regions of California

Data Sources and Assumptions

The data were compiled by McLean from the USDA Forest Service's Forest Survey publications, primarily the report by Bolsinger (1980). Extensive adjustments to the data were required to update all inventories to a common base year (1975) and to develop consistent age class information (see McLean (1981) for details). No estimates of precision can be made for these modified data. Information on the statistical precision of the original inventories can be found in Bolsinger (1980).

Ownership classification is based on the Forest Survey's system. The three categories are defined as follows:

National Forest lands are Federal lands which have been designated by executive order or statute as National Forests, and other lands under the administration of the Forest Service.

Forest Industry lands are owned by companies or individuals operating wood-using plants.

Other lands are a combination of other private timber growers, farmer owned lands, and miscellaneous corporate and non-corporate lands. It also includes other public lands, such as lands administered by the Bureau of Land Management, the Bureau of Indian Affairs, and lands owned by the state, counties, and other local public agencies.

After reviewing information on federal land classification and production, it was assumed that 75 percent of the National Forest and other public timberlands are available for timber production. Determination of available timberland in private ownership was based on Timberland Production Zone (TPZ) classification. Lands designated TPZ by counties may be used only for production of forest products and other compatible uses. In turn, the taxes levied against TPZ lands are to be based on the capability of the lands to produce forest products. Since most land in the Forest Industry category is in TPZ, availability for this ownership class was assumed to be 100 percent. Deducting Forest Industry lands from the total TPZ land gave an availability for other private land ranging from 42 percent in the Central Coast region to 78 percent for the Northern Interior region.

Timberland for which there was little or no information available was excluded. This amounted to all timberland in the Southern California region, all of the Los Padres National Forest, and some 6,000 acres of privately owned timberland on the Monterey Peninsula. Since there has been very little timber production from these areas in the last 20 years, they were assumed to be of little significance to an analysis of state timber production potential.

Land of some national forests which cross the State boundary was excluded when there was insufficient information available to make necessary subdivisions by age. Areas affected include small portions of the Siskiyou, Rogue, and Toiyabe National Forests.

Furthermore, some 758,000 acres of commercial forest land classified as nonstocked were excluded from the study. There was neither suitable information available concerning the reason for its condition, nor any indication of when it might be restocked, if at all.

The following tabulation shows the resulting available commercial forest land in California in 1975 (in thousands of acres).

Region/ Ownership	National Forest	Forest Industry	Other	Total
North Coast	527	1,148	990	2,665
Northern Interior	2,386	593	1,381	4,360
Sacramento	1,493	694	464	2,651
Central Coast	-	-	102	102
San Joaquin	1,131	-	241	1,372
State total	5,537	2,435	3,178	11,150

Source: McLean (1981).

Growing stock volumes on each ownership were used as the basis for construction of yield tables for existing stands (see appendix, tables 1-9). The common regeneration yield table (see appendix, table 10) was based on Forest Survey's estimated average statewide biological potential of 97 cubic feet per acre per year (Bolsinger, 1980). An arbitrary adjustment to 80 percent of this figure was adopted to make allowance for the impact of insects, disease, wind, drought, fire, and management practices. No increase in management intensity was projected. Based on a review of the age of culmination of mean annual increment for the major commercial species in California, a culmination age of 75 years was chosen.

Statewide Simulation Results

Results of RMS80 and SHRUB runs for the entire state are as follows:

RMS80:	Normal Cut	733 MMCF/YR	ENF 61.05 years
SHRUB:	Maximum Volume Control Annual Cut	752 MMCF/YR	No minimum harvest age
	Even-flow Annual Cut	748 MMCF/YR	Minimum harvest age: 60

The RMS80 measurement results may be interpreted as indicating that a fully regulated forest, which is equivalent to the California resource in the base year, has a rotation length of 61.05 years and a sustainable annual harvest of 733 million cubic feet. At this ENF, the relative rotation is less than 1.0. As described in Chapter 4, for relative rotations less than 1.0 the measurement procedure locates the ENF corresponding to the maximum sustainable annual harvest without a minimum harvest age constraint.

The SHRUB volume control option was used to verify that an RMS80 type of harvest schedule could be simulated. This run used the same analysis parameters as RMS80 (an analysis period of three times the age of culmination of mean annual increment and no minimum harvest age). The resulting constant annual harvest level is nearly equal to the normal cut (within 2.5 percent) and the rotation age normalizes at approximately the ENF. The difference in annual harvest between the RMS80 and SHRUB runs can be largely attributed to differing assumptions regarding a regeneration lag: the RMS80 included a two year lag, the SHRUB run had none. (SHRUB does not have this option.)

The even-flow harvest schedule is slightly lower than the maximum volume control level. This is because a minimum harvest age must be specified or the program will determine the even-flow level that exhausts the entire forest by the end of the analysis period. The 60-year limit, chosen to approximate the previous runs, constrains the harvest in the twelfth decade and reduces the cut by 0.5 percent.

The actual and equivalent normal age class distributions are illustrated in Figure 3. (see p. 56)

Looking at the wide distribution of age classes in the existing forest shown in Figure 3, it is not apparent why the ENF rotation is so low. McLean (1981) describes the reason as follows: "The explanation hinges on the difference between yields assumed to arise following regeneration and those for the existing stands in the base year. The substantial gains in productivity achieved by converting rapidly to fully stocked stands has resulted in a measure indicating a relatively short ENF rotation."

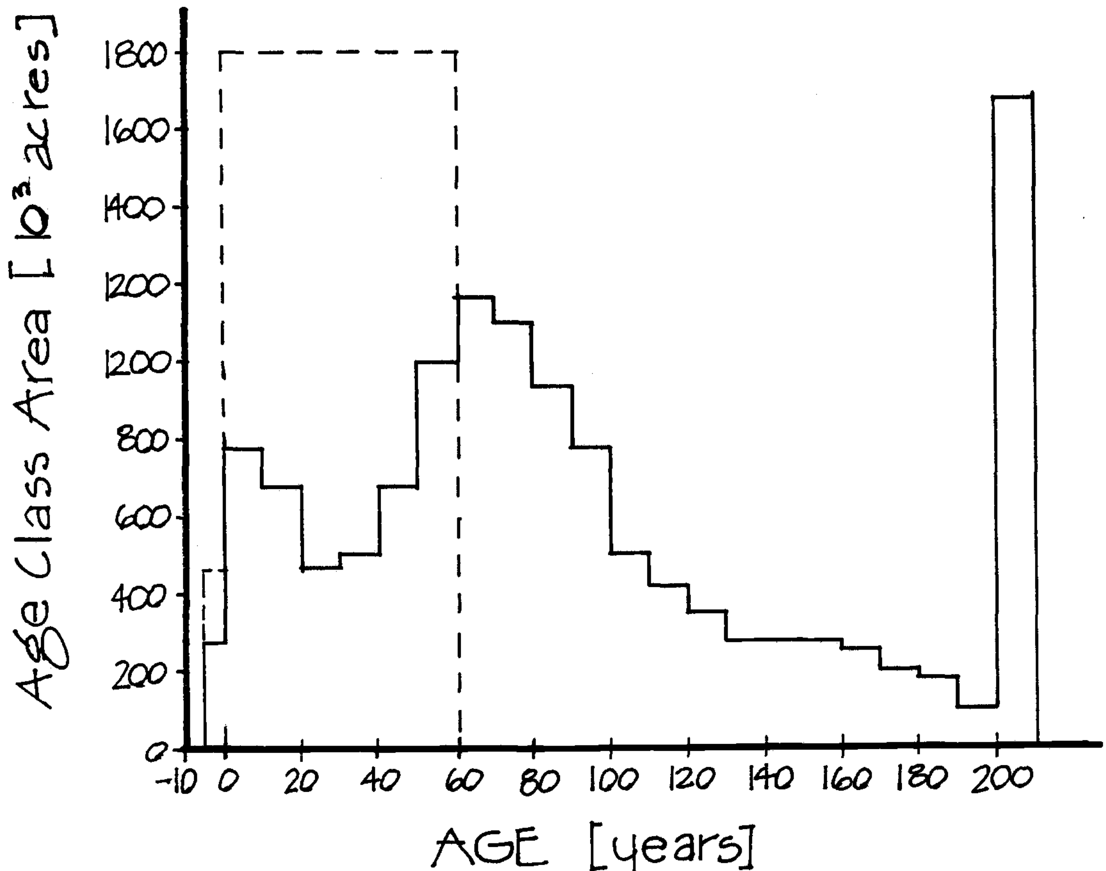

Figure 3: Age Class Distributions for California Commercial Forest Land and its Equivalent Normal Forest in 1975

The normal cut, volume control, and even-flow levels can be compared to the existing harvest level. It is interesting to note that the average annual timber harvest in California for the last ten years (1975-1984) has been approximately 618 million cubic feet (California Department of Forestry, 1975, and California Board of Equalization, 1976-84). The results suggest that the current statewide level of harvest can be sustained indefinitely. Any prolonged increase over the 733-752 MMCF range would decrease the forest's long term average age. A state harvest below this level would result in a gradual accumulation of growing stock over time. However, considering the gross level of aggregation, and the assumptions and data adjustments made in this study, it is difficult to draw these conclusions with much confidence.

Effects of Changes in Yield Assumptions

In preparing the initial data base it was assumed that an average of 80 percent of the biological potential would be achieved for all timberland regenerated after 1975. To examine the effect of alternative regeneration yield tables, analysis was made assuming 70 through 100 percent of the potential is achieved across all regions and ownership groups. The following tabulation shows the results:

Percent of Biological Potential	ENF (years)	Normal Cut (millions of cu ft/year)	Volume Control (millions of cu ft/year)
70	69.17	673	702
80	61.05	733	752
90	55.69	780	798
100	51.59	821	834

Both the normal cut and the maximum volume control harvest level increase with greater assumed regeneration potential. However, as assumed yields increase, the ENF (i.e., forest maturity) declines. This is because regenerated stands grow faster than existing stands, and in order to achieve the greatest sustained harvest, RMS80 rapidly converts existing stands to new young stands.

Clearly the determination of a suitable regeneration function is important in developing the resource description. If the yield achieved in regenerated stands was actually 70 percent of the biological yield potential, then current harvest levels could still be sustained indefinitely. More research is needed to estimate the level of future growth rates with greater confidence.

Effects of Changes in Timberland Availability Assumptions

Another significant factor in timber supply analyses is the area of timberland assumed to be available for timber production over time. The area that is currently available is determined by inventory results, with deductions for areas assumed to be out of production. Future timberland availability is estimated based on past trends in land use changes and projections of conversions to nonforest use.

McLean (1981) performed a sensitivity analysis of area assumptions. He tested the worst case condition that all regional inventories made by the Forest Survey were biased. Furthermore, McLean assumed that the correct results were given by the lower and upper bounds of the confidence intervals determined by the Forest Survey for these inventories. He calculated a statewide confidence interval of ±1.7 percent or 191,000 acres by weighting regional inventory confidence intervals at the 68 percent level according to area. The timberland base was decreased (increased) by this amount, with each age class taking a proportionate reduction (increase) (see appendix, table 11).

McLean made two runs, one at each end of the interval. Using the same acreage figures, the maximum volume control harvest levels were determined by SHRUB. The results of both models are as follows:

Acreage Change (thousands of acres)	ENF (years)	Normal Cut	Maximum Volume Control
		(millions of cu ft/year)	
-191	60.99	720	739
0	61.05	733	752
+191	61.12	745	764

An area change of 1.7 percent resulted in a 1.7 percent adjustment of the normal cut and the maximum volume control harvest level. This gives some indication of the sensitivity of the state long term timber flow potential to changes in the timberland area.

The loss of land from the commercial forest base is a major concern of forest policymakers in California. The urbanization of timberland is increasing. These results indicate that if substantial areas are taken out of timber production, timber availability will be reduced proportionately. Conversely, if the available land base increases (as the result of reforestation efforts or revised inventory estimates), the potential yield will increase.

Regional Simulation Results

Using the regions developed by the Forest Survey (see Figure 2), a more detailed analysis was made. The following tabulation shows the results:

Region	Normal Cut	Maximum Volume Control (million cu ft/yr)	Even-flow
North Coast	212	190	186
Northern Interior	264	247	222
Sacramento	183	184	181
Central Coast	15	9	9
San Joaquin	59	96	97
State Total	733	726	695

The regional normal cut figures are based on McLean's statewide analysis and represent the average contribution to the total cut for the first seven decades. Each region was not rerun separately. For the SHRUB runs the maximum volume control and even-flow harvest levels were determined for each region by ownership class. Here, as in the initial statewide analysis, the strict even-flow schedules with a 60-year minimum harvest age produce generally lower sustained harvest levels than the maximum volume control runs.

An assumption made by both RMS80 and SHRUB is that all acres included in the resource description are interchangeable. When modelling large areas, such as a state, the age class distributions of different regions and ownerships will likely be complementary. If this is true, the potential harvest level of the state will be greater than the sum of the regions. That is why, for both the volume control and the even-flow harvest schedules, the initial statewide estimates of 752 and 748 million cubic feet are greater than the sum of the regional SHRUB runs shown above.

SUMMARY AND CONCLUSIONS

There is a wide array of computer-based timber supply models currently available. Therefore, it is necessary to perform a careful evaluation of models being considered to ensure that the program(s) selected meet(s) analysis needs. The purpose of this paper was to describe and evaluate programs RMS80 and SHRUB for state physical timber supply assessments. Their application to forest planning was also demonstrated.

SHRUB and RMS80 are both physical timber supply models that simulate the growth and harvest of an even-aged forest over time using binary search techniques. SHRUB is an easy-to-use model that is run interactively to generate four types of harvest schedules: area control, volume control, even-flow, and Economic Harvest Optimization. It can be run on a microcomputer and is relatively inexpensive to operate. RMS80 is a somewhat more complex and expensive model that approaches forest planning from an entirely new perspective. It calculates new measures of the quantity of forests called the Equivalent Normal Forest (ENF) and normal cut on a mainframe computer. These measures represent indices of forest maturity and sustainable timber flow potential, respectively.

SHRUB's ease of use and ability to produce four types of harvest schedules are considered highly desirable features. Its most significant limitation for state timber supply assessments is its lack of a hierarchical aggregation system which permits analysis of several forest subdivisions in one computer run. SHRUB could be used effectively to augment a more sophisticated model. It could make preliminary runs and perform sensitivity analyses of data and assumptions at relatively low cost.

RMS80's principle focus is the determination of the ENF and associated normal cut. It also permits the specification of several management options and produces detailed accounts of the effects of these options on costs and revenues over time. These capabilities result in involved operating procedures. Like SHRUB, RMS80 does not permit the hierarchical aggregation of several different levels of forest inventory. More importantly, the use of RMS80 implies the acceptance of the new system of measurement embodied in the ENF and normal cut. This could be an obstacle to its widespread use; anything that is as radically different as a new measure is frequently met with resistance. Furthermore, preconceived ideas about the role of the normal forest in forest planning may hamper an appreciation of these concepts. The framework for description of the resource which RMS80 provides, however, offers useful new insight into the behavior of forest maturity and stocking in response to alternative levels of harvest.

The demonstration of RMS80 and SHRUB for state timber assessments consisted of an analysis of all California timberland which could be reasonably considered as being available for timber production. The inventory data required extensive manipulations to develop consistent age class information and to bring all inventories to a common base year (1975). The tentative nature of the forest description resulted in considerable uncertainty as to the reliability of the analysis.

The RMS80 measurements indicate that the California resource is equivalent to a fully regulated forest which has a rotation length of 61.05 years and a sustainable annual harvest of 733 million cubic feet. These results were duplicated by SHRUB using the volume control harvest schedule. Thus it is possible to approximate the RMS80 forest mass measures with SHRUB.

The average annual timber harvest in California for the last ten years (1975-1984) of approximately 618 million cubic feet is within the level indicated by both models as being sustainable. The analysis also shows that the long term timber flow potential is very sensitive to assumptions regarding future biological productivity and timberland availability.

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APPENDIX

Table 1. Available Commercial Forest Area by Age and Ownership: North Coast Region. 1975.

Age (years)	National Forest	Forest Industry	Other
	- - - (thousands	of acres)	- - -
Awaiting Regen.	48	32	8
0-9	168	129	44
10-19	25	173	145
20-29	14	89	105
30-39	7	97	58
40-49	11	109	84
50-59	11	105	75
60-69	5	89	103
70-79	18	77	50
80-89	22	14	64
90-99	17		24
100-109	18	4	33
110-119	14	30	13
120-129	1	31	11
130-139	2	27	14
140-149	24	30	9
150-159	24	27	11
160-169	25	4	7
170-179	24	3	12
180-189	22	4	9
190-199			11
200+	27	74	100
TOTAL	527	1148	990

Table 2. Available Commercial Forest Area by Age and Ownership: Northern Interior Region. 1975.

Age (years)	National Forest	Forest Industry	Other
	- - - (thousands of acres) - - -		
Awaiting Regen.	47	12	29
0-9	105	37	91
10-19	44	28	79
20-29	20	15	47
30-39	37	12	35
40-49	79	40	100
50-59	174	74	165
60-69	223	81	173
70-79	202	71	169
80-89	186	74	159
90-99	176	44	101
100-109	47	7	22
110-119	46		4
120-129	5		3
130-139	5		4
140-149	6		3
150-159	6		2
160-169	5		2
170-179	5		4
180-189	3		2
190-199	3		
200+	962	98	187
TOTAL	2386	593	1381

Table 3. Available Commercial Forest Area by Age and Ownership: Sacramento Region. 1975.

Age (years)	National Forest	Forest Industry	Other
	- - - (thousands of acres) - - -		
Awaiting Regen.	35	10	9
0-9	42	53	38
10-19	17	26	20
20-29	10	9	8
30-39	78	12	36
40-49	121	11	46
50-59	136	65	63
60-69	152	84	65
70-79	152	77	64
80-89	148	68	28
90-99	144	68	11
100-109	143	47	13
110-119	143	39	14
120-129	53	37	15
130-139	13	37	16
140-149	10	23	11
150-159	8	23	3
160-169	8	5	4
170-179	7		
180-189	9		
190-199	10		
200+	54		
TOTAL	1493	694	464

Table 4. Available Commercial Forest Area by Age and Ownership: Central Coast and San Joaquin Regions 1975.

Age (years)	Central Coast	San Joaquin National Forest	Other
	- - - (thousands	of acres) - - -	
Awaiting Regen.	1	29	5
0-9	4	4	10
10-19	2	14	2
20-29	6	15	7
30-39	12	15	12
40-49	15	24	13
50-59	10	45	18
60-69	8	58	26
70-79	8	63	31
80-89	8	71	24
90-99	7	74	29
100-109	4	86	19
110-119	4	86	17
120-129	4	90	10
130-139	4	89	9
140-149	1	89	6
150-159		72	3
160-169		63	
170-179		53	
180-189		36	
190-199		22	
200+	4	33	
TOTAL	102	1131	241

Table 5. Merchantable Volume by Age and Ownership: North Coast Region.

Age (years)	National Forest	Forest Industry	Other
	- - - (cu ft/acre) - - -		
5	34	70	39
15	113	700	130
25	418	1358	480
35	915	2968	1052
45	1548	3990	1780
55	2271	4620	2612
65	2904	5150	3340
75	3390	5775	3898
85	3729	6230	4288
95	4100	6580	4715
105	4465	6860	5135
115	4745	7210	5457
125	5005	7490	5785
135	5277	7700	6068
145	5500	7875	6325
155	5730	8050	6590
165	5910	8225	6796
175	6070	8330	6980
185	6215	8470	7147
195	6340	8610	7291
205	6440	8750	7406
215	6535	8805	7516
225	6625	8855	7621
235	6710	8900	7721
245	6805	8940	7816

Table 6. Merchantable Volume by Age and Ownership: Northern Interior Region.

Age (years)	National Forest	Forest Industry	Other
	- - - (cu ft/acre) - - -		
5	1	1	1
15	54	19	17
25	347	216	184
35	772	606	516
45	1205	1072	913
55	1599	1543	1315
65	1944	1985	1691
75	2245	2387	2033
85	2505	2750	2342
95	2732	3073	2618
105	2952	3364	2866
115	3128	3624	3087
125	3284	3858	3286
135	3399	4056	3467
145	3522	4261	3629
155	3634	4434	3777
165	3735	4593	3913
175	3826	4739	4037
185	3910	4890	4170
195	3987	5060	4290
205	4057	5200	4400
215	4122	5335	4505
225	4212	5465	4600
235	4268	5590	4695
245	4320	5710	4785

Table 7. Merchantable Volume by Age and Ownership: Sacramento Region

Age (years)	National Forest	Forest Industry	Other
	- - - (cu ft/acre) - - -		
5	6	40	20
15	53	240	160
25	444	670	510
35	1106	1400	990
45	1837	2160	1560
55	2538	2670	2130
65	3176	3120	2610
75	3743	3540	3000
85	4243	3910	3480
95	4684	4250	3730
105	5074	4540	4010
115	5423	4780	4280
125	5734	5000	4520
135	6011	5210	4740
145	6263	5410	4930
155	6489	5570	5100
165	6696	5720	5260
175	6884	5850	5400
185	7056	5970	5530
195	7214	6060	5650
205	7367	6130	5750
215	7515	6195	5845
225	7658	6255	5935
235	7796	6310	5920
245	7929	6355	6000

Table 8. Merchantable Volume by Age and Ownership: Central Coast and San Joaquin Regions.

Age (years)	Central Coast	San Joaquin N. F.	Other
	- - - (cu ft/acre) - - -		
5	50	22	20
15	800	45	180
25	1900	377	610
35	3000	940	1210
45	4050	1563	1740
55	4950	2159	2190
65	5800	2700	2580
75	6600	3181	2910
85	7250	3606	3210
95	7900	3982	3480
105	8450	4315	3730
115	9000	4610	3960
125	9550	4874	4180
135	10000	5111	4380
145	10400	5324	4570
155	10800	5517	4760
165	11150	5693	4940
175	11500	5853	5090
185	11800	5998	5230
195	12100	6133	5360
205	12300	6258	5470
215	12490	6493	5555
225	12670	6493	5635
235	12840	6603	5710
245	13010	6708	5780

Table 9. Statewide Existing Yield (Weighted Average)

Age (years)	Cu ft/acre
10	28
20	278
30	672
40	1490
50	1944
60	2289
70	2707
80	3100
90	3312
100	3624
110	4446
120	4955
130	5394
140	5524
150	5708
160	5942
170	5826
180	6001
190	6287
200	6505
200+	4841

Table 10. Statewide Regeneration Yield Tables

- - - - (cu ft/acre) - - - -

Percent of Biological Potential

Age (years)	70%	80%	90%	100%
10	0	0	0	10
20	93	107	120	133
30	689	788	886	985
40	1624	1856	2088	2320
50	2615	2988	3362	3735
60	3540	4046	4551	5057
70	4366	4990	5614	6238
80	5093	5920	6548	7275
90	5728	6547	7365	8183
100	6286	7184	8082	8980
110	6777	7745	8713	9681
120	7211	8241	9271	10301
130	7597	8682	9768	10853
140	7942	9077	10212	11346
150	8253	9432	10610	11789
160	8533	9752	10971	12189
170	8787	10042	11297	12552
180	9018	10306	11594	12883
190	9229	10548	11866	13184
200	9423	10769	12115	13461
210	9601	10973	12345	13716
220	9766	11161	12557	13952
230	9919	11336	12753	14170
240	10061	11498	12935	14372

Table 11. Statewide Available Timberland

- - - - (Thousands of Acres) - - - -

Age (years)	Baseline	Increased by 191 M ac	Reduced by 191 M ac
Awaiting Regen.	265	270	260
10	725	737	713
20	575	585	565
30	345	351	339
40	411	418	404
50	653	664	642
60	941	957	925
70	1067	1085	1049
80	982	999	965
90	866	881	851
100	695	707	683
110	443	451	435
120	410	417	403
130	260	264	256
140	220	224	216
150	212	216	208
160	179	182	176
170	123	125	121
180	108	110	106
190	85	86	84
200	46	47	45
200+	1539	1565	1513
Total	11150	11341	10959