

# **EVALUATING STAND DENSITY MANAGEMENT ALTERNATIVES USING THE FOREST VEGETATION SIMULATOR**

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## **Abstract**

The Forest Vegetation Simulator (FVS) is a software tool available to forest managers to evaluate stand density management alternatives. FVS is widely used in the United States for this and other purposes. Use of FVS in Canada is limited because metric based variants calibrated to Canadian forest types are generally unavailable. FVS is a versatile and powerful tool, capable of simulating almost any management scenario and allowing users to create custom variables and relationships. In addition, model features allow easy calibration of the growth functions to input data. The suite of available FVS software makes it an attractive choice to aid forest managers faced with making difficult land management decisions.

## **Introduction**

Forest managers are under ever-increasing pressure to design and implement biologically and economically sound stand management alternatives. Costs associated with timber harvesting are continually increasing, requiring any stand entry to generate enough revenue to justify the treatment. The generated revenue must cover the direct cost of the harvest and also the interest that could have been generated by using those monies in other investment alternatives. Generated revenue can be in the form of direct return on the timber harvested, or in delayed return from increased future revenue as a result of increased tree growth resulting from an intermediate treatment. Meanwhile, forest managers must maintain or improve the health, condition, and scenic value of the landscape to satisfy various forest practices legislation. Traditional forest management practices such as clearcutting are often not acceptable. Forest Managers are faced with implementing management alternatives of which the long-term effects to the resource are unknown.

However, forest managers have available to them an ever-increasing array of tools, which can aid resource management, decisions. Computer technology has revolutionized land management decision analyses. Geographic information systems, relational data bases, mapping technologies, visualization software, and growth and yield simulators are among the many tools currently available, and other software products are being rapidly developed. The Forest Vegetation Simulator is one of the products currently available to aid forest managers in making sound biological and economical management decisions.

# What Is the Forest Vegetation Simulator?

## Who Uses It and For What Purposes

The Forest Vegetation Simulator (FVS) is a growth and yield simulator used extensively in the United States. FVS is the standard growth and yield model used in various government agencies including the USDA Forest Service, USDI Bureau of Land Management, and USDI Bureau of Indian Affairs. It is also used by state agencies such as the Washington Department of Natural Resources, industry, educational institutions, and private landowners. Versions of FVS are currently under development for parts of British Columbia, Canada, and the southern United States.

Forest managers have used FVS extensively to summarize current stand conditions, predict future stand conditions under various management alternatives, and update inventory statistics. Output from the model is used as input to forest planning models such as SPECTRUM (USDA 1996). Uses of FVS are not restricted to timber management applications. Other uses of FVS include considering how management practices affect understory composition, determining suitability of a stand for wildlife habitat, estimating hazard ratings, and predicting losses from fire and insect outbreaks.

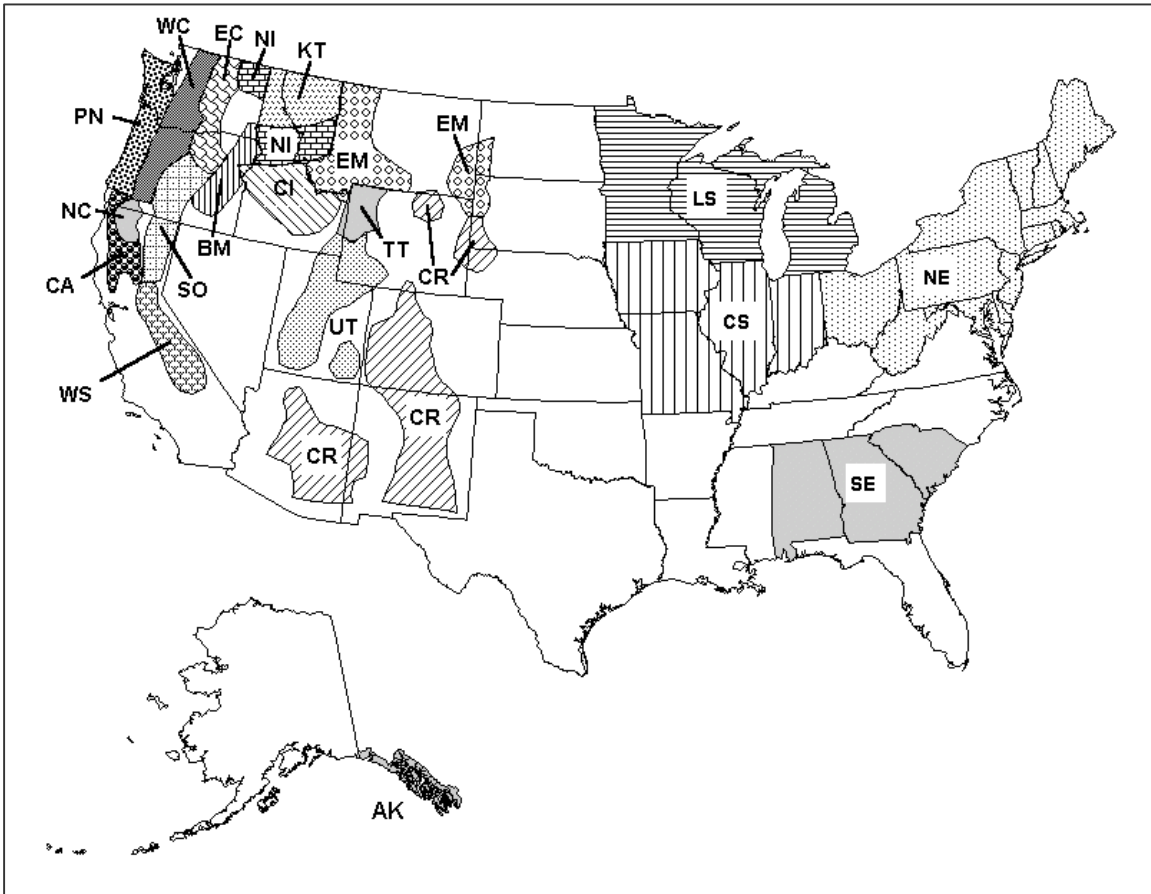
## Products and Support

Versions of the model have been calibrated to a certain geographic areas are called "variants". There are currently twenty geographic variants of FVS in use in the United States (Figure 1). Two others are currently being developed and more are planned for future development. FVS in the United States is supported and maintained by the USDA Forest Service, Forest Management Service Center (FMSC), in Fort Collins, Colorado, with technical assistance from Project 4155 at the Rocky Mountain Forest and Range Experiment Station's Laboratory in Moscow, Idaho. The FMSC staff distributes the computer software, provides hot-line user support, develops new variants, debugs the code, incorporates new enhancements, provides FVS training, and sponsors FVS user conferences.

The suite of FVS software available includes various pre-processors, which screen inventory data and translate it into FVS format; twenty FVS variants calibrated to specific geographic areas, various post-processors which further analyze and summarize FVS output files, and stand visualization software. Each of these software products are stand-alone programs integrated via a Graphical User Interface, called Suppose (Crookston, 1998), which allows users to run the model in a Windows type point-and-click format. With the Suppose interface, users can easily make multiple stand runs, create custom output files, and develop and edit FVS input files. The remainder of this paper will focus only on the growth and yield simulator.

## FVS Basic Description

FVS is a distant-independent individual tree growth and yield model. It treats a stand as the population unit and utilizes standard forest inventory or stand exam data. Local growth rates are used to adjust model growth relationships, which is a distinguishing feature of the model. FVS can portray a wide variety of forest types and stand structures ranging from even-aged to uneven-aged and single to mixed species in single to multi-story canopies. FVS was originally called The Prognosis Model for Stand Development (Stage 1973; Wykoff, Crookston, Stage 1982; Wykoff 1986, Wykoff, Dixon,



**Figure 1: Distribution of FVS variants in the United States.**

Crookston et al 1990) and developed for use in the Inland Empire area of Idaho and Montana. Extensions to the base model have been developed to dynamically schedule activities and compute custom output variables (Crookston 1990), provide for multi-stand simulations (Crookston and Stage 1991), simulate regeneration (Ferguson and Crookston 1984, Ferguson and Crookston 1991), estimate canopy and shrub biomass (Moeur 1985), estimate impacts from various insects and pathogens (Marsden, Eav and Thompson 1993; Stage, Shaw, et al 1990; Monserud and Crookston 1982; Hawksworth, Williams-Cipriani, et al 1992; Crookston, Colbert, et al 1989; Cole and McGregor 1983), and simulate forest fire effects.

Two input files are generally used when running FVS. The first, a keyword file, is required; the second, a tree data file, is required when simulating an existing stand but not required when making a bare ground projection. Keyword records are used to enter stand level parameters such as slope, aspect, elevation, and information about the sampling design, location, and site productivity. They are also used to describe management scenarios, control the printing of output, compute custom variables, and adjust model estimates. Keyword records are mnemonic words (keywords) associated with up to seven parameters. The parameters provide data necessary and specific to the keyword action. The tree data file is composed of records containing tree level information. Species and diameter at breast height are required on each tree record. Optional data includes tree count, diameter growth, height, height growth,

crown ratio, and various other tree level information typically collected in inventory or stand exam procedures.

Four output files are generally produced from FVS. The main output file, treelist output file, summary table output file, and an economics information file. The main output file:

1. Contains information about keyword interpretation and scheduled activities
2. Shows information about model calibration to the input data
3. Provides stand composition statistics through time
4. Tracks individual sample trees through time
5. Produces a stand summary table of the entire simulation
6. Summarizes the simulated management activities

The treelist output file contains detailed information about all the individual tree records being projected. This file is optional and must be requested via a keyword. The third output file contains only the summary table information from the main output file. This file is useful when summarizing information about many stands or providing information to various planning models. The fourth output file contains information needed when running the economics model linked to FVS (Horn, Medema, Schuster 1986) and can be used for other auxiliary output data such as detailed calibration data needed for a post-processor program to develop model multipliers over a broad geographic scale.

The length of time over which simulation results are desired is specified in terms of "cycles". A cycle is a period of time for which increments of tree characteristics are predicted. The default cycle length is 10 years for most variants and the default number of cycles is 1. However, the cycle length and number of cycles is easily adjusted using appropriate keywords. Thinnings are assumed to take place at the beginning of the cycle in which they are scheduled. Consequently, growth projections for a cycle are done using residual stand conditions. Mortality occurs at the end of a cycle, and new tree records generated from regeneration and plantings during a cycle are added into FVS at the end of the cycle. The general model flow is shown in Figure 2.

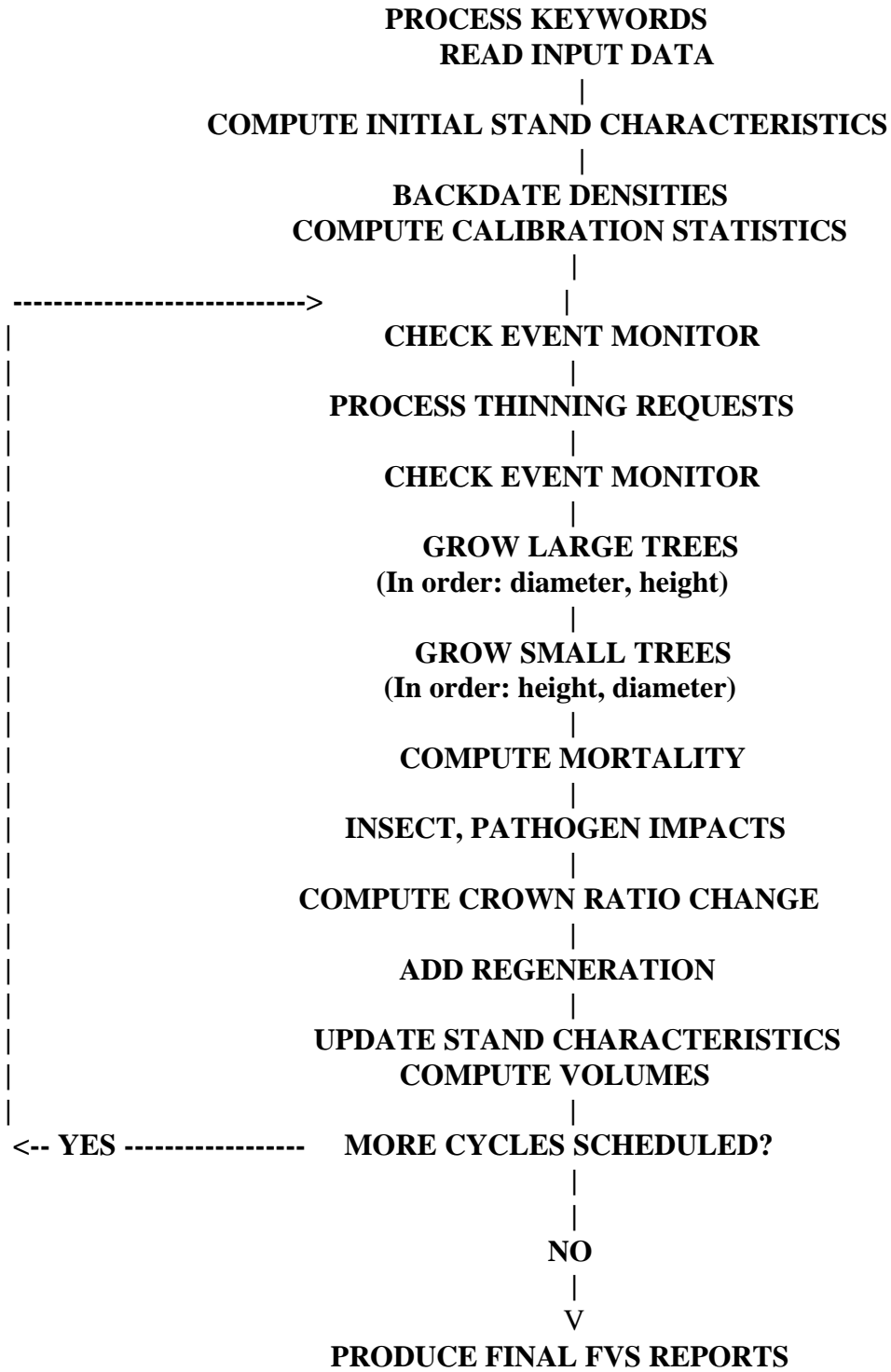
## **Modeling Stand Density Management Alternatives**

Many stand management alternatives can be simulated using FVS keywords. Alternatives can be very simple and explicitly stated where the user specifies in what year a certain activity is to take place. Alternatives can also be very complex where the model monitors user specified parameters and dynamically schedules the activities based on values of the parameters. These concepts will be illustrated in following examples.

Several thinning keywords are available and can be used individually, or in combinations, to produce the desired management action. Thinning can be from below, above, or throughout selected portions of a stand. Thinnings can be to a residual basal area or trees per acre target, where the target is contained in a specified diameter and/or height segment of the population. Stand level targets can also be specified if desired. Residual targets can be specifically set by the user, or dynamically calculated by the model using user-specified equations. Prescription thinnings are permitted which can target individual trees, and automatic thinnings can be scheduled to maintain a stand within a specified density management zone. Also, certain tree attributes, such as dwarf mistletoe rating or tree value class, can be either favored or discriminated against in a thinning.



Figure 2: General FVS Processing Sequence.



## FVS Thinning Methodology

The method by which FVS simulates a harvest is very simple. Each tree record within FVS has a tree count attribute which indicates the number of trees per acre the tree record represents. If the other tree attributes (diameter, height, etc.) fall within the harvest parameters, then the tree count attribute is simply reduced to reflect how many of the trees per acre represented by this tree record are removed. It is possible to remove the entire trees per acre representation, or only a portion of the trees per acre representation, for a tree record during a harvest.

Thinnings can be constrained by specifying standards for minimum acceptable harvests. These constraints can be expressed in volume per acre (merchantable cubic feet or board feet) or basal area (square feet) per acre. Minimum harvest constraints can be changed over time if desired. When minimum harvest constraints are specified, the accumulated removals across **all** thinnings in a cycle must exceed the standards for **all** of the minimum harvest constraints for the cycle or **none** of the thinnings in the cycle will be implemented.

All thinnings are scheduled by date or cycle, and the date or cycle must fall within the bounds of the simulation. Thinning dates do not need to coincide with the beginning of a cycle, but as stated previously, the thinning will occur at the beginning of the cycle in which it is requested. Any number of thinnings may be scheduled during any one-projection cycle. These will be simulated in order of date. Thinnings specified for the same date will be simulated in the order they occur in the input file.

The proportion of trees/acre represented by a tree record to be removed in any thinning is referred to as the cutting efficiency. The default cutting efficiency is 1.0, which means all the trees represented by a tree record will be removed. However, the cutting efficiency, which must range between 0.01 and 1.0, can be easily changed using the keywords. Cutting efficiency can be changed for individual thinnings using the cutting efficiency parameter on the thinning keywords, or can be changed globally using another keyword. In some cases, where residual targets are specified, the model dynamically calculates the cutting efficiency necessary to achieve the target.

## Prescription Thinning

Prescription thinning is designed to allow users to mark individual trees for removal. One attribute associated with each tree record in FVS is a marking code. Marking codes are specified in the input data and values can range from 0 to 9. Prescription thinnings are requested using the ThinPRSC keyword. Keyword parameters are (in order): (1) the date the thinning is requested, (2) cutting efficiency associated with the thinning, and (3) the marking code to be removed in the thinning. For example, the keyword sequence:

ThinPRSC	1998.	1.0	3
ThinPRSC	2008.	0.5	5

would remove the entire trees per acre representation of all tree records with a marking code of 3 in the year 1998, and would remove 50% of the trees per acre representation of all tree records with a marking code of 5 in the year 2008.

## Size Limit Thinnings

Two thinning keywords allow for removing a portion of a given species diameter or height distribution in a stand, without regard to any other tree attributes. This allows for simulation of treatments such as stand cleaning and overstory removal. Size limits can be specified in terms of diameter at breast height or total tree height. The diameter limit thinning is requested with the THINDBH keyword and the height limit thinning by the THINHT keyword. Each of these keywords has seven parameter fields to specify (in order):

1. The date the thinning is scheduled,
2. Smallest diameter (or height) to be removed,
3. Largest diameter (or height) to be removed,
4. Cutting efficiency for this thinning,
5. Species code to be removed,
6. Target trees per acre to be left in the previously specified diameter (or height) class,
7. The target basal area to be left in the previously specified diameter (or height) class.

If both a basal area and a tree per acre target are specified on the same keyword, the trees per acre target is used. However, neither target needs to be specified. Consider, for example, the keyword sequence

```
THINDBH 1998. 5 20. 1. ALL 70. 0.  
THINDBH 1998. 20 99. 1. DF 0. 10.  
THINDBH 1998. 0 5. .5
```

In 1998, the first THINDBH would leave 70 trees per acre of whatever species is in the stand which are 5 inches dbh or greater, up to 20 inches dbh. The "ALL" appearing as the fourth parameter tells the model to harvest all species. The second THINDBH would remove only Douglas-fir 20 inches dbh and larger, leaving 10 square feet of basal area in Douglas-fir with dbh greater than or equal to 20 inches. Species other than Douglas-fir which are 20 inches dbh or greater would not be affected. In each of these instances, since residual targets are specified, the model ignores the specified cutting efficiency of 1.0 and calculates the cutting efficiency it needs to achieve the desired targets while spreading the harvest across the entire specified diameter class. The third THINDBH accounts for logging damage to understory trees and tells the model to remove 50 percent of all the trees less than 5 inches dbh.

## Thinnings Aimed Specifically at Controlling Stand Density

The remaining thinning options allow managing stand density while giving consideration to tree size, species, value class, mistletoe rating, and user defined special status codes. In the prescription thinning, all tree records with a specified marking code are eligible for harvest; in the size limit thinnings, all tree records in the defined size class of the specified species are eligible for harvest. In each of these cases, there is no need for establishing a thinning priority for the tree records; all the tree records meeting the criteria are affected. However, in the remaining thinning options, the forest manager is given the choice of which trees will be favored for harvesting depending on several tree attributes. As a result, each tree



record must be assigned a "removal priority", which will determine the order in which tree records are considered for harvesting.

The thinning priority for each tree record is computed as follows:

$$\text{Priority} = (\text{DBH} * \text{MD}) + \text{SP} + (\text{TVC} * \text{MT}) + (\text{DMR} * \text{MM}) + (\text{STS} * \text{MS})$$

Where: DBH = Diameter at breast height  
MD = -1 if thinning from below, 1 if thinning from above  
SP = User specified species priority (default 0)  
TVC = Tree value class  
MT = User specified tree value class multiplier (default 0)  
DMR = Tree dwarf mistletoe rating (Hawksworth 0-6)  
MM = User specified dwarf mistletoe multiplier (default 0)  
STS = Special tree status (specified on the tree record during data input)  
MS = User specified special tree status multiplier (default 0)

The probability a tree will be removed in a thinning is proportional to its thinning priority. The tree with the largest priority is removed first; thereafter, trees are selected for removal in descending order of priority until the residual stand density objective is achieved. By manipulating the values of the preference terms (SP, MT, MM, MS) and choosing an appropriate density control option, a thinning strategy can be designed to achieve almost any silvicultural objective. Values of the preference multipliers are specified using the SPECREF, MISTREF, and TCONDMLT keywords, and can be changed for every thinning request if desired. Once the preference modifiers are set for a simulation, they remain in effect until replaced with new SPECREF, MISTREF, or TCONDMLT values.

#### Thinning to a Basal Area or Trees Per Acre Target

Keywords are available for thinning to a basal area target from above (THINABA) or below (THINBBA), or to a trees per acre target from above (THINATA) or below (THINBTA). Each of these keywords has seven parameters:

1. Date the thinning is scheduled,
2. Residual basal area or trees per acre target in the specified diameter and/or height range,
3. Cutting efficiency,
4. Smallest diameter to be considered for removal,
5. Largest diameter to be considered for removal,
6. Shortest tree to be considered for removal,
7. Tallest tree to be considered for removal.

FVS does not dynamically adjust the cutting efficiency for thinnings specified with these keywords, and each tree record is considered for thinning only once per thinning request. As a result, if the cutting efficiency is set too low, the model may not be able to attain the residual target specified on the thinning request. In this case, the thinning request will be completed, but the residual stand condition will be greater than the target the user had intended. If the initial stand condition is already less than the target specified, the thinning will be cancelled. Users should look at the "Activity Summary" portion of the

output to see which thinning requests were simulated, which ones (if any) were cancelled, and which ones were done but the effect was not what they intended.

### Automatic Stand Density Control

The last thinning option allows forest managers to automatically maintain stand density within a specified range of normal stocking as determined by maximum stand density index. This keyword (THINAUTO) has four parameter fields specifying (in order):

1. Date when automatic stocking control is scheduled to begin,
2. Percentage of normal stocking defining the lower limit for stand density,
3. Percentage of normal stocking defining the upper limit for stand density,
4. Cutting efficiency specific to the automatic thinning request.

FVS keeps track of the current stand density index for a stand, and the maximum stand density index for a stand. With this keyword, a thinning is automatically scheduled from below when the current stand density exceeds the upper level management threshold. The thinning reduces stand density to the lower level management threshold. For example, assuming the stand density index maximum is 500, consider the keyword:

```
THINAUTO 2000. 45. 70. 1.
```

This keyword would result in a thinning any time, beginning in the year 2000, when the current stand density index exceeded 350 (70% of 500) and the stand would be thinned to a stand density index of 225 (45% of 500).

There are three things users should be aware of when using this keyword. First, these management zones are variant specific since default stand density index maximums are variant and species specific. Stand density index maximums can be set, however, using the SDIMAX keyword. Second, this keyword can create management scenarios impractical to implement on the ground. Forest managers may not be able to afford to make the multiple entries simulated by this keyword, and the resulting volumes may not cover the cost of the thinning. And third, other alternatives (sets of keywords) can be created to achieve automatic stand density control using the other thinning options, and those alternatives do not have the deficiencies associated with this keyword.

### Dynamically Scheduling Thinning Requests

In the examples so far, thinning requests have been scheduled by specifying a date in the first field of the keyword. However, stand management alternatives, and the timing of those alternatives, are often contingent upon several factors. Thinning may be needed if a stand gets too dense, or spraying may be required if an insect outbreak occurs, but how does the forest manager foretell when those events might occur?

The event monitor feature of FVS allows the forest manager to specify a set of conditions that must occur, or thresholds that must be reached, for some management action to be scheduled. The model will monitor those conditions and thresholds and dynamically schedule the management action when the condition and/or threshold are reached. For example, suppose the forest manager wants to harvest 50%

of all trees if the stand basal area exceeds 150 square feet. The keyword sequence to simulate this management alternative is:

```
IF
  BBA GT 150
THEN
  THINDBH 0. 0. 999. 0.5
ENDIF
```

The variable BBA represents the before thinning basal area and is one of many event monitor pre-defined variables which can be used to trigger an activity. When contained in an event monitor sequence, the date field on the management action keyword (in this example the first field of THINDBH) is a "waiting time". This tells FVS to schedule the management action a certain number of years after the condition is found true. In this example, the waiting time is 0 so the thinning is scheduled immediately. The second and third parameters define the diameter range 0 - 999 inches (all trees), the fourth parameter sets the cutting efficiency at .5 or 50%, the fifth through seventh parameter fields are blank so default values are used. The default value for the fifth parameter is all species, and default values for the remaining fields are 0, which says there is no basal area or trees per acre target associated with this thinning request.

Pre-defined variables exist for a suite of before thinning and after-thinning stand values. The event monitor is called twice during a projection cycle; once before thinning to schedule any activities dependent on before-thinning stand values, and once after thinning to schedule any activities dependent on after-thinning stand values. For example, a user may want to plant seedlings following a thinning if the stand density is reduced beyond a certain level. The event monitor can schedule any FVS management activity containing a date field. Multiple conditions and multiple management actions can be specified in the same event monitor sequence.

As a second example of this concept, suppose the management alternative is: if before-thinning crown competition factor is greater than 150, and before-thinning trees per acre is greater than 500, and stand age is greater than 20 but less than 60, then thin from below to a residual stand density of 300 trees per acre and 30 years later clearcut the stand. One keyword sequence to simulate this management alternative is:

```
IF
  BCCF GT 150 AND BTPA GT 500 AND &
  AGE GT 20 AND AGE LT 60
THEN
  THINBTA 0. 300.
  THINDBH 30. 0. 999. 1. ALL 0. 0.
ENDIF
```

The variables BCCF, BTPA, and AGE are pre-defined variables corresponding to the stand values to be monitored. The "0" in the first field of the THINBTA tells FVS to schedule the thin from below immediately, and the "30" in the first field of the THINDBH tells FVS to schedule the clearcut 30 years later. All the keyword parameters have default values. In this example, default values for the last five parameters of the THINBTA keyword are being used. The default values being used are: cutting

efficiency of 1.0, smallest dbh of 0 inches, largest dbh of 999 inches, shortest tree of 0 feet, tallest tree of 999 feet ---- in other words cut all trees from below until the target is reached.

### Creating and Using Custom Variables

In the previous section, the examples used pre-defined variables in the condition statement. Another feature of the event monitor in FVS allows the forest manager to create custom variables which can be used in condition statements, as parameter fields on the keywords, or to report additional output values which are not contained in the standard FVS output. The following example illustrates how custom variables can be created and used.

Assume the forest manager wants to define normal stocking using the equation

$$\text{normal stocking} = 25000 * (\text{quadratic mean diameter} + 1)^{-1.588}$$

and the intensive management alternative is: once the stand exceeds normal stocking, then thin the stand to the normal stocking level; recheck the stand at 3 year intervals and thin as necessary to follow the normal stocking curve. However, insure there is at least five years between entries. One keyword sequence to accomplish this alternative is:

#### Reference

<u>Line</u>	<u>Keyword</u>
( 1)	TIMEINT        0.        3.
( 2)	COMPUTE       0.
( 3)	NORMAL = 25000 * (BADBH+1)**(-1.588)
( 4)	CURRENT = BTPA
( 5)	RATIO = NORMAL / CURRENT
( 6)	END
( 7)	IF                5
( 8)	RATIO LT 1.
( 9)	THEN
(10)	THINDBH    0.    PARS(0.,999.,1-RATIO,ALL,0.,0.)
(11)	ENDIF

Line 1: Since the stand needs to be monitored at 3-year intervals, set the time interval for all cycles to 3 years.

Lines 2 to 6: Define the variables NORMAL to be the trees per acre considered normal stocking, CURRENT to be the current trees per acre in the stand, and RATIO to be the ratio between normal stocking and current stocking. In this formulation, when RATIO exceeds 1 then the stand is below normal stocking and if it is less than 1 then the stand is above normal stocking. The variables BADBH and BTPA are the predefined variable representing before thinning quadratic mean diameter, and before thinning trees per acre, respectively. The "0" as the first parameter on the COMPUTE keyword tells the model to compute values for the three variables, NORMAL, CURRENT, and RATIO, every cycle. The computed values of these variables will

appear in the FVS output "Activity Summary" table, and can be displayed in charts and graphs using the Suppose interface.

Lines 7 to 11: If the value of RATIO is less than 1 (overstocked condition) then schedule a thinning. A THINDBH option is being used in this example so the thinning will be spread across all tree records uniformly. The cutting efficiency needed to reduce the stand to the normal stocking level is 1-RATIO, and all species will be cut. The string inside the parenthesis of the PARMS statement is the values for the 2nd to 7th parameters required by the THINDBH keyword. The PARMS statement is useful when entering arithmetic expressions as parameter values for a keyword. The "5" appearing as the first parameter on the IF keyword tells the model: once the condition of the if statement is found "true", then don't consider making this test for another 5 years.

### FVS Power and Versatility

The above examples illustrate how management scenarios might evolve as a forest manager first tries to use FVS and then becomes increasingly more knowledgeable about its capabilities. Hopefully they also stimulate the imagination about what might be possible once a user becomes proficient with all the capabilities of the model. FVS is extremely powerful and versatile. Approximately 150 keywords, only, a few of which are illustrated here, are available to control the base model with regeneration and mistletoe modules included. Other keywords are available to control additional FVS extensions such as those for insect and pathogen outbreaks and effects, multi-stand processing for landscape simulations, and fire effects.

The way the FVS keyword system is designed borders on a programming language all its own. Extremely complex management scenarios can be simulated for wildlife or other purposes. Users taking advantage of the ability to create custom variables, define mathematical relationships, and conditionally schedule events, have created "models" of their own using the FVS model. Keyword sets hundreds of lines long achieve mind-boggling results never dreamed of when the FVS system was first developed. Highly creative minds push the limits of the model to further extremes on a daily basis. New capabilities are added continually, by the development staff, in response to the never-ending user request "Can you make the model do...?". And yet with all the power, versatility, and capabilities, FVS remains a relatively easy model to use for the forest manager who only occasionally needs simple projections and is content with a basic knowledge of how the model operates.

### **How Can FVS Be Used In Canada?**

Three possibilities currently exist for using FVS in Canada: (1) use one of the FVS variants being developed for British Columbia, (2) develop new variants for Alberta and other Canadian Provinces, (3) use currently existing US variants to simulate Canadian stands. The first alternative may be the most promising in terms of implementing FVS in the shortest time frame with the least complications. The BC variants will be based on metric units, which is an advantage over trying to use the US variants. It takes about a year to develop and test a new variant. So the second alternative, while clearly being the best solution, is not timely. The third alternative could be implemented in the least amount of time if the problem with measurement units could be overcome. In any case, the first and third alternatives should

be viewed as short-term solutions for a given geographic area, and the second alternative as the long-term solution. The remainder of this paper examines the third alternative.

## **Self Calibration to the Input Data**

FVS will automatically calibrate its growth equations, by species, to match the input data unless this feature is "turned off" by user keywords or insufficient observations exist in the input data to calibrate the specific equation. To understand this feature, a basic understanding of FVS structure is necessary.

FVS growth relationships are broken into two categories: those for "small" trees, and those for "large" trees. In most variants the diameter break between a small and large designation is 3.0 inches dbh. The small tree growth relationships are height driven. Height growth is estimated first, then diameter growth is estimated from height growth. The large tree growth relationships are diameter driven. Diameter growth is estimated first, then height growth from diameter growth and other tree and stand variables. Around the 3.0 inch break point (or the appropriate break between the large and small tree relationships); growth estimates from the small and large tree equations are blended to assure a smooth transition between the two sets of relationships.

FVS is a forward predicting model. To calibrate the growth relationships, FVS "backdates" the stand by subtracting growth measurements, adding in recent mortality, growing the stand forward to the current inventory year, comparing the estimated tree attributes with the actual tree attributes at the inventory year, and computing adjustment factors based on the difference of actual and estimated values. Calibrated equations are (1) large tree diameter growth, (2) small tree height growth, (3) height-diameter relationships, and in some variants (4) the maximum stand density index. The large tree diameter growth equation for a species is adjusted if 5 diameter increments exist in the input data on trees whose backdated dbh is larger than 3.0 inches. The small tree height growth equation for a species is adjusted if 5 height increments exist in the input data on trees whose diameter is less than 5.0 inches. Height-diameter relationships are adjusted for any species which has 3 or more heights measured on trees which are 3.0" dbh or greater. The maximum stand density index is adjusted if the initial stand density index exceeds 90% of the initial maximum stand density index.

The self-calibration feature of FVS extends the geographic range over which the model can be used, assuming the same factors affecting growth in one area also affect growth in the same relative way in another area. If this assumption cannot be accepted, the only other option is to refit the relationships using data from the geographic area of interest. If this assumption can be accepted, then the model equations can be calibrated rather easily.

The diameter and height growth adjustment factors, called scale factors, are attenuated over time. The attenuation is asymptotic to one-half the difference between the initial value of the scale factor and 1. However, if there is a consistent bias in the scale factors for any species over a representative inventory of stands from a geographic area, the average value of the scale factors for the species can be entered into FVS as an equation multiplier using keywords. Multipliers entered with keywords are not attenuated over time. In effect then, the average scale factor becomes a new estimate of the model intercept, and the user has adjusted the growth equation to the particular geographic area. The suite of available FVS software provides users with a way of collecting and analyzing scale-factors so multipliers, if needed, can be easily determined.

## Summary

The Forest Vegetation Simulator is a versatile and powerful software tool available to forest managers. The model can be used to evaluate stand density management alternatives, but its potential for aiding land management decisions extends far beyond this single application. The suite of FVS software available, including the GUI interface, the model itself, visualization software, many auxiliary output processing programs, links to forest planning models, and so forth, make it an attractive choice to aid forest managers faced with making difficult land management decisions. Since the FVS growth equations can be readily calibrated to the input data, the geographic range of a particular FVS variant can be extended beyond the data used to develop the equations.

Although FVS is the growth and yield model endorsed and supported nationally in the United States, making it available to Canadian forest managers will require a significant effort. Development of FVS variants is underway for British Columbia, but these variants are years away from being readily available. Other Canadian Provinces are only beginning to hear about FVS and what it can do. Furthermore, use of existing United States variants by Canadian forest managers is hampered by the difference in measurement systems.

A concerted effort is needed to make FVS technology generally available in Canada. An initial step in this direction is a Memorandum of Understanding currently existing between the British Columbia Ministry of Forests and the United States Forest Service. This agreement provides for cooperation and communication between FVS specialists in the US and BC. It also provides for sharing experience and expertise relating to all facets of the FVS system. With efforts like these, FVS may soon become a reality for forest managers in the Canadian Provinces.

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