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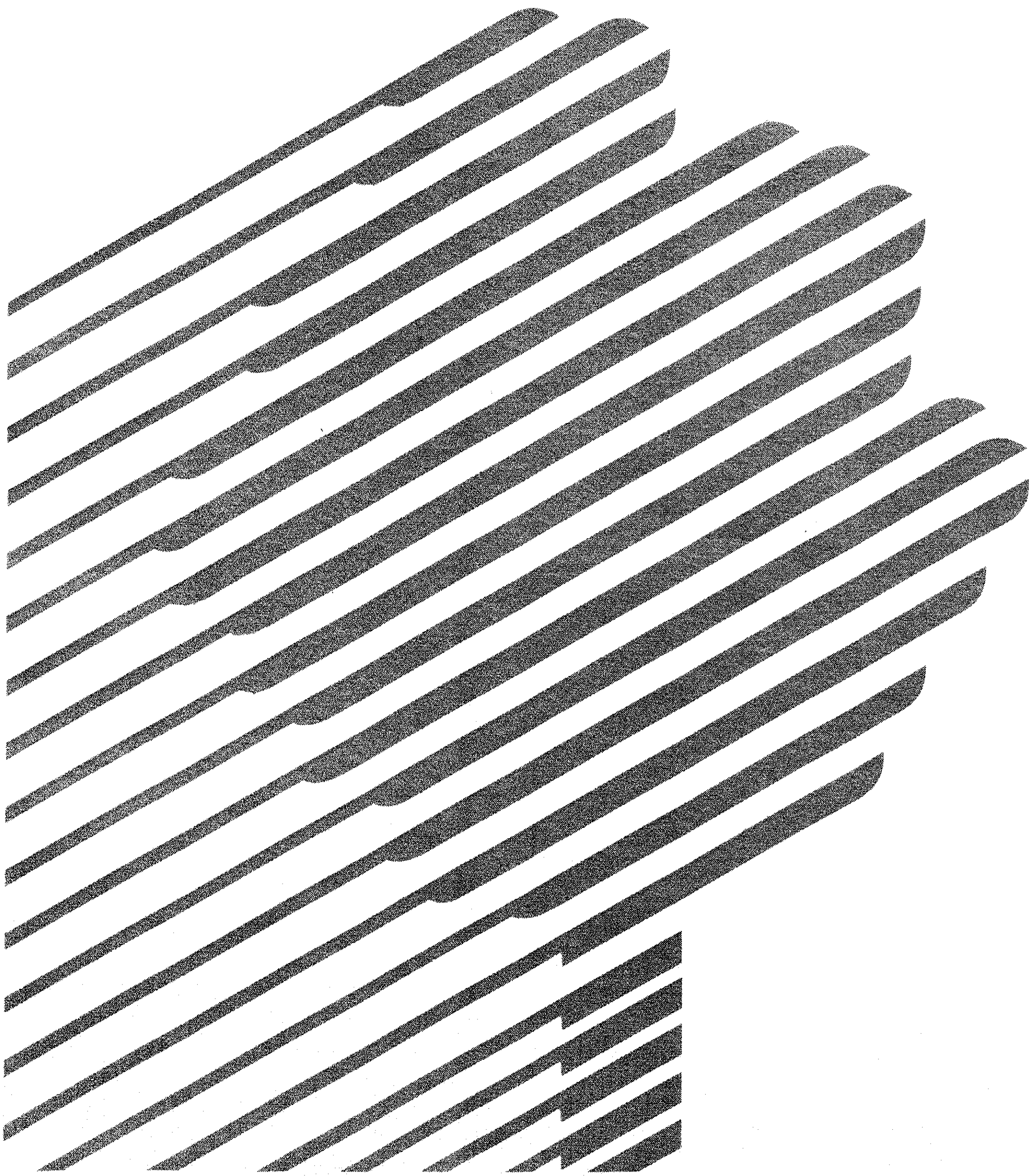
A Guide to the TWIGS Program for the North Central United States

Cynthia L. Miner, Nancy R. Walters, and Monique L. Belli



DISCLAIMER

TWIGS was developed at the North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service, (NCFES). The economic analysis routine was developed and added by the Department of Forest Resources, University of Minnesota (UMFR). The Forest Resources Systems Institute (FORS) provided partial funding for adding stocking guides and economic analysis enhancements.

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North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
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Preface

This guide describes the FORTRAN version of the TWIGS program. FORTRAN TWIGS 3.0 was developed for use on the IBM computer and on the Data General MV 4000 and MV 8000 computers. A previous version (2.01) was written in Apple Pascal and is still available. All versions of TWIGS are based on and use growth-and-yield equations from the mainframe program STEMS.

TWIGS was developed at the North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service. The economic analysis routine was developed and added by the Department of Forest Resources, University of Minnesota. TWIGS was adapted for the Data General in cooperation with Region 9 of the USDA Forest Service. Incorporation of stocking guides and enhanced economics into TWIGS was partially funded by the Forest Resources Systems Institute, which receives Federal financial assistance.

The evolution of STEMS and TWIGS has involved many people. Primary in the research were Gary Brand, David Belcher, Roland Buchman, Burton Essex, Stephen Fairweather, Jerold Hahn, Margaret Holdaway, Tim Krohn, Rolfe Leary, Allen Lundgren, Lewis Ohmann, Stephen Shifley, and Brad Smith. Programmers who helped develop and refine the TWIGS and STEMS software include Kevin Nimerfro, Kevin Low, Michael Steinbach, and David Kowalski. Ray Ellis, Timber Management, was instrumental in "custom-fitting" TWIGS for Region 9's use. The authors provided a link between the users and researchers, coordinating distribution and refinement of the software. Essential to the refinement of TWIGS were criticism and suggestions from many individuals from various agencies, industries, and organizations.

Contents

A GUIDE TO THE TWIGS PROGRAM FOR THE NORTH CENTRAL UNITED STATES

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Nancy R. Walters,
and
Monique L. Belli

TWIGS is a growth-and-yield simulation program with management and economic components developed for use in the North Central United States. Two variants are available: Lake States (Minnesota, Michigan, and Wisconsin) and Central States (Indiana, Illinois, and Missouri). As an individual-tree growth model, TWIGS projects the diameter-at-breast-height growth and the mortality of individual trees in the context of a stand, whether of single or mixed species and sizes.

The program can be used in evaluating the productivity and economic effects of different silvicultural prescriptions. TWIGS, thus, is useful to forest managers and planners as they make silvicultural and forest planning decisions and update stand inventories. Although TWIGS has several components and is fairly complex, with a little practice the user-friendly program can be used easily and creatively. The program, therefore, is also well-suited as a demonstration and teaching aid.

To operate TWIGS (fig. 1), the user enters a list of trees representing the stand to be projected; a companion computer program, TREEGEN, may be used to create this tree list. To simulate growth, TWIGS uses diameter-growth and natural mortality equations developed from permanent plots in the North Central United States. Projected yields are based on equations that estimate the volume of saw logs, pulpwood, and residue from the projected sizes

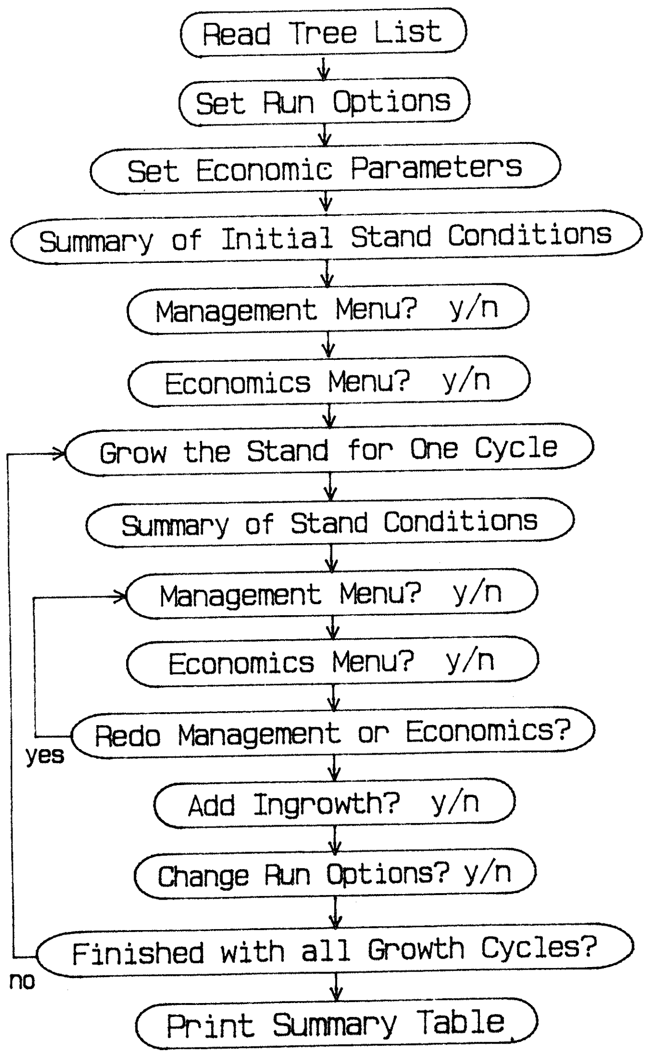


Figure 1.—*Flowchart of a TWIGS Projection.*

CYNTHIA MINER and **NANCY WALTERS**, formerly Foresters, North Central Forest Experiment Station, St. Paul, Minnesota; **MONIQUE BELLI** formerly Research Forester, North Central Forest Experiment Station, St. Paul, Minnesota.

of trees. From run menus provided by the interactive TWIGS program, the user chooses growth-simulation parameters (such as the number and length of growth cycles), values for economic analysis, actions for management, and characteristics for ingrowth.

During the growth projection, the user can manage the stand by choosing from a variety of silvicultural prescriptions. After management, a real or nominal economic analysis can be made to examine the internal rate of return, net present values, benefit/cost ratio, and other economic performance measures. The user also has the opportunity to add new trees (ingrowth) after each growth cycle. Stand reports show changes in productivity and volume after each cycle of growth and management simulation.

This paper describes the basic principles and technical aspects of the TWIGS program. For the novice TWIGS user, the guide explains how to use the program. (Users are assumed to be familiar with the hardware with which TWIGS is used.) With this guide in hand and the TWIGS program on the screen, those of you who are using the program for the first time should be able to do so without assistance. Users with previous TWIGS experience may find this guide provides new insights into the program. Detailed information about the program is in the appendices, including growth equations, coefficients, and validation tables. For further information, see the references listed in the bibliography. Source codes are available on diskette.

The following section describes the principles of TWIGS. Please look this section over before going on to the operating instructions for TREEGEN and TWIGS. You may wish to read these principles, particularly the cautions, once again carefully after first using the TWIGS program and later on for reference.

THE PRINCIPLES OF THE TWIGS PROGRAM

Forecasting Growth and Mortality

Growth and mortality equations are the core of TWIGS as a growth simulator. These equations were developed for the Lake States from measurements of 1,500 plots with 80,000 trees and for the Central States from measurements of 3,000 plots with 60,000 trees. Following is a general discussion of the equations used for the 31 species groups in TWIGS. See appendix A for a list of the species groups. Appendix B includes the mathematical model forms for growth, mortality, and crown ratio, along with the species-specific regression coefficients.

Growth Equation.—This equation annually estimates diameter growth for each sample tree and updates the crown ratio of the tree:

$$\text{Annual Diameter Growth} = \text{Potential Growth} \times \text{Competition Modifier}$$

Potential growth is predicted for each tree as if it were growing without competition. This growth varies by species and is calculated with tree-crown ratio, diameter at breast height (d.b.h.), and site index.

Competition modifiers reduce the potential tree growth to reflect stand competition based on stand basal area and the size of each tree in relation to the tree of average stand diameter.

Site Index.—TWIGS requires site index as an input for the potential growth equation. With both Central and Lake States TWIGS, the user can input one stand site index or different site indices for each species in the stand. Site index conversion tables in *Lake States* TWIGS will automatically convert stand site index to species site index (Carmean 1979, 1982; Carmean and Vasilevsky 1971). In *Central States* TWIGS, no site index conversion tables exist; if a stand site index is entered, this index is applied to all species on the tree list.

Tree Mortality.—TWIGS calculates this equation by estimating the probability of death for each tree in a given year. The tree's current d.b.h. and vigor are used to estimate mortality. The TWIGS program does not incorporate catastrophic mortality, such as from fire or insect epidemics, into the equation.

Model Assumptions and Applications

To obtain the best results from TWIGS and to know the programs limits, a user should be aware of the model's assumptions. Note that most of what follows can also be found in the cautions component of TWIGS.

A Regional Model.—TWIGS and its parent mainframe model, STEMS, are regional growth projection systems. Data used to develop the Lake States variant came from Michigan, Minnesota, and Wisconsin. Most of the data used to calibrate the Central States variant came from Indiana and Missouri. A small amount of additional data, however, came from western Kentucky and Tennessee, from southeastern Ohio and from northern Illinois (fig. 2).

Because the TWIGS data came from across each region, the program reflects the average species growth and mortality for the Lake or Central States regions, not for specific localities. The equations that estimate this growth and mortality have gone through intensive validation, substantiating the quality of the estimates at a *regional* level (Holdaway and Brand 1986). When TWIGS is used to estimate growth of one stand in a specific locale within a region, the actual growth may or may not be close to the TWIGS estimate of the average tree growth. TWIGS, therefore, should be used to compare the relative differences in growth, yield, and economic effects between alternative management strategies rather than to project exact growth and yields that will occur 10, 20, or 50 years from now. If the user requires localized estimates, methods have been developed for improving TWIGS estimates for local conditions with additional diameter-growth information (Smith 1983, Holdaway 1985, Gertner 1984).

Stand Conditions and Species.—Reliable results can be obtained with TWIGS on the average; nonetheless, the data used to develop the program

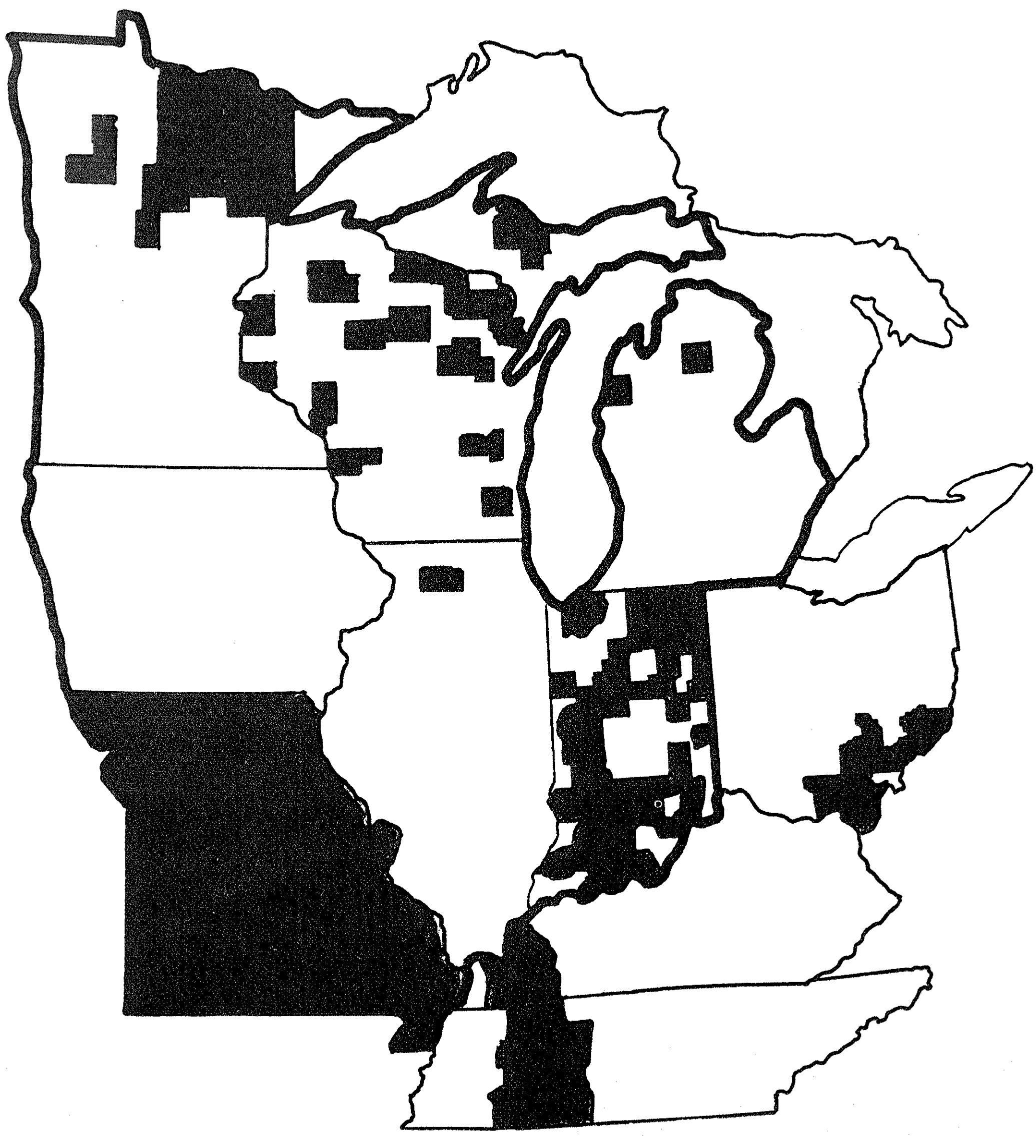


Figure 2.—*Location of data plots. Counties containing at least one plot are shaded.*

cannot reflect the complexity and variability of forest stands. Reasonable results should not be expected if the tree list used to initiate the projection does not fall within the range of conditions represented by the data that were used to develop the TWIGS projection models. To assure the best results with TWIGS:

- include at least 10 sampled trees per tree list,
- avoid projection of plantations in the Central States,
- avoid tree lists comprised predominantly of trees less than 2 inches d.b.h.,
- set the projection interval to 5 years or less, and
- limit the total projection to 30 years.

Below are stand-condition and species recommendations specific to the Central and Lakes States variants. Appendix C shows how well the species were represented by the data that were used to develop the TWIGS equations and serves as a rough guide to the reliability of equation sets for species and species groups.

Central States TWIGS was designed to estimate growth and mortality of forest-grown trees on sample plots in Missouri, Indiana, and Illinois. The data used in the development of the Central States models include:

- even-aged and uneven-aged, mixed hardwood forest stands and softwood stands of natural origin,
- site indices of 40 to 99 feet, base age 50 years (majority 65 to 75 feet),
- basal areas of 25 to 125 square feet per acre, and
- mean stand diameters between 2 and 22 inches (majority between 4 inches and 21 inches d.b.h.).

Species were not equally represented in the data base used in developing the Central States model. The species with greatest representation were the oaks, hard maple, and shortleaf pine. Eastern redcedar, yellow poplar, and tupelo/gum were poorly represented in the data base, and confidence in projections for these species is diminished accordingly. Best results are expected for species that are well represented in the data base and are growing within the range of stand and site conditions described above.

Lake States TWIGS was designed to estimate growth and mortality of forest-grown trees on sample plots in Michigan, Minnesota, and Wisconsin. More reliable results are expected from the northern portions of these states. Most of the stands used to develop Lake States TWIGS had:

- site indices of 45 to 75 feet, base age 50 years,
- basal areas of 25 to 150 square feet per acre, and
- mean stand diameters between 4 and 10 inches.

Species were not equally represented in the data base used in developing the Lake States model. Jack pine, red pine, and sugar maple were well represented; silver maple, white ash, and hickory were not. More confidence can be placed in projections of species that are well represented.

Species Groups.—To simplify reporting growth and mortality projection results, Lake States and Central States TWIGS classify trees into 31 species groups (appendix A). These species groups combine minor species with other species of the same genus or with those having similar silvical characteristics. Growth and mortality for the trees in each species group are estimated by one of 28 different equation sets in Lake States TWIGS and 22 different equation sets in Central States TWIGS. Some species groups, therefore, share the same projection equations, and trees in those groups grow and die identically.

For example, equations calibrated with shortleaf pine data in Central States TWIGS are used to estimate change for shortleaf pine trees *plus* trees in the "Virginia pine" group and the "other pines" species group. This is because insufficient data existed to fit unique equations for Virginia pine and some of the other softwoods. Projection of an occasional Virginia pine or white pine tree with the shortleaf pine equations would not make a significant difference. Central States TWIGS, however, should not be used to forecast the development of a real or hypothetical Virginia pine or white pine plantation.

"Virginia pine" and "other pines" are maintained as separate species groups in Central States TWIGS because some users expressed an interest in separating these volumes in output summaries and because equations specific to Virginia pine or other pines may be developed. The same situation exists for some other species groups that, like Virginia pine, were retained as separate groups to increase program flexibility and to make it easy to add equation sets.

Validation of Growth Equations

In the validation of *Lake States* STEMS, which also applies to TWIGS, Holdaway and Brand (1986) found that STEMS undergrows trees on the average by 0.06 inches in 10 years. On 71 percent of these trees, STEMS predicted the diameter to within 0.5 inches of the observed diameter after 10 years of growth. Likewise, the model overestimated stand basal area an average of 0.9 square feet per acre after 10 years of growth. On 72 percent of the plots examined, STEMS predicted the basal area within 10 square feet per acre of true value. See appendix D for detailed tables of predicted and observed values for diameters, basal area, and mortality. Preliminary results from the yet unpublished *Central States* STEMS evaluation are also in appendix D. An independent evaluation of TWIGS for Illinois forests is reported by Kowalski and Gertner (in prep.).

Volume Equations

In TWIGS, estimated board-foot, cord, and cubic-foot volumes are based on Upper Peninsula of Michigan equations for Lake States TWIGS (Raile *et al.* 1982) and Indiana equations for Central States TWIGS (Smith and Weist 1982). Volume equations and coefficients are in appendix E. Both sets of volume equations were developed from measurements of d.b.h., merchantable height, top diameter outside bark (top d.o.b.), site index, and tree class. Trees can fall into any of three condition classes (Doman *et al.* 1981):

- acceptable (code 20),
- undesirable (code 30), and
- cull (code 40).

The product class limits as set by the volume equations are pictured in figure 3 where:

Saw-log volume includes acceptable trees with a d.b.h. equal to or greater than 9 inches (softwood) or with a d.b.h. equal to or greater than 11 inches (hardwood). Minimum top saw-log diameters are 7 inches (softwood) or 9 inches (hardwood).

Pulpwood volume includes acceptable and undesirable trees with a d.b.h. equal to or greater than 5 inches (excluding the saw-log portion of acceptable sawtimber size trees, which is tallied under saw-log volume). Minimum top d.o.b. is 4 inches. One cord equals 79 cubic feet.

Total merchantable volume is the sum of the saw-log and pulpwood volume.

Residue includes volume in tops (less than 4 inches d.o.b. to a 1-inch d.o.b.), limbs, trees less than 5 inches d.b.h., and cull trees.

OPERATING THE TREEGEN PROGRAM

TREEGEN is a computer program, separate from TWIGS, that puts stand and tree information into a format that TWIGS can read (appendix F). TREEGEN creates tree lists for both Lake States and Central States TWIGS using lists of species names and codes. Because you will use TREEGEN to create a tree list before using TWIGS, the TREEGEN operating instructions are presented next. When running TWIGS, you will retrieve the tree list file created by TREEGEN.

This section begins with introductory information about TREEGEN, which is later explained in detail. Please read the entire section before you begin TREEGEN. One thing to keep in mind if you

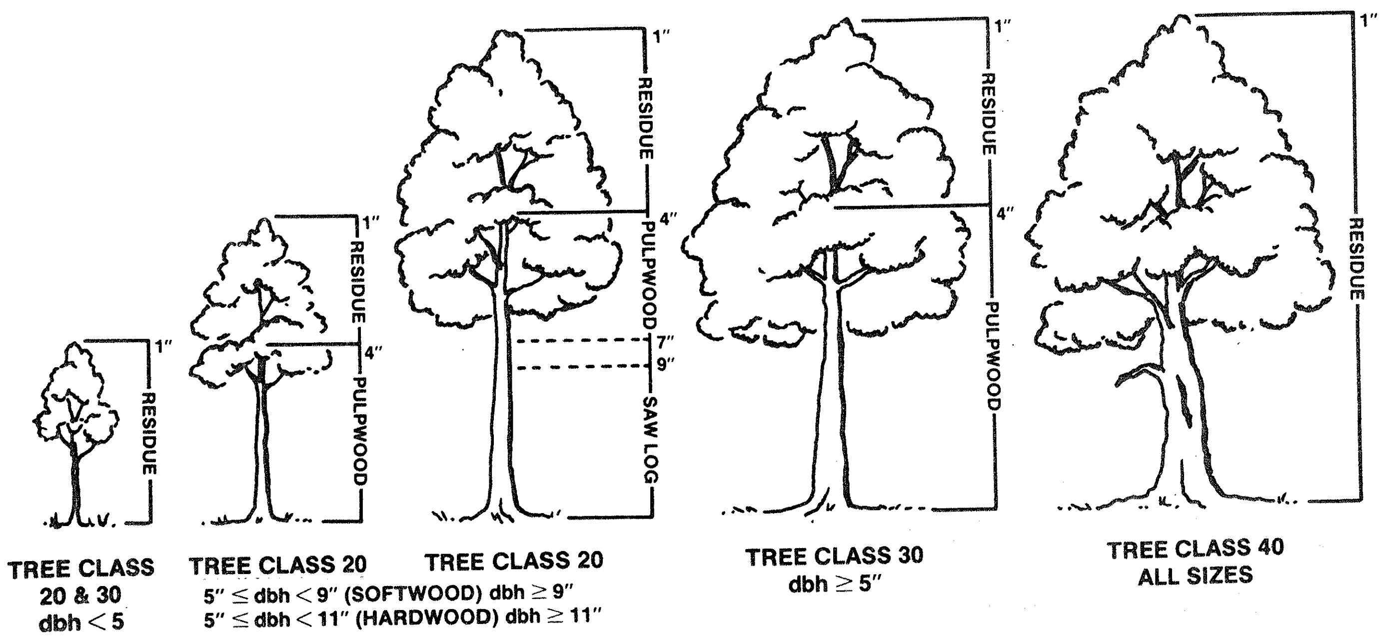


Figure 3.—*Product class limits used in TWIGS.*

use an option to print: be sure your printer is on; otherwise, the program may not function.

TWIGS was designed to use individual tree information from actual plots. For example, data taken from Forest Service plot cards, such as card code 8 from the silvexam tally sheet, can be used. Reliable, actual individual tree information will give the most accurate projection. Sometimes detailed information, however, may not be available or necessary for a TWIGS projection. In these instances, TREEGEN can create a tree list with stand level data and parameters that indicate the general shape of the diameter distribution of the stand. The user can choose from either a normal or Weibull diameter distribution to create a tree list that most closely approximates the desired stand. Whether the user enters the information with the individual tree entry or either of the two stand-level entry methods, the resultant tree lists are on a per acre basis and are in the identical format (fig. 4). Also for each method, a maximum of 500 trees can be entered into a list.

First, TREEGEN displays its inputs and outputs (these will be explained later in this section). Second, the program gives you options to select whether or not the list of species names and codes is to be shown on the screen, printed, or both. The species codes will be needed to enter trees; a printout, therefore, is convenient to have for reference. These codes are also provided in appendix A.

The third step in TREEGEN is to provide the following information:

- property name (up to 16 characters),
- stand name (up to 8 characters),
- year of measurement, and
- age at year of measurement (in an uneven-aged stand, use the age of the component of the stand that will most likely be managed).

After entering the above data, you are given the opportunity to change the values before going on to the following item:

- Stand site index. Enter the Forest Service species code (appendix A) and then the site index for that

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                               ::
::  TREE LIST FILE IS LSTLIST                                    ::
::                                                               ::
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


  17 Trees will be read for property "CLOQUET          ", STAND "COMP 284"
YEAR= 1987, AGE= 56, SITE INDEX FOR RED PINE     = 55.0
```

SEQ NUM	STEMS CODE	USFS CODE	STEMS GRP NAME	DBH	CROWN RATIO	TREES/AC	TREE STATUS	TREE CLASS
1	2	125	RED PINE	5.0	.0	28.0	1	20
2	2	125	RED PINE	6.0	.0	21.0	1	20
3	2	125	RED PINE	7.0	.0	28.0	1	20
4	2	125	RED PINE	8.0	.0	42.0	1	20
5	2	125	RED PINE	9.0	.0	28.0	1	20
6	2	125	RED PINE	10.0	.0	14.0	1	20
7	2	125	RED PINE	11.0	.0	49.0	1	20
8	2	125	RED PINE	12.0	.0	14.0	1	20
9	2	125	RED PINE	13.0	.0	14.0	1	20
10	1	105	JACK PINE	6.0	.0	7.0	1	20
11	1	105	JACK PINE	10.0	.0	21.0	1	20
12	1	105	JACK PINE	11.0	.0	7.0	1	20
13	26	375	PAP.BIRCH	5.0	.0	7.0	1	20
14	26	375	PAP.BIRCH	6.0	.0	7.0	1	20
15	26	375	PAP.BIRCH	7.0	.0	7.0	1	20
16	26	375	PAP.BIRCH	8.0	.0	7.0	1	20
17	3	129	WHITE PINE	8.0	.0	7.0	1	20

```
TREE LIST HAS  17 TREES, TPA= 308.0, BATOT= 132.9, DBH=  8.6
```

Figure 4.—*Tree list.*

species. In both Lake and Central States TWIGS, you can also enter *species-specific* site indices. Lakes States TWIGS, however, includes tables that will convert a *stand* site index to species-specific site indices if species-specific site indices are unavailable. Central States TWIGS does not have site-index conversion tables. If available for Lake or Central States, enter the actual species-specific site indices into TREEGEN. Actual data will always be more reliable than the data the TWIGS program would generate with conversion tables.

You will be given an opportunity to change the site index for each species. Once a species has been entered, however, the species cannot be deleted.

The fourth step in TREEGEN is to select the method you will use to create a tree list from the following:

- normal distribution,
- Weibull distribution, and
- individual tree.

Normal Distribution

This option is used for cases in which individual tree information is not available and generally for even-aged stands. A normal distribution typifies a bell-shaped "normal curve" with most of the trees centered around the mean diameter class (fig. 5).

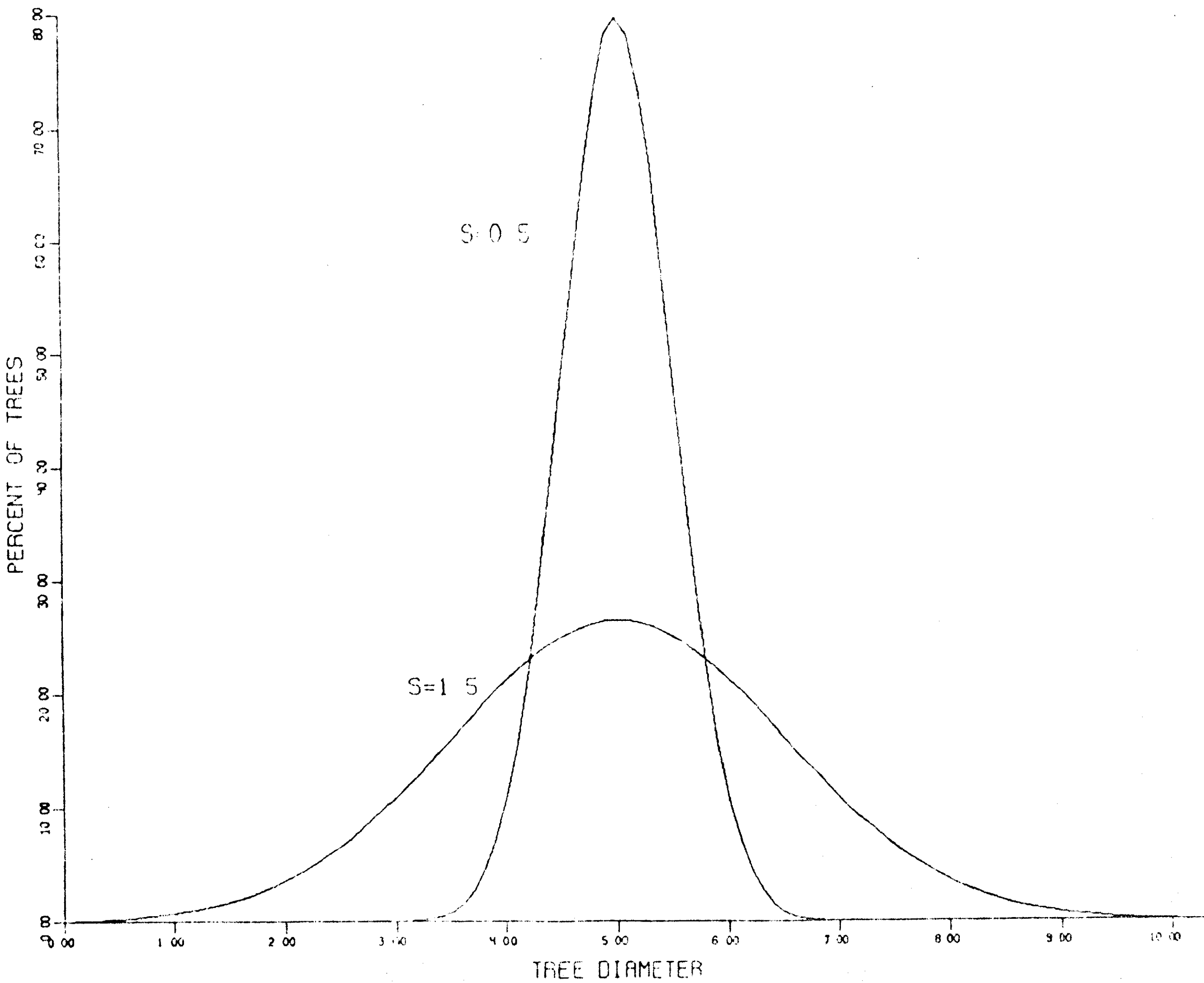


Figure 5.—*Normal distribution with two different standard deviations (s = standard deviation).*

Any number of species groups, each with a different normal diameter distribution, can be included in the tree list.

For the normal distribution option, you provide the following:

- Forest Service species code (appendix A),
- number of trees per acre represented by this species group, from 0.1 to 4,000 trees,
- average d.b.h. (1.0 inch-30.0 inches), and
- standard deviation. TREEGEN automatically defines the limits of the standard deviation so that it cannot be larger than

  [Average d.b.h.] /3.

  If the standard deviation is small, most of the trees will center about the mean diameter and a high and narrow bell-shaped curve results. Conversely, a large standard deviation indicates fewer trees are close to the mean diameter and a broad curve results (fig. 5).

  When you have completed an entry for a species and wish to add another entry, press "0" to accept the completed entry. You will then be shown a list of the new trees that have been added and will be given the opportunity to add another species group entry.

When finished with all normal distribution entries, press "Z." The tree list and a summary can then be printed, displayed, or both. If you wish to make changes, display or print the tree list so that you can identify the trees to be changed. The last step in TREEGEN is to type a file name for the tree list. You will use this file name while operating TWIGS.

Weibull Distribution

This option is for when individual tree information is not available and when the stand being created is even- or uneven-aged. The Weibull distribution produces a wide range of diameter distribution shapes. One shape is the reversed J-shaped curve of a balanced, uneven-aged stand, often having two or more age classes occupying an equal area (fig. 6a). Another shape is the humped-curve of an irregular uneven-aged stand that does not include all age classes; this curve often represents an unmanaged or high-graded stand (fig. 6b).

You provide the following information for each species group:

- Forest Service species code (appendix A).
- Number of trees per acre represented by this species group from 0.1 to 4,000 trees.
- *A Parameter* (valid entries are 0-29.9 inches). This is the location parameter that specifies the diameter of the smallest tree on the tree list. Changing this location parameter shifts, on a graph, the diameter distribution to the right or left of the original diameter axis (compare fig. 6c and 6d). Setting A = 1 is usually appropriate for young stands and even-aged stands.
- *B Parameter* (valid entries are > 0). Also called the scale parameter, this corresponds to the diameter of a tree at the 63rd percentile of the diameter distribution. In other words, 63 percent of the trees on the tree list will have diameters smaller than the sum of the parameters A and B. Conversely, 37 percent of the trees on the list will have diameters larger than the sum of parameters A + B. For given A and C parameters, higher values of B correspond to a flatter diameter distribution.
- *C Parameter.* As the shape parameter, this parameter defines the general shape of the diameter distribution. Specifically:

  C < 1 creates a reversed J-shape distribution (fig. 6a),

  C = 1 creates an exponential distribution (fig. 6e), and

  C > 1 creates a distribution with a single peak or hump (fig. 6b).

  The shape of the hump changes with the value of C, as follows:

  1 < C < 3.6 creates a long tail on the right (fig. 6b),

  C = 3.6 approximates a normal distribution (figs. 6c and 6d), and

  C > 3.6 creates a long tail on the left (fig. 6f).

For information on how to estimate parameters B and C from the mean and standard deviation of the stand, see Shifley and Lentz (1986).

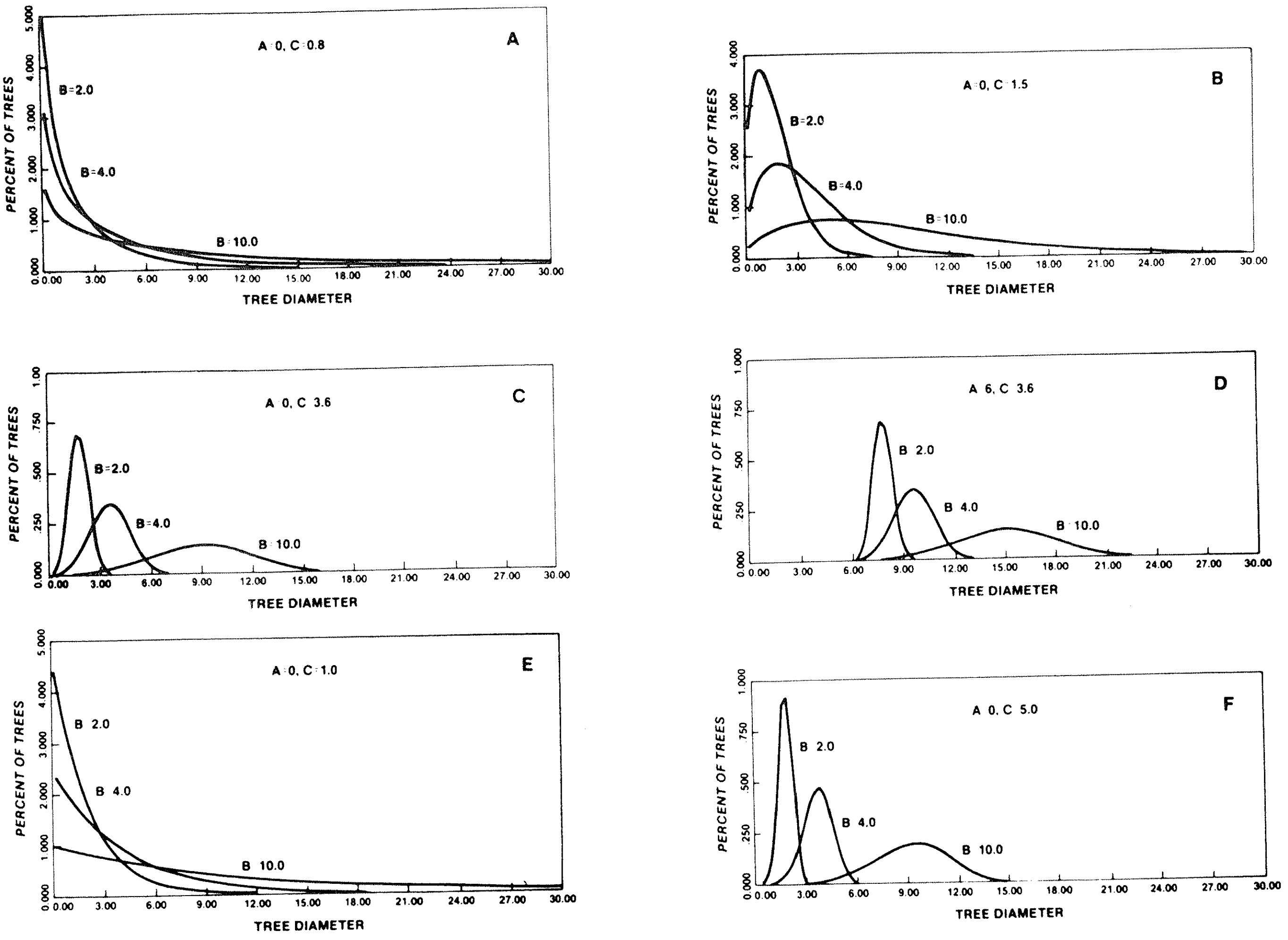


Figure 6.—*Weibull distribution: a. Reversed J shape; C < 1. b. Hump shape; C > 1. c. Low A parameter; C = 3.6. d. High A parameter; C=3.6. e. Exponential; C=1. f. With long tail on left; C > 3.6.*

When you have completed an entry for a species and wish to add another entry, press "0" to accept the completed entry. You will then be shown a list of the new trees that have been added and be given the opportunity to add another species group entry.

When finished with all entries, press "Z." At this point, if you wish to make changes, display or print the tree list so that you can identify the trees to be changed. The last step in TREEGEN is to type a file name for the tree list. You will use this file name while operating TWIGS.

Individual Tree

With this tree list entry option, you can create a tree list directly from a sample of individual trees in a stand. The sample can be from any size plot (variable or fixed-radius) and can represent one plot or a combination of plots. Forest Service silvexam stand tally sheet R9-2400-14 provides the necessary information for building a tree list.

Expansion Factor.—The tree expansion factor puts the sample trees on a per acre basis. The factor varies by the type and size of the plot and the number of plots being combined into one tree list. For instance, the tree expansion factor for a variable-radius plot varies with the size of the sample tree and is calculated with the following equation:

$$\text{Tree expansion factor} = BAF/(0.005454D^2\ n);$$

where BAF = basal area factor of the prism or single gauge,
n = the number of sample plots, and
D = diameter at breast height.

The user can supply the expansion factor or let TREEGEN calculate it. One of these options must be selected before any expansion factors are entered.

If TREEGEN is used to calculate the expansion factor, the user provides the BAF and n.

Calculating the expansion factor for a fixed plot is easier than for a variable-radius plot. For example, one sample tree on a tenth-acre fixed plot would represent 10 trees per acre. If five tenth-acre plots were being combined into one tree list, each tree would represent two trees per acre.

The expansion factor can minimize the amount of data entry. If more than one sample tree on the plot has the same characteristics (such as species, d.b.h., crown ratio, status, and tree class), those trees can be represented by one tree list entry. The expansion factor for that entry is multiplied by the number of sample trees being aggregated. For instance, if 12 live red pine trees are on a tenth-acre plot with a d.b.h. of 6 inches, tree class 20, and no crown ratio measured, only one of those 12 trees need be entered. The expansion factor for that one entry would be 120 (12 trees × 10 trees per acre).

Sample Trees.—The information required for each sample tree is:

- Forest Service species code (see appendix A),
- tree d.b.h. (1.0-30.0 inches),
- crown ratio code (0.0-9.9; 0.0 = not measured). An optional variable, the crown ratio is defined as the percent of the total height of the tree in live crown. The codes 1, 2,..., 9 represent crown ratios of 1-10 percent, 11-20 percent,..., 81-100 percent, respectively. If 0.0 is entered, TWIGS automatically calculates the crown ratio. See appendix B for the crown ratio equation and coefficients.
- Expansion factor (number of trees per acre from 0.1 to 4,000 trees).
- Tree status (1=live, 2=cut, 3=dead).
- Tree class (20=acceptable, 30=undesirable, 40=cull).

After you provide the above characteristics, indicate how many sample trees have these characteristics. To expedite this process, constants can be assigned. When the tree list is complete, the stand summary can be printed or displayed. At this point, you may make changes. The last step in TREEGEN is to type a file name for the tree list. You will use this file name when you operate TWIGS.

OPERATING THE TWIGS PROGRAM

We advise first-time TWIGS users to read all of the instructions for TWIGS before beginning to run the program. Before you begin, have ready a computer file that contains a list of trees representing the stand to be projected. This file can be generated with TREEGEN, as previously described.

The TWIGS components are described in the order in which they appear in the program. As the components are discussed, 14 basic steps used to operate TWIGS are explained. In these steps, you select parameters and values that characterize the projection of a stand. Appendix G shows an example projection for the 30-year-old red pine stand that is on the distribution disk for Lake States TWIGS (file name LSTLIST).

Note that you will only be able to move forward in TWIGS. To exit the program, move forward until you get to the run options where you select option "J" to end TWIGS. As in TREEGEN, be sure that the printer is on if you select the printing option, or TWIGS may not function. Also note, all input and output are on a per acre basis.

Cautions

After displaying a software disclaimer, the TWIGS program gives you an opportunity to see the cautions described in this guide's section on forecasting growth and mortality.

> **Step 1**
> Indicate if you want to see a list of cautions for applying TWIGS: Y = yes and N = no.

Run Options

TWIGS uses a menu of run options to characterize the projection (fig. 7). In the run options, the number of growth cycles, the length of each growth cycle, and other run characteristics are determined. These options can be changed at the beginning and periodically throughout the program run. Each option has a default value that is used unless the user changes it. Once a run option is changed, the new value is used as the default for subsequent TWIGS runs.

```
==========================================================================
   R U N   O P T I O N S

 OPTION   VALUE   DESCRIPTION
==========================================================================
   A        1     Years in projection interval
   B       10     Years in growth cycle
   C        2     Number of cycles
   D        1     Management: 0=off, 1=on
   E        1     Economic evaluation: 0=off, 1=on
   F        0     Message level: 0=normal,other=debug
   G        1     0=Only screen is used, 1=printer is used
   H        2     0=No volumes, 1=Volumes in INT. 1/4", 2=Volumes in SCRIBNER
   I        1     Diameter classes:
                    0=No diameter class breakouts
                    1=Three classes: 0-4.9, 5.0-10.9, 11.0+
                    2=Five classes: 0-2.9, 3.0-4.9, 5.0-10.9, 11.0-16.9, 17.0+
                    3=User-specified diameter classes
   J        0     1=Immediately end the program
```

Figure 7. *Menu of Run Options.*

Step 2
Run Options. Select the options that will characterize the projection to be made. When you are finished, press "Z."

Following is a description of the run options. Note that if you want to end the program immediately, change option "J" from 0 to 1. Additionally, option "G" indicates if a printer is to be used. If option "G" has the value of 1 and the printer is not on line, the program will not run.

Option A. YEARS IN PROJECTION INTERVAL is the frequency at which the growth and mortality equations will be applied. For example, with a projection interval of 1 year, the equations are applied annually. With a projection interval of 5 years, the equations are applied every 5 years and the average annual growth and mortality over that 5-year period are used.

Because of the effect of averaging, more years in a projection interval mean less accurate growth predictions. IBM-PC and Apple users will notice that more years in a projection interval also mean faster TWIGS calculations; for some TWIGS users, therefore, a trade-off exists between accuracy and speed. In any case, we suggest that the projection interval not be set over 5 years; higher intervals substantially reduce the quality of the projections (see the validation section).

Option B. YEARS IN GROWTH CYCLE determines how often you will receive a stand and stock report during the projection and have the opportunity to manage the stand. For example, a 10-year growth cycle means that a stand report is presented at the end of every 10 years; at this point, you have the options to manage the stand, see an economic analysis, and add ingrowth. During this 10-year period, growth and mortality equations will be applied as often as specified for YEARS IN PROJECTION INTERVAL (option A). If option A was set to 5 years, then equations will be applied twice in a 10-year growth cycle. Note that the YEARS IN GROWTH CYCLE must be a multiple of YEARS IN PROJECTION INTERVAL.

Option C. NUMBER OF CYCLES determines how many growth cycles there will be during a TWIGS run. For example, three growth cycles of 10 years each will give a projection period of 30 years. Moreover, if the user chooses a PROJECTION INTERVAL of 5 years, then the growth and mortality equations will be applied six times during that 30-year period.

Option D. If the MANAGEMENT option is turned on, you have the opportunity to manage the stand during each growth cycle. If this option is turned off, you will have no opportunity to manage the stand before the first growth cycle. This and other options, however, can be changed periodically throughout the run.

Option E. The ECONOMIC EVALUATION option can be turned off if an economic evaluation is not needed.

Option F. The MESSAGE LEVEL can be used by a programmer to debug TWIGS.

Option G. The PRINTER option allows TWIGS to be used without a printer.

Option H. The VOLUME option determines if volumes will be calculated, and whether in International ¼ inch rule, Doyle rule (Central States), or Scribner Decimal C rule (Lake States).

Option I. DIAMETER CLASSES creates diameter-class limits for stand reports. These same limits can also be used for diameter-class thinning when simulating management.

Option J. The TERMINATION option, when changed from **0** to **1**, ends the program immediately.

Tree List

The tree list is usually generated with the TREEGEN program, described earlier. If the tree list is on file, you access the file for TWIGS by the following steps.

Step 3
Species Names and Codes. Press "Y" if you want to see a list of species names and codes. You also have the option to print the list. The printed list is convenient for later reference, particularly if you want to add trees later with the ingrowth component. The species list is also shown in appendix A.

Step 4
Tree List File Name. Type the tree list file name to enter it into the projection, or press "D" to see a directory of files from which to choose a tree list file.

Step 5
Tree List Presentation. Choose to see the tree list or move directly to the next component of TWIGS. If in the run options you decided not to use the economics component, go to page 20. If you chose to do an economics evaluation, go to the following Economics section.

Economics

The TWIGS economic component is designed to help evaluate the economic performance of project alternatives. The user should understand the conceptual basis of financial analysis and the data inputs required for applying the results. Background information on financial analysis concepts and applications and forestry project analysis can be found in: Guide to Forestry Investment Analysis (Rose *et al.*, 1988). An example of conducting an investment analysis with TWIGS is in Blinn *et al.* (in prep.).

TWIGS can be used to organize and develop a cash-flow table and to set stumpage rates for various products and species. All cash flows are entered in base-year dollars on a per acre basis as positive values and are assumed to take place at the *beginning* of the year of occurrence.

TWIGS Economic Analysis Inputs.—Before you select options from the Economics Menu, the initial stumpage rate default values are displayed (fig. 8). The Economics Menu (fig. 9) is then shown with the economic parameters that are to be defined. This is where the stumpage-rate default values can be changed.

Step 6
Economics Options. Select the economics options (fig. 9) for characterizing your economic evaluation. Program default values have been set for appropriate options. If not changed, these default values are used for the economic analysis. Once changed, the option value is retained and becomes the new default value for subsequent TWIGS runs. Type "Z" when you are finished selecting options, which are described next.

Options A, B, and C set sawtimber, poletimber, and residue stumpage prices. The default values apply to all species, unless otherwise indicated in Option D. New stumpage rates for all species may be entered by selecting the appropriate option. Product class limits are shown in figure 3.

Option D sets individual sawtimber, poletimber, and residue stumpage rates for up to 10 species. To change individual species-product stumpage rates, enter the appropriate three-digit Forest Service species code (appendix A), select the products to be altered, and enter the new stumpage rate. Individual stumpage rates set in this option are *not* retained for subsequent TWIGS runs.

Option E sets the annual real stumpage price inflation rate. The default value is 0 (zero) percent.

```
DEFAULT STUMPAGE RATES:

        SAWTIMBER      POLETIMBER     RESIDUE
        $/1000 BDFT    $/CORD         $/100 CUFT
        -----------    -----------    -----------
        $     29.00    $      6.00    $       .00
```

Figure 8. *Initial stumpage-rate default values as defined by TWIGS.*

```
ECONOMICS MENU:

OPTION  VALUE  DESCRIPTION
  A   $ 29.00  Stumpage rate per 1000 board feet of sawtimber (default value).
  B   $  6.00  Stumpage rate per cord of poletimber (default value).
  C   $   .00  Stumpage rate per 100 cuft of residue (default value).
  D            Change stumpage rates for a species ( 0 set, 10 available).
  E         0  Annual stumpage price inflation rate (in percent).
  F         1  Set option to print cash flow table
               0 = Do not display table
               1 = Display table
  G      1987  Base year for economic analysis (less than or equal to 1987).
  H      5.00  Real discount rate (in percent).
  I            See, add or edit the diary of cost and revenue activities (per
               acre).
  J         0  Set option to discount the cash flows.
               0 = Discount all cash flows through 2007.
               1 = Do not consider cash flows beyond the
                   current projection year (1987).
  K            Show economic evaluation on screen.
  L            Show economic evaluation on screen & printer.

  Type option letter or type  Z  to continue:
```

Figure 9.—*Economics Menu with default values.*

With this option, you can enter a real rate of increase in stumpage rates, based upon historical data or other information. The value entered is applied to all species-product stumpage prices incorporated in the analysis.

Option F gives you the opportunity to suppress or print the cash-flow tables. The individual cash-flow table is displayed 5 years at a time.

Option G sets the base year to which all cash flows are discounted in the economic analyses. This option must be set to a year that is less than or equal to the current year of the projection. The default value is the measurement year from the tree list data file. The base year may be changed to a year previous to the measurement year to allow past costs and revenues to be considered. *If you plan to input past activities, change the base year (Option G) before entering these individual activities (Option I).* For any activity, a year of occurrence previous to the base year is not accepted by the program. If the Soil Expectation Value criterion is to be used when comparing investment alternatives, the base year should be set to the year of planting.

Option H, when selected, allows you to choose the type of economic analysis and the rate for discounting all cash flows. TWIGS will perform either a *real* or a *nominal* analysis, depending upon whether or not the user chooses to incorporate a general inflation rate into the analysis. A real analysis assumes that all input values are in real terms, net of inflation. A nominal analysis combines a real discount rate with a general inflation rate. Further information on determining an appropriate discount rate may be found in Rose *et al.* (in prep.). All cash flows are discounted to the beginning of the base year when a TWIGS economic analysis is calculated.

> *Real analysis* requires the real discount rate (0.01 to 100 percent)
>
> *Nominal analysis* requires the nominal discount rate followed by a general inflation rate. TWIGS automatically calculates the assumed real rate (fig. 10, option H).

Option I displays the diary of cost and revenue activities, allowing addition or editing of the activities. All cash flows should be entered on a per acre basis in the year in which they occur. A maximum of 40 total cash-flow activities (including sale incomes described below) may be entered in the cash-flow diary for any analysis. All cash flows are assumed to occur at the beginning of the indicated year. Cost and revenues from this diary are *not* retained for subsequent TWIGS runs.

Whenever the user prescribes TWIGS management treatments that result in timber removal, a cash-flow entry entitled "sale income" is automatically entered into the cash-flow diary. This entry displays the actual cash flow that occurred and the appropriate stumpage inflation rate (option E). In the management portion of TWIGS, harvested trees may be uncut. If the trees are uncut in management, the revenue generated by the timber harvest will be automatically removed from the diary.

Note that sale-income diary entries are calculated with stumpage prices that are set before the management treatment is applied. If stumpage prices are changed after management and you want the previously calculated sale income(s) to reflect the new stumpage prices, you must hand calculate and edit the sale income diary entry(s).

If no cash-flow activities have been entered into the diary, you may type either "1" to enter the first activity or "0" to return to the economics menu (fig. 11). After entering an activity, the current state of the diary is shown with the options to either edit an existing activity, add a new activity, or return to the economics menu (fig. 12). To *edit* an activity,

```
ECONOMICS MENU:
OPTION  VALUE  DESCRIPTION
  A    $ 29.00  Stumpage rate per 1000 board feet of sawtimber (default value).
  B    $  6.00  Stumpage rate per cord of poletimber (default value).
  C    $   .00  Stumpage rate per 100 cuft of residue (default value).
  D             Change stumpage rates for a species ( 0 set, 10 available).
  E          0  Annual stumpage price inflation rate (in percent).
  F          1  Set option to display cash flow table
                0 = Do not display table
                1 = Display table
  G       1987  Base year for economic analysis (less than or equal to 1987).
  H       7.10  Nominal discount rate (in percent).
          2.00  General inflation rate (in percent).
  I             See, add or edit the diary of cost and revenue activities
                (per acre).
  J          0  Set option to discount the cash flows.
                0 = Discount all cash flows through 2007.
                1 = Do not consider cash flows beyond the
                    current projection year (1997).
  K             Show economic evaluation on screen.
  L             Show economic evaluation on screen & printer.

 Type option letter or type  Z  to continue:
```

Figure 10.—*Economics menu reflecting a 7.1-nominal discount rate and a 2-percent general inflation rate, as set under option H.*

```
THERE ARE NOT COST OR REVENUE ACTIVITIES SPECIFIED YET.

Type 1 and press <ENTER> to add a new activity, or
Type 0 and press <ENTER> to continue:
```

Figure 11.—*Initial menu for adding the first cost or revenue activity.*

```
DIARY OF COST AND REVENUE ACTIVITIES:

      (ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY       NAME          YEAR(S)        COST     REVENUE   INFLATION RATE
-----   -------------   ----------    --------   ---------  --------------
  1     ADMIN. COSTS    1987-1997       21.73       .00          .00
  2     INVENTORY         1987          75.00       .00          .00

Type the number of the activity to be edited and press <ENTER> or Type 3
and press <ENTER> to add a new activity, or
Type 0 and press <ENTER> to continue:
```

Figure 12.—*Menu for editing or adding activities after two activities have been entered.*

you must enter the sequential number of the activity when the diary is shown. All information for that activity must be reentered.

To *add* an activity, enter the next sequential number indicated by the program. Cost and revenue activities will be automatically ordered so that all costs will be printed in the diary before any revenues, regardless of the order in which they are entered. All cash flows are entered per acre in base-year dollars.

For each activity, you are asked to enter the following information:

- Type of activity: 1=cost and 2=revenue.
- Descriptive name up to 12 characters in length.
- Additional interest rate above or below the general inflation rate (if appropriate). This allows you to inflate or deflate activities that historically change at a different rate than the general inflation rate. For example, in a real analysis where the general inflation rate is implied to be 0 (zero) and the desired activity inflation rate is 1.5 percent, enter 1.5 for the additional interest rate. For a nominal analysis, if the general inflation rate is 2 percent and the desired activity inflation rate is 1.5 percent, enter −0.5 for the additional interest rate.
- Type of occurrence: 1=single, 2=annual, and 3=periodic. All activities and their associated cash flows are assumed to take place at the beginning of the specified year of occurrence.

Single Occurrence is an activity that occurs once during the projection, such as land cost. You provide the *year of occurrence* (greater than or equal to the current base year and less than or equal to the last year of the projection) and the per acre *cash flow* in base-year dollars.

Annual Occurrence is an activity that occurs in each year for 2 or more consecutive years with the same cash flow occurring every year, such as property taxes. You provide the *year the activity first occurs* (greater than or equal to the base year and less than the last year of the projection), the *year the activity last occurs* (greater than the beginning year and less than or equal to the last year of the projection), and the per acre *cash flow* in today's dollars.

Periodic Occurrence is an activity that occurs more than once but not in consecutive years or that occurs in consecutive years with varying cash flows, such as sale administration. You provide the *number of times the activity occurs* and the appropriate per acre *cash flow* for each year of occurrence. *Years of occurrence* may be entered in any order and will be reordered sequentially by the program.

A periodic activity may occur every year for the length of the projection. Because activities are assumed to occur at the beginning of each year, multiple occurrences for an activity in the same year are not allowed. After each activity is entered, TWIGS checks for multiple occurrences so that the user can correct the entry before returning to the economics menu.

Option J specifies if future cash flows are to be discounted. Zero ("0") is entered to consider all cash flows through the end of the projection. All past, present, and future cash flows, therefore, can be incorporated into the analysis. One ("1") is entered when cash flows are to be considered only through the current projection year; thus, the user needs to only consider past and present cash flows. For instance, you might enter a "1" for option J if you are considering clearcutting the stand at the current projection age and want to only evaluate cash flows that could have occurred before and at the time of liquidation. If the current year is equal to the base year, option J is automatically set to "0" (zero).

Option K requests an economic analysis and indicates that output reports will be shown only on the screen.

Option L also requests an economic analysis but indicates that the output reports will be simultaneously shown on the screen and the printer. If the printer was set to off when the initial run options were set, the analysis will still be printed when this option is chosen. Be sure to turn the printer on if you select the print option.

Outputs from the Economic Analysis.— Following is a description of the economic analysis output. Appendix G shows examples of this output in which a real analysis with a discount rate of 5 percent was selected with the base year in 1987. The stumpage price inflation rate was set at 1.2 percent.

The *summary of economic analysis inputs table* (fig. 13) summarizes the input values from sale of timber and entries from option I. The two sale incomes were calculated and entered in this table by TWIGS after management treatments were prescribed.

The *annual cash-flow table* (fig. 14) contains the data necessary to calculate the various measures of investment performance. The table is primarily a listing of the cash-flow amounts for each year of the project, incorporating inflation where appropriate. The cash-flow tables also present total expenditures and receipts and net revenues for each year in the analysis.

The table for the *profile of net present values* (fig. 15) for the investment at various discount rates allows the user to assess the effect of different discount rates used in the analysis on net present value. For a nominal analysis, the table includes columns for both real and nominal discount rates.

The measures of *project performance* (fig. 16) are calculated at the user-supplied discount rate. These investment performance measures include: (1) net present value (NPV), (2) equivalent annual income (EAI), (3) soil expectation value (SEV), (4) benefit/cost ratio, (5) payback period, and (6) real internal rate of return. If a nominal analysis is chosen, the nominal internal rate of return is also listed. Definitions and interpretations of these measures of performance can be found in Rose *et al.* (in prep.).

The *sensitivity analysis* table (fig. 17) shows the sensitivity of the performance measures NPV, EAI, and SEV to a 10-percent change in the input values. Increases in costs or decreases in revenues will decrease NPV, EAI, and SEV by the amounts indicated in the table. Conversely, decreases in costs or increases in revenues will increase the performance measures. The larger the amount indicated in the table, the greater the impact of a change in the initial cash flow.

The amount of change in NPV, EAI, and SEV resulting from something other than a 10-percent change in input cash flow values can be calculated directly from the sensitivity analysis table. For example, a 20-percent change would double the values in the table; a 30-percent change would triple them; and a 5-percent change would halve them.

The *risk analysis* table (fig. 18) shows the percent change, up to 100 percent, required for each input cash-flow value to force NPV to exactly $0.00 (zero). When the percent change equals 100 percent and the dollar change is less than the calculated NPV, the input variable will not alone alter the overall project enough to make NPV $0.00 (zero).

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	YEAR 1992	1993	1994	1995	1996
Buy Land	.00	.00	.00	.00	.00
Property Tax	1.09	1.14	1.18	1.23	1.28
Sale Prep.	.00	.00	.00	.00	.00
Sale Admin.	.00	.00	.00	.00	.00
TOT ANN COST	1.09	1.14	1.18	1.23	1.28
CUM TOT COST	392.97	394.11	395.29	396.52	397.81
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	.00	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-1.09	-1.14	-1.18	-1.23	-1.28
CUM NET REV	-310.02	-311.16	-312.34	-313.57	-314.85

Figure 13.—*Summary of the economic analysis input values.*

ECONOMIC ANALYSIS INPUTS

NOMINAL DISCOUNT RATE	7.00%
GENERAL INFLATION RATE	4.00%
STUMPAGE PRICE INFLATION RATE	1.20%
BASE YEAR FOR THE ANALYSIS	1987
END YEAR FOR THE ANALYSIS	2007

DIARY OF COST AND REVENUE ACTIVITIES:

(ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY	NAME	YEAR(S)	COST	REVENUE	INFLATION RATE
1	Buy Land	1987	300.00	.00	.00
2	Property Tax	1987-2007	.90	.00	.00
3	Sale Prep.	1987	65.00	.00	.00
		2007	65.00	.00	.00
4	Sale Admin.	1987	22.00	.00	.00
		2007	22.00	.00	.00
5	Sell Land	2007	.00	300.00	.00
6	SALE INCOME	1987	.00	82.95	1.20
7	SALE INCOME	2007	.00	987.07	1.20

Figure 14.—*Portion of a cash flow table.*

PROFILE OF NET PRESENT VALUE (NPV) FOR THE INVESTMENT AT VARIOUS DISCOUNT RATES

(INVESTMENT LENGTH = 21 YEARS)

(NPV VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

REAL RATE	NOMINAL RATE	NPV
.00%	4.00%	$ 1143.06
2.00%	6.08%	$ 666.91
4.00%	8.16%	$ 351.89
6.00%	10.24%	$ 141.83
8.00%	12.32%	$ .75
10.00%	14.40%	$ -94.70
12.00%	16.48%	$ -159.69
14.00%	18.56%	$ -204.24
16.00%	20.64%	$ -234.95
18.00%	22.72%	$ -256.25
20.00%	24.80%	$ -271.09
22.00%	26.88%	$ -281.49
24.00%	28.96%	$ -288.80
26.00%	31.04%	$ -293.96
28.00%	33.12%	$ -297.62
30.00%	35.20%	$ -300.22
32.00%	37.28%	$ -302.07
34.00%	39.36%	$ -303.38
36.00%	41.44%	$ -304.32
38.00%	43.52%	$ -304.98
40.00%	45.60%	$ -305.44
42.00%	47.68%	$ -305.77
44.00%	49.76%	$ -305.99
46.00%	51.84%	$ -306.15
48.00%	53.92%	$ -306.25
50.00%	56.00%	$ -306.31

Figure 15.—*Profile of net present values.*

INVESTMENT PERFORMANCE ANALYSIS

NOMINAL DISCOUNT RATE = 7.00%   GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

NET PRESENT VALUE (NPV)	$	511.62
EQUIVALENT ANNUAL INCOME (EAI)	$	34.02
SOIL EXPECTATION VALUE (SEV)	$	1179.49
BENEFIT/COST RATIO		2.14
YEARS TO PAY BACK AT DISCOUNT		20 YEARS
REAL INTERNAL RATE OF RETURN		8.01%
NOMINAL INTERNAL RATE OF RETURN		12.33%

Figure 16.—*Project performance table.*

SENSITIVITY ANALYSIS

(SENSITIVITY OF PERFORMANCE TO A 10% CHANGE IN INPUT VALUES)
NOMINAL DISCOUNT RATE = 7.00%   GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

ITEM CHANGED	NPV CHANGE	EAI CHANGE	SEV CHANGE
Buy Land	$ 30.00	$ 2.00	$ 69.16
Property Tax	$ 1.44	$ .10	$ 3.33
Sale Prep.	$ 10.18	$ .68	$ 23.47
Sale Admin.	$ 3.45	$ .23	$ 7.94
Sell Land	$ 16.99	$ 1.13	$ 39.16
SALE INCOME	$ 8.30	$ .55	$ 19.12
SALE INCOME	$ 70.95	$ 4.72	$ 163.57

Figure 17.—*Sensitivity of three performance measures.*

RISK ANALYSIS

(INPUT VALUE CHANGES WHICH WILL MAKE NPV EXACTLY EQUAL TO $0.00)
NOMINAL DISCOUNT RATE = 7.00% GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

ITEM CHANGED	PERCENT CHANGE	DOLLAR CHANGE
Buy Land	100.00%	$ -300.00
Property Tax	100.00%	$ -14.43
Sale Prep.	100.00%	$ -101.81
Sale Admin.	100.00%	$ -34.46
Sell Land	-100.00%	$ -169.87
SALE INCOME	-100.00%	$ -82.95
SALE INCOME	-72.11%	$ -511.62

Figure 18.—*Risk analysis table.*

Stand Summary Report

Before growth and management are simulated, TWIGS presents a stand conditions table (fig. 19) and, if you chose the volume option, stand volumes (fig. 20). If in the run options, you decided not to use the management and economics components, go to the Growth Simulation section on page 25. If you selected to use economics only, go to the Economics and Management Repeated section on page 23. For users managing the stand, proceed to the following section on management.

Management

During management, the screen displays the current stand statistics and a management menu (fig. 21), and you select actions from the menu. TWIGS will make any indicated cut and print a record of the cut. The current stand statistics are displayed after each cut. The menu is shown again so you can continue with the projection or simulate another management action to refine the previous action or experiment with several actions.

Note: if you chose to use the economic option, then in this component, when all management is completed for the growth cycle, the stumpage value of all trees cut during the cycle is computed and automatically entered into a diary of cost and revenue activities for economic analysis. The sale income and the residual stand value will be shown on a per acre basis for saw logs, pulpwood, residue, and total volumes.

Step 7
Management Decision. Indicate if you will manage or skip management. If you choose not to manage, go to step 10.

Within the management component of TWIGS, users may view selected stocking guides that allow visual tracking of management effects on basal area and number of trees per acre. Using this stocking guide option (action K) requires either a graphics monitor or a graphics card for a monochrome monitor.

Step 8
Graphics Capabilities. The first time management is accessed, indicate if you have graphics capabilities (graphic monitor or a graphics card for a monochrome monitor).

Step 9
Management Simulation. The current stand statistics and management menu are displayed (fig. 21), and you select from the options. When management has been completed, press "Z" to continue the projection.

Current Stand Statistics.—These statistics describe live and cut trees on a per acre basis. The statistics presented are: number of trees

REPORT FOR STAND "BACK40". YEAR= 1987. INITIAL CONDITIONS.
AGE= 30, CYCLE= 0, SITE INDEX FOR RED PINE = 60.0

SPECIES GR.	LIVE TREE/AC	BA/ ACRE	AVG DBH	AVG CAI	CUT TREE/AC	CUT BA/AC	MORTALITY TREE/AC	MORTALITY BA/AC	GROUP SI
JACK PINE									
.0- 4.9	95	6.2	3.4	.00	0	.0	0	.0	60.0
5.0-10.9	0	.0	.0	.00	0	.0	0	.0	
11.0+	0	.0	.0	.00	0	.0	0	.0	
GROUP TOTALS	95	6.2	3.4	.00	0	.0	0	.0	
RED PINE									
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	60.0
5.0-10.9	332	133.9	8.6	.00	0	.0	0	.0	
11.0+	2	1.1	11.8	.00	0	.0	0	.0	
GROUP TOTALS	333	135.1	8.6	.00	0	.0	0	.0	
ALL SPECIES									
.0- 4.9	95	6.2	3.4	.00	0	.0	0	.0	
5.0-10.9	332	133.9	8.6	.00	0	.0	0	.0	
11.0+	2	1.1	11.8	.00	0	.0	0	.0	
STAND TOTALS	428	141.3	7.4	.00	0	.0	0	.0	

CAI = CURRENT ANNUAL DIAMETER INCREMENT.

Figure 19.—*Stand conditions table.*

```
                     S T A N D   V O L U M E
                     -----------------------

                                                      TOTAL
                SAWLOG               PULPWOOD      MERCHANTABLE       RESIDUE
            --------------        --------------   ------------   --------------
-------------
SPECIES  GR.   CUFT      BDFT      CUFT     CORDS        CUFT         CUFT      TONS
--------------------------------------------------------------------------------------
JACK  PINE       0         0         0        .0           0           156       3.9
RED   PINE     810      4641      1528      19.3        2338          1251      25.5
--------------------------------------------------------------------------------------
STAND   TOTALS 810      4641      1528      19.3        2338          1407      29.4


BDFT VOLUMES ARE IN INT. 1/4.

MEAN ANNUAL INCREMENT = 77.9 CUFT/YEAR.
```

Figure 20.—*Volume table.*

```
CURRENT STAND STATISTICS: 1987, CYCLE 0 FOR STAND "COMP 284".

                                                       SAWLOG  [TOTAL MERCH.]
      TREES/AC  BATOT BASAW BAPOLE BASAP  DBH  DBH>5    BDFT     CUFT   CORDS

LIVE:   428     141.3  44.3  90.8   6.2   7.4   8.6     4641     2338    29.6
CUT:      0        .0    .0    .0    .0                    0        0      .0

* BDFT VOLUMES ARE IN SCRIBNER.  CUT VALUES ARE FOR THIS YEAR ONLY.
* TOTAL MERCH. IS FOR TREES >= 5" DBH TO A 4" top d.o.b..

Select One Of The Following Actions:
  A: Clearcut.
  B: Thin  (instructions will appear).
  C: Thin by diameter class.
  D: Remove all of one tree class, regardless of species.
  E: Remove all hardwoods or softwoods.
  F: Remove all of one species.
  G: Remove all of one size class, regardless of species.
  H: Remove and/or uncut individual trees.
  I: Row thin.
  J: Uncut all trees cut this year.
  K: Display stocking guide.
  L: Display the tree list.
  Z: Continue with the projection.

Action?
```

Figure 21.—*Management menu with current stand statistics table.*

(TREES/AC), total basal area (BATOT), basal area for sawtimber (BASAW), poles (BAPOLE), and saplings (BASAP), average d.b.h. ($\overline{DBH}$), and average d.b.h. for trees more than 5 inches d.b.h. ($\overline{DBH} > 5$). Volume is included in board feet for saw logs and in cubic feet and cords for trees more than 5 inches d.b.h. to a 4-inch top d.o.b., excluding culls but including undesirable trees (fig. 3).

Management Menu.—This menu offers the following actions to choose from:

Action A clearcuts the stand. If you change your mind, use option J to bring the trees back to life.

Action B prompts a series of options to thin:

a. from above, below, or by tree list order,
b. to favor (leave) certain species,
c. to a prescribed basal area,
d. to a prescribed number of trees/acre, and
e. to an upper and/or lower diameter limit.

You will be given all options, although some may not apply to the actions you are taking. When an option is not applicable, press "enter" or "new line." Any combination of options may be specified; but cutting stops when any one of the thinning specifications has been met. For instance, if the user has decided the stand will be thinned from below (a), back to 90 square feet per acre of residual basal area (c), to an upper diameter limit of 11 inches (e), then TWIGS will cut the smallest tree on the tree list first, regardless of species, until it reaches 90 square feet residual *OR* an 11-inch tree.

Action C thins by the diameter classes specified in the run options (option I). Within each diameter class, the thin options apply that were described above in action B.

Action D removes acceptable, undesirable, or cull tree-classes from the tree list. All trees of a selected class are removed regardless of species.

Action E removes all softwoods or hardwoods from the tree list.

Action F removes all of any species specified from the tree list.

Action G removes all of one size-class from the tree list. Upper and lower diameter limits are specified by the user.

Action H simulates a selection cut. Each tree list entry is displayed, one at a time on the screen, and you have the option to:

a. leave the tree as is,
b. cut all or part of the trees/acre represented by the entry,
c. uncut the tree if it was previously cut during this management period, and
d. skip the rest of the tree list.

Running tallies of remaining basal area and trees per acre are kept on the screen.

Action I simulates a row thin. You determine the proportion of the stand to cut (that is, every other row, every third row, or a certain percent of the stand). TWIGS will split every tree list entry and will assign cut status to the specified proportion of the tree's expansion factor. As a result, when action I is selected, the number of entries on the tree list doubles.

Action J uncuts the trees that were cut during the current management period. By cutting and uncutting trees, you can examine the effects of several alternative prescriptions within a growth cycle.

Action K displays selected stocking guides on the screen or on the screen and printer. The stocking guides available in TWIGS are:

Lake States:
- Aspen (Perala 1986)
- Oak (Gingrich 1967)
- Jack pine (Benzie 1977a)
- Red pine (Benzie 1977b)
- White pine (Philbrook *et al.* 1973)
- White spruce (Benzie and Rauscher 1987)

Central States:
- Oak (Gingrich 1967)
- Shortleaf pine (Rogers 1983)

The number of the projection cycle in which the stocking guide is called is used to mark the stocking level. Figure 22 shows a stocking guide that was called before the stand was grown (projection cycle 0), thus a "0" is used to indicate the stocking level. More than one growing-stock-level marker indicates the levels before and after cutting.

Action L displays the current tree list so you can see which entries have been cut and how each entry has increased in diameter.

Action Z ends the management process with an "after management" stand report and then continues the projection.

Economics and Management Repeated

If you did not select either the management or economics components, go on to the Growth Simulation section. If you indicated in the run options that

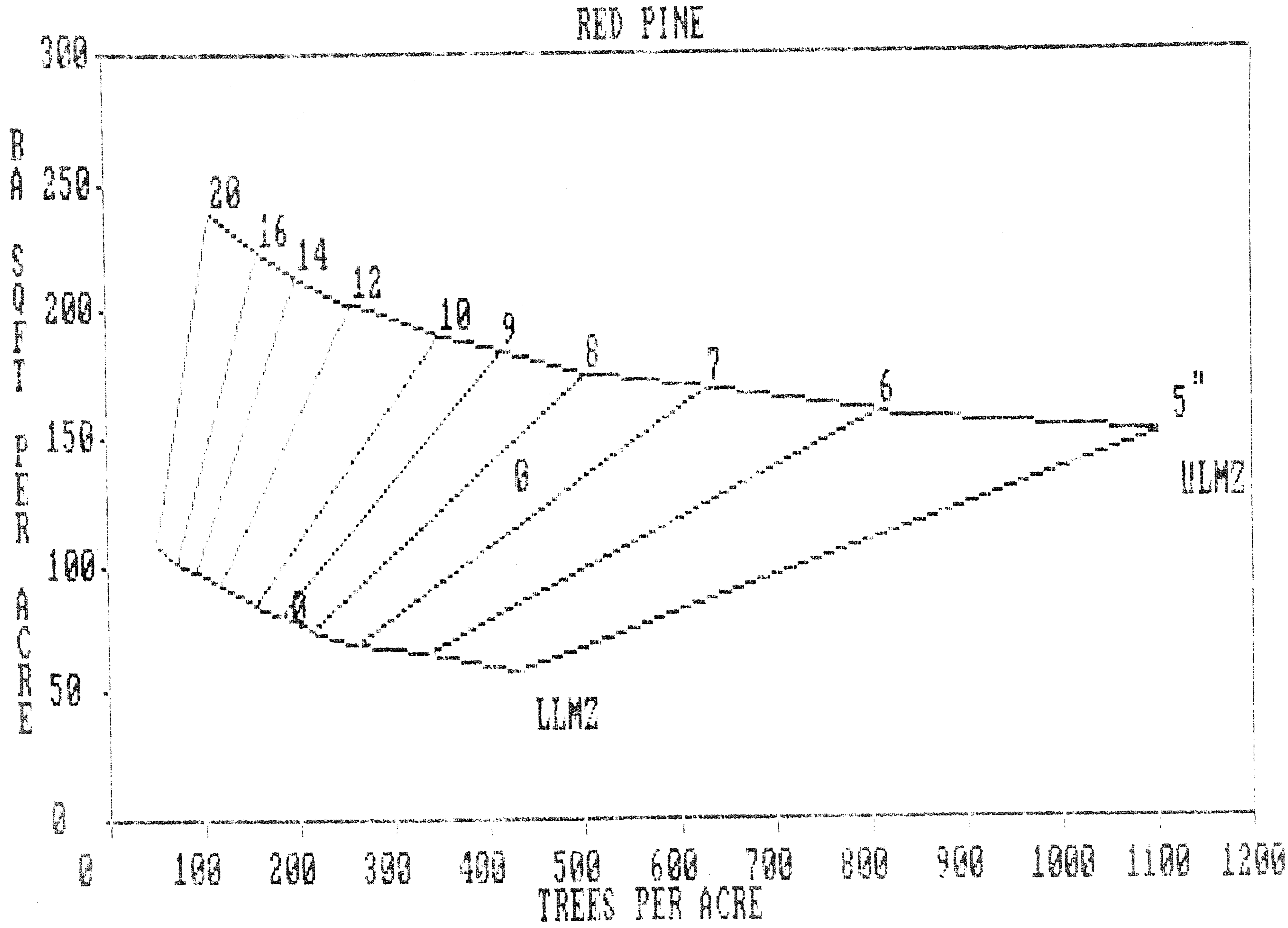


Figure 22.—*Red pine stocking guide. Zero's (0) mark the stocking level before and after cutting.*

the management and economics components were to be used, then the TWIGS program will offer options for going back to the economic and management components as many times as necessary within a growth cycle to examine management and economic alternatives and their effects on stand conditions and economic values.

Step 10
Economic/Management Sequence. Indicate if you want to redo the management/economics sequence. If you press "Y," go to step 6; if you press "N," proceed to the growth simulation component or to ingrowth component, depending on which growth cycle you are in.

Growth Simulation

TWIGS presents a banner that identifies the cycle, the year, the number of growth intervals, and the number of years in the growth cycle. The program then applies the growth and mortality equations, and stand growth is projected as indicated in the run options. Next, after you press enter, the stand summary table is presented (fig. 19).

For those who selected management and economics in the run options, you are given the option to manage and later to do an economics analysis (steps 7 to 10), to do only an economic analysis (step 6), and to redo the management/economic sequence. When none of these options are selected, go to the following section on ingrowth.

Ingrowth

At the end of each growth cycle, you have the opportunity to add ingrowth trees to the stand being projected. In TWIGS, "ingrowth" refers to those trees that naturally enter the stand and are at least 1-inch d.b.h. TWIGS gives no guidelines about what species, what size, or how many trees would likely appear in the particular stand being simulated, but does give the user the opportunity to supply this information. The information can be based on actual data, or it can be hypothetical. The sample trees entered are automatically added to the bottom of the tree list being projected; in future growth cycles these trees are grown, killed, and cut along with the rest of the trees on the list.

Step 11
Ingrowth. Press "Y" to add trees into the stand. If you decide to add ingrowth trees, TWIGS prompts for the following information (which is the same data needed for the TREEGEN program to generate a tree list).

- Forest Service species code (appendix A),
- tree d.b.h. in inches,
- crown ratio (optional),
- number of trees per acre,
- tree status (live, dead, or cut), and
- tree class (acceptable, undesirable, or cull).

In ingrowth, after you have finished adding all trees, you may change stand age and see a list and report of the trees you added into the stand.

Continuation and Completion

Following are the steps for further developing and completing the TWIGS run. If you have more growth cycles to complete, go to step 12. If this is your last growth cycle, go to step 14.

Step 12
Run Options. Change run options (fig. 7), if you wish. Note at this point that you can discontinue the TWIGS run with option "J."

Step 13
Go to growth simulation component.

Step 14
Growth cycles and tree list file. When the growth cycles that were requested in the run options are completed, you will have the option to add more growth cycles and go to step 12. If you decide not to add other cycles, you will be given the option to write the tree list to another file, run TWIGS again, or end the program.

Summary of Management and Growth Projection

A summary of the entire TWIGS run (fig. 23) is printed at the completion of a run, regardless of

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                    ::
::              SUMMARY OF MANAGEMENT AND GROWTH PROJECTION           ::
::                                                                    ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

Stand Description:

Stand Name: COMP 284
Initial Year of Projection: 1987
Initial Age: 56
Site Index Species: RED PINE   Site Index: 55.0

Management Applied:

Thin, from below to 90 square feet of basal area in 1987
Clearcut in 2007

							VOLUME					
							SAWLOG		PULPWOOD		RESIDUAL	
YEAR	AGE	MGMT STATUS	TREES/AC LIVE	DIED	BA/ AC	AVG DBH	CUFT	BDFT	CUFT	CORD	CUFT	TONS
1987	56	BEFORE	308	0	133	8.6	1671	8268	720	9	1283	27
1987	56	CUT	150	0	43	.0	224	1094	436	6	347	8
1987	56	AFTER	158	0	90	10.1	1447	7174	284	4	936	19
1997	66	BEFORE	158	0	117	11.5	2297	11511	111	1	1310	26
2007	76	BEFORE	157	0	142	12.8	2903	15534	157	2	1676	33
2007	76	CUT	157	0	142	.0	2903	15534	157	2	1676	33
2007	76	AFTER	0	0	0	.0	0	0	0	0	0	0

Figure 23.—*Summary table of the management and growth projection.*

which options you select in step 14. The stand is identified and described by initial year of projection, initial age, and site index. Management is summarized in a short description and in a table that shows stand information before and after management.

SUMMARY

TWIGS is an individual-tree, growth-and-yield microcomputer program developed for forest species of and conditions in the Central and Lake States. The program was designed as a decisionmaking tool for natural resource professionals and is also suitable as a forestry demonstration and teaching tool.

The individual-tree growth model for TWIGS uses both diameter growth (as a product of potential growth where little or no competition exists) and a competition modifier to project growth. Natural mortality is estimated from tree species, size, and vigor. Volumes for saw logs, pulpwood, and residue are calculated by species groups.

Initially, a companion program, TREEGEN, is used to create a tree list for TWIGS. The user enters this tree list and interactively adds values and parameters for growth, management, and economics into TWIGS. TWIGS simulates management as the user indicates and provides an evaluation of the effects of each management prescription from a productivity and economic basis. Selective cutting, row thinning, clearcutting, and a variety of other management actions can be chosen so that almost any cutting scenario can be examined.

With inputs such as stumpage-price rates, stumpage-price inflation rate, discount rate, and costs (annual or one-time), the economic component provides real or nominal economic analyses. Economic performance measures are net present value, equivalent annual income, soil expectation value, benefit/cost ratio, payback period, and real internal rate of return. Other outputs include risk analysis and cash-flow tables.

REFERENCES

Benzie, J.W. 1977a. Manager's handbook for jack pine in the north central States. Gen. Tech. Rep. NC-32. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 18 p.

Benzie, J.W. 1977b. Manager's handbook for red pine in the north central States. Gen. Tech. Rep. NC-33. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 22 p.

Benzie, J.W.; Rauscher, H.M. 1987. North Central Forest Experiment Station, Grand Rapids, MN. Unpublished information.

Blinn, C.R.; Rose, D.W.; Belli, M.L. 1988. Guide to analyzing investment options using TWIGS. Gen. Tech. Rep. NC-123. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 15 p.

Buchman, Roland G.; Lentz, Ellen L. 1984. More Lake States tree survival predictions. Res. Note NC-312. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

Buchman, Roland G. 1983. Survival predictions for major Lake States tree species. Res. Pap. NC-233. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 7 p.

Buchman, Roland G.; Pederson, S.P.; Walters, N.R. 1983. A tree survival model with application to species of the Great Lakes region. Canadian Journal of Forest Research. 13(4): 601-608.

Carmean, Willard H.; Vasilevsky, Alexander. 1971. Site-index comparisons for tree species in northern Minnesota. Res. Pap. NC-65. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Carmean, Willard H. 1979. Site index comparisons among northern hardwoods in northern Wisconsin and upper Michigan. Res. Pap. NC-169. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 17 p.

Carmean, Willard H. 1982. Unpublished final progress report: site index comparisons for Lake States Forest Service (FREP computations). St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 p.

Doman, Andrew P.; Ennis, R.; Weigel, D.R. 1981. North Central forest resources evaluation field instructions. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 118 p.

Gertner, George Z. 1984. Localizing a diameter increment model with a sequential Bayesian procedure. Forest Science. 30(4): 851-864.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science. 13: 38-53.

Hahn, Jerold T.; Leary, Rolfe A. 1979. Potential diameter growth functions. In: A generalized forest growth projection system applied to the Lake States region. Gen. Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 22-26.

Hahn, Jerold T. 1984. Tree volumes and biomass equations for the Lake States. Res. Pap. NC-250. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Holdaway, Margaret R. 1984. Modeling the effect of competition on tree diameter growth as applied in STEMS. Gen. Tech. Rep. NC-94. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 9 p.

Holdaway, Margaret R. 1985. Adjusting STEMS growth model for Wisconsin forests. Res. Pap. NC-267. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Holdaway, M.R. 1986. Modeling tree crown ratio. The Forestry Chronicle. 62: 451-455.

Holdaway, M.R.; Brand, G.J. 1986. An evaluation of Lake States STEMS 85. Res. Pap. NC-269. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

Kowalski, D.G.; Gertner, G.Z. Validation of TWIGS 3.0 for Illinois forests. For. Res. Note 87.5. Illinois Agricultural Experiment Station. (In prep.)
Markwardt, L.J. 1930. Comparative strength properties of woods grown in the United States. Tech. Bull. 158. Washington, DC: U.S. Department of Agriculture, Forest Service. 38 p.
Perala, D.A. 1986. Managing aspen in the North Central States. In: Proceedings, Woodland owners and users conference; 1986 February 1; Grand Rapids, MN. St. Paul, MN: University of Minnesota, Office of Special Programs: 89-98.
Philbrook, J.S.; Barrett, J.P.; Leak, W.B. 1973. A stocking guide for eastern white pine. Res. Note NE-168. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 3 p.
Raile, Gerhard K. 1987. Unpublished information.
Raile, Gerhard K.; Smith, W. Brad; Weist, Carol A. 1982. A net volume equation for Michigan's Upper and Lower Peninsulas. Gen. Tech. Rep. NC-80. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 p.
Raile, Gerhard K.; Jakes, Pamela A. 1982. Tree biomass in the North Central Region. Res. Pap. NC-220. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 22 p.
Rogers, R. 1983. Guides for thinning shortleaf pine. In: Jones, Earle P., Jr., ed. Proceedings, 2d Biennial southern silvicultural research conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 217-225.
Rose, D.W.; Blinn, C.R. 1985. A guide to forestry project analysis. Staff Pap. Ser. 53. St. Paul, MN: University of Minnesota, Department of Forest Resources. 37 p.
Rose, D.W.; Blinn, C.R.; Brand, G.J. 1988. A guide to forestry investment analysis. Res. Pap. NC-284. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 23 p.
Shifley, Stephen; Lentz, Ellen. 1986. Quick estimation of the three-parameter Weibull to describe tree size distributions. Forest Ecology Management. 13: 195-203.
Smith, W. Brad. 1983. Adjusting the STEMS regional forest growth model to improve local predictions. Res. Note NC-297. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.
Smith, W. Brad. 1987. Unpublished information.
Smith, W. Brad; Weist, Carol A. 1982. A net volume equation for Indiana. Resour. Bull. NC-63. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 7 p.
U.S. Department of Agriculture, Forest Service. 1983. Biomass energy technology final report, silvicultural production systems, Department of Energy, Contract DE-AI01-80CS83013, projecting future supplies of biomass for energy in the North Central United States. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 38 p.
Young, H.E.; Hoar, L.E.; Tryon, T.C. 1976. A forest biomass inventory of some public land in Maine. In: Oslo biomass studies. Orono, ME: University of Maine, Life Sciences and Agricultural Experiment Station: 285-302.

APPENDIX A

TREE SPECIES AND SPECIES GROUP CODES

Lake States TWIGS

GROUP CODE	SPECIES CODE	SPECIES
1	105	jack pine
	130	scotch pine
2	125	red pine
3	129	white pine
4	94	white spruce
5	12	balsam fir
6	95	black spruce
7	71	tamarack
8	241	northern white cedar
9	261	hemlock
10	001	other softwoods*
11		black-green ash
	543	black ash
	544	green ash
12	742	cottonwood
13	317	silver maple
14	316	red maple
15		elm
	972	american elm
	975	red elm
	977	rock elm
16	371	yellow birch
17	951	basswood

GROUP CODE	SPECIES CODE	SPECIES
18		hard maple
	318	sugar maple
	314	black maple
19	541	white ash
20		white oaks
	802	white oak
	804	swamp white oak
	823	burr oak
	826	chinkapin oak
21		select red oak
	833	northern red oak
22		other red oak
	837	black oak
	809	northern pin oak
23		hickory
	402	bitternut hickory
	403	pignut hickory
	407	shagbark hickory
24	743	bigtooth aspen
25	746	quaking aspen
	741	balsam poplar
26	375	paper birch
27-29		(not used)
30	300	other hardwoods*
31	999	noncommercial spp.

*Any USFS species not listed here is put into "other softwoods" if USFS code <300 or into "other hardwoods" if USFS code $\geq$ 300.

Central States TWIGS

GROUP CODE	SPECIES CODE	SPECIES
1	068	eastern redcedar
	060	juniper
2	110	shortleaf pine
3	132	virginia pine
	131	loblolly pine
4		other softwoods
	129	white pine
5		(not used)
6		walnut
	602	black walnut
	601	butternut

GROUP CODE	SPECIES CODE	SPECIES
7		tupelo
	694	swamp tupelo (blackgum)
	691	water tupelo
	693	black tupelo
8		select hickory
	407	shagbark hickory
	405	shellbark hickory
	409	mockernut hickory

GROUP CODE	SPECIES CODE	SPECIES
9		other hickory
	403	pignut hickory
	400	hickory spp.
	401	water hickory
	402	bitternut hickory
	404	pecan
	408	black hickory
10		beech
	531	american beech
11	543	black ash
	545	pumpkin ash
	546	blue ash
12	742	cottonwood
13		soft maple
	316	red maple
	313	boxelder
	317	silver maple
14		cherry
	762	black cherry
15		elm
	972	american elm
	461	sugarberry
	462	hackberry
	971	winged elm
	970	elm spp.
	974	Siberian elm
	975	red elm
	977	rock elm
16	621	yellow poplar
17		basswood
	951	american basswood
18		hard maple
	318	sugar maple
19		white and green ash
	541	white ash
	540	ash spp.
	544	green ash
20	802	white oak
21		red oak
	833	northern red oak
	812	southern red oak
22	837	black oak
23	806	scarlet oak
24	824	blackjack oak
25	826	chinkapin oak
	804	swamp white oak
	823	bur oak
	825	swamp chestnut oak

GROUP CODE	SPECIES CODE	SPECIES
26	835	post oak
	836	Delta post oak
27	832	chestnut oak
28	830	pin oak
	809	northern pin oak
	813	cherrybark oak
	817	shingle oak
	822	overcup oak
	827	water oak
	828	Nuttall oak
	831	willow oak
	834	Shumard oak
29		other upland hardwoods
	931	sassafras
	331	Ohio buckeye
	452	catalpa
	521	persimmon
	550	honey locust spp.
	552	honey locust
	741	balsam poplar
	743	bigtooth aspen
	746	quaking aspen
	901	black locust
30		other lowland species
	731	sycamore
	221	baldcypress
	373	river birch
	611	sweetgum
	920	willow spp.
	922	black willow
31		noncommercial species
	999	misc. noncommercial
	391	blue beech
	471	redbud
	491	dogwood spp.
	500	hawthorn spp.
	571	Kentucky coffeetree
	641	osage orange
	651	cucumber tree
	653	sweetbay
	680	mulberry
	681	white mulberry
	682	red mulberry
	701	ironwood
	711	sourwood

APPENDIX B

GROWTH, MORTALITY, AND CROWN RATIO EQUATIONS AND COEFFICIENTS

LAKE STATES

GROWTH EQUATION AND COEFFICIENTS

Annual Diameter Growth = Potential Growth * Competition Modifier + Diameter Adjustment Factor

$$\text{Potential Growth} = b_1 + b_2 D^{b_3} + b_4 SI\ CR\ D^{b_5} \qquad [B1]$$

Where:

Potential growth = potential annual d.b.h. growth (inches/yr);
D = current tree diameter (d.b.h. in inches);
SI = site index (feet at age 50);
CR = tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9); and
$b_1,\ldots,b_5$ = species specific equation coefficients from Table B1.

Source: Hahn and Leary (1979)

Table B1. Coefficients to calculate potential growth in Lake States TWIGS, equation B1.

Lake States					
Species Group	b_1	b_2	b_3	b_4	b_5
1	.16062	-.0000090	3.6245	.00004000	1.0000
2	.09446	-.0001200	2.0596	.00035000	.2423
3	.25578	-.0008800	1.7263	.00004000	1.0000
4	.17056	-.0145160	1.0660	.00052000	.2730
5	.12200	-.0008000	1.9890	.00006000	1.0000
6	.10713	-.0010700	2.0017	.00006000	.9113
7	.11147	-.0000100	3.0685	.00003000	1.0000
8	.13403	-.0000010	3.6880	.00002000	1.0000
9	.16872	-.0000003	3.5738	.00001000	1.0000
10	.16062	-.0000090	3.6245	.00004000	1.0000
11	.05881	.0000000	5.0559	.00024000	.3155
12	.10948	-.0000400	2.2226	.00050000	.0663
13	.10948	-.0000400	2.2226	.00050000	.0663
14	.10948	-.0000400	2.2226	.00050000	.0663
15	.28496	-.0018200	1.5297	.00003000	1.0000
16	.15155	-.0000030	3.3104	.00007000	.5730
17	.25402	-.0000040	2.9396	.00001000	1.0000
18	.18772	-.0000070	2.5839	.00028000	.0839
19	.21167	-.0000030	3.3131	.00001000	.1243
20	.12654	-.0000040	2.7538	.00005000	.6209
21	.15535	-.0000001	3.5367	.00018000	.2590
22	.17358	-.0000700	2.4451	.00003000	.9522
23	.16471	-.0021610	1.3949	.00004000	.7163
24	.23490	-.0094200	1.1041	.00036000	.1539
25	.21645	-.0000910	2.6030	.00004400	1.0000
26	.10971	-.0003200	2.0236	.00034000	.2129
27	.37510	-.0247900	.9629	.00004000	1.0000
28	.37510	-.0247900	.9629	.00004000	1.0000
29	.37510	-.0247900	.9629	.00004000	1.0000
30	.37510	-.0247900	.9629	.00004000	1.0000
31	.37510	-.0247900	.9629	.00004000	1.0000

MODIFIER EQUATION AND COEFFICIENTS

$$\text{Competition Modifier} = 1 - e^{-f(R)g(AD)[(BA_{max} - BA)/BA]^{1/2}} \qquad [B2]$$

Where:

Competition modifier = an index of competition, always bounded between zero and one;

BA_{max} = maximum basal area (ft^2/acre) expected for the species (Table B2);

BA = current basal area (ft^2/acre);

R = relative d.b.h. of the tree (ratio of the tree's d.b.h. to the average stand diameter);

AD = average stand diameter (inches);

f(R) = a function characterizing the individual tree's relative diameter effect on the modifier

$$f(R) = b_1[1 - e^{b_2 R}]^{b_3} + b_4;$$

g(AD) = a function characterizing the average stand diameter effect on the modifier,

$$g(AD) = c_1(AD + 1)^{c_2}; \text{ and}$$

$b_1,\ldots,b_4,c_1,c_2$ = species specific equation coefficients from Table B2.

Source: Holdaway (1984)

Table B2. Coefficients to calculate the competition modifier for Lake States TWIGS, equation B2.

				Lake States			
Species Group	BA_{max}	b_1	b_2	b_3	b_4	c_1	c_2
1	225.0	1.7800	-3.000	16.20	.2270	40200	.2300
2	300.0	.7190	-10.900	1688.00	.3750	2.03000	-.3540
3	300.0	1.3600	-2.640	11.50	.3860	.09700	.7550
4	350.0	5.0000	-1.010	3.64	.0000	1.50700	-.5200
5	325.0	1.7600	-1.510	2.63	.2330	.92700	-.2990
6	300.0	3.8000	-1.520	6.54	.3480	.52200	.1730
7	250.0	1.7800	-3.000	16.20	.2270	.03900	1.0000
8	350.0	2.5400	-1.140	2.26	.0000	.52600	.1360
9	300.0	1.2700	-1.340	1.05	.0000	.04600	1.0000
10	300.0	1.3600	-2.640	11.50	.3860	.09700	.7550
11	250.0	5.0000	-.568	1.83	.0630	.26000	.4190
12	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
13	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
14	250.0	1.4000	-2.030	10.40	.6940	.18100	.4450
15	250.0	5.0000	-.970	4.40	.2680	.10000	.6290
16	250.0	.6790	-10.970	1568.00	.4830	.20200	.4540
17	325.0	1.5900	-3.270	26.70	.4120	.35300	.1820
18	250.0	1.1700	-4.590	29.19	.4300	.14200	.5240
19	250.0	5.0000	-1.380	8.26	.3260	.45300	.3400
20	300.0	1.9800	-.974	1.64	.0000	.05100	1.0000
21	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
22	250.0	1.9800	-.974	1.64	.0000	1.36500	-.2080
23	250.0	1.6600	-2.620	9.97	.5150	.28000	.2280
24	250.0	1.1300	-4.640	164.60	.6480	.09300	1.0000
25	250.0	1.0800	-6.600	346.10	.3950	.20900	.5430
26	275.0	1.9800	-1.750	3.67	.2320	.11000	.6780
27	350.0	2.3100	-1.670	3.94	.0000	.44100	.1730
28	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
29	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
30	275.0	1.9800	-.974	1.64	.0000	.27800	.3650
31	275.0	1.9800	-.974	1.64	.0000	.27800	.3650

$$\text{Diameter Adjustment Factor} = a_1 D + a_2 D^2 + a_3 \qquad [B3]$$

Where:
Diameter adjustment factor = adjustment in annual d.b.h. growth (inches/yr);
D = current tree diameter (d.b.h. in inches); and
a_1, a_2, a_3 = species specific equation coefficients from Table B3.

Source: Holdaway (1985).

Table B3. Coefficients to calculate the diameter adjustment factor for Lake States TWIGS, equation B3.

	Lake States		
Species Group	a_1	a_2	a_3
1	-.0174	.00065	.069
2	.0000	-.00017	.018
3	-.0043	.00011	.029
4	.0000	.00000	.000
5	-.0112	.00040	.030
6	-.0248	.00162	.037
7	-.0093	.00042	.048
8	-.0050	.00000	-.004
9	-.0043	.00022	.039
10	.0000	.00000	.000
11	-.0115	.00032	.051
12	.0000	.00000	.000
13	.0109	.00000	-.106
14	.0008	.00004	-.017
15	-.0102	.00023	.028
16	-.0021	.00010	.001
17	.0000	.00007	-.037
18	.0014	.00002	-.024
19	-.0113	.00066	-.002
20	-.0079	.00039	.048
21	.0015	-.00003	-.026
22	.0026	.00000	-.088
23	.0000	.00000	.000
24	.0124	-.00022	-.079
25	-.0132	.00079	.031
26	-.0066	.00038	.011
27	.0000	.00000	.000
28	.0000	.00000	.000
29	.0000	.00000	.000
30	.0085	-.00026	-.088
31	-.0046	.00000	-.070

CROWN RATIO EQUATION AND COEFFICIENTS

$$CR = \frac{b_1}{1 + b_2 RBA} + b_3 [1 - e^{b_4 D}] + CF \qquad [B4]$$

Where:

CR = individual tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9);
RBA = 10-year running average stand basal area (ft^2/ac);
D = current tree diameter (d.b.h. in inches);
CF = correction factor computed as: initial predicted CR - initial observed CR; and
$b_1,...,b_4$ = species specific equation coefficients from Table B8.

Source: USDA Forest Service (1983)

Table B8. Coefficients to calculate crown ratio code for Central States TWIGS, equation B4.

	Central States			
Species Group	b_1	b_2	b_3	b_4
1	4.0862	.009553	4.230	-.65539
2	3.8229	.015548	3.670	-.09307
3	3.8229	.015548	3.670	-.09307
4	3.8229	.015548	3.670	-.09307
5	.0000	.000000	.000	.00000
6	5.3258	.005879	187.864	-.00032
7	3.5960	.024137	3.378	-.56073
8	4.0007	.013160	3.241	-1.05537
9	4.0007	.013160	3.241	-1.05537
10	3.7332	.004015	3.632	-.04124
11	4.7419	.074792	3.327	-.87106
12	4.5860	.004527	4.275	-.01943
13	4.7334	.005145	1.549	-.19205
14	3.7332	.004015	3.632	-.04124
15	4.2114	.000570	2.492	-.02658
16	3.7332	.004015	3.632	-.04124
17	3.7332	.004015	3.632	-.04124
18	4.5228	.004882	2.324	-.22893
19	4.7419	.074792	3.327	-.87106
20	4.6207	.004194	2.627	-.16836
21	4.6941	.005722	2.046	-.23262
22	5.6002	.007243	1.713	-.16631
23	4.1573	.010524	2.618	-.46232
24	3.6371	.009565	3.058	-.60477
25	4.1897	.008983	3.391	-.15663
26	3.6936	.003876	2.733	-.23391
27	5.8825	.008243	332.983	-.00022
28	1.9729	.037414	5.315	-1.07581
29	3.7332	.004015	3.632	-.04124
30	4.5860	.004527	4.275	-.01943
31	4.3510	.001539	110.671	-.00154

MORTALITY EQUATION AND COEFFICIENTS

$$\text{Survival} = b_1 - [1/(1 + e^n)] \qquad [B5]$$

Where:

Survival = the trees' annual probability of survival;

$n = b_2 + b_3 DGR^{b_4} + b_5(D-1)^{b_6} e^{-b_7(D-1)}$;

DGR = predicted annual diameter growth (inches);
D = current tree diameter (d.b.h. in inches); and
$b_1,\ldots,b_7$ = species specific equation coefficients from Table B5.

Source: Buchman, et al. (1983), Buchman (1983), Buchman and Lentz (1984)

Table B5. Coefficients to calculate survival rate in Lake States TWIGS, equation B5.

	Lake States						
Species Group	b_1	b_2	b_3	b_4	b_5	b_6	b_7
1	.9966	.5902	18.00	.7110	.01144	4.7640	.6834
2	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
3	.9989	1.6150	1568.00	2.2680	.87120	.4320	.1012
4	.9994	.9724	314.20	1.9150	.28386	1.3021	.1683
5	.9984	1.9241	28.71	1.0210	4.42100	3.6400	1.6720
6	.9946	1.6990	53.78	1.2190	.68277	.9598	.2250
7	.9970	1.6807	53.78	1.2190	.68277	.9598	.2250
8	.9990	2.2089	86.74	1.0000	.19312	1.5881	.2157
9	.9991	3.0762	27.14	1.1006	.06678	3.4908	.4888
10	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
11	.9990	1.6657	53.78	1.2190	.68277	.9598	.2250
12	.9964	1.0260	368.59	1.7248	.34484	1.9680	.2919
13	.9964	1.0260	368.59	1.7248	.34484	1.9680	.2919
14	.9964	1.0260	368.60	1.7250	.34480	1.9680	.2919
15	.9941	.5794	11.63	.6440	.26550	2.9630	.4715
16	.9975	2.2028	19.11	.8298	1.51710	2.1691	.7958
17	.9979	1.1097	28.39	1.0450	.40350	2.0390	.2769
18	.9979	2.4852	60.76	1.2050	.85030	1.0100	.2394
19	.9992	1.3148	1392.50	2.4835	.03413	4.9703	.8110
20	.9994	2.2907	1000.00	1.8500	.06576	4.2280	.7366
21	.9977	.5639	29.09	1.1370	.01004	3.8340	.3177
22	.9977	.5638	29.09	1.1370	.01004	3.8340	.3177
23	.9980	2.0115	313.96	2.4521	.01149	4.1021	.3479
24	.9908	.3772	34.55	1.0886	.09314	3.4186	.5346
25	.9908	.3772	34.55	1.0890	.09314	3.4190	.5346
26	.9991	1.9539	8.38	.3982	1.71000	2.4440	.8923
27	.9997	1.9953	57.97	1.0120	.26480	1.6260	.1273
28	1.0000	99.0000	1.00	1.0000	.10000	1.0000	1.0000
29	1.0000	99.0000	1.00	1.0000	.10000	1.0000	1.0000
30	.9928	2.1665	88.78	1.6255	.00295	4.8551	.5613
31	.9952	2.0387	153.60	1.2989	.33279	3.0610	.8202

GROWTH EQUATION AND COEFFICIENTS

Annual Tree Basal Area Growth = Potential Growth * Competition Modifier

$$\text{Potential Growth} = (b_1 BA^{b_2} - b_3 TBA)(b_4 + b_5 SI + b_6 CR) \qquad [B6]$$

Where:

Potential growth = potential tree basal area growth (ft^2/yr);
TBA = tree basal area (ft^2/tree);
SI = site index (feet at age 50);
CR = tree crown ratio code (0-10%=1, 11-20%=2, ... 71-80%=8, 81%+=9); and
$b_1,\ldots,b_6$ = species specific equation coefficients from Table B6.

Source: USDA Forest Service (1983)

Table B6. Coefficients to calculate potential growth in Central States TWIGS, equation B6.

	Central States					
Species Group	b_1	b_2	b_3	b_4	b_5	b_6
1	.03922	.51499	.014859	.39742	.0007180	.074914
2	.03996	.14593	.009710	.82519	.0004757	.045452
3	.03996	.14593	.009710	.82519	.0004757	.045452
4	.03996	.14593	.009710	.82519	.0004757	.045452
5	.00000	.00000	.000000	.00000	.0000000	.000000
6	.06447	.43471	.010538	.08016	.0074174	.080557
7	.03503	.49430	.014747	.49661	.0077439	.000000
8	.05274	.55320	.018400	.42132	.0053480	.043101
9	.05274	.55320	.018400	.42132	.0053480	.043101
10	.09306	.64110	.030538	.62209	.0000000	.085091
11	.06565	.50860	.014956	.72314	.0003053	.058527
12	.13392	.54184	.030730	.75132	.0031739	.000000
13	.16952	.73000	.076330	.49370	.0057751	.004969
14	.09306	.64110	.030538	.62209	.0000000	.085091
15	.09366	.62629	.034261	.68951	.0043781	.004288
16	.07754	.59212	.016181	.61431	.0000000	.087708
17	.09306	.64110	.030538	.62209	.0000000	.085091
18	.04857	.61582	.014586	.85147	.0011077	.011213
19	.06565	.50860	.014956	.72314	.0003053	.058527
20	.06090	.55888	.013611	.73498	.0034682	.008474
21	.06332	.59455	.015945	.69043	.0038526	.011732
22	.07176	.53297	.018148	.79907	.0020395	.013021
23	.08797	.65940	.041193	.72584	.0013168	.034728
24	.03825	.54171	.013672	.85593	.0028003	.000000
25	.03628	.60465	.010894	.20651	.0068989	.073313
26	.04509	.62527	.021865	.67032	.0001721	.058600
27	.08655	.69260	.036875	.00627	.0127311	.026572
28	.08102	.41668	.013233	.09305	.0032289	.111761
29	.09306	.64110	.030538	.62209	.0000000	.085091
30	.13392	.54184	.030730	.75132	.0031739	.000000
31	.07158	.64291	.029430	.29425	.0012965	.139643

MODIFIER EQUATION AND COEFFICIENTS

$$\text{Competition Modifier} = b_9[1 - e^{-(b_7/BAL + b_8D^2)(1 - BA/200)^{1/2}}] \quad [B7]$$

Where:

Competition modifier = an index of competition, always bounded between zero and one;

BAL = basal area (ft^2/acre) of all trees larger than this tree;
D = current tree diameter (d.b.h. in inches);
BA = stand basal area (ft^2/acre); and
b_7, b_8, b_9 = species specific equation coefficients from Table B7.

Source: USDA Forest Service (1983)

Table B7. Coefficients to calculate competition modifier for Central States TWIGS, equation B7.

	Central States		
Species Group	b_7	b_8	b_9
1	78.28	.015577	.63527
2	16.66	.008177	.70245
3	16.66	.008177	.70245
4	16.66	.008177	.70245
5	.00	.000000	.00000
6	109.46	.031778	.34065
7	44.06	.015989	.52659
8	46.40	.012405	.45019
9	46.40	.012405	.45019
10	68.78	.014203	.46704
11	41.56	.049642	.42627
12	53.18	.007198	.40176
13	48.53	.105569	.49498
14	68.78	.014203	.46704
15	46.11	.008685	.46063
16	.00	.310056	.64505
17	68.78	.014203	.46704
18	97.04	.025604	.60090
19	41.56	.049642	.42627
20	75.41	.006791	.49141
21	115.41	.007526	.62906
22	84.95	.002934	.51575
23	71.64	.002610	.74850
24	44.03	.009052	.70245
25	123.44	.046581	.52519
26	80.00	.008079	.59464
27	66.34	.002098	.58700
28	36.38	.008695	.62321
29	68.78	.014203	.46704
30	53.18	.007198	.40176
31	141.35	.013700	.35210

CROWN RATIO EQUATION AND COEFFICIENTS

$$CR = \frac{b_1}{1 + b_2 RBA} + b_3 [1 - e^{b_4 D}] + CF \qquad [B4]$$

Where:

CR = individual tree crown ratio code (0-10%=1, 11-20%=2,...71-80%=8, 81%+=9);
RBA = 10-year running average stand basal area (ft^2/ac);
D = current tree diameter (d.b.h. in inches);
CF = correction factor computed as: initial predicted CR - initial observed CR; and
$b_1,...,b_4$ = species specific equation coefficients from Table B4.

Source: Holdaway (1986).

Table B4. Coefficients to calculate crown ratio code for Lake States TWIGS, equation B4.

	Lake States			
Species Group	b_1	b_2	b_3	b_4
1	6.64	.0135	3.200	-.0518
2	5.35	.0053	1.528	-.0330
3	6.79	.0058	7.590	-.0103
4	7.84	.0057	1.272	-.1420
5	5.63	.0047	3.523	-.0689
6	5.54	.0072	4.200	-.0530
7	6.00	.0053	.431	-.0012
8	5.71	.0077	2.290	-.2530
9	5.71	.0077	2.290	-.2530
10	5.71	.0077	2.290	-.2530
11	4.50	.0032	.795	-.1050
12	4.35	.0046	1.820	-.2740
13	4.85	.0050	9.810	-.0099
14	4.35	.0046	1.820	-.2740
15	4.40	.0025	1.000	-.0940
16	4.18	.0025	1.410	-.5120
17	4.44	.0037	2.090	-.0650
18	3.40	.0066	2.870	-.4340
19	4.49	.0029	1.210	-.0650
20	5.84	.0082	3.260	-.0490
21	4.20	.0016	2.760	-.0250
22	5.06	.0033	1.730	-.0610
23	6.21	.0073	9.990	-.0100
24	4.11	.0054	1.650	-.1100
25	4.00	.0024	-2.830	.0210
26	5.00	.0066	4.920	-.0263
27	4.00	.0024	-2.830	.0210
28	4.00	.0024	-2.830	.0210
29	4.00	.0024	-2.830	.0210
30	4.00	.0024	-2.830	.0210
31	4.00	.0024	-2.830	.0210

MORTALITY EQUATION AND COEFFICIENTS

$$\text{Survival} = 1 - [1/(1 + e^{n})] \qquad \text{[B8]}$$

Where:

Survival = the tree's annual probability of survival;

$$n = c_1 + c_2(D + 1)^{c_3} e^{-c_4 D - c_5 BAL};$$

D = current tree diameter (d.b.h. in inches);
BAL = basal area (ft^2/acre) of all trees larger than this tree; and
$c_1,\ldots,c_5$ = species specific equation coefficients from Table B9.

Source: USDA Forest Service (1983)

Table B9. Coefficients to calculate probability of mortality for Central States TWIGS, equation B8.

	Central States				
Species Group	c_1	c_2	c_3	c_4	c_5
1	.0000	2.1313	1.2026	.16766	.006042
2	3.1106	.0116	4.1007	.37008	.012051
3	3.1106	.0116	4.1007	.37008	.012051
4	3.1106	.0116	4.1007	.37008	.012051
5	.0000	.0000	.0000	.00000	.000000
6	3.2101	.0123	2.1410	.05819	.000000
7	3.8940	16.7618	.4343	.21302	.046427
8	.0000	3.1518	.4444	.04833	.002578
9	.0000	3.1518	.4444	.04833	.002578
10	4.2508	.0043	2.4946	.06922	.014006
11	2.9379	.0127	3.3049	.24199	.008169
12	2.8282	.6661	.5506	.04233	.003375
13	3.4213	.0018	3.9486	.26708	.007647
14	2.8497	.0022	3.3528	.14147	.006456
15	1.7401	2.1316	.0000	.06621	.002796
16	3.4213	.0018	3.9486	.26708	.007647
17	2.8497	.0022	3.3528	.14147	.006456
18	4.2508	.0043	2.4946	.06922	.014006
19	2.9379	.0127	3.3049	.24199	.008169
20	.0000	2.9567	.5198	.03853	.003337
21	1.4669	1.6808	.6456	.05612	.003648
22	.0000	2.0325	.6311	.05430	.001745
23	.0000	1.9628	.8272	.08023	.006422
24	.3720	1.3479	.9159	.10719	.004255
25	2.2851	.0494	2.6376	.17328	.003045
26	1.1666	1.6463	.7875	.08305	.005003
27	.7915	1.4153	.9521	.07507	.007156
28	.0000	2.9198	.4006	.03519	.004352
29	2.8497	.0022	3.3528	.14147	.006456
30	2.8282	.6661	.5506	.04233	.003375
31	2.7525	.0061	10.3078	3.25895	.000000

APPENDIX C

ROUGH GUIDE TO RELIABILITY OF EQUATIONS

The tables below summarize the relation between species groups and the number of observations used to calibrate the equations for Lake and Central States TWIGS found in Appendix B. The column with the number of observations is provided as a rough indicator of the strength of the data base used to develop that particular set of equations. If no number is given, that species group uses the same projection equations as a larger group of which it is a subset.

The same set of observations was used for all three equations in Central States TWIGS. In Lake States TWIGS a different number of observations was used for each of the equations, therefore a range is presented. In general, the more observations available to develop an equation set, the more confidence one should have in the ability of that equation to perform reliably under a variety of forest conditions.

Table C1. Number of observations used in the development of the equations for Central States TWIGS.

Species Group	Uses Equations for This Group	Number of Observations
1 E. redcedar	E. redcedar	190
2 Shortleaf pine	Shortleaf pine	1,600
3 Virginia	Shortleaf pine (Group 2)	--
4 Other pines	Shortleaf pine (Group 2)	--
5 (not used)		
6 Walnut	Walnut	260
7 Tupelo	Tupelo	230
8 Select hickory	Select hickory	2,500
9 Other hickories	Select hickory (Group 8)	--
10 Beech	Other upland hdwds (Group 29)	--
11 Black ash	White & green ash (Group 19)	--
12 Cottonwood	Other lowland hdwds (Group 30)	--
13 Soft maple	Soft maple	350
14 Cherry	Other upland hdwds (Group 29)	--
15 Elm	Elm	550
16 Yellow poplar	Yellow poplar	130
17 Basswood	Other upland hdwds (group 29)	--
18 Hard maple	Hard maple	330
19 White & green ash	White & green ash	430
20 White oak	White oak	3,770
21 Red oak	Red oak	1,040
22 Black oak	Black oak	3,560
23 Scarlet oak	Scarlet oak	1,100
24 Blackjack oak	Blackjack oak	570
25 Chinkapin oak	Chinkapin oak	290
26 Post oak	Post oak	2,230
27 Chestnut oak	Chestnut oak	190
28 Pin oak	Pin oak	590
29 Other upland hdwds	Other upland hdwds	460
30 Other lowland hdwds	Other lowland hdwds	340
31 Noncommercial spp.	Noncommercial spp.	510

Table C2. Number of observations used in the development of the equations for Lake States TWIGS.

Species Group	Uses Equations for This Group	Number of Observations
1 Jack pine	Jack pine	664 - 8,934
2 Red pine	Red pine	390 - 39,998
3 White pine	White pine	538 - 2,394
4 White spruce	White spruce	227 - 3,548
5 Balsam fir	Balsam fir	771 - 17,169
6 Black spruce	Black spruce	316 - 13,212
7 Tamarack	Tamarack	61 - 2,673
8 N. white-cedar	N. white-cedar	813 - 2,782
9 Hemlock	Hemlock	140 - 1,447
10 Other softwoods	various groups	--
11 Black ash	Black ash	174 - 912
12 Cottonwood	Red maple (Group 14)	--
13 Silver maple	Red maple (Group 14)	--
14 Red maple	Red maple	937 - 3,860
15 Elm	Elm	344 - 4,337
16 Yellow birch	Yellow birch	343 - 1,129
17 Basswood	Basswood	813 - 4,056
18 Sugar maple	Sugar maple	2,251 - 9,383
19 White ash	White ash	148 - 2,818
20 White oak	White oak	480 - 1,666
21 N. red oak	N. red oak	1,158 - 3,378
22 Other red oak	Other red oak	80 - 3,021
23 Hickory	Hickory	114 - 3,573
24 Bigtooth aspen	Bigtooth aspen	94 - 1,426
25 Quaking aspen	Quaking aspen	2,124 - 6,892
26 Paper birch	Paper birch	748 - 2,364
27 (not used)		
28 (not used)		
29 (not used)		
30 Other hardwoods	Other hardwoods	190 - 219
31 Noncommercial spp.	Noncommercial spp.	175

APPENDIX D

VALIDATION TABLES

Lake States TWIGS Validation

Table D1. Summary of mean d.b.h. errors.

Table D2. Summary of mean basal area errors.

Table D3. Predicted and observed tree mortality rates.

Central States TWIGS Validation

Table D4. Summary of mean error in d.b.h. growth.

Table D5. Summary of mean error in basal area growth.

Table D6. Predicted and observed plot change (d.b.h., number of trees, basal area).

Table D7. Predicted and observed tree mortality rates.

Table Di.--Summary of the mean d.b.h. errors (inches) by Lake States species in 10 years using the STEMS85 model. The number of trees appears in parentheses. Positive values are overpredictions.

Species	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	-.11	(1,813)	-.19	(1,334)	-.12	(66)	-.18	(52)	.16	(182)	.17	(179)
Red pine	-.16	(1,374)	-.18	(879)	-.28	(64)	-.13	(69)	-.34	(135)	.08	(227)
White pine	-.04	(310)	-.20	(139)	.05	(36)	-.16	(36)	.09	(74)	.52	(25)
White spruce	.19	(171)	-.11	(64)	1.16	(14)	.37	(54)	.09	(39)	--	
Balsam fir	-.19	(693)	-.25	(326)	-.17	(150)	-.09	(125)	-.15	(89)	.15	(3)
Black spruce	-.29	(769)	-.29	(614)	-.26	(29)	-.19	(42)	-.36	(82)	-.19	(2)
Tamarack	.07	(334)	.12	(278)	-.17	(27)	-.27	(21)	-.05	(7)	.78	(1)
N. white-cedar	-.05	(916)	.12	(333)	-.03	(107)	-.01	(191)	-.02	(232)	.16	(53)
Hemlock	.11	(306)	--		.27	(50)	-.05	(122)	.19	(119)	.25	(15)
Black ash	.02	(189)	-.03	(51)	.16	(51)	.00	(35)	.03	(8)	-.09	(44)
Red maple	-.12	(798)	-.24	(68)	-.03	(191)	-.09	(64)	-.18	(258)	-.09	(217)
Elm	-.22	(194)	--		-.16	(48)	-.33	(126)	.08	(8)	.52	(12)
Yellow birch	-.09	(270)	.71	(2)	-.08	(92)	-.03	(78)	-.17	(83)	-.08	(15)
Basswood	.11	(274)	--		.01	(86)	.07	(150)	-.22	(5)	.62	(33)
Sugar maple	.01	(878)	--		.08	(293)	-.09	(354)	-.05	(164)	.34	(67)
White ash	-.04	(61)	--		-.19	(18)	-.43	(12)	--		.20	(31)
White oak	.21	(255)	--		--		--		--		.21	(255)
Northern red oak	.01	(258)	-.51	(3)	.08	(119)	-.19	(25)	-.23	(24)	.06	(87)
Northern pin oak	.14	(286)	--		.40	(4)	--		--		.13	(282)
Bigtooth aspen	.10	(227)	.45	(36)	-.11	(64)	-.14	(30)	-.05	(37)	.32	(60)
Quaking aspen	.08	(933)	.10	(388)	-.15	(134)	.04	(237)	.23	(118)	.25	(56)
Paper birch	.03	(1,102)	.02	(752)	-.19	(101)	-.32	(123)	.05	(96)	.01	(30)
All	-.06	(12,696)	-.12	(5,267)	-.03	(1,753)	-.08	(1,992)	-.06	(1,897)	.15	(1,787)

Includes all species on the property

Table D2.--Summary of the mean basal area errors (ft^2/ac) by Lake States species in 10 years using the STEMS85 model. The number of plots appears in parentheses. Positive values are overpredictions.

Forest type	All	Cloquet	Chequamegon	Nicolet	Hiawatha	Manistee
Jack pine	-2.5 (127)	-5.9 (79)	1.5 (7)	2.6 (6)	4.0 (20)	2.1 (15)
Red pine	-2.5 (85)	-3.6 (49)	2.8 (6)	-4.7 (4)	-9.1 (11)	4.2 (15)
White pine	-2.4 (13)	3.9 (6)	-2.7 (2)	-14.3 (2)	-6.6 (3)	--
White spruce	-3.1 (10)	5.9 (4)	-2.4 (1)	3.6 (4)	-4.4 (1)	--
Balsam fir	5.3 (51)	5.9 (23)	1.1 (14)	2.9 (8)	16.6 (6)	--
Black spruce	-4.3 (40)	-6.4 (29)	-2.5 (2)	11.3 (3)	-2.9 (6)	--
Tamarack	.0 (23)	1.7 (19)	-6.6 (2)	-10.2 (2)	--	--
N. white-cedar	-.7 (47)	1.7 (14)	.6 (8)	-4.0 (9)	-4.8 (14)	19.9 (20)
Hemlock	-12.5 (7)	--	--	-11.8 (4)	-13.4 (3)	--
Lowland hdwds.	16.4 (30)	4.4 (3)	18.2 (5)	3.1 (2)	-11.7 (1)	20.7 (19)
N. hardwoods	1.6 (135)	--	2.8 (40)	-1.2 (49)	-3.1 (28)	14.0 (18)
White oak	3.3 (15)	--	--	--	--	3.3 (15)
N. red oak	.6 (15)	--	-.7 (4)	-8.8 (1)	-8.7 (2)	4.7 (8)
Oak-pine	1.4 (10)	--	--	--	-21.3 (1)	3.9 (9)
Oak-hickory	.7 (35)	--	6.8 (1)	--	--	.5 (34)
Aspen	4.0 (121)	7.0 (30)	2.0 (23)	1.4 (42)	3.1 (14)	10.8 (12)
Paper birch	.7 (58)	1.0 (36)	1.1 (8)	-5.4 (9)	9.3 (4)	7.8 (1)
All	.9 (822)	-1.1 (292)	2.3 (123)	-.8 (145)	-1.1 (114)	7.1 (148)

Table D3.--Predicted and observed annual tree mortality rates by Lake States species for all validation properties using STEMS 85.

Species	No. of trees	Annual tree mortality rate: Predicted	Annual tree mortality rate: Observed
		(Percent)	
Jack pine	2,336	1.6	1.8
Red pine	1,397	.1	.3
White pine	363	.1	1.7
White spruce	187	1.0	.6
Balsam fir	1,092	1.1	2.0
Black spruce	1,024	2.7	1.4
Tamarack	370	1.3	.7
N. white-cedar	987	.4	.8
Hemlock	323	.5	.6
Black ash	254	1.5	2.0
Red maple	852	1.8	1.4
Elm	293	3.0	4.1
Yellow birch	321	1.1	2.0
Basswood	303	2.0	1.2
Sugar maple	946	1.3	1.7
White ash	65	1.7	2.2
White oak	274	.1	1.9
N. red oak	273	4.2	1.5
N. pin oak	312	5.1	2.6
Bigtooth aspen	270	2.3	1.6
Quaking aspen	1,468	1.9	3.3
Paper birch	1,191	.4	.9
All[1]	15,240	1.4	1.6

[1]Includes all species on the property

Table D4.--Mean error in predicted 10-year tree diameter growth (in inches) by species group and diameter class for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group	Diameter class (inches)															
	1.0-4.9		5.0-8.9		9.0-10.9		11.0-14.9		15.0-20.9		21.0-24.9		25+		All classes	
Name	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.	DBH err.	No. obs.
E. redcedar	-.05	(126)	.10	(123)	.10	(20)	.22	(16)	-.10	(1)	0	(0)	0	(0)	.04	(286)
Shortleaf pine	-.02	(172)	.13	(1345)	.09	(390)	.01	(235)	-.20	(34)	0	(0)	0	(0)	.09	(2176)
Soft maple	.48	(76)	.55	(101)	.63	(75)	.46	(143)	.07	(100)	-.12	(23)	-.71	(19)	.36	(537)
Hard maple	.15	(108)	.13	(144)	-.18	(294)	-.19	(565)	-.27	(419)	-.19	(85)	-.47	(21)	-.16	(1636)
Hickory	.01	(952)	.07	(1538)	.06	(609)	-.09	(811)	-.36	(316)	-.86	(24)	-1.21	(8)	-.01	(4258)
Ash	.14	(145)	.25	(231)	.07	(163)	-.09	(279)	-.39	(138)	-.59	(26)	-.89	(8)	-.01	(990)
Walnut	-.02	(55)	.10	(165)	-.20	(95)	.01	(182)	-.18	(70)	-.43	(9)	-2.60	(1)	-.03	(577)
Tupelo	.05	(93)	.06	(50)	.09	(36)	.03	(90)	-.07	(62)	-.25	(11)	-.59	(5)	.01	(347)
White oak	.17	(636)	.02	(1914)	.04	(835)	.01	(1418)	-.12	(762)	-.15	(146)	-.36	(100)	.01	(5811)
Scarlet oak	.23	(170)	.18	(753)	.20	(273)	.22	(268)	.02	(128)	-.43	(21)	-1.38	(11)	.16	(1624)
Blackjack oak	-.02	(164)	.11	(297)	.05	(121)	.06	(154)	.06	(40)	-.47	(3)	0	(0)	.06	(779)
Chinkapin oak	-.02	(50)	.03	(229)	.06	(61)	-.03	(84)	-.29	(38)	-.62	(14)	-1.55	(5)	-.04	(481)
Red oak	.14	(90)	.16	(448)	.11	(246)	-.06	(434)	-.13	(456)	-.33	(125)	-.73	(49)	-.03	(1848)
Post oak	.01	(626)	-.00	(1112)	.03	(450)	.07	(655)	.02	(312)	-.17	(63)	-.27	(13)	.02	(3231)
Black oak	.25	(534)	.07	(1833)	.06	(786)	.13	(1081)	-.05	(685)	-.15	(137)	-.37	(52)	.07	(5108)
Oth. upland oaks	-.02	(11)	-.17	(43)	-.16	(27)	-.11	(57)	-.32	(31)	-.94	(6)	-.80	(8)	-.22	(183)
Oth. lowland oaks	-.00	(57)	.34	(97)	.30	(57)	.19	(97)	.12	(100)	.38	(22)	-.22	(22)	.18	(452)
Elm	.07	(256)	.24	(321)	.07	(150)	-.04	(225)	-.03	(110)	-.22	(26)	-.59	(11)	.08	(1099)
Oth. upland hdwds	.22	(225)	.31	(124)	.25	(229)	.31	(425)	.27	(331)	.37	(81)	.20	(53)	.28	(1468)
Oth. lowland hdwds	-.47	(38)	.04	(97)	.20	(135)	.24	(274)	.13	(344)	-.23	(77)	-.27	(60)	.09	(1025)
Noncommercial spp.	.11	(509)	.37	(119)	.14	(26)	-1.25	(13)	-.41	(5)	0	(0)	0	(0)	.12	(672)
Yellow poplar	.20	(2)	-.53	(13)	-.20	(2)	-.23	(28)	-.22	(12)	.95	(2)	-.28	(2)	-.23	(61)
TOTAL	.10	(5095)	.09	(11097)	.07	(5080)	.04	(7534)	-.08	(4494)	-.18	(901)	-.42	(448)	.04	(34649)

Table D5.--Error in predicted 10-year tree basal area growth as a percent of initial tree basal area by species group and diameter class for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group	Diameter class (inches)															
	1.0-4.9		5.0-8.9		9.0-10.9		11.0-14.9		15.0-20.9		21.0-24.9		25+		All classes	
Name	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.	% err.	No. obs.
E. redcedar	-3.7	(126)	3.1	(123)	1.8	(20)	4.0	(16)	-1.2	(1)	0	(0)	0	(0)	.1	(286)
Shortleaf pine	-7.1	(172)	3.9	(1345)	1.5	(390)	.2	(235)	-2.8	(34)	0	(0)	0	(0)	2.1	(2176)
Soft maple	67.2	(76)	14.6	(101)	13.6	(75)	8.1	(143)	-.1	(100)	-1.9	(23)	-5.8	(19)	16.0	(537)
Hard maple	14.3	(108)	3.9	(144)	-4.9	(294)	-3.8	(565)	-3.6	(419)	-2.0	(85)	-3.8	(21)	-2.0	(1636)
Hickory	.7	(952)	2.0	(1538)	1.2	(609)	-1.8	(811)	-4.7	(316)	-8.1	(24)	-8.9	(8)	.3	(4258)
Ash	6.5	(145)	7.4	(231)	.7	(163)	-1.7	(279)	-5.4	(138)	-5.9	(26)	-7.1	(8)	1.4	(990)
Walnut	-14.6	(55)	1.8	(165)	-5.8	(95)	-.2	(182)	-2.5	(70)	-4.3	(9)	-19.7	(1)	-2.3	(577)
Tupelo	14.4	(93)	1.7	(50)	1.7	(36)	.4	(90)	-.9	(62)	-2.4	(11)	-4.7	(5)	4.1	(347)
White oak	21.2	(636)	-.1	(1914)	.6	(835)	.0	(1418)	-1.6	(762)	-1.6	(146)	-2.6	(100)	2.1	(5811)
Scarlet oak	32.5	(170)	5.8	(753)	4.3	(273)	3.9	(268)	.2	(128)	-4.1	(21)	-10.7	(11)	7.3	(1624)
Blackjack oak	-.1	(164)	3.3	(297)	.8	(121)	.8	(154)	.8	(40)	-4.4	(3)	0	(0)	1.6	(779)
Chinkapin oak	-7.1	(50)	.7	(229)	.9	(61)	-.4	(84)	-3.7	(38)	-5.9	(14)	-11.0	(5)	-.9	(481)
Red oak	18.2	(90)	5.3	(448)	1.9	(246)	-1.6	(434)	-1.9	(456)	-3.3	(125)	-5.7	(49)	1.2	(1848)
Post oak	-4.9	(626)	-.5	(1112)	.3	(450)	1.0	(655)	.1	(312)	-1.6	(63)	-2.0	(13)	-.9	(3231)
Black oak	40.7	(534)	1.8	(1833)	1.0	(786)	2.0	(1081)	-.8	(685)	-1.5	(137)	-2.9	(52)	5.3	(5108)
Other upland oaks	-8.4	(11)	-5.9	(43)	-3.8	(27)	-2.4	(57)	-4.2	(31)	-8.9	(6)	-5.9	(8)	-4.5	(183)
Other lowland oaks	-20.8	(57)	10.6	(97)	6.3	(57)	3.1	(97)	1.3	(100)	3.5	(22)	-1.5	(22)	1.5	(452)
Elm	3.3	(256)	6.8	(321)	.7	(150)	-1.4	(225)	-.8	(110)	-2.3	(26)	-4.0	(11)	2.4	(1099)
Oth. upland hdwds	21.2	(225)	10.1	(124)	4.9	(229)	4.9	(425)	3.2	(331)	3.5	(81)	1.6	(53)	7.3	(1468)
Oth. lowland hdwds	-194.8	(38)	-4.9	(97)	3.4	(135)	3.1	(274)	1.4	(344)	-2.7	(77)	-1.7	(60)	-6.2	(1025)
Noncommercial spp.	3.5	(509)	13.2	(119)	2.6	(26)	-24.0	(13)	-7.0	(5)	0	(0)	0	(0)	4.5	(672)
Yellow poplar	58.0	(2)	-23.1	(13)	-5.1	(2)	-5.3	(28)	-4.1	(12)	9.4	(2)	-1.6	(2)	-6.2	(61)
TOTAL	8.8	(5095)	2.6	(11097)	1.1	(5080)	.4	(7534)	-1.2	(4494)	-1.9	(901)	-3.1	(448)	2.1	(34649)

Table D6. Comparison of observed and predicted plot change using Central States TWIGS.

Category	Tree Diameter[a] (inches/tree)		Number of Trees[b] (number/acre)		Basal Area[b] (sq. ft./acre)	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
Initial	9.1(5.3)	9.0(5.1)	671(860)	649(888)	66(26)	61(25)
Observed (after 10 years of growth)	10.4(5.6)	10.2(5.4)	453(608)	428(563)	66(34)	64(35)
Predicted (from 10 years of simulation)	10.4(5.5)	10.2(5.3)	416(459)	403(462)	69(33)	66(33)
Difference	.052(.72)	.025(.73)	-37(284)	-25(248)	3(13)	2(14)

[a] Means with standard deviations in parentheses for 7697 calibration trees and 7510 validation trees.

[b] Means with standard deviations in parentheses for 577 calibration plots and 566 validation plots.

Calibration data is a subset of those data used to develop models and coefficients. Validation data is the 1/4 of plots reserved prior to model development.

Table D7.--Comparison of observed and predicted mortality rates by species group for Central States TWIGS. Data from Missouri (76%) and Indiana (24%) continuous forest inventory plots.

Species group Name	No. of trees	Annual tree mortality Predicted	Observed	Difference
		- - - - - - - (Percent) - - - - -		
E. redcedar	301	2.1619	2.2698	-.1079
Shortleaf pine	2298	1.7066	1.6901	.0165
Soft maple	645	2.7740	1.8495	.9245
Hard maple	1701	1.7677	1.7196	.0482
Hickory	4653	2.3397	2.1220	.2177
Ash	1121	4.3729	4.4429	-.0701
Walnut	662	2.9315	3.1595	-.2281
Tupelo	377	1.3030	.8211	.4819
White oak	6180	2.1984	1.9390	.2595
Scarlet oak	1862	4.8290	3.4251	1.4039
Blackjack oak	1059	5.8929	5.6654	.2275
Chinkapin oak	518	3.4640	1.4867	1.9773
Red oak	2003	1.8909	3.2118	-1.3209
Post oak	3639	2.6904	2.8299	-.1395
Black oak	5722	2.9793	3.4726	-.4933
Other upland oaks	197	3.2301	2.6135	.6166
Other lowland oaks	524	3.3416	2.3492	.9924
Elm	2204	4.6019	3.7001	.9017
Other upland hdwds.	1732	6.7222	6.9149	-.1927
Other lowland hdwds.	1182	2.9285	4.7090	-1.7804
Noncommercial spp.	967	3.7874	4.2246	-.4372
Yellow poplar	63	1.8191	.1771	1.6420
TOTAL	39610	3.2226	3.1790	.0436

APPENDIX E

LAKE AND CENTRAL STATES TWIGS

WEIGHT AND VOLUME EQUATIONS AND COEFFICIENTS

TWIGS calculates the weight and volume of each tree individually using generalized equations with species specific coefficients. The individual tree weights and volumes are summed by species and product class, then presented in the Volume Report (fig. 20). The product class limits are diagrammed in figure 3.

INDEX TO APPENDIX E

ACCEPTABLE TREE CLASS VOLUME

The following general equation is used for cubic foot and board foot volume of acceptable (tree class 20) trees. This net merchantable tree volume equation was developed for the Upper Peninsula of Michigan (Raile et al., 1982). Total net cubic foot volume of acceptable trees is computed using equation E1 and the coefficients in Table E1. Net board foot volume is computed using equation E1 along with the coefficients in Table E2. Net cubic foot saw log volume is calculated using equation E1 and the coefficients in Table E3.

$$V_{20} = a\ SI^{b}[1 - e^{-c\ D}]^{d} \qquad [E1]$$

Where:

V_{20} = net volume of an acceptable tree (tree class 20);

SI = species specific site index (feet at age 50);
D = current tree diameter (d.b.h. in inches); and
a,b,c,d = species specific equation coefficients from Table E1, Table E2, or Table E3.

Table E1. Coefficients to calculate total net cubic foot volume for acceptable trees in Lake States TWIGS, equation E1.

	Lake States			
Species Group	a	b	c	d
1	43.	.249415	.0633760	3.3981
2	208.	.101513	.0434772	3.2805
3	7116254.	.246024	.0005161	2.7799
4	794.	.086980	.0246854	3.0336
5	5907203.	.212635	.0005561	2.7161
6	23975168.	.148390	.0003563	2.6941
7	44.	.000000	.1601605	5.6228
8	829654.	.055217	.0006650	2.3394
9	7702181.	.305867	.0002745	2.5641
10	43.	.249415	.0633760	3.3981
11	26920.	.140461	.0031300	2.4281
12	7257393.	1.016275	.0001747	2.8370
13	84.	.138548	.0576398	3.1838
14	84.	.138548	.0576398	3.1838
15	140.	.438708	.0191369	2.5388
16	4117942.	.291399	.0002105	2.3009
17	221.	.121958	.0359248	2.9440
18	500.	.007421	.0282525	2.7577
19	26920.	.140461	.0031300	2.4281
20	226.	.060183	.0407774	3.0682
21	226.	.060183	.0407774	3.0682
22	226.	.060183	.0407774	3.0682
23	14.	.338689	.1181669	4.4888
24	158.	.213605	.0315426	2.7168
25	158.	.213605	.0315426	2.7168
26	7256.	.109934	.0036266	2.0926
27	14.	.338689	.1181669	4.4888
28	14.	.338689	.1181669	4.4888
29	14.	.338689	.1181669	4.4888
30	14.	.338689	.1181669	4.4888
31	14.	.338689	.1181669	4.4888

Table E2. Coefficients to calculate net board foot volume (International 1/4-inch rule) for acceptable trees in Lake States TWIGS, equation E1.

	Lake States			
Species Group	a	b	c	d
1	169.	.39511	.0512433	3.196
2	2969.	.25519	.0179006	2.761
3	36276656.	.14236	.0008274	2.973
4	35253.	.00000	.0110881	2.866
5	27980.	.33410	.0096929	3.261
6	28937072.	.06307	.0014004	3.165
7	63.	.22695	.3284979	26.891
8	5756055.	.00000	.0007904	2.463
9	2586729.	.05437	.0013930	2.636
10	169.	.39511	.0512433	3.196
11	10925208.	.02244	.0008219	2.564
12	15938236.	.75718	.0002925	2.740
13	120.	.27194	.1734226	11.676
14	120.	.27194	.1734226	11.676
15	1211353.	.57651	.0001273	1.834
16	400.	.31603	.0458705	3.418
17	201.	.26549	.1115628	6.420
18	712.	.00000	.0995210	5.866
19	10925208.	.02244	.0008219	2.564
20	1007.	.00000	.0688690	4.382
21	1007.	.00000	.0688690	4.382
22	1007.	.00000	.0688690	4.382
23	8070.	.63809	.0003951	1.346
24	393.	.19532	.0640377	3.681
25	393.	.19532	.0640377	3.681
26	9103704.	.00000	.0001737	1.882
27	8070.	.63809	.0003951	1.346
28	8070.	.63809	.0003951	1.346
29	8070.	.63809	.0003951	1.346
30	8070.	.63809	.0003951	1.346
31	8070.	.63809	.0003951	1.346

Table E3. Coefficients to calculate net cubic foot saw log volume for acceptable trees in Lake States TWIGS, equation E1.

Species Group	Lake States a	b	c	d
1	9.	.53396	.0854854	4.216
2	173.	.13296	.0419059	3.166
3	27973504.	.15545	.0003431	2.776
4	765.	.02644	.0277262	3.168
5	350.	.39522	.0244354	3.503
6	13205354.	.02868	.0008994	3.047
7	12.	.22306	.2933120	20.224
8	329.	.04549	.0318424	3.132
9	13742.	.09324	.0050556	2.643
10	9.	.53396	.0854854	4.216
11	2361292.	.08194	.0004847	2.400
12	9227411.	.62755	.0001703	2.606
13	34.	.18168	.1402485	8.552
14	34.	.18168	.1402485	8.552
15	315786.	.63848	.0000997	1.886
16	233.	.18111	.0285956	2.971
17	33.	.23508	.1324740	8.230
18	116.	.00000	.0971358	5.752
19	2361292.	.08194	.0004847	2.400
20	92.	.00000	.1129755	6.721
21	92.	.00000	.1129755	6.721
22	92.	.00000	.1129755	6.721
23	2361292.	.08194	.0004847	2.400
24	36.	.25513	.0895516	4.727
25	36.	.25513	.0895516	4.727
26	36.	.25513	.0895516	4.727
27	116.	.00000	.0971358	5.752
28	116.	.00000	.0971358	5.752
29	116.	.00000	.0971358	5.752
30	116.	.00000	.0971358	5.752
31	116.	.00000	.0971358	5.752

UNDESIRABLE TREE CLASS VOLUME

The net cubic foot volume of undesirable (tree class 30) trees is determined by taking a proportion of the total acceptable tree class volume.

$$V_{30} = a\ V_{20} \qquad [E2]$$

Where:

V_{30} = net cubic foot volume of an undesirable tree (tree class 30);
V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1; and
a = species specific value from Table E4.

Table E4. Values to calculate net cubic foot volume for undesirable trees in Lake States TWIGS (Hahn 1984), equation E2.

Lake States	
Species Group	a
1	.822
2	.888
3	.834
4	.883
5	.889
6	.879
7	.832
8	.828
9	.751
10	.780
11	.798
12	.803
13	.832
14	.832
15	.868
16	.803
17	.860
18	.823
19	.822
20	.860
21	.856
22	.893
23	.848
24	.793
25	.782
26	.857
27	.000
28	.000
29	.000
30	.790
31	.832

RESIDUE WEIGHT

Calculating weight for each tree in the residue product class is a multistep process that incorporates coefficients and multipliers from many sources. The process is outlined here with reference to sources.

Residue includes the tops and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees, all trees less than 5 inches d.b.h., and cull trees (tree class 40).

STEP 1 Calculate weight of trees less than 5 inches d.b.h. (equation developed by G. K. Raile using data from Young *et al*. 1976).

$$WT_{lt5} = \frac{.8(4.89\ D^{2.432})}{2000} \qquad [E3]$$

Where:

WT_{lt5} = weight of a tree less than 5 inches d.b.h. in tons; and

D = current tree diameter (d.b.h. in inches).

STEP 2 Calculate bark adjustment factors for trees with a d.b.h. 5 inches or greater (Raile, 1986).

$$Badj = a + b(D) \qquad [E4]$$

Where:
Badj = bark adjustment factor;
D = current tree diameter (d.b.h. in inches); and
a,b = species specific equation coefficients from Table E5.

Table E5. Coefficients to calculate bark adjustment factors in Lake States TWIGS, equation E4.

	Lake States	
Species Group	a	b
1	0.8677	0.00854
2	1.0179	-.00550
3	0.9588	0.00000
4	1.0552	0.00000
5	0.9992	0.00000
6	0.9577	0.00504
7	1.0552	0.00000
8	1.0343	0.00000
9	0.8468	0.00000
10	0.8677	0.00854
11	0.9844	0.00000
12	0.9739	0.00000
13	1.0219	0.00000
14	1.0219	0.00000
15	0.9895	0.00000
16	1.0241	0.00000
17	0.9707	0.00000
18	1.0442	-.00164
19	0.9611	0.00000
20	0.9348	0.00000
21	0.9658	0.00191
22	0.9720	0.00000
23	0.9611	0.00000
24	0.9151	0.00365
25	0.9151	0.00365
26	0.9821	0.00205
27	1.0000	0.00000
28	1.0000	0.00000
29	1.0000	0.00000
30	1.0000	0.00000
31	1.0000	0.00000

STEP 3 Calculate weight of bark on bole (Raile 1986).

$$WT_{bark} = \frac{V_{20}\ (1.646 - Badj)\ 37}{2000} \qquad [E5]$$

Where:

WT_{bark} = weight of bark on bole in tons;

V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1; and

Badj = bark adjustment factor from equation E4.

STEP 4 Convert bole volume to bole weight (Raile 1986).

$$WT_{bole} = \frac{V_{20}\ (WT_{sp})\ Badj}{2000} \qquad [E6]$$

Where:

WT_{bole} = weight of bole in tons;

V_{20} = total net cubic foot volume of an acceptable (tree class 20) tree calculated using equation E1 and coefficients from Table E1;

Badj = bark adjustment factor from equation E4; and

WT_{sp} = wood density in pounds per cubic foot for each species from Table E6.

Table E6. Wood density in pounds per cubic foot for species in Lake States TWIGS (Markwardt 1930), equations E6 and E10.

Lake States	
Species Group	WT_{sp}
1	50.0
2	42.0
3	36.0
4	35.0
5	45.0
6	32.0
7	47.0
8	28.0
9	43.0
10	43.0
11	49.0
12	40.0
13	48.0
14	48.0
15	50.0
16	57.0
17	43.0
18	56.0
19	49.0
20	62.0
21	62.0
22	63.0
23	63.0
24	43.0
25	43.0
26	50.0
27	52.0
28	52.0
29	52.0
30	50.0
31	50.0

STEP 5 Calculate weight of top and limbs for a tree equal to or greater than 5 inches d.b.h. (Raile 1986).

$$WT_{top} = .45(WT_{bole} + WT_{bark}) \qquad [E7]$$

Where:

WT_{top} = weight of top and limbs in tons;
WT_{bole} = weight of bole in tons from equation E6; and
WT_{bark} = weight of bark in tons from equation E5.

STEP 6 Calculate total weight of a cull tree (tree class 40).

$$WT_{cull} = (WT_{top} + WT_{bole} + WT_{bark})b \qquad [E8]$$

Where:

WT_{cull} = total weight of a cull tree in tons;

WT_{top} = weight of top and limbs in tons from equation E7;

WT_{bole} = weight of bole in tons from equation E6;

WT_{bark} = weight of bark in tons from equation E5; and

b = species specific equation coefficients from Table E7.

Table E7. Coefficients to calculate total weight of cull trees in Lake States TWIGS (Hahn, 1984), equation E8.

Lake States	
Species Group	b
1	.369
2	.257
3	.354
4	.440
5	.366
6	.423
7	.416
8	.388
9	.281
10	.478
11	.328
12	.294
13	.377
14	.377
15	.360
16	.360
17	.367
18	.383
19	.378
20	.344
21	.364
22	.335
23	.343
24	.403
25	.382
26	.351
27	.000
28	.000
29	.000
30	.358
31	.358

STEP 7 Calculate total residue by summing values for all trees. (Each tree contributes to only one category on the right-hand side of the equation.)

$$\text{Residue Weight} = WT_{lt5} + WT_{top} + WT_{cull} \qquad [E9]$$

Where:

Residue weight = tons of residue per acre;

WT_{lt5} = weight in tons of trees less than 5 inches d.b.h. from equation E3;

WT_{top} = weight in tons of top and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees from equation E7; and

WT_{cull} = weight in tons of cull trees (tree class 40) from equation E8.

RESIDUE VOLUME

Compute total cubic feet of residue by dividing total tons of residue by species specific equation coefficients from Table E6.

$$\text{Residue volume} = \frac{\text{residue weight (2000)}}{WT_{sp}} \qquad [E10]$$

Where:

Residue volume = cubic feet per acre;

Residue weight = tons per acre from equation E9; and

WT_{sp} = wood density in pounds per cubic foot for each species from Table E6.

ACCEPTABLE AND UNDESIRABLE TREE CLASS VOLUME

The following equation was used for cubic foot and board foot volume of acceptable (tree class 20) trees and for cubic foot volume of undesirable (tree class 30) trees. This net volume equation was developed for Indiana (Smith and Weist 1982).

$$V = a\ SI^{b}[1 - e^{-c\ D^{d}}] \qquad [E11]$$

Where:

V = net volume;
SI = site index (feet at age 50);
D = current tree diameter (d.b.h. in inches); and
a,b,c,d = species specific equation coefficients in Tables E8-E11.

Table E8. Coefficients to calculate net cubic foot volume for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	24.3201	.8216	.000044	2.5616
2	32.7134	.3785	.000089	2.7986
3	32.7134	.3785	.000089	2.7986
4	32.7134	.3785	.000089	2.7986
5	.0000	.0000	.000000	.0000
6	65.4786	.0383	.000265	2.7537
7	15.8460	.5938	.000063	2.8574
8	24.3795	.5106	.000086	2.7597
9	24.3795	.5106	.000086	2.7597
10	16.7211	.5991	.000080	2.7109
11	168.5280	.0904	.000099	2.6121
12	16.7211	.5991	.000080	2.7109
13	948.9211	.0000	.000059	2.3163
14	16.7211	.5991	.000080	2.7109
15	341.7616	.0000	.000083	2.5673
16	16.7211	.5991	.000080	2.7109
17	16.7211	.5991	.000080	2.7109
18	948.9211	.0000	.000059	2.3163
19	168.5280	.0904	.000099	2.6121
20	21.1498	.5754	.000110	2.5942
21	126.1555	.2152	.000081	2.5973
22	126.1555	.2152	.000081	2.5973
23	126.1555	.2152	.000081	2.5973
24	126.1555	.2152	.000081	2.5973
25	21.1498	.5754	.000110	2.5942
26	21.1498	.5754	.000110	2.5942
27	16.7211	.5991	.000080	2.7109
28	16.7211	.5991	.000080	2.7109
29	16.7211	.5991	.000080	2.7109
30	16.7211	.5991	.000080	2.7109
31	16.7211	.5991	.000080	2.7109

Table E9. Coefficients to calculate net cubic foot saw-log volume for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	32.7134	.3785	.000089	2.7986
2	8.5339	.5167	.000231	2.7641
3	8.5339	.5167	.000231	2.7641
4	8.5339	.5167	.000231	2.7641
5	8.5339	.5167	.000231	2.7641
6	528.3431	.1433	.000030	2.4206
7	4.0386	.6312	.000064	3.1986
8	142.5035	.0034	.000116	2.6411
9	142.5035	.0034	.000116	2.6411
10	15.0211	.4755	.000087	2.8131
11	527.1757	.0000	.000078	2.2867
12	15.0211	.4755	.000087	2.8131
13	190.0165	.0000	.000199	2.3569
14	15.0211	.4755	.000087	2.8131
15	77.4351	.0922	.000154	2.6564
16	15.0211	.4755	.000087	2.8131
17	15.0211	.4755	.000087	2.8131
18	190.0165	.0000	.000199	2.3569
19	527.1757	.0000	.000078	2.2867
20	32.6541	.4767	.000084	2.6689
21	108.1743	.0818	.000175	2.4623
22	108.1743	.0818	.000175	2.4623
23	108.1743	.0818	.000175	2.4623
24	108.1743	.0818	.000175	2.4623
25	32.6541	.4767	.000084	2.6689
26	32.6541	.4767	.000084	2.6689
27	15.0211	.4755	.000087	2.8131
28	15.0211	.4755	.000087	2.8131
29	15.0211	.4755	.000087	2.8131
30	15.0211	.4755	.000087	2.8131
31	15.0211	.4755	.000087	2.8131

Table E10. Coefficients to calculate net board foot volume (International 1/4-inch rule) for acceptable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	68.6358	.6359	.000082	2.8486
2	68.6528	.9374	.000040	2.6643
3	68.6528	.9374	.000040	2.6643
4	68.6528	.9374	.000040	2.6643
5	68.6528	.9374	.000040	2.6643
6	68.6472	.5722	.000087	2.8488
7	178.1367	.3166	.000083	2.8811
8	1151.2737	.0000	.000077	2.7331
9	1151.2737	.0000	.000077	2.7331
10	164.5671	.4052	.000061	2.8766
11	68.6341	.7813	.000079	2.5203
12	164.5671	.4052	.000061	2.8766
13	68.6272	.5665	.000140	2.7006
14	164.5671	.4052	.000061	2.8766
15	693.5429	.0476	.000071	2.9203
16	164.5671	.4052	.000061	2.8766
17	164.5671	.4052	.000061	2.8766
18	68.6272	.5665	.000140	2.7006
19	68.6341	.7813	.000079	2.5203
20	103.7664	.6707	.000076	2.6670
21	871.4258	.0682	.000112	2.5879
22	871.4258	.0682	.000112	2.5879
23	871.4258	.0682	.000112	2.5879
24	871.4258	.0682	.000112	2.5879
25	103.7664	.6707	.000076	2.6670
26	103.7664	.6707	.000076	2.6670
27	164.5671	.4052	.000061	2.8766
28	164.5671	.4052	.000061	2.8766
29	164.5671	.4052	.000061	2.8766
30	164.5671	.4052	.000061	2.8766
31	164.5671	.4052	.000061	2.8766

Table E11. Coefficients to calculate net cubic foot volume for undesirable trees in Central States TWIGS, equation E11.

	Central States			
Species Group	a	b	c	d
1	22.7769	.4240	.000057	2.9092
2	22.7769	.4240	.000057	2.9092
3	22.7769	.4240	.000057	2.9092
4	22.7769	.4240	.000057	2.9092
5	.00	.0000	.000000	.0000
6	57.1662	.4545	.000048	2.5027
7	57.1662	.4545	.000048	2.5027
8	18.6983	.4097	.000132	2.7085
9	18.6983	.4097	.000132	2.7085
10	57.1662	.4545	.000048	2.5027
11	5.0944	.6960	.000158	2.6118
12	57.1662	.4545	.000048	2.5027
13	72.0477	.0743	.000166	2.7068
14	57.1662	.4545	.000048	2.5027
15	25.5502	.1927	.000200	2.7686
16	57.1662	.4545	.000048	2.5027
17	57.1662	.4545	.000048	2.5027
18	72.0477	.0743	.000166	2.7068
19	5.0944	.6960	.000158	2.6118
20	104.1617	.0890	.000119	2.5916
21	21.1882	.6788	.000073	2.4026
22	21.1882	.6788	.000073	2.4026
23	21.1882	.6788	.000073	2.4026
24	21.1882	.6788	.000073	2.4026
25	104.1617	.0890	.000119	2.5916
26	104.1617	.0890	.000119	2.5916
27	57.1662	.4545	.000048	2.5027
28	57.1662	.4545	.000048	2.5027
29	57.1662	.4545	.000048	2.5027
30	57.1662	.4545	.000048	2.5027
31	57.1662	.4545	.000048	2.5027

RESIDUE WEIGHT

Residue includes the tops and limbs of acceptable (tree class 20) trees and undesirable (tree class 30) trees, all trees less than 5 inches d.b.h., and cull trees (tree class 40).

Residue weight is calculated in three steps.

STEP 1 Calculate weight of tops and limbs of all tree classes and bole weight of cull trees (Raile and Jakes 1982).

$$WT_{tlc} = a\ D^b \qquad [E12]$$

Where:

WT_{tlc} = weight in green tons of tops and limbs for all tree classes and bole of cull trees;
D = current tree diameter (d.b.h. in inches); and
a,b = species specific equation coefficients from Table E12.

Table E12. Coefficients to calculate weight of tops, limbs, and cull trees in Central States TWIGS, equation E12.

Central States						
Species Group	Tops and limbs Tree class 20		Boles Tree class 40		Tops and limbs Tree class 30 and 40	
	a	b	a	b	a	b
1	.0013360	1.8396	.0001840	2.7407	.0001480	2.7578
2	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
3	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
4	.0014100	2.0285	.0018440	1.8345	.0020830	1.8429
5	.0000000	.0000	.0000000	.0000	.0000000	.0000
6	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
7	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
8	.0019400	1.9741	.0002210	2.8099	.0001760	2.8005
9	.0019400	1.9741	.0002210	2.8099	.0001760	2.8005
10	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
11	.0002690	2.6291	.0001170	2.1310	.0009300	2.1301
12	.0001100	2.9053	.0004680	2.5535	.0003630	2.5537
13	.0004590	2.4164	.0011240	2.1090	.0001390	2.7753
14	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
15	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
16	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
17	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
18	.0003650	2.5440	.0007360	2.3281	.0005820	2.3264
19	.0002690	2.6291	.0001170	2.1310	.0009300	2.1301
20	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
21	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
22	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
23	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
24	.0004430	2.5155	.0004680	2.5535	.0003630	2.5537
25	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
26	.0004850	2.4591	.0004190	2.5684	.0003200	2.5687
27	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
28	.0004070	2.4564	.0009420	2.2122	.0007490	2.2100
29	.0006090	2.3201	.0004680	2.5535	.0003630	2.5537
30	.0001100	2.9053	.0004680	2.5535	.0003630	2.5537
31	.0004070	2.4564	.0004190	2.5684	.0003200	2.5687

STEP 2 Calculate weight of trees less than 5 inches d.b.h. (Equation developed by G. K. Raile using data from Young *et al*. 1976)

$$WT_{lt5} = \frac{.8(4.89D^{2.432})}{2000} \qquad [E3]$$

Where:

WT_{lt5} = weight in tons of a tree less than 5 inches d.b.h.; and

D = current tree diameter (d.b.h. in inches).

STEP 3 Calculate total residue by summing values for all trees.

$$\text{Residue weight} = WT_{tlc} + WT_{lt5} \qquad [E13]$$

Where:

Residue weight = tons of residue per acre;
WT_{tlc} = weight in tons of tops and limbs from all tree classes and bole of cull trees from equation E12; and
WT_{lt5} = weight in tons of trees less than 5 inches d.b.h. from equation E3.

RESIDUE VOLUME

Compute total cubic feet of residue by dividing total tons of residue by species specific equation coefficients in Table E13.

$$\text{Residue Volume} = \frac{\text{Residue weight (2000)}}{WT_{sp}} \qquad [E14]$$

Where:

Residue volume = cubic feet per acre;
Residue weight = tons per acre from equation E13; and
WT_{sp} = wood density in pounds per cubic foot for each species from Table E13.

Table E13. Wood density in pounds per cubic foot for species in Central States TWIGS (Markwardt 1930), equation E14.

Species Group	WT_{sp}
1	37.0
2	51.0
3	51.0
4	51.0
5	0.0
6	58.0
7	62.0
8	64.0
9	64.0
10	38.0
11	48.0
12	49.0
13	45.0
14	38.0
15	54.0
16	38.0
17	38.0
18	56.0
19	48.0
20	62.0
21	63.0
22	62.0
23	63.0
24	65.0
25	63.0
26	63.0
27	63.0
28	54.0
29	38.0
30	49.0
31	59.0

LAKE AND CENTRAL STATES TWIGS

LOG RULE CONVERSION FACTORS

The following log rule conversion factors were used to convert International 1/4" rule to Scribner or Doyle (Smith 1986).

Diameter Class	To Scribner (Lake States)		To Doyle (Central States)	
	Hardwood	Softwoods	Hardwoods	Softwoods
9.0-10.9"	.00	.80	.00	.50
11.0-12.9"	.73	.87	.45	.51
13.0-14.9"	.82	.98	.54	.62
15.0-16.9"	.88	1.04	.62	.65
17.0-18.9"	.93	1.08	.67	.78
19.0-20.9"	.98	1.12	.72	.82
21.0-22.9"	1.02	1.10	.77	.84
23.0-24.9"	1.06	1.10	.79	.91
25.0-26.9"	1.10	1.08	.82	1.00
27.0-28.9"	1.14	1.10	.89	.95
29.0-30.9"	1.15	1.09	.92	1.05
31.0-32.9"	1.19	1.11	.94	1.09
33.0+	1.23	1.09	.97	1.13

APPENDIX F

TREE LIST FORMAT

Although TREEGEN formats the input provided by the user for TWIGS, the users may find it more convenient in some cases to edit an existing tree list file than to create a new one with TREEGEN. This Appendix describes the format of a tree list file.

A tree list file consists of one header line of stand characteristics, two lines specifying species specific site indices, and one line for each individual tree entry:

```
Walt's Woods    mxdjack     1986      39       1       0       22
  61   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   1   1 105   4.0    .0   54.0   1  20
   2   1 105   5.0    .0  295.0   1  20
   3   1 105   6.0    .0   62.0   1  20
   4   1 105   7.0    .0   60.0   1  20
   5   1 105   8.0    .0   81.0   1  20
   6   1 105   9.0    .0   11.0   1  20
   7   1 105  10.0    .0   31.0   1  20
   8   1 105  11.0    .0    1.0   1  20
   9   1 105  12.0    .0    1.0   1  20
  10   3 125   3.0    .0   19.0   1  30
  11   3 125   5.0    .0    7.0   1  30
  12   3 125   7.0    .0    4.0   1  30
  13   2 125   3.0    .0   38.0   1  20
  14   2 125   6.0    .0   24.0   1  20
  15   2 125  11.0    .0    1.0   1  20
  16  25 746   3.0    .0   19.0   1  20
  17  25 746   5.0    .0   34.0   1  20
  18  25 746   6.0    .0   14.0   1  20
  19  25 746   7.0    .0    4.0   1  20
  20  25 746   8.0    .0   11.0   1  20
  21  25 746   9.0    .0    6.0   1  20
  22  25 746   6.0    .0    5.0   1  30
```

The HEADER LINE contains

a. Property name (optional), in columns 1-16 (Walt's Woods).
b. Stand name (optional), in columns 17-24 (mxdjack).
c. Year the stand was measured, in columns 25-32 (1986).
d. Stand age at the year the stand was measured, in columns 33-40 (39).
e. Species group used to measure site index, in columns 41-48 (1).
f. Red pine plantation denotation, in columns 49-56; Lake States TWIGS only (0, where: 0 = no, 1 = yes).
g. Number of tree list entries, in columns 57-64 (22).

The species specific SITE INDICES LINES contain a 4-column field for each of the 31 species groups. In the above tree list only the first field is used (SI=61).

Each INDIVIDUAL TREE entry includes

a. Sequential tree entry number (integer) not to exceed 500.
b. STEMS species groups code (integer). See Appendix A.
c. USFS species code (integer). See Appendix A.
d. Diameter at breast height (real number) in inches.
e. Crown ratio code (real number). See page .
f. Expansion factor (real number). See page .
g. Status (integer) where 1 = live, 2 = cut, 3 = dead. All trees on an initial tree list should have status = 1.
h. Tree class (integer) where 20 = acceptable, 30 = undesirable, and 40 = cull.

The format specification for the individual tree entries is (3I4, 2F6.1, F8.1, 2I4).

APPENDIX G

PRINTOUT FROM AN EXAMPLE TWIGS RUN

```
Welcome to the wonderful world of ---
 TTTTT  W     W   III    GGGG  SSSS        The
   T    W     W    I     G     S           Woodsman's
   T    W WW W     I     G GG  SSSS        Ideal
   T    WW   WW    I     G  G     S        Growth projection
   T    W     W   III    GGGG  SSSS        System

Lake States 3.0 (July 1987).

Microsoft FORTRAN for the IBM microcomputer

Written by: Kevin K. Nimerfro and Monique L. Belli
With direction from: Gary J. Brand, Nancy R. Walters,
                     Charles R. Blinn, Dietmar W. Rose



::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                              ::
::  Tree List File is LSTLIST                                   ::
::                                                              ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


  17 Trees will be read for property "CLOQUET", stand "COMP 284"
year= 1987, age= 56, site index for RED PINE= 55.0, plantation= 0
```

Seq num	Stems code	USFS code	Stems grp name	Dbh	Crown ratio	Trees/ac	Tree status	Tree class
1	2	125	RED PINE	5.0	.0	28.0	1	20
2	2	125	RED PINE	6.0	.0	21.0	1	20
3	2	125	RED PINE	7.0	.0	28.0	1	20
4	2	125	RED PINE	8.0	.0	42.0	1	20
5	2	125	RED PINE	9.0	.0	28.0	1	20
6	2	125	RED PINE	10.0	.0	14.0	1	20
7	2	125	RED PINE	11.0	.0	49.0	1	20
8	2	125	RED PINE	12.0	.0	14.0	1	20
9	2	125	RED PINE	13.0	.0	14.0	1	20
10	1	105	JACK PINE	6.0	.0	7.0	1	20
11	1	105	JACK PINE	10.0	.0	21.0	1	20
12	1	105	JACK PINE	11.0	.0	7.0	1	20
13	26	375	PAP.BIRCH	5.0	.0	7.0	1	20
14	26	375	PAP.BIRCH	6.0	.0	7.0	1	20
15	26	375	PAP.BIRCH	7.0	.0	7.0	1	20
16	26	375	PAP.BIRCH	8.0	.0	7.0	1	20
17	3	129	WHITE PINE	8.0	.0	7.0	1	20

Tree list has 17 trees, tpa= 308.0, batot= 132.9, $\overline{\text{dbh}}$= 8.6

S T U M P A G E   R A T E S

User has not yet supplied stumpage rates.

Default stumpage rates:

	Sawtimber $/1000 bdft	Poletimber $/cord	Residue $/100 cuft
	-----------	-----------	-----------
	$ 29.00	$ 6.00	$ .00

ANALYSIS FOR STAND: COMP 284
STAND AGE IN 1987 IS 56 YEARS

ECONOMIC ANALYSIS INPUTS

NOMINAL DISCOUNT RATE	7.00%
GENERAL INFLATION RATE	4.00%
STUMPAGE PRICE INFLATION RATE	1.20%
BASE YEAR FOR THE ANALYSIS	1987
END YEAR FOR THE ANALYSIS	2007

DIARY OF COST AND REVENUE ACTIVITIES:

(ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY	NAME	YEAR(S)	COST	REVENUE	INFLATION RATE
1	Buy Land	1987	300.00	.00	.00
2	Property Tax	1987-2007	.90	.00	.00
3	Sale Prep.	1987	65.00	.00	.00
		2007	65.00	.00	.00
4	Sale Admin.	1987	22.00	.00	.00
		2007	22.00	.00	.00
5	Sell Land	2007	.00	300.00	.00

S T U M P A G E   R A T E S

User-defined stumpage rates:

USFS code	Sawtimber $/1000 bdft	Poletimber $/cord	Residue $/100 cuft
125	$ 62.35	$ 9.30	$ .00
129	$ 62.35	$ 9.30	$ .00
375	$ 9.90	$ 2.20	$ .00
105	$ 39.05	$ 9.50	$ .00

Default stumpage rates:

Sawtimber $/1000 bdft	Poletimber $/cord	Residue $/100 cuft
$ 29.00	$ 6.00	$ .00

STAND CONDITIONS FOR 1987

(INITIAL CONDITIONS)

Report for stand "COMP 284". Year= 1987. INITIAL CONDITIONS. Age= 56,
Cycle= 0, Site index for RED PINE= 55.0

Species gr.	Live tree/ac	Ba/ acre	Avg dbh	Avg cai	Cut Tree/ac	Cut Ba/ac	Mortality Tree/ac	Mortality Ba/ac	Group si
JACK PINE									56.5
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	28	12.8	9.0	.00	0	.0	0	.0	
11.0+	7	4.6	11.0	.00	0	.0	0	.0	
Group totals	35	17.4	9.4	.00	0	.0	0	.0	
RED PINE									55.0
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	161	50.1	7.4	.00	0	.0	0	.0	
11.0+	77	56.2	11.5	.00	0	.0	0	.0	
Group totals	238	106.3	8.7	.00	0	.0	0	.0	
WHITE PINE									53.3
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	7	2.4	8.0	.00	0	.0	0	.0	
11.0+	0	.0	.0	.00	0	.0	0	.0	
Group totals	7	2.4	8.0	.00	0	.0	0	.0	
PAP.BIRCH									54.6
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	28	6.6	6.5	.00	0	.0	0	.0	
11.0+	0	.0	.0	.00	0	.0	0	.0	
Group totals	28	6.6	6.5	.00	0	.0	0	.0	
All species									
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	224	72.0	7.5	.00	0	.0	0	.0	
11.0+	84	60.9	11.5	.00	0	.0	0	.0	
Stand totals	308	132.9	8.6	.00	0	.0	0	.0	

cai = current annual diameter increment.

Stand Volume

Species gr.	Sawlog cuft	Sawlog bdft	Pulpwood cuft	Pulpwood cords	Total Merchantable cuft	Residue cuft	Residue tons
JACK PINE	224	1094	63	.8	286	151	3.6
RED PINE	1447	7174	501	6.3	1949	1051	21.2
WHITE PINE	0	0	31	.4	31	17	.3
PAP.BIRCH	0	0	125	1.6	125	64	1.6
Stand totals	1671	8268	720	9.1	2391	1283	26.7

Bdft volumes are in SCRIBNER.

mean annual increment = 42.7 cuft/year.

Note:

- Definition of tree classes:
  20=Acceptable 30=Undesirable, 40=Cull trees.

- Sawlog volume comes from acceptable trees with a dbh >= 9" (softwood) or with a dbh >= 11" (hardwood). Minimum top sawlog diameters are 7" (softwood) or 9" (hardwood).

- Pulpwood volume comes from acceptable and undesirable trees with a dbh >= 5" (excluding the sawlog portion of acceptable sawtimber size trees which is tallied under sawlog volume). Minimum top DOB is 4". One cord equals 79 cuft.

- Total merchantable volume is the sum of the sawlog and pulpwood volume.

- Residue includes volume in tops (<4" DOB to a 1" DOB), limbs, trees less than 5" DBH, and cull trees.

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                            ::
::                      M A N A G E M E N T   I N   1987                      ::
::                                                                            ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

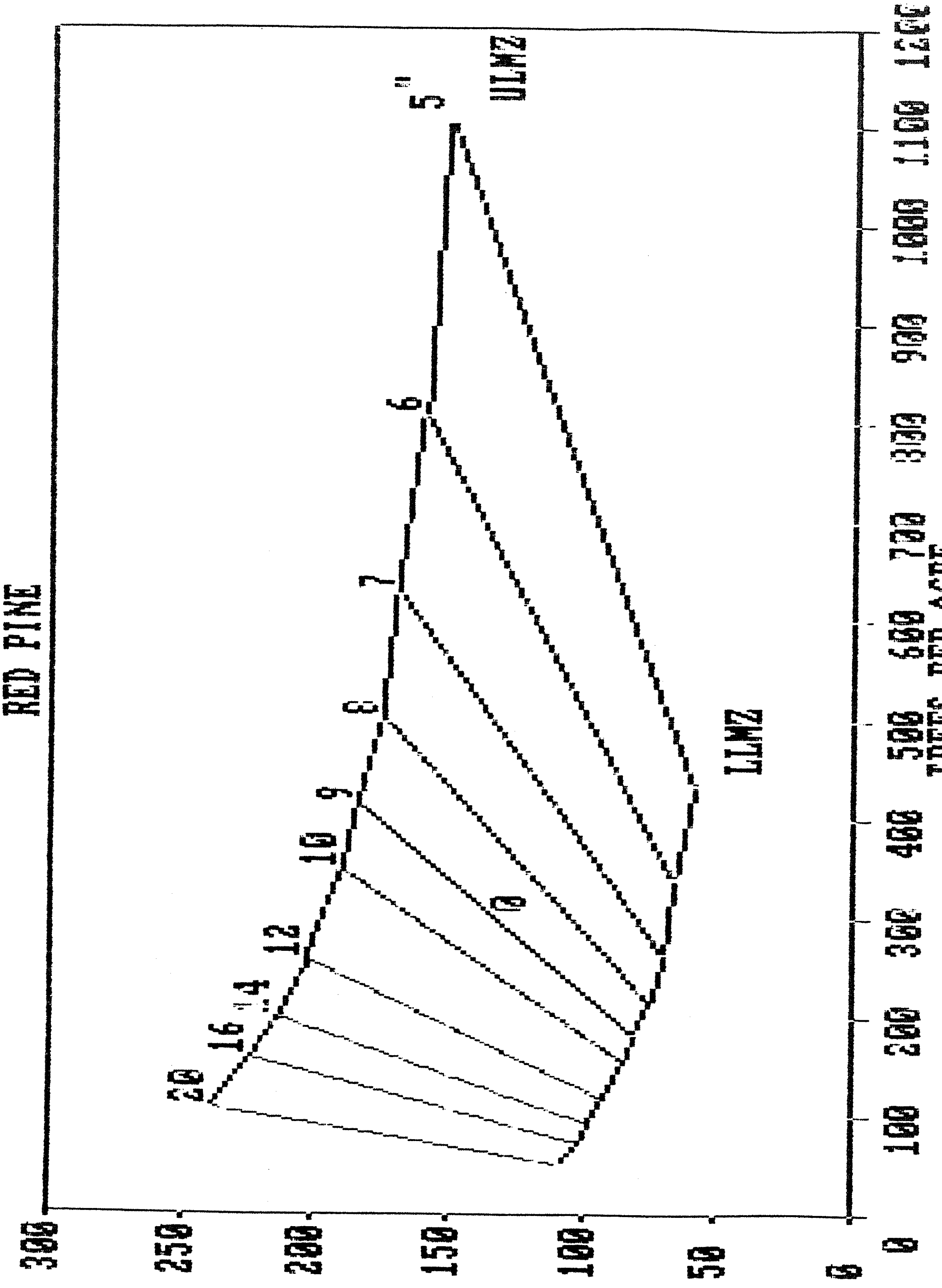
```
********************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
********************************************************************************
```

	Trees/ac	Batot	Basaw	Bapole	Basap	Dbh	Dbh>5	Sawlog bdft	[Total cuft	Merch.] cords
LIVE:	308	132.9	92.3	40.5	.0	8.6	8.6	8268	2391	30.3
CUT :	0	.0	.0	.0	.0			0	0	.0

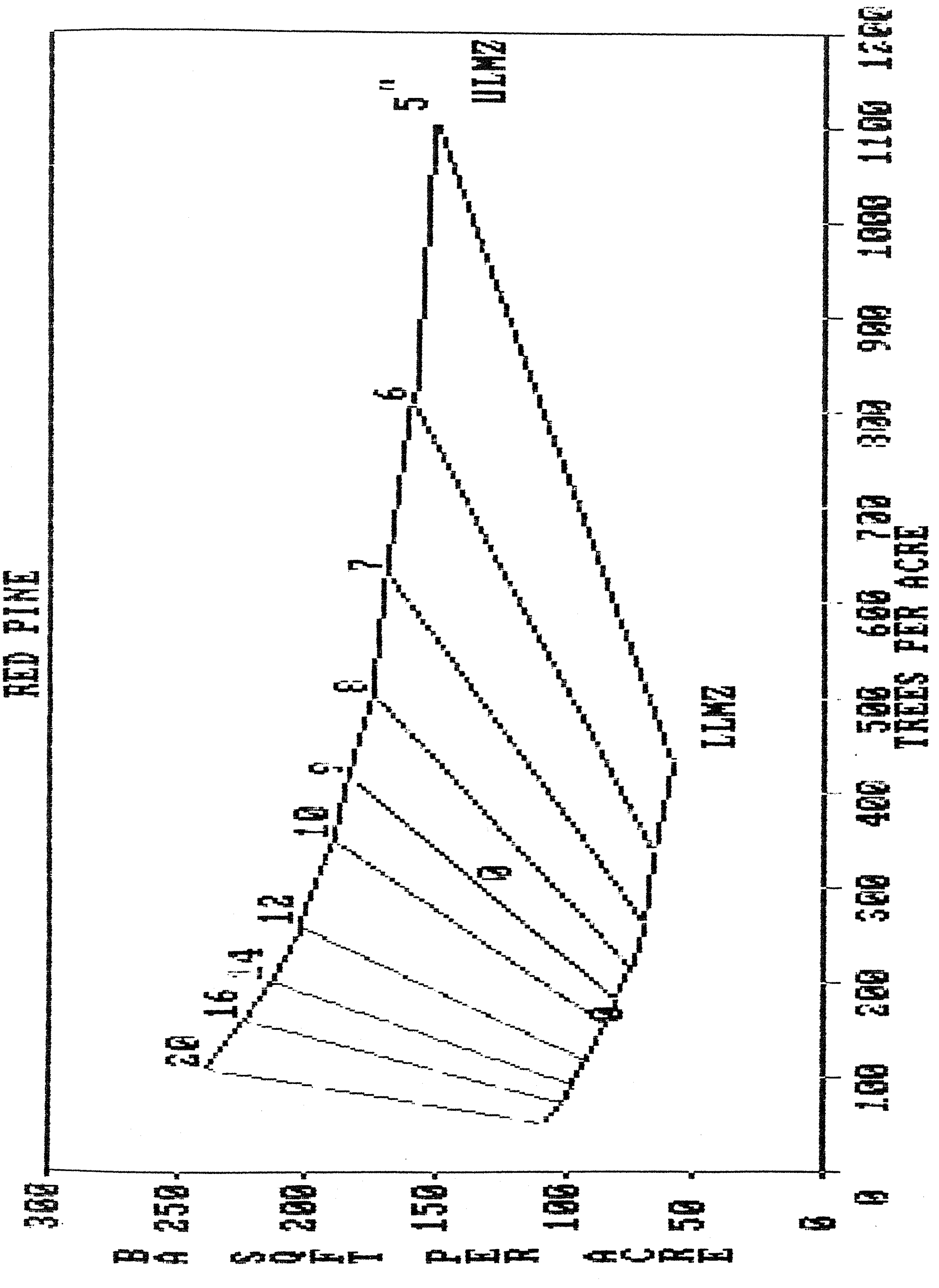
* Bdft volumes are in SCRIBNER. Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

NOTE: Cycle numbers are used to locate current and previous stand conditions on the stocking guide. Cycle 0 represents initial conditions. Duplicated numbers indicate before and after cutting.

LLMZ stands for lower level management zone (B-line).
ULMZ stands for upper level management zone (A-line).


RED PINE
BA SQFT PER ACRE
TREES PER ACRE
0
50
100
150
200
250
300
100
200
300
400
500
600
700
800
900
1000
1100
1200
ULMZ
LLMZ
5"
6
7
8
9
10
12
14
16
20

```
*****************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
*****************************************************************************

                                                        Sawlog  [Total Merch.]
      Trees/ac Batot Basaw Bapole Basap  Dbh  Dbh>5      bdft    cuft   cords
LIVE:      308 132.9  92.3   40.5    .0  8.6   8.6       8268    2391    30.3
CUT :        0    .0    .0     .0    .0                     0       0      .0
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

***  Management action:  THIN.

========== Thin in year 1987.  Critical values are:
Thin from below with favored species (most to least favored):
        RED PINE

========== ba, trees, dbh limits for cut are:     90.0 N/A    [none,none]

Tree 13,  PAP.BIRCH    , dbh=  5.0   Cut values: trees/ac=   7.0, ba/ac=   1.0
Tree 10,  JACK PINE    , dbh=  6.0   Cut values: trees/ac=   7.0, ba/ac=   1.4
Tree 14,  PAP.BIRCH    , dbh=  6.0   Cut values: trees/ac=   7.0, ba/ac=   1.4
Tree 15,  PAP.BIRCH    , dbh=  7.0   Cut values: trees/ac=   7.0, ba/ac=   1.9
Tree 16,  PAP.BIRCH    , dbh=  8.0   Cut values: trees/ac=   7.0, ba/ac=   2.4
Tree 17,  WHITE PINE   , dbh=  8.0   Cut values: trees/ac=   7.0, ba/ac=   2.4
Tree 11,  JACK PINE    , dbh= 10.0   Cut values: trees/ac=  21.0, ba/ac=  11.5
Tree 12,  JACK PINE    , dbh= 11.0   Cut values: trees/ac=   7.0, ba/ac=   4.6
Tree  1,  RED PINE     , dbh=  5.0   Cut values: trees/ac=  28.0, ba/ac=   3.8
Tree  2,  RED PINE     , dbh=  6.0   Cut values: trees/ac=  21.0, ba/ac=   4.1
Tree  3,  RED PINE     , dbh=  7.0   Cut values: trees/ac=  28.0, ba/ac=   7.5
Tree 18,  RED PINE     , dbh=  8.0   Cut values: trees/ac=   2.6, ba/ac=    .9
Thinning is complete for year 1987

*****************************************************************************
Current stand statistics: 1987, cycle  0 for stand "COMP 284".
*****************************************************************************

                                                        Sawlog  [Total Merch.]
      Trees/ac Batot Basaw Bapole Basap  Dbh  Dbh>5      bdft    cuft   cords
LIVE:      158  90.0  76.2   13.8    .0 10.1  10.1       7174    1731    21.9
CUT :      150  42.9  16.1   26.8    .0                  1094     659     8.3
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

NOTE:  Cycle numbers are used to locate current and previous
stand conditions on the stocking guide.  Cycle 0 represents initial
conditions.  Duplicated numbers indicate before and after cutting.

LLMZ stands for lower level management zone (B-line).
ULMZ stands for upper level management zone (A-line).
```



RED PINE
ULMZ
LLMZ
5"
6
7
8
9
10
12
14
16
20
Q
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TREES PER ACRE
0
50
100
150
200
250
300
BA SQFT PER ACRE

****
Current stand statistics: 1987, cycle 0 for stand "COMP 284".
****

	Trees/ac	Batot	Basaw	Bapole	Basap	$\overline{\text{Dbh}}$	$\overline{\text{Dbh}}$>5	Sawlog bdft	[Total Merch.] cuft	cords
LIVE:	158	90.0	76.2	13.8	.0	10.1	10.1	7174	1731	21.9
CUT :	150	42.9	16.1	26.8	.0			1094	659	8.3

* Bdft volumes are in SCRIBNER. Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

*** Management action: VALUE AFTER MANAGEMENT.

Income from sale of cut trees in 1987 is $ 82.95 per acre.

Sawlogs = 1094 bdft, $ 42.71
Pulpwood = 5.5 cords, $ 40.24
Residue = 347.3 cuft, $ .00

Value of residual stand (all live trees) is $ 480.73 per acre.

Sawlogs = 7174 bdft, $ 447.30
Pulpwood = 3.6 cords, $ 33.43
Residue = 935.7 cuft, $ .00

Management complete for year 1987

STAND CONDITIONS FOR 1987

(AFTER MANAGEMENT)

Report for stand "COMP 284". Year= 1987. AFTER MANAGEMENT.
Age= 56, Cycle= 0, Site index for RED PINE= 55.0

Species gr.	Live tree/ac	Ba/ acre	Avg dbh	Avg cai	Cut Tree/ac	Cut Ba/ac	Mortality Tree/ac	Mortality Ba/ac	Group si
JACK PINE									56.5
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	0	.0	.0	.00	28	12.8	0	.0	
11.0+	0	.0	.0	.00	7	4.6	0	.0	
Group totals	0	.0	.0	.00	35	17.4	0	.0	
RED PINE									55.0
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	81	33.8	8.7	.00	80	16.3	0	.0	
11.0+	77	56.2	11.5	.00	0	.0	0	.0	
Group totals	158	90.0	10.1	.00	80	16.3	0	.0	
WHITE PINE									53.3
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	0	.0	.0	.00	7	2.4	0	.0	
11.0+	0	.0	.0	.00	0	.0	0	.0	
Group totals	0	.0	.0	.00	7	2.4	0	.0	
PAP.BIRCH									54.6
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	0	.0	.0	.00	28	6.6	0	.0	
11.0+	0	.0	.0	.00	0	.0	0	.0	
Group totals	0	.0	.0	.00	28	6.6	0	.0	
All species									
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	81	33.8	8.7	.00	143	38.2	0	.0	
11.0+	77	56.2	11.5	.00	7	4.6	0	.0	
Stand totals	158	90.0	10.1	.00	150	42.9	0	.0	

cai = current annual diameter increment.

S t a n d   V o l u m e

Species gr.	Sawlog cuft	Sawlog bdft	Pulpwood cuft	Pulpwood cords	Total Merchantable cuft	Residue cuft	Residue tons
JACK PINE	0	0	0	.0	0	0	.0
RED PINE	1447	7174	284	3.6	1731	936	18.8
WHITE PINE	0	0	0	.0	0	0	.0
PAP.BIRCH	0	0	0	.0	0	0	.0
Stand totals	1447	7174	284	3.6	1731	936	18.8

Bdft volumes are in SCRIBNER.
mean annual increment = 42.7 cuft/year.

Begin cycle 1 for 1987

Trees will be projected in 20 intervals for a total of 20 years.

:: STAND CONDITIONS FOR 2007 ::

:: (AFTER PROJECTION CYCLE) ::

Report for stand "COMP 284". Year= 2007. AFTER PROJECTION CYCLE.
Age= 76, Cycle= 1, Site index for RED PINE= 55.0

Species gr.	Live tree/ac	Ba/ acre	Avg dbh	Avg cai	Cut Tree/ac	Cut Ba/ac	Mortality Tree/ac	Mortality Ba/ac	Group si
RED PINE									55.0
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	39	24.3	10.7	.11	0	.0	0	.2	
11.0+	118	117.7	13.5	.11	0	.0	1	.5	
Group totals	157	142.1	12.8	.11	0	.0	1	.7	
All species									
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	39	24.3	10.7	.11	0	.0	0	.2	
11.0+	118	117.7	13.5	.11	0	.0	1	.5	
Stand totals	157	142.1	12.8	.11	0	.0	1	.7	

cai = current annual diameter increment.
Note: Mortality values are for 1987 to 2007

```
                              S t a n d   V o l u m e
                              -----------------------

                                                          Total
                     Sawlog              Pulpwood      Merchantable        Residue
               -------------        -------------   -------------    -------------
Species gr.    cuft     bdft        cuft    cords        cuft        cuft     tons
------------------------------------------------------------------------------------
RED PINE       2903    15534         157      2.0        3061        1676     33.3
------------------------------------------------------------------------------------
Stand totals   2903    15534         157      2.0        3061        1676     33.3

Bdft volumes are in SCRIBNER.

mean annual increment = 48.9 cuft/year.
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
::                                                                            ::
::                   M A N A G E M E N T   I N   2007                         ::
::                                                                            ::
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


********************************************************************************
Current stand statistics: 2007, cycle  1 for stand "COMP 284".
********************************************************************************

                                                          Sawlog  [Total Merch.]
       Trees/ac Batot Basaw Bapole Basap  Dbh  Dbh>5      bdft     cuft   cords
 LIVE:      157 142.1 142.1     .0    .0 12.8   12.8     15534     3061    38.7
 CUT :        0    .0    .0     .0    .0                     0        0      .0
* Bdft volumes are in SCRIBNER.  Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.


***  Management action:  CLEARCUT.


========== Clearcut in  2007  Cut values are:
========== 157.46 trees/acre and   142.06 basal area cut.
```

****
Current stand statistics: 2007, cycle 1 for stand "COMP 284".
****

	Trees/ac	Batot	Basaw	Bapole	Basap	$\overline{\text{Dbh}}$	$\overline{\text{Dbh}}$>5	Sawlog bdft	[Total cuft	Merch.] cords
LIVE:	0	.0	.0	.0	.0	.0	.0	0	0	.0
CUT :	157	142.1	142.1	.0	.0			15534	3061	38.7

* Bdft volumes are in SCRIBNER. Cut values are for this year only.
* Total Merch. is for trees >= 5" dbh to a 4" top DOB.

*** Management action: VALUE AFTER MANAGEMENT.

Income from sale of cut trees in 2007 is $ 987.07 per acre.

Sawlogs = 15534 bdft, $ 968.57
Pulpwood = 2.0 cords, $ 18.50
Residue = 1675.8 cuft, $ .00

Value of residual stand (all live trees) is $ .00 per acre.

Sawlogs = 0 bdft, $ .00
Pulpwood = .0 cords, $ .00
Residue = .0 cuft, $ .00

Management complete for year 2007

STAND CONDITIONS FOR 2007

(AFTER MANAGEMENT)

Report for stand "COMP 284". Year= 2007. AFTER MANAGEMENT.
Age= 76, Cycle= 1, Site index for RED PINE= 55.0

Species gr.	Live tree/ac	Ba/ acre	Avg dbh	Avg cai	Cut Tree/ac	Cut Ba/ac	Mortality Tree/ac	Mortality Ba/ac	Group si
RED PINE									55.0
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	0	.0	.0	.00	39	24.3	0	.2	
11.0+	0	.0	.0	.00	118	117.7	1	.5	
Group totals	0	.0	.0	.00	157	142.1	1	.7	
All species									
.0- 4.9	0	.0	.0	.00	0	.0	0	.0	
5.0-10.9	0	.0	.0	.00	39	24.3	0	.2	
11.0+	0	.0	.0	.00	118	117.7	1	.5	
Stand totals	0	.0	.0	.00	157	142.1	1	.7	

cai = current annual diameter increment.
Note: Mortality values are for 1987 to 2007
Cut values are for year 2007 only.

Stand Volume

Species gr.	Sawlog cuft	Sawlog bdft	Pulpwood cuft	Pulpwood cords	Total Merchantable cuft	Residue cuft	Residue tons
RED PINE	0	0	0	.0	0	0	.0
Stand totals	0	0	0	.0	0	0	.0

Bdft volumes are in SCRIBNER.

mean annual increment = 48.9 cuft/year

ECONOMICS FOR 2007

ANALYSIS FOR STAND: COMP 284
STAND AGE IN 2007 IS 76 YEARS

ECONOMIC ANALYSIS INPUTS

NOMINAL DISCOUNT RATE	7.00%
GENERAL INFLATION RATE	4.00%
STUMPAGE PRICE INFLATION RATE	1.20%
BASE YEAR FOR THE ANALYSIS	1987
END YEAR FOR THE ANALYSIS	2007

DIARY OF COST AND REVENUE ACTIVITIES:

(ALL CASH FLOWS ARE IN BASE YEAR DOLLARS PER ACRE)

ENTRY	NAME	YEAR(S)	COST	REVENUE	INFLATION RATE
1	Buy Land	1987	300.00	.00	.00
2	Property Tax	1987-2007	.90	.00	.00
3	Sale Prep.	1987	65.00	.00	.00
		2007	65.00	.00	.00
4	Sale Admin.	1987	22.00	.00	.00
		2007	22.00	.00	.00
5	Sell Land	2007	.00	300.00	.00
6	SALE INCOME	1987	.00	82.95	1.20
7	SALE INCOME	2007	.00	987.07	1.20

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	1987	1988	1989	1990	1991
Buy Land	300.00	.00	.00	.00	.00
Property Tax	.90	.94	.97	1.01	1.05
Sale Prep.	65.00	.00	.00	.00	.00
Sale Admin.	22.00	.00	.00	.00	.00
TOT ANN COST	387.90	.94	.97	1.01	1.05
CUM TOT COST	387.90	388.84	389.81	390.82	391.87
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	82.95	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	82.95	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-304.95	-.94	-.97	-1.01	-1.05
CUM NET REV	-304.95	-305.88	-306.86	-307.87	-308.92

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	1992	1993	1994	1995	1996
Buy Land	.00	.00	.00	.00	.00
Property Tax	1.09	1.14	1.18	1.23	1.28
Sale Prep.	.00	.00	.00	.00	.00
Sale Admin.	.00	.00	.00	.00	.00
TOT ANN COST	1.09	1.14	1.18	1.23	1.28
CUM TOT COST	392.97	394.11	395.29	396.52	397.81
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	.00	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-1.09	-1.14	-1.18	-1.23	-1.28
CUM NET REV	-310.02	-311.16	-312.34	-313.57	-314.85

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	1997	1998	1999	2000	2001
Buy Land	.00	.00	.00	.00	.00
Property Tax	1.33	1.39	1.44	1.50	1.56
Sale Prep.	.00	.00	.00	.00	.00
Sale Admin.	.00	.00	.00	.00	.00
TOT ANN COST	1.33	1.39	1.44	1.50	1.56
CUM TOT COST	399.14	400.52	401.96	403.46	405.02
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	.00	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-1.33	-1.39	-1.44	-1.50	-1.56
CUM NET REV	-316.19	-317.57	-319.01	-320.51	-322.07

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	2002	2003	2004	2005	2006
Buy Land	.00	.00	.00	.00	.00
Property Tax	1.62	1.69	1.75	1.82	1.90
Sale Prep.	.00	.00	.00	.00	.00
Sale Admin.	.00	.00	.00	.00	.00
TOT ANN COST	1.62	1.69	1.75	1.82	1.90
CUM TOT COST	406.64	408.33	410.08	411.90	413.80
Sell Land	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
SALE INCOME	.00	.00	.00	.00	.00
TOT ANN RECP	.00	.00	.00	.00	.00
CUM TOT RECP	82.95	82.95	82.95	82.95	82.95
ANN NET REV	-1.62	-1.69	-1.75	-1.82	-1.90
CUM NET REV	-323.69	-325.38	-327.13	-328.95	-330.85

ANNUAL CASH FLOW PATTERN

(ALL VALUES ARE IN BASE YEAR DOLLARS PER ACRE INFLATED TO YEAR OF OCCURRENCE)

ITEM	YEAR 2007
Buy Land	.00
Property Tax	1.97
Sale Prep.	142.42
Sale Admin.	48.20
TOT ANN COST	192.60
CUM TOT COST	606.40
Sell Land	657.34
SALE INCOME	.00
SALE INCOME	2745.51
TOT ANN RECP	3402.85
CUM TOT RECP	3485.80
ANN NET REV	3210.25
CUM NET REV	2879.40

PROFILE OF NET PRESENT VALUE (NPV) FOR THE INVESTMENT AT VARIOUS DISCOUNT RATES
(INVESTMENT LENGTH = 21 YEARS)

(NPV VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

REAL RATE	NOMINAL RATE	NPV
.00%	4.00%	$ 1143.06
2.00%	6.08%	$ 666.91
4.00%	8.16%	$ 351.89
6.00%	10.24%	$ 141.83
8.00%	12.32%	$ .75
10.00%	14.40%	$ -94.70
12.00%	16.48%	$ -159.69
14.00%	18.56%	$ -204.24
16.00%	20.64%	$ -234.95
18.00%	22.72%	$ -256.25
20.00%	24.80%	$ -271.09
22.00%	26.88%	$ -281.49
24.00%	28.96%	$ -288.80
26.00%	31.04%	$ -293.96
28.00%	33.12%	$ -297.62
30.00%	35.20%	$ -300.22
32.00%	37.28%	$ -302.07
34.00%	39.36%	$ -303.38
36.00%	41.44%	$ -304.32
38.00%	43.52%	$ -304.98
40.00%	45.60%	$ -305.44
42.00%	47.68%	$ -305.77
44.00%	49.76%	$ -305.99
46.00%	51.84%	$ -306.15
48.00%	53.92%	$ -306.25
50.00%	56.00%	$ -306.31

INVESTMENT PERFORMANCE ANALYSIS

NOMINAL DISCOUNT RATE = 7.00% GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

NET PRESENT VALUE (NPV)	$	511.62
EQUIVALENT ANNUAL INCOME (EAI)	$	34.02
SOIL EXPECTATION VALUE (SEV)	$	1179.49
BENEFIT/COST RATIO		2.14
YEARS TO PAY BACK AT DISCOUNT		20 YEARS
REAL INTERNAL RATE OF RETURN		8.01%
NOMINAL INTERNAL RATE OF RETURN		12.33%

Soil Expectation Value (SEV) is the capitalized value of an infinitely long series of cash flows associated with a timber management alternative that starts with BARE LAND. While a SEV was determined from the inputted cash flows, the calculated value is not appropriate for interpretation unless the base year for the analysis was set to the year of planting, all timber management cash flows were incorporated for the entire rotation, and all cash flows were in base year dollars. Land purchase costs and land sale returns must be removed from the cash flow stream before SEV is computed.

SENSITIVITY ANALYSIS

(SENSITIVITY OF PERFORMANCE TO A 10% CHANGE IN INPUT VALUES)
NOMINAL DISCOUNT RATE = 7.00% GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

ITEM CHANGED	NPV CHANGE	EAI CHANGE	SEV CHANGE
Buy Land	$ 30.00	$ 2.00	$ 69.16
Property Tax	$ 1.44	$ .10	$ 3.33
Sale Prep.	$ 10.18	$ .68	$ 23.47
Sale Admin.	$ 3.45	$ .23	$ 7.94
Sell Land	$ 16.99	$ 1.13	$ 39.16
SALE INCOME	$ 8.30	$ .55	$ 19.12
SALE INCOME	$ 70.95	$ 4.72	$ 163.57

Soil Expectation Value (SEV) is the capitalized value of an infinitely long series of cash flows associated with a timber management alternative that starts with BARE LAND. While a SEV sensitivity analysis was performed for investment cash flows, the calculated values are not appropriate for interpretation unless the base year for the analysis was set to the year of planting, all timber management cash flows were incorporated for the entire rotation, and all cash flows were in base year dollars. Land purchase costs and land sale returns must be removed from the cash flow stream before SEV sensitivity analysis is computed.

RISK ANALYSIS

(INPUT VALUE CHANGES WHICH WILL MAKE NPV EXACTLY EQUAL TO $0.00)
NOMINAL DISCOUNT RATE = 7.00%   GENERAL INFLATION RATE = 4.00%
(INVESTMENT LENGTH = 21 YEARS)

(ALL MONETARY VALUES ARE IN BASE YEAR DOLLARS PER ACRE)

ITEM CHANGED	PERCENT CHANGE	DOLLAR CHANGE
Buy Land	100.00%	$ -300.00
Property Tax	100.00%	$ -14.43
Sale Prep.	100.00%	$ -101.81
Sale Admin.	100.00%	$ -34.46
Sell Land	-100.00%	$ -169.87
SALE INCOME	-100.00%	$ -82.95
SALE INCOME	-72.11%	$ -511.62

NOTE: WHEN PERCENT CHANGE EQUALS 100% AND DOLLAR CHANGE IS SMALLER THAN $ 511.62, THE INPUT VARIABLE WILL NOT ALTER THE OVERALL INVESTMENT SELECTION, GIVEN THE CURRENT DECISION CRITERIA.

Projection is complete for this stand.

Summary of Management and Growth Projection

Stand Description:

Stand Name: COMP 284
Initial Year of Projection: 1987
Initial Age: 56
Site Index Species: RED PINE Site Index: 55.0

Management Applied:

Thin, from below to 90 square feet of basal area in 1987
Clearcut in 2007

Year	age	Mgmt Status	Trees/ac Live	Trees/ac Died	Ba/ ac	Ave dbh	Sawlog Cuft	Sawlog Bdft	Pulpwood Cuft	Pulpwood Cord	Residual Cuft	Residual Tons
1987	56	BEFORE	308	0	133	8.6	1671	8268	720	9	1283	27
1987	56	CUT	150	0	43	.0	224	1094	436	6	347	8
1987	56	AFTER	158	0	90	10.1	1447	7174	284	4	936	19
2007	76	BEFORE	157	1	142	12.8	2903	15534	157	2	1676	33
2007	76	CUT	157	0	142	.0	2903	15534	157	2	1676	33
2007	76	AFTER	0	1	0	.0	0	0	0	0	0	0

APPENDIX H

BIBLIOGRAPHY OF PUBLICATIONS RELATED TO STEMS AND TWIGS

Descriptions of STEMS and TWIGS and Their Components

1. Belcher, D.M.; Holdaway, M.R.; Brand, G.J. 1983. A description of STEMS--the Stand Tree Evaluation and Modeling System. Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 18 p.

2. Belcher, David M. 1982. TWIGS: The Woodsman's Ideal Growth Projection System. In: Proceedings, Microcomputers, a new tool for foresters; 1982 May 18-20; West Lafayette, IN. West Lafayette, IN: Purdue University: 70-95.

3. Belcher, David M. 1981. User's guide to STEMS (Stand and Tree Evaluation and Modeling System). Gen. Tech. Rep. NC-70. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 49 p.

4. Blinn, Charles R.; Brand, Gary J. 1987. Recent enhancements to Lake States and Central States TWIGS. Compiler. 5(2): 12-15.

5. Blinn, Charles R.; Rose, Dietmar W.; Belli, Monique L. 1988. Guide to analyzing investment options using TWIGS. Gen. Tech. Rep. NC-123. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. (In prep.)

6. Brand, Gary J., Holdaway, M.R. 1983. Users need performance information to evaluate models. Journal of Forestry. 81(4): 235-237.

7. Brand, Gary J. 1981. "Grow"--A computer subroutine that projects the growth of trees in Lake States' forests. Res. Pap. NC-207. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 11 p.

8. Brand, Gary J. 1981. Simulating timber management in Lake States forests. Gen. Tech. Rep. NC-69. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 25 p.

9. Brand, Gary J.; Holdaway, Margaret R.; Shifley, Stephen R. 1987. A description of the TWIGS and STEMS individual-tree based growth simulation models and their applications. In: Ek, Alan R.; Shifley, Stephen R.; Burk, Thomas E., eds. Forest growth modeling and prediction: proceedings, IUFRO conference; 1987 August 23-27; Minneapolis, MN. Gen. Tech. Rep. NC-120: SAF-87.12. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 2: 950-960.

10. Buchman, Roland G.; Lentz, Ellen L. 1984. More Lake States tree survival predictions. Res. Note NC-312. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.

11. Buchman, Roland G. 1983. Survival predictions for major Lake States tree species. Res. Pap. NC-233. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 7 p.

12. Buchman, Roland G.; Pederson, S.P.; Walters, N.R. 1983. A tree survival model with application to species of the Great Lakes region. Canadian Journal of Forestry. 13(4): 601-608.

13. Buchman, Roland G.; Shifley, S.R. 1983. Guide to evaluating forest growth projection systems. Journal of Forestry. 81(4): 232-234.

14. Buchman, R.G. 1978. Timely resource information through process modeling: the North Central system experience. In: Integrated inventories of renewable natural resources national workshop; 1978 January 8-12; Tucson, AZ. Tucson, AZ: 344-349.

15. Buchman, Roland G. 1985. Performance of a tree survival model on national forests. Northern Journal of Applied Forestry. 2(4): 114-116.

16. Ek, Alan R.; Randall, Bryan L.; Hahn, Jerold T.; Buchman, Roland G. 1985. STEMS model projection capability with plot and tree data aggregation. Northern Journal of Applied Forestry. 2(4): 121-127.

17. Hahn, J.T.; Belcher, D.M.; Holdaway, M.R.; Brand, G.J.; Shifley, S.R. 1979. FREP 78: The updated tree growth projection system. In: Frayer, W.E., ed. Forest resource inventories, Volume I. SAF-IUFRO proceedings. Fort Collins, CO: Colorado State University, Department of Forest and Wood Sciences: 211-222.

18. Holdaway, M.R. 1986. Modeling tree crown ratio. The Forestry Chronicle . 62: 451-455.

19. Holdaway, Margaret R. 1985. Adjusting STEMS growth model for Wisconsin forests. Res. Pap. NC-267. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

20. Holdaway, Margaret R. 1984. Modeling the effect of competition on tree diameter growth as applied in STEMS. Gen. Tech. Rep. NC-94. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 9 p.

21. Holdaway, M.R.; Brand, G.J. 1983. An evaluation of the STEMS tree growth projection system. Res. Pap. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 20 p.

22. Holdaway, M.R.; Brand, G.J. 1986. An evaluation of Lake States STEMS85. Res. Pap. NC-269. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

23. Leary, R.A. 1980. A design for survivor growth models. In: Brown, K.M.; Clarke, F.R., eds. Proceedings, Forecasting forest stand dynamics. Thunder Bay, ON: Lakehead University, School of Forestry: 62-81.

24. Lundgren, A.L.; Essex, B.L. 1978. A computerized tree growth projection system for forest resource evaluation in the Lake States. In: Navon, Daniel, comp. Operational forest management planning methods: proceedings, meeting of IUFRO Steering Systems Project Group; 1978 June 18-24; Bucharest, Romania: International Union of Forestry Research Organizations: 13-23.

25. Miner, Cynthia L. 1984. TWIGS: A computer program that simulates forest growth and management. National Woodlands. 7(5): 11-12.

26. Miner, Cynthia L.; Walters, Nancy R. 1984. STEMS: A nontechnical description for foresters. Res. Pap. NC-252. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 12 p.

27. Rose, D.W.; Blinn, C.R.; Brand, G.J. 1988. Guide to forestry investment analysis. Res. Pap. NC-284. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. (In prep.)

28. Shifley, Stephen R. 1987. A generalized system of models forecasting Central States tree growth. Res. Pap. NC-279. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 10 p.

29. Shifley, Stephen R. 1982. A preliminary comparison of three tree growth models for Central States species. In: Muller, Robert N., ed. Proceedings, 4th Central hardwood forest conference; 1982 November 8-10; Lexington, KY. Lexington, KY: University of Kentucky, Department of Forestry: 169-184.

30. Shifley, S.R.; Fairweather, S.E. 1981. Individual-tree diameter growth and mortality models for western Oregon. Unpublished study report, available from authors, North Central Forest Experiment Station, St. Paul, Minnesota.

31. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. Biomass energy technology final report, silvicultural production systems, Department of Energy, Contract DE-AI01-80CS83013, Projecting Future Supplies of Biomass for Energy in the North Central United States. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 38 p.

32. U.S. Department of Agriculture, Forest Service. 1979. A generalized forest growth projection system applied to the Lake States region. Gen. Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 96 p.

STEMS and TWIGS Applications and Related Publications

1. Brand, Gary J.; Shifley, Stephen R.; Ohmann, Lewis F. 1986. Linking wildlife and vegetation models to forecast the effects of management. In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison, WI: The University of Wisconsin Press: 383-387.

2. Buchman, Roland G. 1985. Performance of a tree survival model on National Forests. Northern Journal of Applied Forestry. 2(4): 114-116.

3. Ek, A.R.; Birdsall, E.T.; Spears, R.J. 1981. Total and merchantable tree height equations for Lake States tree species. Staff Pap. Ser. 27. St. Paul, MN: University of Minnesota, Department of Forest Resources. 41 p.

4. Ek, A.R. 1980. A preliminary trial of alternative methods for treating mortality in the multipurpose forest projection system (MFPS) model. Staff Pap. Ser. 8. St. Paul, MN: University of Minnesota, Department of Forest Resources. 6 p.

5. Ek, A.R.; Rose, R.W.; Checky, M.T. 1980. A brief description of MFPS: A multipurpose forest projection system. Staff Pap. Ser. 16. St. Paul, MN: University of Minnesota, Department of Forest Resources. 6 p.

6. Ek, Alan R. 1983. Use of forest growth models in management inventories. In: Forest inventory for improved management: proceedings, IUFRO Subject Group 4.02 meeting; 1983 September 5-9; Helsinki, Finland. Res. Note 17. Helsinki, Finland: University of Helsinki, Department of Forest Mensuration and Management: 129-136.

7. Ek, Alan R.; Randall, Bryan L.; Hahn, Jerold T.; Buchman, Roland G. 1985. STEMS model projection capability with plot and tree data aggregation. Northern Journal of Applied Forestry. 2(4): 121-127.

8. Ffolliott, Peter F.; Brooks, Kenneth N.; Guertin, D. Philip. 1984. Multiple-resource modeling--Lake States' application. Northern Journal of Applied Forestry. 1(4): 80-84.

9. Gertner, George Z. 1984. Localizing a diameter increment model with a sequential Bayesian procedure. Forest Science. 30: 851-864.

10. Gertner, George Z.; Dzialowy, Paul J. 1984. Effects of measurement errors on an individual tree-based growth projection system. Canadian Journal of Forest Research. 14: 311-316.

11. Jakes, P.J.; Smith, W.B. 1983. An area control alternative: Michigan's predicted timber yields 1981-2010. Res. Pap. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 98 p.

12. Jakes, P.J.; Bertsch, R.; Smith, W.B. 1982. Looking ahead at Michigan's timber harvest. Northern Logger and Timber Processor. 31(3): 10, 38.

13. Jakes, Pamela J.; Smith, W. Brad. 1980. Predicted yields from selected cutting prescriptions in northern Minnesota. Res. Pap. NC-188. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 29 p.

14. Latimer, M.J. 1985. Practical application of TWIGS program. Minnesota Forests. Winter: 6-7.

15. Moeur, M.; Ek, A.R. 1981. Plot, stand, and cover-type aggregation effects on projections with an individual tree based stand growth model. Canadian Journal of Forest Research. 11: 309-315.

16. Moeur, M.; Ek, A.R.; Rose, D.W. 1980. Assessment of the growth and yield potential of the Cloquet Forest with a computer-based growth projection model. Staff Pap. Ser. 15. St. Paul. MN: University of Minnesota, Department of Forest Resources. 48 p.

17. Raile, Gerhard K.; Smith, W. Brad. 1982. A simulated inventory update: Wisconsin's 1979 timber resource. Res. Pap. NC-209. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 40 p.

18. Shifley, Stephen R.; Brand, Gary J. 1984. Chapman-Richards growth function constrained for maximum tree size. Forest Science. 30(4): 1066-1070.

19. Shifley, Stephen; Lentz, Ellen. 1986. Quick estimation of the three-parameter Wiebull to describe tree size distributions. Forest Ecology Management. 13: 195-203.

20. Shifley, Stephen R.; Brand, Gary J.; Ohmann, Lewis F. 1986. Timber and squirrels: forecasting and evaluating the options. Northern Journal of Applied Forestry. 3(2): 46-49.

21. Smith, W. Brad. 1983. Adjusting the STEMS regional forest growth model to improve local predictions. Res. Note NC-297. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

22. Smith, W. Brad; Jakes, Pamela J. 1981. Projecting treatment opportunities for current Minnesota forest conditions. Res. Pap. NC-215. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 21 p.

23. Smith, W.B.; Raile, G.K. 1979. FREP--Application of the tree growth projection system for inventory update. In: Frayer, W.E., ed. Forest resource inventories, Volume I, SAF-IUFRO proceedings. Fort Collins, CO: Colorado State University, Department of Forest and Wood Sciences: 223-230.

24. Walters, Nancy R. 1985. The transfer of TWIGS. In: Foresters' future: leaders or followers? proceedings, 1985 Society of American Foresters national convention; 1985 July 28-31; Fort Collins, CO. SAF 85-13. Bethesda, MD: Society of American Foresters: 53-56.

25. Walters, Nancy R.; Miner, Cynthia L. 1986. TWIGS: a tool for forestry professionals. In: Massey, Joseph G.; Greber, Brian J.; Cooney, Timothy M., eds. Software solutions: proceedings, computer symposium, software fair and 2d annual meeting of the Forest Resources Systems Institute; 1985 April 21-24; Clarksville, IN. Florence, AL: Forest Resources Systems Institute: Madison, WI: Forest Products Research Society: 29-32.

Miner, Cynthia L.; Walters, Nancy R.; Belli, Monique L. 1988. A guide to the TWIGS program for the North Central United States. Gen. Tech. Rep. NC-125. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 105 p.

This is a complete reference to TWIGS, a forest growth-and-yield program with management and economic components developed for Lake and Central States tree species. The guide describes how TWIGS models growth and yield and how the model can be applied to obtain the best results. Step-by-step operating instructions are provided for TWIGS and its companion program, TREEGEN, which generates tree lists in readable format for TWIGS. The appendices include equations, coefficients, validation tables, and an example printout of a projection run.

KEY WORDS: Growth and yield (simulation), forest stand management (simulation), economics, computer programs (forestry), silviculture, STEMS.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager to meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION