A User's Guide for Western Biomass: Software to Calculate Cost and Production of Biomass Harvesting, Processing, and Transportation

Fei Pan, PhD, Research Associate and Han Sup-Han, Assoc. Professor
Humboldt State University, Arcata, CA

William J. Elliot, Research Engineer
USDA Forest Service Rocky Mountain Research Station, Moscow, ID

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Chapter 1

A model application using realistic data

4.1 Introduction

Thinning from below is often used to improve the fire-tolerance of the dense, small-diameter stands (Healthy Forests 2002). The amount of woody biomass resulting from increased thinning activities could be substantial. Removal of the biomass with subsequent use for energy generation avoids the heavy emissions of smoke and air pollutants from open-burning of biomass residues and creates a renewable source of energy (Morris 1999).

Use of forest biomass will become commonplace only when it becomes economically advantageous for users (GAO 2005). Harvesting, processing, and transporting forest biomass of sub-merchantable size is expensive when using conventional harvesting systems, due to the high capital costs of equipment and decreased production rates when handling small material (Han et al. 2002). Compounding the problems associated with estimating production and costs are that estimates of harvest and transport costs for biomass are either incomplete or are based on localized knowledge not applicable to other regions (Becker et al., No date). There is a need for a general analytical tool that can aid forest managers in developing cost-effective fuels reduction treatments.

4.1.1 Application of Western Biomass

This manual reports the usage of a Microsoft Excel spreadsheet-based, public domain forest engineering and financial program called Western Biomass. The software was developed for use by forest managers, planners, and project contractors to estimate the production rates and costs of fuel reduction treatments through evaluation of harvest prescriptions, product recovery scenarios, and the machines to be used.

The Western Biomass model is based on an accumulation of scientific and engineering information on harvest production and cost of fuels reduction projects over the past 30 years. To make the site-specific production equations applicable in more general conditions, the model applies a method of combining multiple regression equations (Pan et al., 2008b) to make a weighted average of operation cycle time, which is the most critical factor in estimating machine productivity. The Western Biomass model also uses an embedded linkage with the widely used forest growth and yield model, FVS, to predict the biomass quantity of the recovered products. This greatly improves the accuracy of estimating the biomass amounts when performing production cost calculations.

Development of Western Biomass was supported by funding from the National Fire Plan through USDA Forest Service, Rocky Mountain Research Station. Researchers at the University of Idaho created the program with assistance from the Rocky Mountain Research Station.

4.1.2 Model Users

The target audience for the Western Biomass model includes forest managers, forest planners, contactors and loggers, forest consultants, and community development and non-profit organizations. The model allows forest managers and planners to compare silvicultural prescriptions, evaluate contract bid rates, and assess the stumpage value of material removed. Contractors are able to use the model to estimate production rates and costs of operations and to generate cost estimates for project bidding. The model can be further used to assess project feasibility, assist in project design, and for community development purposes. The Western Biomass model is not intended to take the place of sound financial analysis, but to supplement business planning.

4.2 Getting started

4.2.1 Required User-Inputs

For any project simulation, the Western Biomass model requires user input values for:

• Harvest system selection;

• Product recovery scenario (single or multiple products);

• Equipment type selection;

• Biomass weight calculation selection;

• Amount of biomass retention on the site;

• Loss of biomass in primary transportation (skidding, forwarding);

• Harvest area treated;

• Secondary transportation road type selection; and

• Machine hourly cost calculation method selection.

In the following descriptions, all places that require numeric user input are marked in a light yellow color in the "Inputs" worksheet of the Western Biomass model.

4.2.2 Optional User-Inputs

Default input values are provided for most production parameters including:

• Machine productivity variables (ex. skidder travel distance);

• Number of machines (ex. 3 sawlog trucks if they are used);

• Truck load weight (ex. 12 Bone dry tons for 120 cubic yards chip van); and

• Mobilization cost variables.

In all cases, model default values can be overridden by the best-estimate of the user. If the user-defined value (optional user-inputs) is kept unchanged at 0, the model will take the/ default value for calculation; otherwise, a user-defined value will be automatically used.

Variables less likely to be changed on a case-by case basis are contained in a "Defaults" worksheet. These default values include variables for calculating machine hourly cost (i.e. machine economic life), skidder / forwarder loading capacity (ex. the grapple enclosure area of the skidder), and biomass moisture content. User input adjustments are allowed in this worksheet as well. The areas accepting user input values are marked light blue in the "Default" worksheet.

4.2.3 Software Outputs

The Western Biomass model provides various outputs to facilitate different user needs. Among those are production rates in terms of bone dry tons per productive machine hour (BDT/PMH) and bone dry tons per scheduled machine hour (BDT/SMH), costs in terms of dollars per bone dry ton ($/BDT), costs in terms of dollars per acre ($/ac), and costs in dollars per thousand board feet ($/MBF) for sawlog products. Users are given choices of viewing the costs of a hot operation only (production of sequential operations depend on the production of earlier operations), cold decking biomass only (material processed in each operational component is decked for the next component so sequential operations do not depend on production of the previous operation), or both. Prediction errors resulting from combining multiple productivity equations are calculated automatically by the Western Biomass model. These productivity errors are then transformed to an error estimate about production cost, which allows the development of a confidence interval around the point estimates of production cost. The confidence intervals are presented in the form of minimum-maximum value interval in the "Results" worksheet.

4.2.4 Software Disclaimer

The Western Biomass software is in the public domain. It can be downloaded to PC at the following webpage: http://fsweb.moscow.rmrs.fs.fed.us/fswepp/ .

The software was developed for softwood species in the western United States. The model has not been developed or applied to hardwood species. Models used in other regions of the country may be subject to different site and terrain conditions and these factors may influence equipment productivity. This model was developed around production equations developed during the dry season in the region and assume experienced equipment operators. Operations during the wet season or with less skilled operators may result in the greater variations in equipment productivity and generally lower productivity.

It is important to note that the Western Biomass model is a decision-support tool and is not a substitute for a thorough financial analysis. The accuracy of the software relies on the quality of data entered and the reliability of other software.

4.3 Using the model

4.3.1 Model Inputs

Step 1 - Harvest Prescription and FVS Prediction

The Western Biomass software is a stand level harvesting production and cost prediction model. Production and cost estimates are based upon specific harvest prescriptions and stand conditions, including tree stem weight, crown weight, whole-tree weight, stand density, diameter breast height (DBH), total volume, merchantable volume, tree height, biomass retention amounts on site, biomass losses in primary transportation, and total harvest area.

The Forest Vegetation Simulator (FVS) is a tree growth and yield model (Dixon, 2008) and is the US Forest Service's nationally supported framework for forest vegetation modeling (Fig 4-1). The FVS model is capable of calculating the stand condition information required by the Western Biomass model, as shown in the case study in Part IV. The FVS model will automatically generate an external Microsoft Excel spreadsheet database with a default file name of FVSOut.xls, storing the calculated stand information. Users of the Western Biomass model need to open this database, **delete the first four columns in the worksheet of "FVS_Compute" and then save this change**. Moving this file from the folder of "FVS data" to the Western Biomass default data link folder "C:/Western Biomass" will let the Western Biomass model automatically transfer the FVS predicted information as input values. Refer to the illustrative example in Part IV for the detailed procedures of the FVS data preparations.

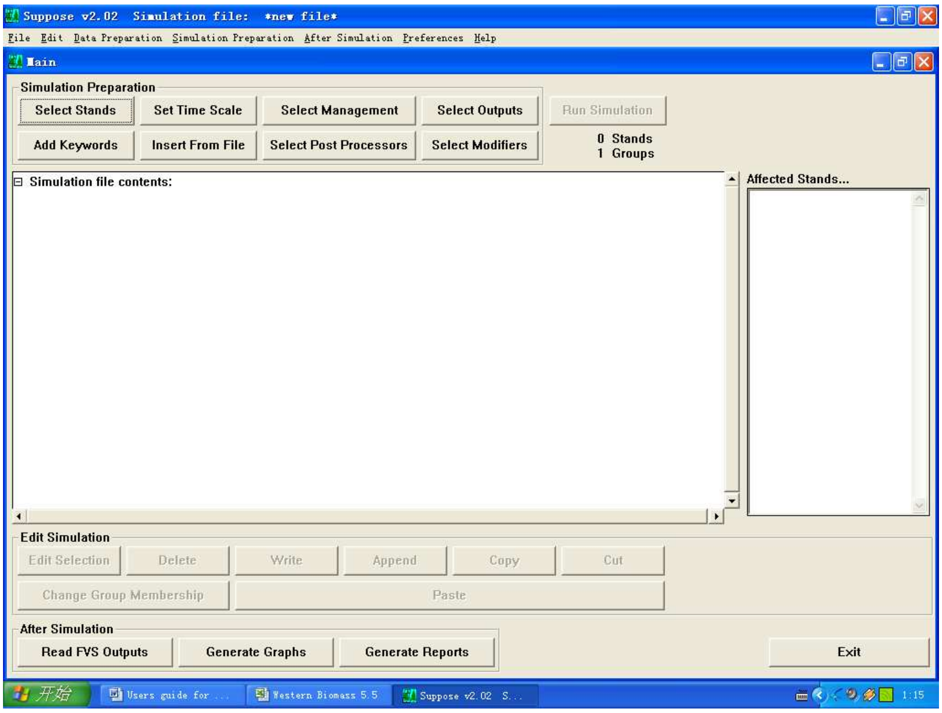


Figure 4-1: FVS (Suppose) model interface

Obtaining stand conditions through the FVS model will generally be more accurate than a knowledge-based estimate. However, if the FVS model is unavailable or the user is unfamiliar with FVS, the Western Biomass software allows inputs and use of user-defined stand condition information (see details in the “Biomass weight” section). Either the FVS-predicted or the user-defined stand conditions will be used as the input values for the Western Biomass software productivity and cost predictions.

Step 2 – Harvest System Selection

The first section in the Western Biomass software requiring a user-input value is the section of “Harvest System Selection” (Fig 4-2). Users can make a selection from a whole-tree system, a cut-to-length system, or a second entry system. The definitions of these three systems are as follows:

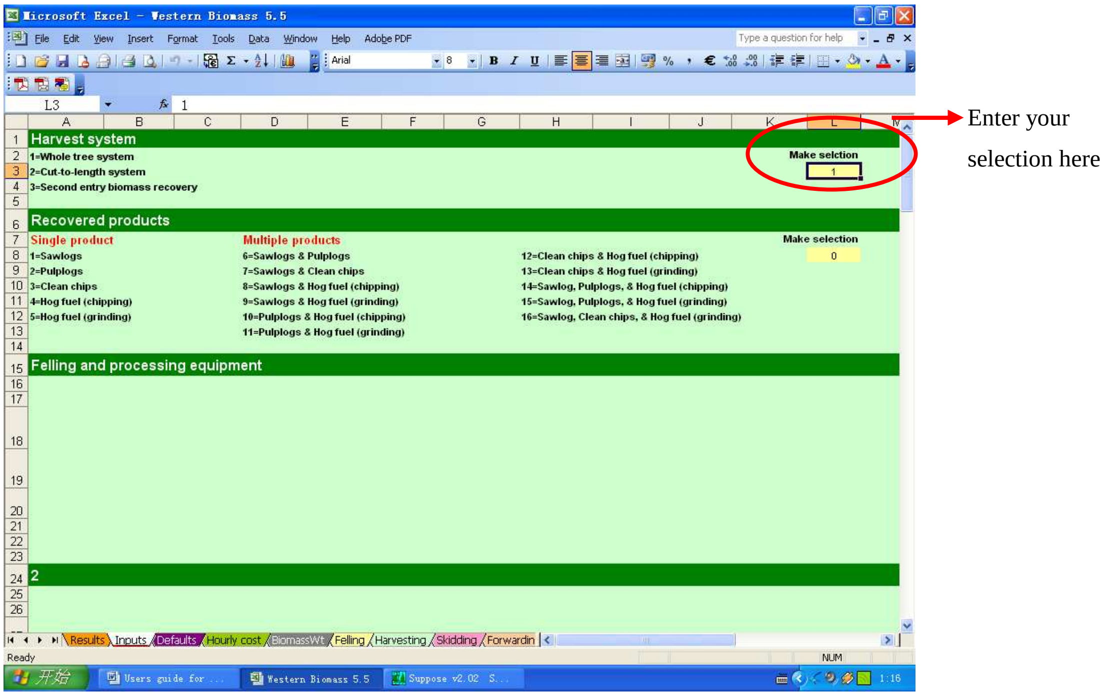


Figure 4-2: Harvest system selection in the Western Biomass model

Whole-tree system (**WT**) is a mechanized harvesting system where trees are felled by a feller-buncher prior to primary transportation to the landing or roadside with top and limbs intact by a skidder. The trees are then delimbed, topped, and bucked at the landing with a processor. This method requires that slash be treated at the landing (McDonald, 1999).

Cut-to-length system **(CTL)** is a mechanized harvesting system in which trees are delimbed and cut into log lengths at the stump area. CTL is typically a two-person, two-machine operation with a harvester that fells, delimbs, and bucks the trees and a forwarder for transporting the processed logs from the felling to a landing area close to a road accessible by trucks (McDonald, 1999).

Second entry biomass recovery system involves recovery of the largest sizes of the primary commercial product on one entry and recovery of the smaller commercial pieces and residue on a second entry. The order of the two entries can be varied (Johnson, 1989).

Step 3 – Product Recovery Scenario

Given the selection of a harvest system, the associated product recovery scenarios will appear (Fig 4-3). There are sixteen, eleven, and six product recovery scenarios designed for the whole-tree system, cut-to-length system, and second entry biomass recovery systems, respectively.

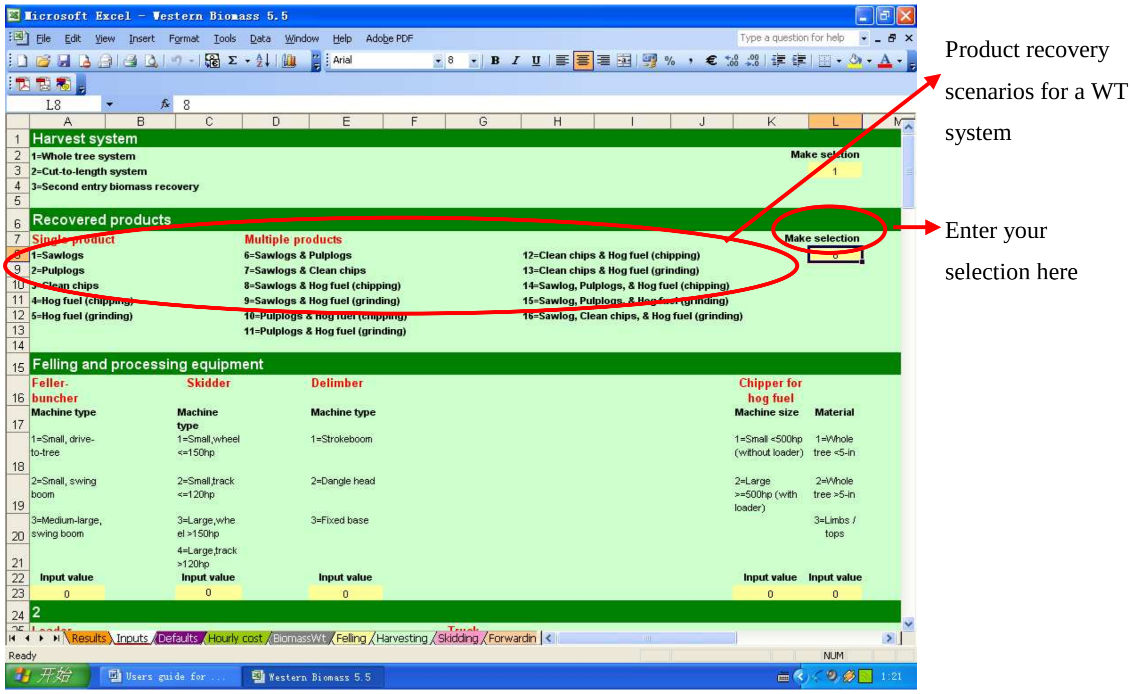


Figure 4-3: Product recovery scenario selection in the Western Biomass model

In the six product recovery scenarios of the second entry biomass recovery system, the choice of using a slash bundler to collect biomass is temporarily unavailable due to the lack of useful production equations. The selections of “Harvesting sawlogs after biomass harvesting” and “Harvesting biomass after sawlog harvesting” are currently considered as advanced applications of this model due to the fact that stand conditions will be changed after initial activity. Advanced applications require a more experienced user to make the necessary adjustments to defaults and the stand and biomass conditions.

Step 4 – Felling and Processing Equipment Selection

Feller-buncher

A typical mechanical feller-buncher consists of an excavator-based carrier with a felling attachment such as a hydraulically driven disc or chainsaw. It can move the trees to bunches after felling and can work in either clear cut or partial cut prescriptions.

Four major characteristics distinguish the various types of feller-buncher: 1) the method for advancing the felling head to the tree, 2) the carrier type, 3) the machine's size, and 4) the type of felling head (McDonald, 1999). The Western Biomass software contains three major types of feller-buncher: small drive-to-tree feller-bunchers, medium-sized swing-boom feller-bunchers, and large-sized swing-boom feller-bunchers with leveling cabs (Fig 4-4). This categorization is primarily based on the machine advancing method and the machine size. The type of cutting head (saw) is not used to further distinguish the feller-bunchers, as the hotsaw felling head (continuous rotation of a disk saw) is considered as the most popular type in the western states and is the only felling head included in the model.

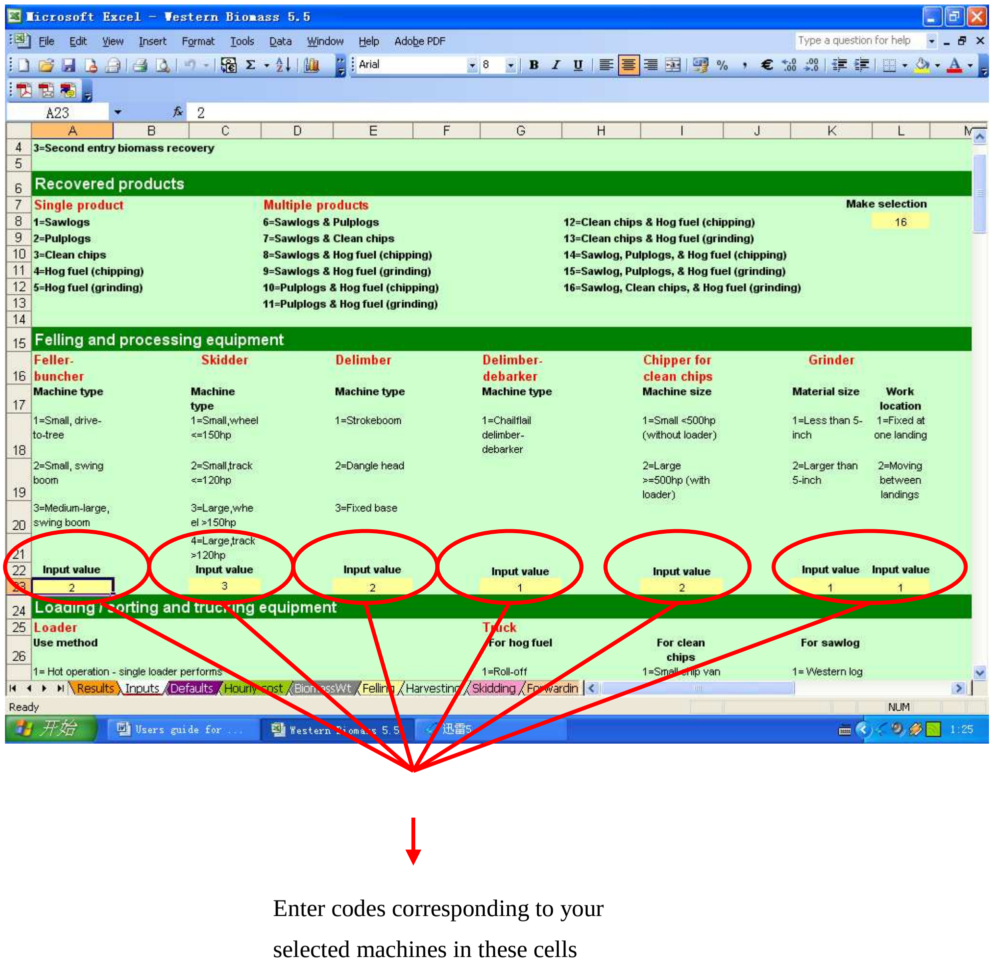


Figure 4-4: Harvesting and processing equipment selection in the Western Biomass model

Skidder

A skidder is ground-based equipment that travels from the landing or roadside to the stump and returns with a payload of trees. It requires that haul roads be located within an acceptable skidding distance from the felling site, and that the site have terrain that is not too steep or broken and have soils strong enough to support the machine (McDonald, 1999).

Two major features distinguish the various skidders from one another: the carrier type and the machine size. These two features were both considered for the Western Biomass software and resulted in four major categories of skidders: small wheeled skidder, small tracked skidder, large wheeled skidder, and large tracked skidder (Fig 4).

An additional characteristic of skidders is the method used for holding the trees. This can further divide the skidders into three groups: grapple skidder, cable skidder, and clam bunk skidder. The Western Biomass software includes only grapple skidders. The exclusion of cable skidders was due to the lack of available information and the probability that they would not be used in a complete tree recovery operation that included biomass. A clam bunk skidder operates more like a forwarder with a self contained loader and large bunk, but is designed to move whole trees rather than logs. The Western Biomass model does not include this type of skidder because of the lack of data. Clam bunk skidders have not been commonly used in western harvesting operations.

Feller-processor (Harvester)

Harvesters combine the felling and log manufacturing functions into one machine. Single-grip harvesters use a single, boom-mounted head for both felling and manufacturing, while double-grip harvesters have separate felling and processing heads (McDonald, 1999).

The categorization for harvesters in the Western Biomass model was based upon the machine engine size (Fig 4-4). Harvesters with horsepower less than or equal to 150hp were regarded as small harvesters; otherwise, they were defined as large harvesters. All the harvesters included in the Western Biomass are single-grip type as that machine type is more common in western operations.

Forwarder

Forwarders are highly specialized machines used in cut-to-length (CTL) systems with equipment such as feller-processors and shortwood loaders and trucks. Forwarders are built on an articulated chassis with two, three, or four axles and large rubber tires. On forwarders with two rear axles, the rear tires are usually equipped with tracks over the tires; the front axles may or may not have tracks. The rear of the forwarder consists of a bunk to hold logs, and a log loader mounted behind the cab. The logs are loaded onto the forwarder using its log loader, and then carried to the roadside where they are unloaded (McDonald, 1999).

The Western Biomass software divides the forwarders into two major groups based on machine load capacity: large forwarders and small forwarder (Fig 4-4). Forwarders with load capacity of less than or equal to 10 tons were considered as small forwarders (e.g. Timberjack 230-A, 8-ton forwarder); otherwise, they were regarded as large forwarders (e.g. Valmet 892, 14-ton forwarder).

Delimber

Whole-tree delimbing typically involves cutting trees into logs that meet the merchantability requirements of the secondary transport system and the mills.

Processor types (dangle-head and stroke delimbers) are used to classify the delimbers in the Western Biomass software (Fig 4-4). Both the dangle-head processors and stroke delimbers are widely used in both roadside and landing operations and are documented in the Western Biomass software. Stroke delimbers have a sliding boom with a grapple at the end for picking up the logs and movable knives that circle the log and remove the branches. Dangle-head processors consist of a processing head mounted at the end of the loading-type boom, often mounted on an excavator-style carrier. The processing head includes grapple arms, delimbing knives, a cutoff saw, and a drive system for moving the logs through the processor. Less common is “fix-based” processor where delimbing knives move along a fixed conveyor base. Production information for this type of delimber is so limited that the Western Biomass software currently does not support this machine.

Delimber-Debarker

Chain-flail delimbers can be stand-alone machines, or, when also used to debark logs, can be integrated into chippers. Chain-flail delimbers remove the branches from trees by means of chains fastened to one or more rotating drums. The branches are literally beaten off the stems by the force of the flailing chains. These machines were originally developed as a method for delimbing small trees. However, chain flails cannot cut the tops off the trees, so additional processing is still required after they have completed their work if log-length products are being produced. Because of this limitation, chain flails are seldom used except as part of an integrated delimber-debarker-chipper machine (McDonald, 1999). Chain-flail delimber-debarkers are similar to delimbers, but are purpose-built, and have more aggressive settings for removing bark. These machines are large and heavy, and are usually seen as part of a semi-permanent installation.

Modern technology has built the function of delimbing, debarking, and chipping into single machine, such as Peterson Pacific 5000-G delimber-debarker-chipper. This concept reduces capital expenditures and allows the use of a single engine, which reduces machine mobilization, fuel consumption and maintenance. The Western Biomass model assumes that the chain-flail delimber-debarker always works with a pulp wood chipper to accomplish the functions of delimbing, debarking, and chipping. This machine selection would only be used in a system designed to produce both “clean chips” for hauling to a pulp mill and “hog fuel” for hauling to an energy facility.

Chipper

Chippers can be used for chip production from raw logs or from salvage and debris cleanup. There are two types of chippers — disc and drum. The main differences between them include the amount of energy consumed to produce chips, their ability to produce chips of uniform size, and their ability to simultaneously handle different size logs, limbs and tops (McDonald, 1999). Disc chippers require less energy because of the kinetic energy stored in the quickly spinning disc. They can also produce more uniform chips than drum chippers from larger-diameter logs, but they do not perform as well for short pieces. Disc chippers are preferred for long logs, while drum chippers are preferred when handling short, non uniform material likely to be present in landing debris or in cleanup operations.

The Western Biomass model splits the chippers into two major categories: chippers for clean chips and chippers for hog fuel (Fig 4-4). In each group, chippers are further characterized by their horsepower. Chippers with engine size less than 500 hp are defined as small chippers (e.g. Morbark 18 chipper, 200 hp); otherwise, they are treated as large chippers (e.g. Morbark 27 chipper, 650 hp). In addition to the engine size, chippers used for producing hog fuel also need to be characterized by the average piece size, which is considered as a significant factor influencing the chipper productivity.

Grinder (Hogger)

Grinders are used to grind waste material (limbs, tops, and small whole tree) into a mixture that can be used for fuel in various power-generation plants. They are usually large horsepower machines (typically greater than 500 hp in engine size) working in energy plants, landings, or roadsides operations.

The definition of grinders in the Western Biomass model requires selection of working location (one landing or moving between landings) and material piece size, which have the greatest effects on grinding productivity (Fig 4-4). The Western

Biomass model works for horizontal grinders. Due to the limited information on the productivity of the tub grinders, they are not included in the model.

Step 5 – Loading / Sorting and Trucking Equipment Selection

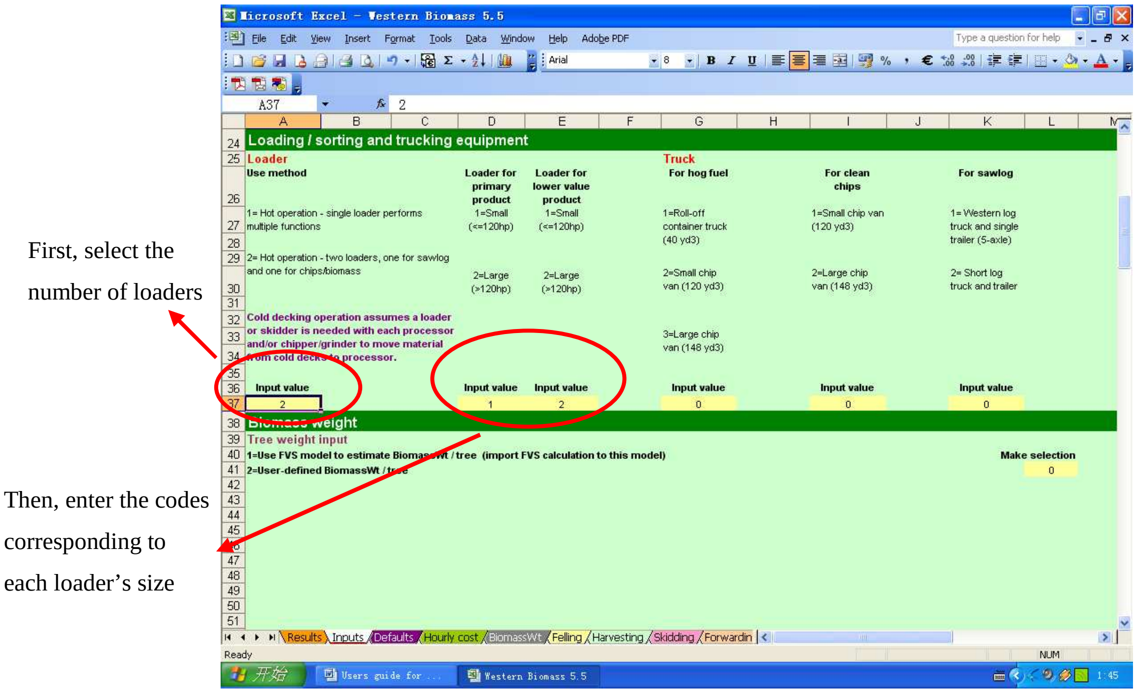


Figure 4-5: Loading / sorting equipment selection in the Western Biomass model

Loader

Loaders fall into two categories: front-end loaders, which travel between the log pile and the truck while loading, and swing loaders, which remain more-or-less in one location while loading (McDonald, 1999).

The Western Biomass model characterizes loaders by their horsepower (Fig 4-5). Any loaders with engine size greater than 150 horsepower are defined as large loaders (e.g. CAT 324 D FM log loader, 188 hp); otherwise, they fall into the small loader category (e.g. Prentice RT-100 log loader, 130 hp).

Selection of loading / sorting equipment in the Western Biomass model has two sub-steps. The first sub-step requires model users to choose the number of loaders that will be used in a hot operation if that is the case being modeled. Cold decking operations assumes a loader is needed with each processor and/or chipper/grinder to move materials from cold decks to the processor. The following sub-step asks users to define the loader(s) engine size for recovered products.

Hauling equipment

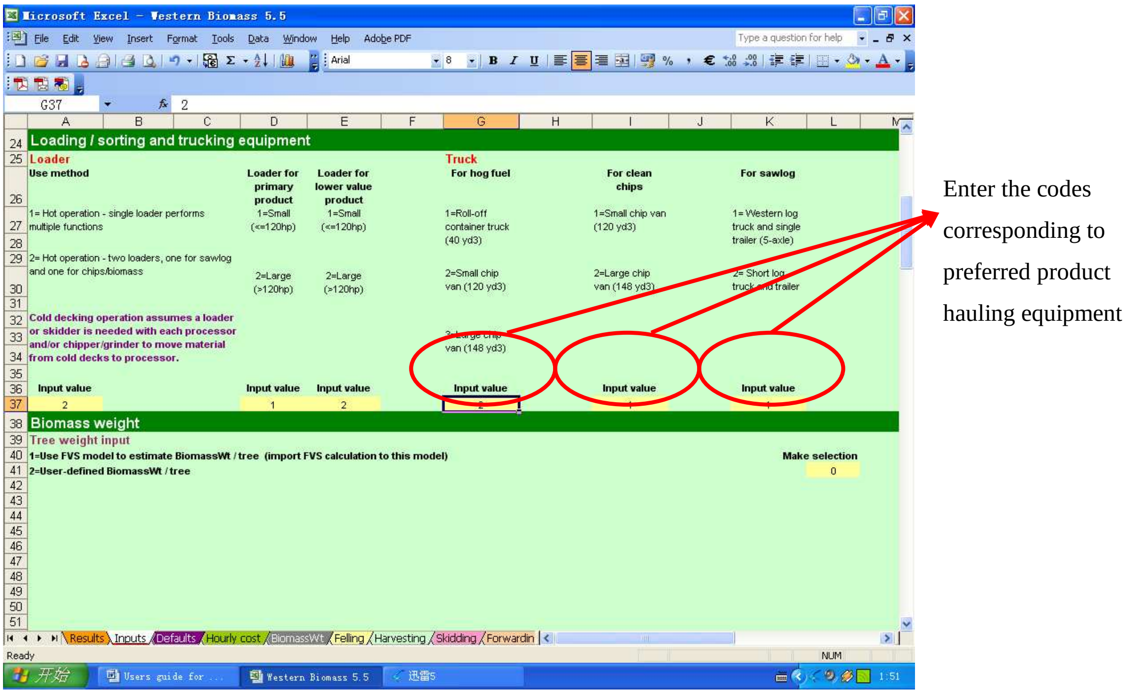


Figure 4-6: Hauling equipment selection in the Western Biomass model

The Western Biomass model requires selection of hauling equipment for each recovered product (Fig 4-6).

a) Hauling equipment for hog fuel and clean chips

The Western Biomass model allows choices for hauling hog fuel, including roll-on/-off container truck (10-ton container), trucks with 120 cubic yard chip van, and trucks with 148 cubic yard chip van.

Roll-on/-off container truck refers to a straight frame truck configuration in which modular containers are “rolled” onto and off of the straight frame truck by means of a truck-mounted hydraulic winch and a hook. This system is often designed to be short (30 feet) and with a higher ground clearance (1 foot) to better negotiate sharp curves on many western forest roads, limited landing areas, and uneven road surface conditions (Han et al 2008).

Truck with chip van refers to a truck design in which chip vans can be hooked or disconnected from the truck. It is commonly used for landing-to-market chip hauling. Trucks with chip vans are often long (48 feet for chip van) and have low ground clearance, which limits their maneuverability on forest roads with poor surface conditions and sharp curves.

b) Hauling equipment for sawlog, pulp logs, and biomass logs

Western-style logging truck refers to a design of truck-trailer combination that is equipped with 5 axles and single log trailers to facilitate long tree length transportation. The trailers are connected to the truck in a way that allows maneuverability on narrow roads with sharp curves. The Western Biomass model also allows selection of trucks with short trailers as a method for hauling short logs resulting from cut-to-length harvesting.

Step 6 – Biomass Weight

To facilitate the calculation of machine productivity, the first part of the Biomass Weight section in the Western Biomass model directly transfers the predictions from the FVS model (ex: DBH and tree height) and uses FVS projections as intermediate parameters to calculate variable values (e.g. biomass weight per tree and biomass volume per tree) (Fig 4-7). The Western Biomass model also allows entering user-defined stand parameters independent of FVS output. This choice is suitable for the users who are not familiar with the FVS model or where the FVS-ready data are unavailable (Fig 4-8).

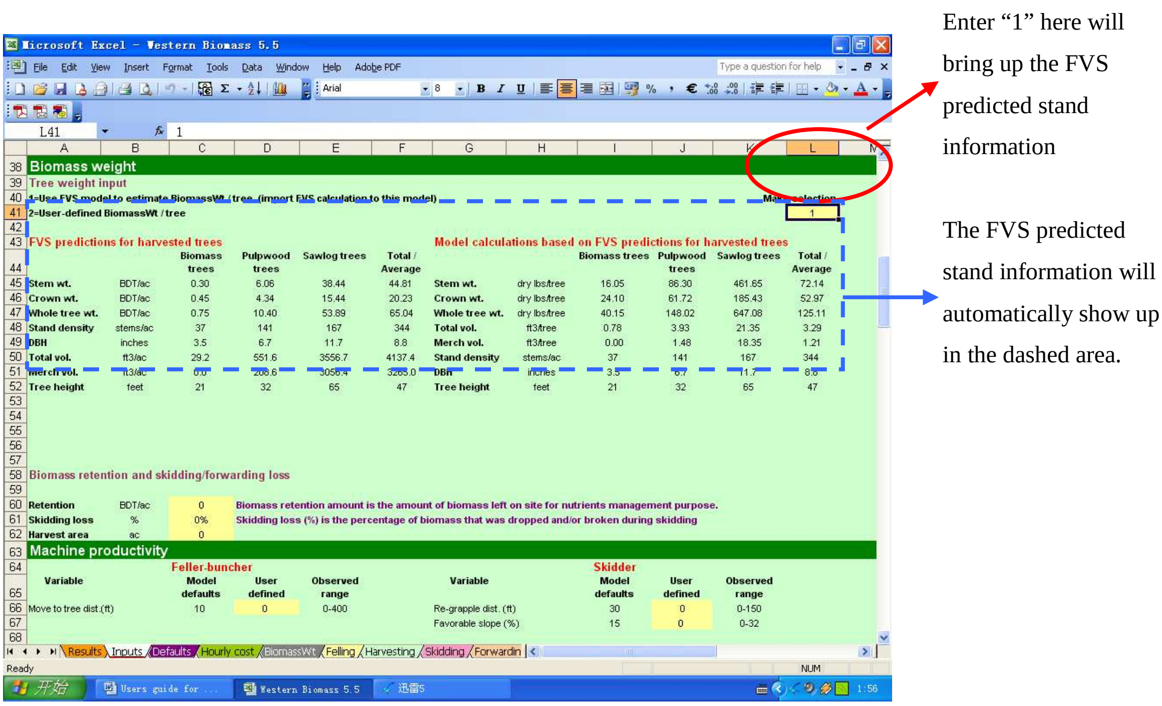
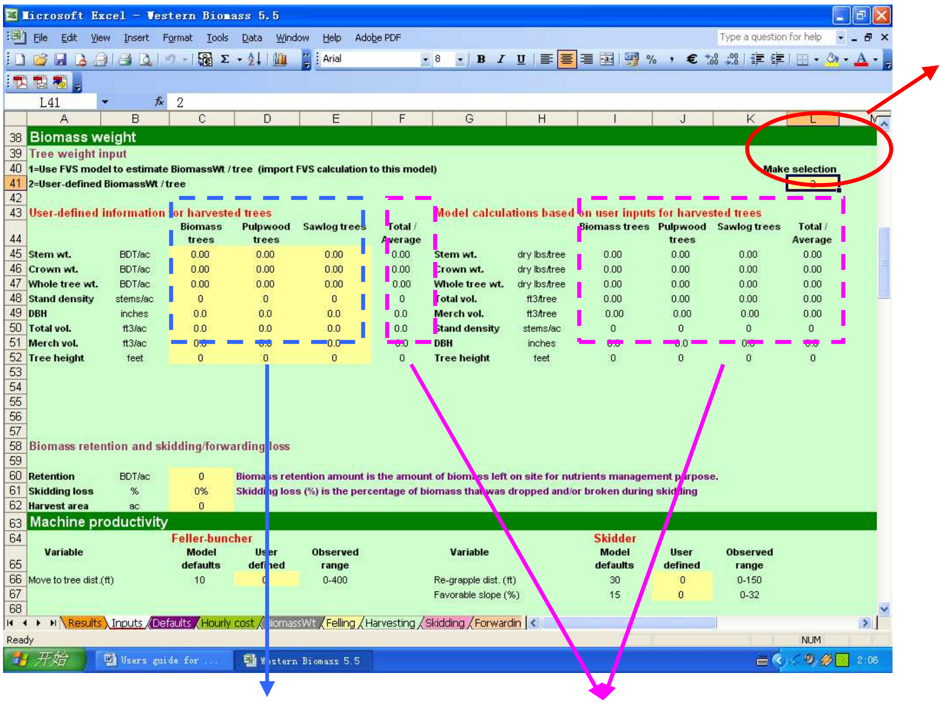


Figure 4-7: Transferring FVS predicted stand information in the Western Biomass model



Users are required to enter stand information if "2" is

If "2" is entered in the cell "L41", users need to enter stand information in the yellow-marked area.

Model calculated stand information based on user input values will show up automatically in these areas.

Figure 4-8: User input stand information in the Western Biomass model

Enter the biomass retention amount, skidding / forwarding loss percentage, and total harvesting area here

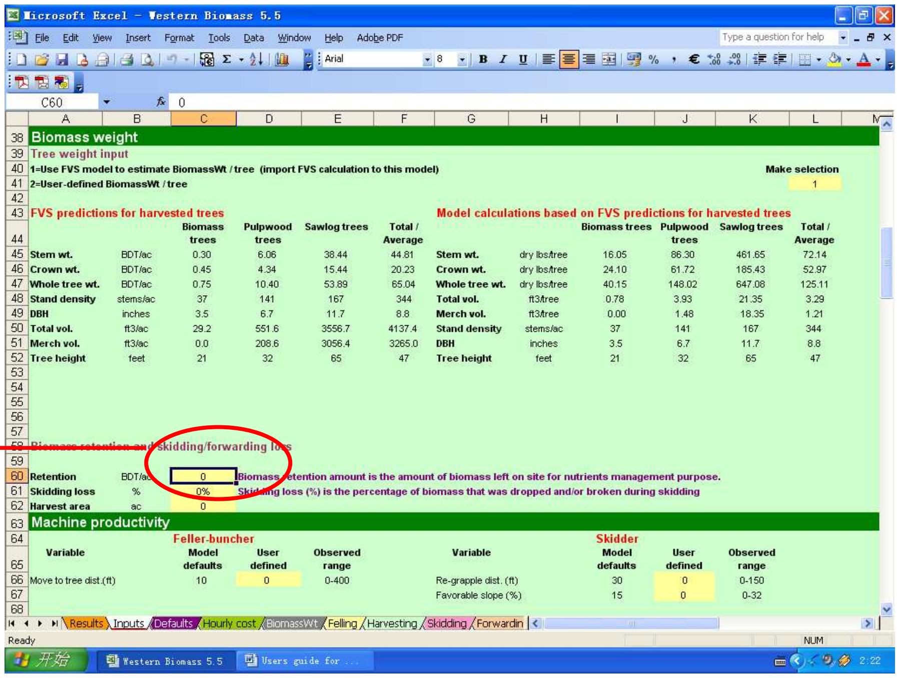


Figure 4-9: Enter the biomass retention amount, skidding / yarding loss, and total harvest area in the Western Biomass model

The second part of the Biomass Weight section requires inputs for biomass retention amount (BDT/ac), skidding/forwarding loss (% of total harvested trees), and total harvested area (ac) (Fig 4-9). The biomass retention amount specifies the amount of biomass in BDT/ac that is to be left on the site for retention of site nutrients. It may be a target value specified in a prescription or the amount of residue that will naturally be left on a site even after a whole tree or biomass removal operation. This amount will be deducted from the total harvested biomass to determine the amount of actual collected biomass. Skidding/forwarding loss refers to the percent of recovered trees that naturally break off during primary transportation of the trees to the landing. This material is left on site and will also be subtracted from the total harvested biomass. The Western Biomass model users should enter the value of the total harvested area based upon specific project prescription. This value will be used by the model to project the machine mobilization cost in terms of dollar per acre and to convert production costs in dollars per BDT to dollars per acre.

Step 7 – Machine Productivity Inputs

Based on the machines selected for conducting the project, the Western Biomass model will automatically select the best suitable machine productivity projection equations. The independent variables required by these selected equations will be reflected in the section of Machine Productivity Inputs (Fig 4-10).

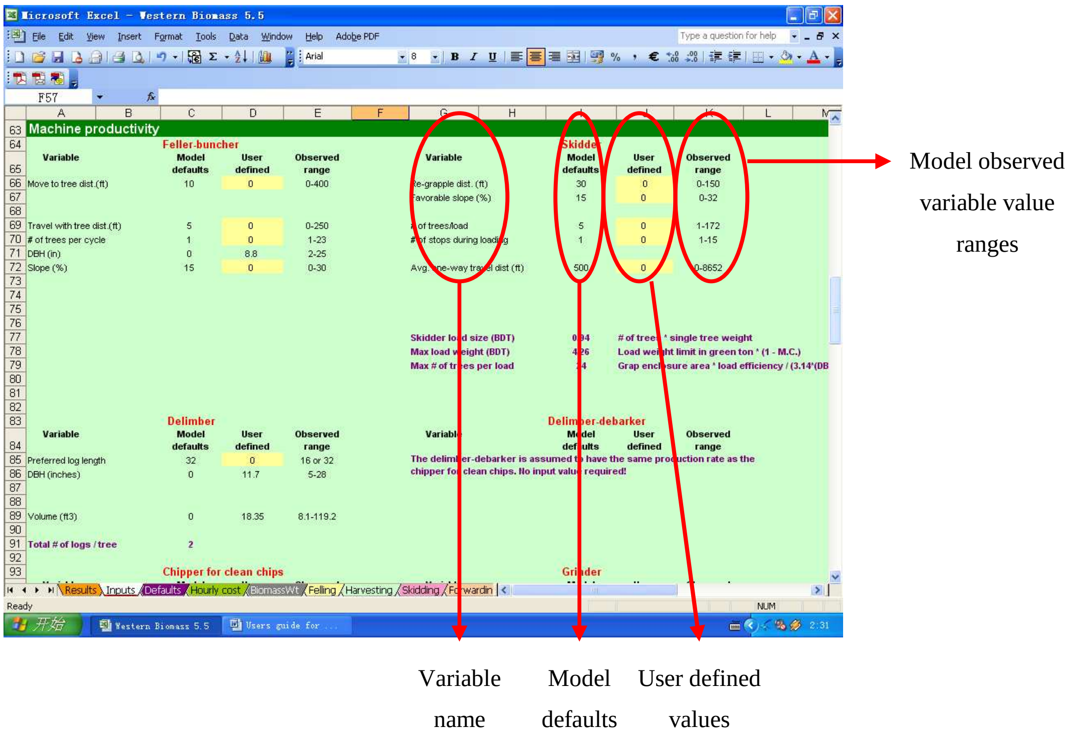


Figure 4-10: Machine productivity variable inputs in the Western Biomass model

The section of machine productivity inputs contains four columns for a specific machine: variable name, model default values, user-defined values, and observed variable value range. The column of Variable shows the names of the independent variables that are included in the automatically selected machine productivity projection equations. These variable names are followed by the units that are commonly used. Productivity equations with metric units have been converted to English units. The Model Defaults column shows the values that are initially used by the Western Biomass model for the machine productivity calculation. These model default values are embedded in the software code. Overriding any model default value is allowed, however, and requires users to make inputs in the corresponding yellow-marked cells in the User-defined column where an initial value is set at zero. When a cell in the User-defined column is changed from zero to a non-zero value, the corresponding model default value will be automatically changed to zero and the Western Biomass model will use the user-defined value for calculations. The column of the Observed Range reflects the independent variable range that is covered by all software-included predictive equations. This is designed to provide the model users with a usual operational range. An out-of-range user-defined value is allowed by the model, but a bias correction procedure will be used to weight the out-of range variable values (Pan et al., 2008b). Out of range equations will be given less emphasis in the final result than those with values within the observed range.

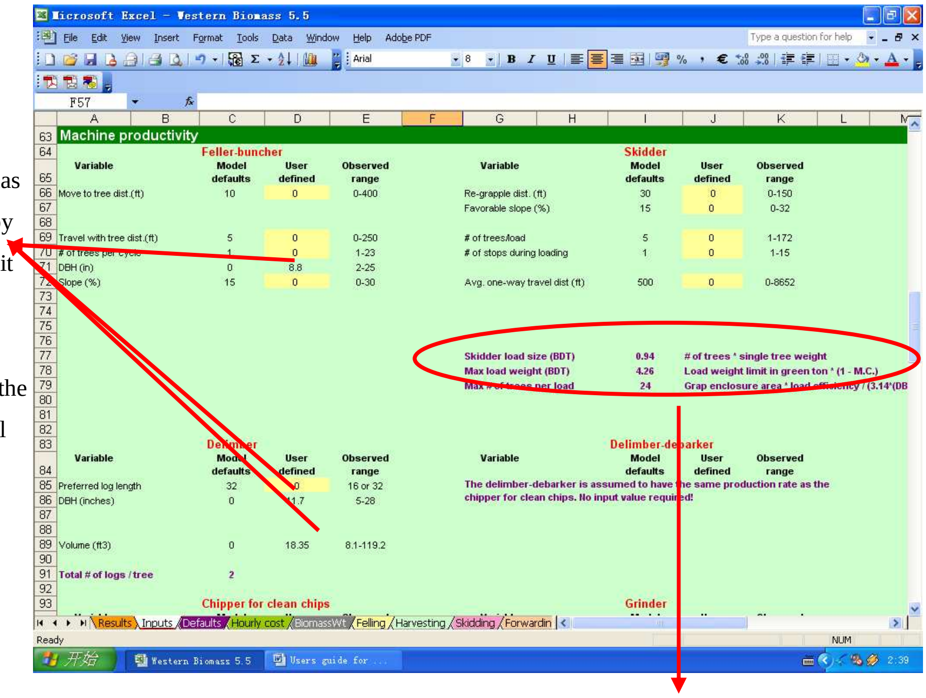


Figure 4-11: Automatic FVS prediction transfer and machine load capacity reminders in the Western Biomass model

It is important to note that any FVS-predicted stand / tree parameters will be automatically transferred to the Machine Productivity section as a user-defined value if that variable is required by a model-selected predictive equation (Fig 4-11). For example, if the FVS model predicts that the tree size is 8.8 inches in DBH and DBH is also a required variable to calculate the feller-buncher cycle time, the value of 8.8 in the Biomass Weight section will be transferred to the cell of user-defined DBH in the Machine Productivity section. When this happens, the color of the cell of the user-defined DBH will be changed from yellow to green, indicating there is no need to make any further value change.

The purple-marked area between lines 77 to 79 calculates a skidder / forwarder loading capacity reminder (Fig 11). It uses machine maximum load capacity and tree size / weight information predicted by the FVS model to estimate the maximum number of pieces that can be delivered per cycle by a skidder or a forwarder. Users should use this as a reference when entering the value for the variable of “Number of trees per cycle”. Exceeding the calculated machine capacity in pieces per cycle will result in unrealistic production and cost estimates.

Step 8 – Landing-to-Mill Transportation

The Western Biomass model uses the Byrne, Nelson, and Googins (BNG) travel time model to calculate the trucking cycle time. The BNG travel time model was first introduced by Byrne, Nelson, and Googins (BNG) in 1940’s. This model was tested again in 1990’s and was proved to be the best model for predicting logging truck travel times on various road standards (Moll and Copstead, 1996).

The forest road travel speeds of long chip trucks and short container trucks are generally slower than typical logging trucks on forest roads due to the design of chip van and container truck-trailer combinations. The Western Biomass model uses a chip truck study and a container truck study conducted by Pan et al (2008a) and Han et al (2008), respectively, and calculates speeds for chip trucks and container trucks traveling on forest roads as a percentage of the speeds that would be realized by typical logging trucks. These percentages will be assigned in the Western Biomass model to adjust the logging truck travel speed to either chip van or container truck speed if the equipment is selected as the hauling method.

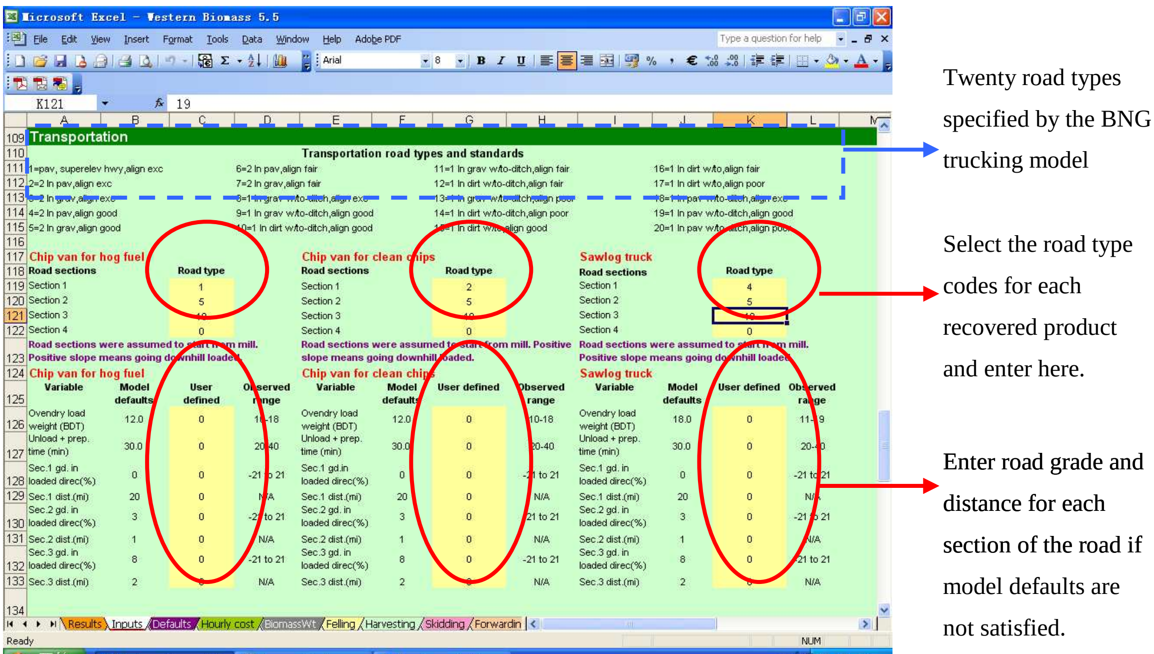


Figure 4-12: Transportation network road definitions in the Western Biomass model

Twenty road types and standards defined by the BNG model are listed as a reference for inputting road type codes (Fig 4-12). In the Western Biomass model, chip vans are not allowed to travel on spur road and gravel road with poor alignment, and road type codes representing that condition will not be accepted by the model. In reality, this implies that a different hauling combination need to be specified to operate on those roads or that road improvements are needed before conventional chip vans can operate in the specified setting. Road type codes need to be entered for each section of the transportation network. The road sections are assumed to begin at the mill and proceed to the landing. The hauling cycle will include the time traveling both ways along the specified route.

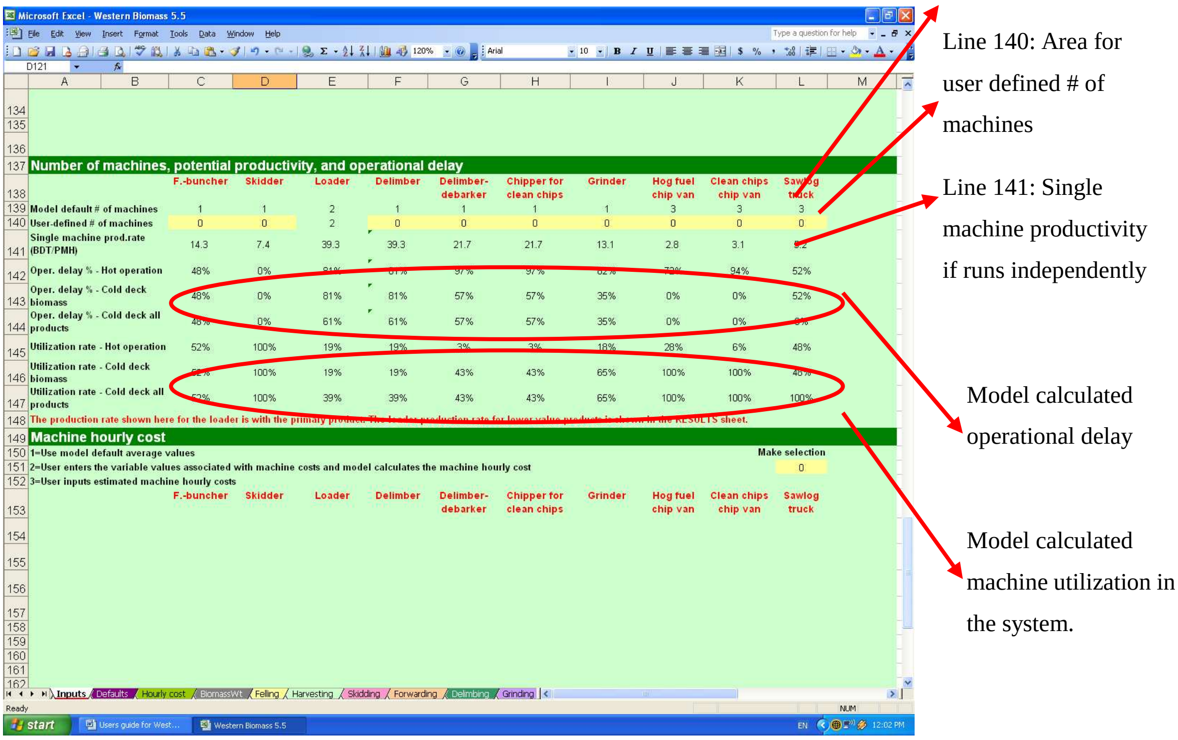
Once the road type code is entered, the road grade and distance input area for that section of road will appear in the spreadsheet. The Western Biomass model assumes that the road grade refers to the grade traveling downhill in the loaded direction, which is consistent with the BNG trucking time model. This means a positive value for grade will be entered when traveling loaded downhill. Values of model defaults, user-defined values, and the observed range of values are also available in this part. Users need to be aware that road grades should be within the range of -21 to 21 percent; otherwise, the inputs will not be accepted by the model. The road distances refer to the one-way distance for that section of road.

In addition to defining the road standard, grade, and distance, model users also need to provide an estimated truck unloading and safety preparation time. A transportation cycle includes four parts: travel empty to the landing, loading, travel loaded to the mill, and unloading.

Finally, users need to provide the allowed oven dry weight for a truck load based on federal and regional legal transportation limits. This load weight will be used to predict the loading time (e.g. grinder loads hog fuel to chip van) and hauling production rates.

Step 9 – Number of Machines, Potential Productivity, and Operational Delay

Line 139: Model default # of machines



	F.-buncher	Skidder	Loader	Delimber	Delimber-debarker	Chipper for clean chips	Grinder	Hog fuel chip van	Clean chips chip van	Sawlog truck
Model default # of machines	1	1	2	1	1	1	1	3	3	3
User-defined # of machines	0	0	2	0	0	0	0	0	0	0
Single machine prod.rate (BDT/PMH)	14.3	7.4	39.3	39.3	21.7	21.7	13.1	2.8	3.1	[illegible]
Oper. delay % - Hot operation	48%	0%	[illegible]	[illegible]	97%	97%	[illegible]	[illegible]	94%	52%
Oper. delay % - Cold deck biomass	48%	0%	81%	81%	57%	57%	35%	0%	0%	52%
Oper. delay % - Cold deck all products	48%	0%	61%	61%	57%	57%	35%	0%	0%	[illegible]
Utilization rate - Hot operation	52%	100%	19%	19%	3%	3%	18%	28%	6%	48%
Utilization rate - Cold deck biomass	52%	100%	19%	19%	43%	43%	65%	100%	100%	48%
Utilization rate - Cold deck all products	52%	100%	39%	39%	43%	43%	65%	100%	100%	100%

The production rate shown here for the loader is with the primary product. The loader production rate for lower value products is shown in the RESULTS sheet.

Machine hourly cost
1=Use model default average values
2=User enters the variable values associated with machine costs and model calculates the machine hourly cost
3=User inputs estimated machine hourly costs
Make selection: 0

Figure 13: Enter number of machines in the Western Biomass model

Timber harvesting / biomass recovery operations often involve the use of multiple pieces of equipment. System production rates can be constrained by the machine that has the lowest productivity in the system. Under this circumstance, an operation manager can improve system productivity by adjusting the number of machines so that the productivity of various system components can be matched. The section of Number of Machines, Potential Productivity, and Operational Delay is created to allow analysis of these factors.

Model line 139 shows the model default number of machines in the system (Fig 4-13). Line 141 contains production rates of single machine if they are operated independently of each other. Users can use the single machine productivities as a reference to balance the system productivity by adjusting the number of machines in each machine component. Lines 142 through 147 show the machine operational delays and utilization rates in a system as a result of user-defined number of machines.

<u>Step 10 – Machine Hourly Cost</u>

The Western Biomass model enables users three choice for calculation of the machine hourly cost (Dollar per scheduled machine hour, or $/SMH): 1) use model default machine hourly costs (Fig 4-14), 2) input variable values that allows the model to calculate the machine hourly costs (Fig 4-15), and 3) enter user estimated machine hourly costs directly as $/SMH (Fig 4-16).

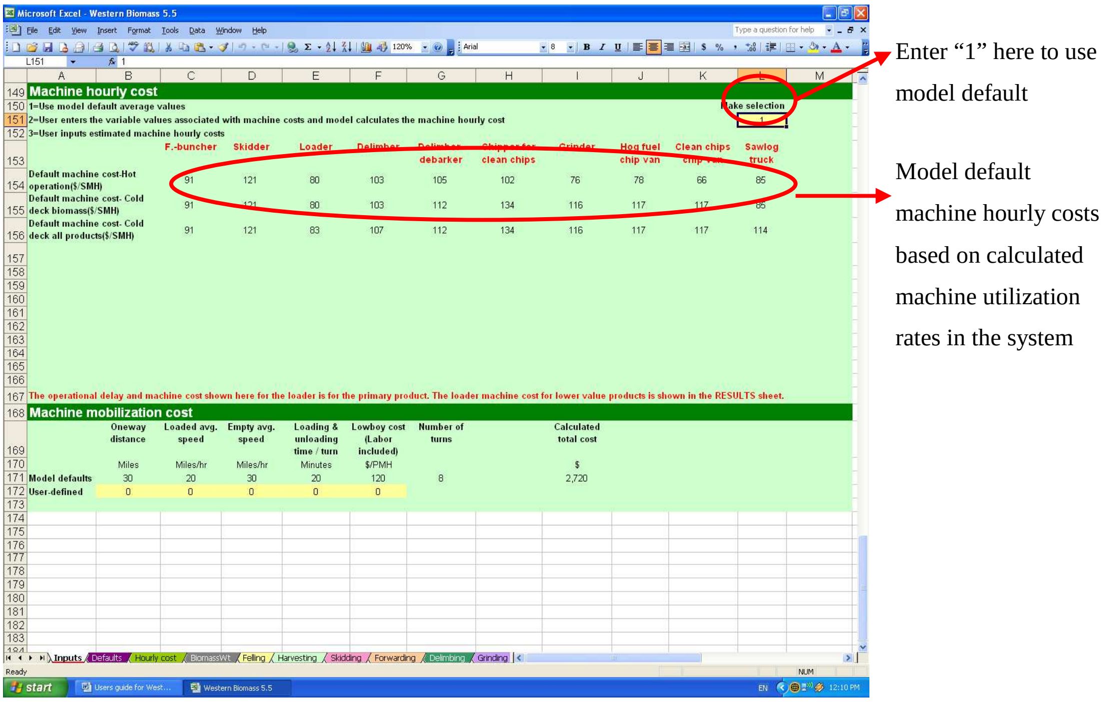
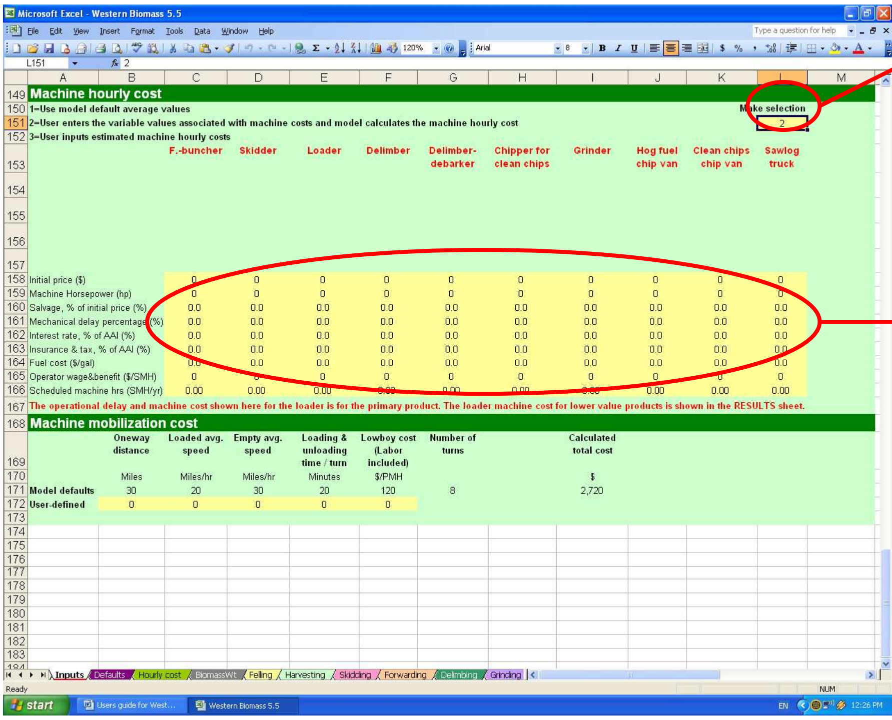


Figure 4-14: Use of model default machine hourly costs in the Western Biomass model

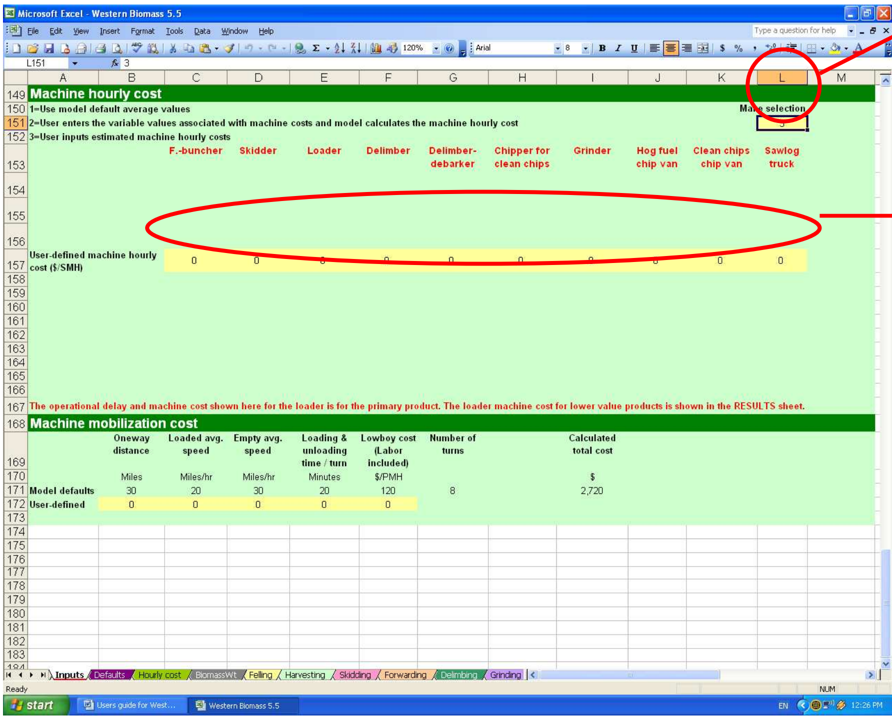
Entering “1” in the cell “L151” will bring up the model default machine hourly cost for the three operation methods – hot operations, cold decking biomass, and cold decking all the products. The machine utilization rates calculated in the lines 145 through 147 are applied here.



Enter "2" here to let the model use your inputs to calculate the machine hourly cost

Area for entering user defined values to calculate machine hourly costs

Figure 4-15: Use user defined values to calculate machine hourly costs in the Western Biomass model



Enter "3" here to input the user defined machine hourly costs

Area for entering user defined machine hourly costs

Figure 4-16: Use user defined machine hourly costs in the Western Biomass model

If users prefer to use a self-defined machine initial price, horsepower, salvage value, mechanical delay percentage, interest rate, insurance rate, tax rate, fuel cost, labor cost, and SMH, a number “2” should be entered in the cell “L151”. However, there are default values for machine economic life, repair and maintenance cost, fuel consumption rate, lube and oil cost. These will be used to calculate machine rates for this option, but these can be changed in the “Defaults” worksheet if required. The values specified in the “Defaults” worksheet apply globally across all machines in the machine rate calculation.

When users believe they have a direct estimate of machine hourly costs, a number “3” representing user-defined machine hourly costs should be entered. It is important to note here that the user-defined machine hourly costs are independent of any utilization rates calculated by the model and should be entered very carefully.

<u>Step 11 – Machine Mobilization Cost</u>

The last section of the “Inputs” sheet represents the machine mobilization costs. The Western Biomass model includes machine move-in costs as part of total production costs. The machine move-out costs are excluded, as they are usually assigned to the subsequent recovery projects.

The Western Biomass model embedded the features of model default values and user-defined values for the one-way distance, loaded / empty average speeds, loading / unloading time per turn, and lowboy costs (Fig 4-17). The model will automatically calculate the number of turns based on the number of machines specified in the section of Number of Machines. A total machine mobilization cost will then be projected in terms of total dollars. When divided by the acres specified for the treatment area, these values are converted to $/ac and subsequently to $/BDT.

Line 171: Model default variable values to calculate the machine mobilization cost

Line 172: Yellow marked area for entering user defined variable values to calculate the machine mobilization cost

Cell “I172”: model calculated machine mobilization cost

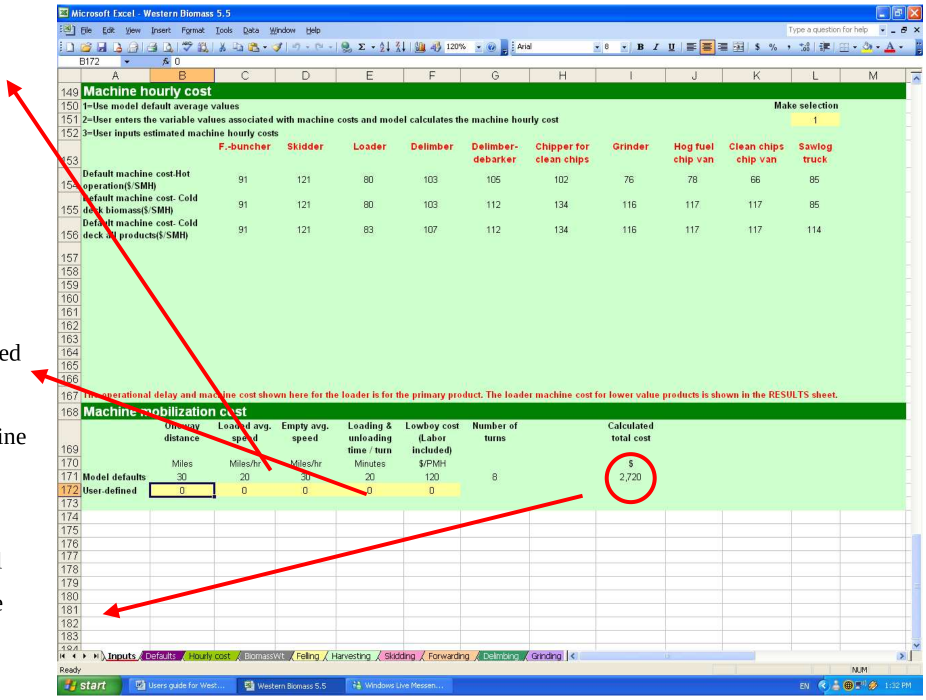


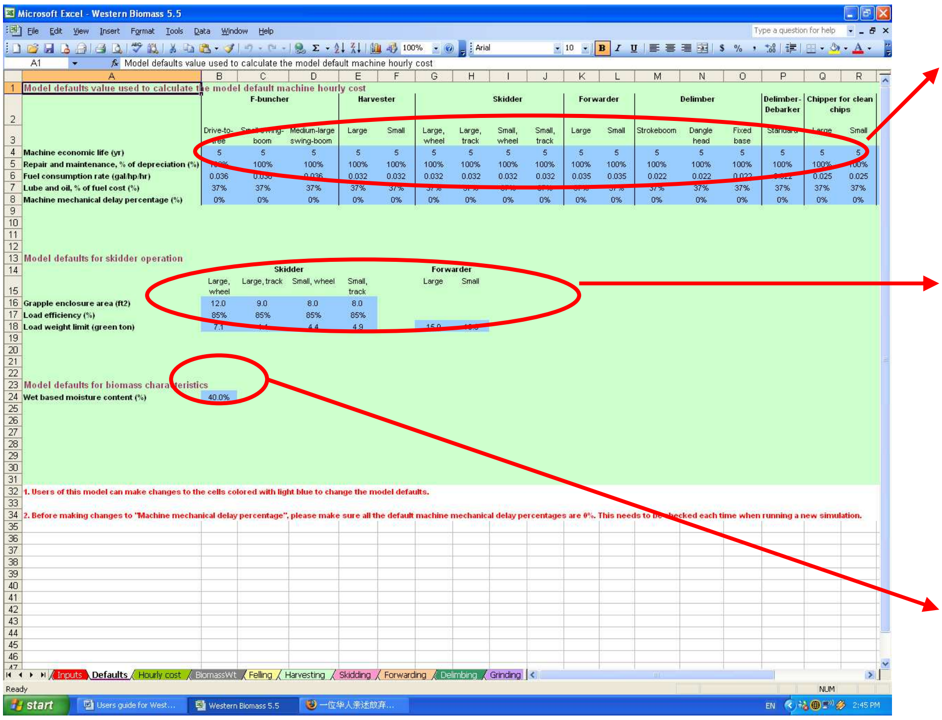
Figure 4-17: Calculate machine mobilization cost in the Western Biomass model

It is important to note that the BNG trucking model is not applied in the section of Machine Mobilization Costs section for the following three reasons: 1) The BNG trucking model is designed for logging trucks. The performance of trucks with lowboy is different from common logging trucks. 2) There was no study found that focused on the performance of trucks with lowboys so a speed difference could not be assigned to adjust the BNG trucking table. 3) The machine mobilization costs usually represent small portion of the total production cost, especially when the harvest area is large.

4.3.2 Model Process

<u>Other working sheets 1 – Defaults (User adjustment inputs allowed)</u>

The first part of the “Default” worksheet contains of default values used for the machine hourly costs calculation (Fig 4-18). These variables include machine economic life, repair and maintenance cost, fuel consumption rate, lube and oil cost, and mechanical delay percentages. Users can make changes to the default values so that the model-default machine hourly cost will best reflect the true values for their situation.



Default values to calculate machine hourly costs. Users may change the default values in the blue-marked area

Default values to calculate skidder / forward load capacities. Users may change the default values in the blue-marked area

Model default tree / biomass wet-based moisture content. Users may change the default values in the blue-marked

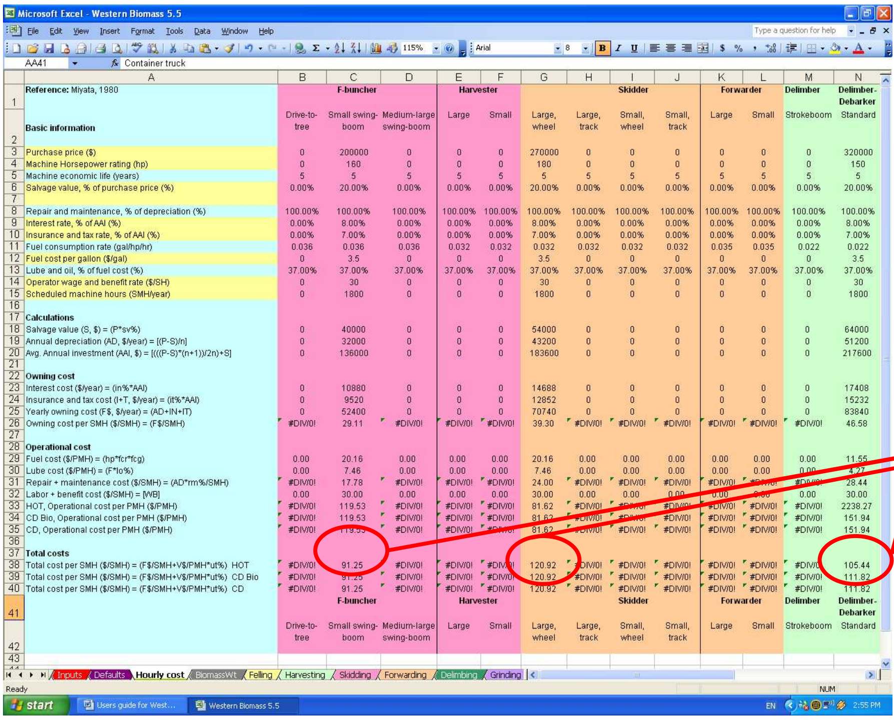
Figure 4-18: Worksheet of “Defaults” in the Western Biomass model

The second part of the “Default” worksheet is designed to help the model predict maximum load capacities of the skidder and forwarder. The blue-marked places reflect the default variable values used to calculate the loading capacities in the cells “I78” and “I79” of the “Inputs” worksheet. User-defined adjustments are allowed. For example, users can make changes to the “skidder grapple enclosure area” based on an alternate machine specification.

The bottom section of the “Default” worksheet has the model default “wet-based tree moisture content”. It has a direct linkage with the model default tree moisture content for the chipping operation in the “Inputs” worksheet.

Other working sheets 2 – Hourly cost (User adjustments not allowed)

The worksheet labeled “Hourly cost” performs calculations for the default machine hourly costs and calculates hourly costs based on user-input (Fig 4-19). The calculations follow standard machine hourly cost estimate principles introduced by Miyata (1980). The resulting machine hourly costs reflect the difference for various operation methods, including hot operations, cold decking biomass, and cold decking all the products. These results are automatically transferred to the “Inputs” sheet (lines 154 through 156) and the “Results” sheet (column B).



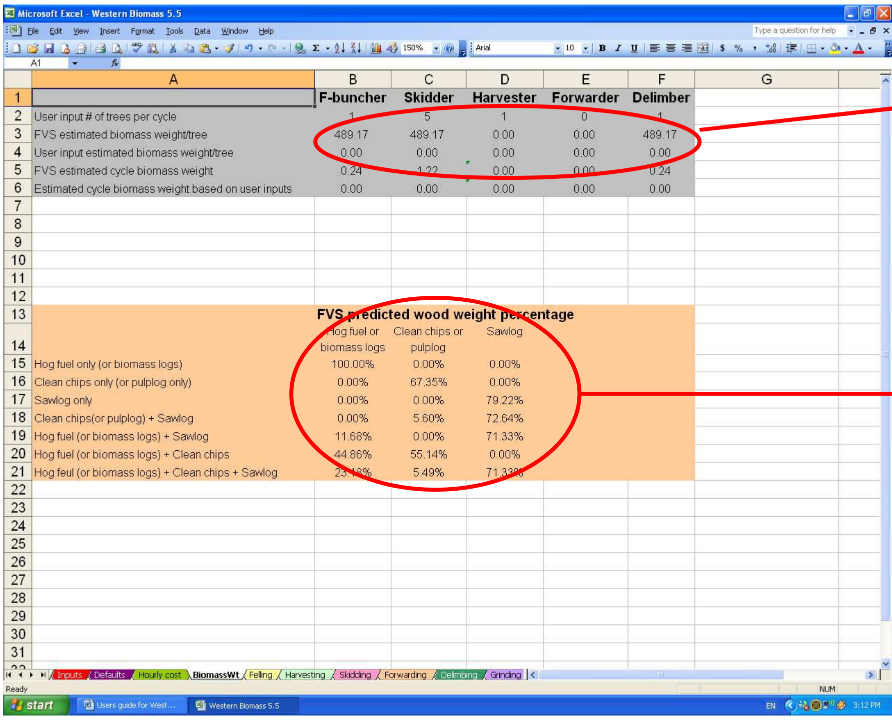
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Reference: Miyata, 1980		F-buncher		Harvester				Skidder		Forwarder		Delimber	Delimber-Debarker
2	Basic information	Drive-to-tree	Small swing-boom	Medium-large swing-boom	Large	Small	Large, wheel	Large, track	Small, wheel	Small, track	Large	Small	Strokeboom	Standard
3	Purchase price ($)	0	200000	0	0	0	270000	0	0	0	0	0	0	320000
4	Machine Horsepower rating (hp)	0	160	0	0	0	180	0	0	0	0	0	0	150
5	Machine economic life (years)	5	5	5	5	5	5	5	5	5	5	5	5	5
6	Salvage value, % of purchase price (%)	0.00%	20.00%	0.00%	0.00%	0.00%	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	20.00%
7														
8	Repair and maintenance, % of depreciation (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
9	Interest rate, % of AAI (%)	0.00%	8.00%	0.00%	0.00%	0.00%	8.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	8.00%
10	Insurance and tax rate, % of AAI (%)	0.00%	7.00%	0.00%	0.00%	0.00%	7.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	7.00%
11	Fuel consumption rate (gal/hp/hr)	0.036	0.036	0.036	0.032	0.032	0.032	0.032	0.032	0.032	0.035	0.035	0.022	0.022
12	Fuel cost per gallon ($/gal)	0	3.5	0	0	0	3.5	0	0	0	0	0	0	3.5
13	Lube and oil, % of fuel cost (%)	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%	37.00%
14	Operator wage and benefit rate ($/SH)	0	30	0	0	0	30	0	0	0	0	0	0	30
15	Scheduled machine hours (SMH/year)	0	1800	0	0	0	1800	0	0	0	0	0	0	1800
16														
17	Calculations													
18	Salvage value (S, $) = (P*sv%)	0	40000	0	0	0	54000	0	0	0	0	0	0	64000
19	Annual depreciation (AD, $/year) = [(P-S)/n]	0	32000	0	0	0	43200	0	0	0	0	0	0	51200
20	Avg. Annual investment (AAI, $) = [(((P-S)*(n+1))/2n)+S]	0	136000	0	0	0	183600	0	0	0	0	0	0	217600
21														
22	Owning cost													
23	Interest cost ($/year) = (in%*AAI)	0	10880	0	0	0	14688	0	0	0	0	0	0	17408
24	Insurance and tax cost (I+T, $/year) = (it%*AAI)	0	9520	0	0	0	12852	0	0	0	0	0	0	15232
25	Yearly owning cost (F$, $/year) = (AD+IN+IT)	0	52400	0	0	0	70740	0	0	0	0	0	0	83840
26	Owning cost per SMH ($/SMH) = (F$/SMH)	#DIV/0!	29.11	#DIV/0!	#DIV/0!	#DIV/0!	39.30	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	46.58
27														
28	Operational cost													
29	Fuel cost ($/PMH) = (hp*fcr*fcg)	0.00	20.16	0.00	0.00	0.00	20.16	0.00	0.00	0.00	0.00	0.00	0.00	11.55
30	Lube cost ($/PMH) = (F*lo%)	0.00	7.46	0.00	0.00	0.00	7.46	0.00	0.00	0.00	0.00	0.00	0.00	4.27
31	Repair + maintenance cost ($/SMH) = (AD*rm%/SMH)	#DIV/0!	17.78	#DIV/0!	#DIV/0!	#DIV/0!	24.00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	[illegible]	[illegible]	28.44
32	Labor + benefit cost ($/SMH) = [WB]	0.00	30.00	0.00	0.00	0.00	30.00	0.00	0.00	0.00	0.00	[illegible]	0.00	30.00
33	HOT, Operational cost per PMH ($/PMH)	#DIV/0!	119.53	#DIV/0!	#DIV/0!	#DIV/0!	81.62	#DIV/0!	[illegible]	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	2238.27
34	CD Bio, Operational cost per PMH ($/PMH)	#DIV/0!	119.53	#DIV/0!	#DIV/0!	#DIV/0!	81.62	#DIV/0!	[illegible]	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	151.94
35	CD, Operational cost per PMH ($/PMH)	#DIV/0!	[illegible]	#DIV/0!	#DIV/0!	[illegible]	81.62	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	151.94
36														
37	Total costs													
38	Total cost per SMH ($/SMH) = (F$/SMH+V$/PMH*ut%) HOT	#DIV/0!	91.25	#DIV/0!	#DIV/0!	#DIV/0!	120.92	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	105.44
39	Total cost per SMH ($/SMH) = (F$/SMH+V$/PMH*ut%) CD Bio	#DIV/0!	91.25	#DIV/0!	#DIV/0!	#DIV/0!	120.92	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	111.82
40	Total cost per SMH ($/SMH) = (F$/SMH+V$/PMH*ut%) CD	#DIV/0!	91.25	#DIV/0!	#DIV/0!	#DIV/0!	120.92	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	111.82
41			F-buncher		Harvester				Skidder		Forwarder		Delimber	Delimber-Debarker
42		Drive-to-tree	Small swing-boom	Medium-large swing-boom	Large	Small	Large, wheel	Large, track	Small, wheel	Small, track	Large	Small	Strokeboom	Standard
43														

Model calculated machine hourly costs for different operation methods. The model only calculates user-selected machines. User inputs are NOT allowed in this worksheet

Figure 4-19: Worksheet of “Hourly cost” in the Western Biomass model

<u>Other working sheets 3 – BiomassWt (User adjustments not allowed)</u>

The first function of the worksheet “BiomassWt” (Fig 4-20) is to predict the cycle biomass weights for calculating machine production rates, as reflected in lines 1 through 6. This section derives tree weight information from eight FVS predictions or user-defined values in the “Biomass weight” section of the “Inputs” worksheet. It also collects the values of piece count per cycle from the “Inputs” sheet. Using this information, this worksheet then projects the cycle biomass weights. The biomass weight information is then used to calculate the machine production rates in the “Inputs” sheet, line 141.



	A	B	C	D	E	F
1		F-buncher	Skidder	Harvester	Forwarder	Delimber
2	User input # of trees per cycle	1	5	1	0	1
3	FVS estimated biomass weight/tree	489.17	489.17	0.00	0.00	489.17
4	User input estimated biomass weight/tree	0.00	0.00	0.00	0.00	0.00
5	FVS estimated cycle biomass weight	0.24	1.22	0.00	0.00	0.24
6	Estimated cycle biomass weight based on user inputs	0.00	0.00	0.00	0.00	0.00

	FVS predicted wood weight percentage		
	Hog fuel or biomass logs	Clean chips or pulplog	Sawlog
Hog fuel only (or biomass logs)	100.00%	0.00%	0.00%
Clean chips only (or pulplog only)	0.00%	67.35%	0.00%
Sawlog only	0.00%	0.00%	79.22%
Clean chips(or pulplog) + Sawlog	0.00%	5.60%	72.64%
Hog fuel (or biomass logs) + Sawlog	11.68%	0.00%	71.33%
Hog fuel (or biomass logs) + Clean chips	44.86%	55.14%	0.00%
Hog feul (or biomass logs) + Clean chips + Sawlog	[illegible]	5.49%	71.33%

This section calculates cycle biomass weight for selected machines. User inputs are NOT allowed.

This section calculates tree weight percentage for different recovered products. User inputs are NOT allowed.

Figure 4-20: Worksheet of "BiomassWt" in the Western Biomass model

The worksheet "BiomassWt" also calculates a projection of tree weight percentages for the various recovered products. Although the FVS model can estimate the weights in terms of BDT per acre for various products, due to biomass losses in skidding or forwarding and possible specifications for biomass retention on the site for nutrient management, the actual recovered product weights will be different from the FVS projections. The weight percentage projection in the "BiomassWt" sheet specifies the weight percentage distribution for each delivered-to-landing product. This information will be used to calculate the product recovery cost in terms of dollar per acre.

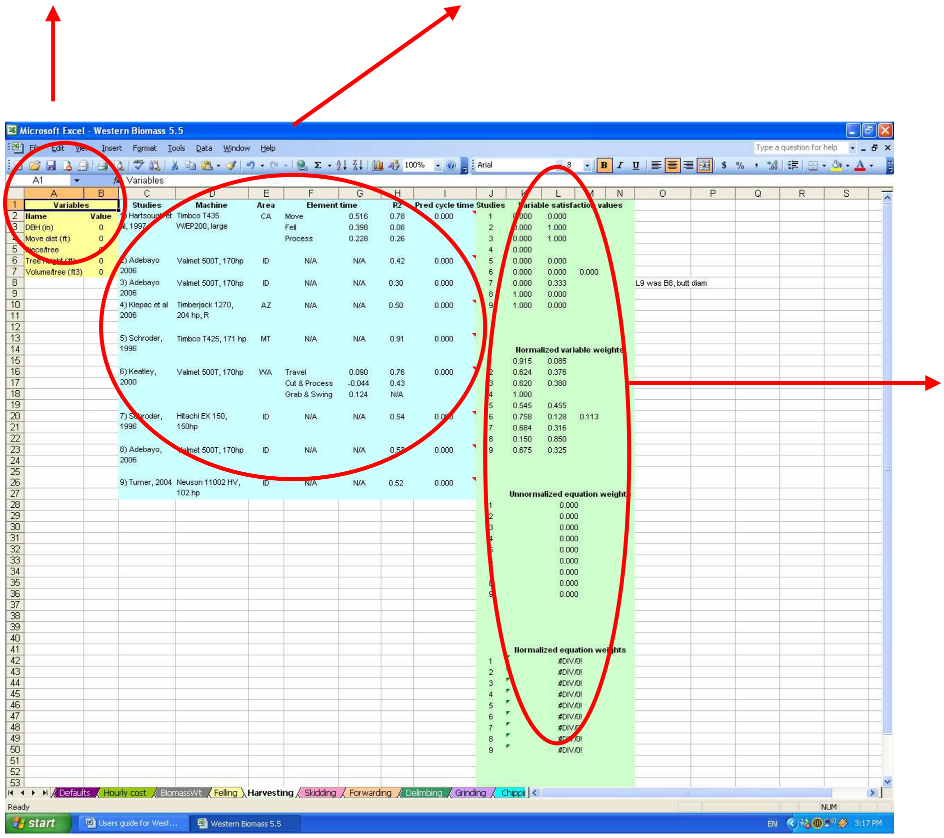
Other working sheets 4 – Felling, Harvesting, Skidding, Forwarding, Delimbing, Grinding, ChippingHogfuel, ChippingCleanchip (User adjustments not allowed)

The machine cycle time prediction worksheets store the regression equations obtained from published studies (Fig 4-21) and analyzed for inclusion in the model. When model users select specific machines, the sheet will filter out unqualified equations and keep the suitable equations for use. The independent variables for the selected suitable equations will be sent to the "Inputs" sheet, asking for either model default or user-defined values. Once these variable values are available, these worksheet will calculate the machine operation cycle times. For example, in the "Felling" worksheet, the predicted felling cycle times are shown in column "I".

All regression equations that did not qualify for use will have a predicted cycle time of zero.

This area transfer independent variable values from the "Inputs" sheet. User inputs are

This area stores the published productivity equations and calculates the cycle time or production rate for each selected equation based on input variable values.



This area calculates a weighted average cycle time or production rate from multiple selected equations. User inputs are NOT allowed.

Figure 4-21: A typical worksheet in the Western Biomass model to calculate the weighted average cycle time or production rate

After calculating the operation cycle time for each selected regression equation, the worksheets will use the established theory for combining multiple regression equations to obtain a weighted average cycle time. For example, in the "Skidding" worksheet the sheet area "J1:N17" performs the calculation of the variable satisfaction values. Then, these variable satisfaction values are used to calculate the normalized variable weights in the area of "J18:N34". The calculation of un-normalized equation weights in the area of "J35:N51" combines the variable satisfaction values with the normalized variable weights, and provides the information to calculate the normalized the equation weights in the area "J52:N68". A weight averaged operation cycle time will be finally reached at the cell "K70". This value is the product sum of the individual cycle times and the normalized equation weights. The weighted average operation cycle will then be used to predict the machine production rates in the line 141 in the "Inputs" worksheet.

Other working sheets 5 – Hauling (User adjustments not allowed)

The BNG trucking model is stored as the first part of the "Hauling" worksheet (Fig 4-22). This worksheet also has direct link with the user selected road type, road grade, and road distance in the "Inputs" sheet (purple-marked area). Using the input information, the BNG trucking model will calculate the transportation time for each section of the road network. The calculated total cycle time represents the sum of the two-way transportation time (calculated by the BNG model), loading time (from the "Inputs" worksheet), and the unloading time (from the "Inputs worksheet). The estimated hauling cycle time will then be used to calculate the hauling production rates for each recovered product, as reflected in the "Inputs" sheet, line 141.

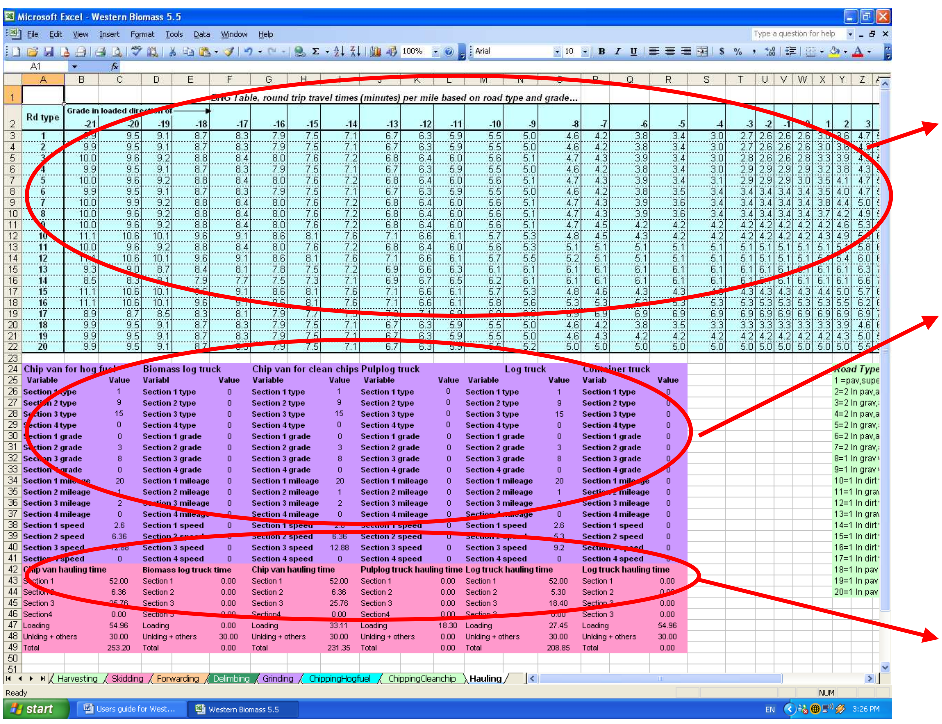


Figure 4-22: "Hauling" worksheet in the Western Biomass model

4.3.3 Model Outputs

Cost Prediction Summary

The "Results" worksheet of the Western Biomass model summarizes the cost predictions for each recovered product (Figs 4-23 and 4-24). Users can select to view the results for the corresponding operation methods: hot operation, cold decking biomass only, or cold decking all the products.

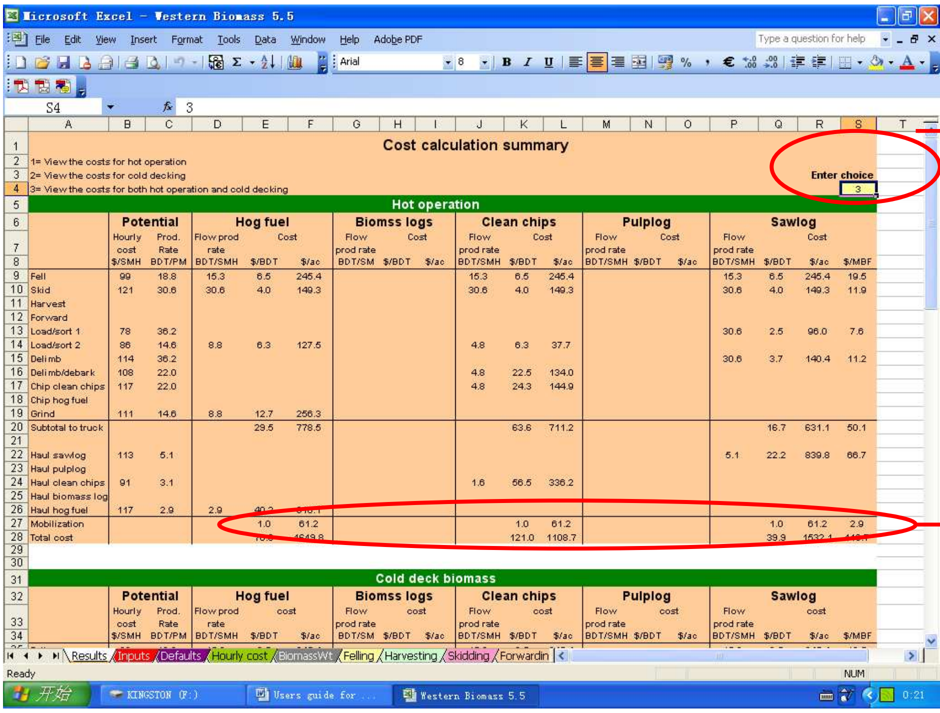


Figure 4-23: Cost prediction results summary worksheet in the Western Biomass model

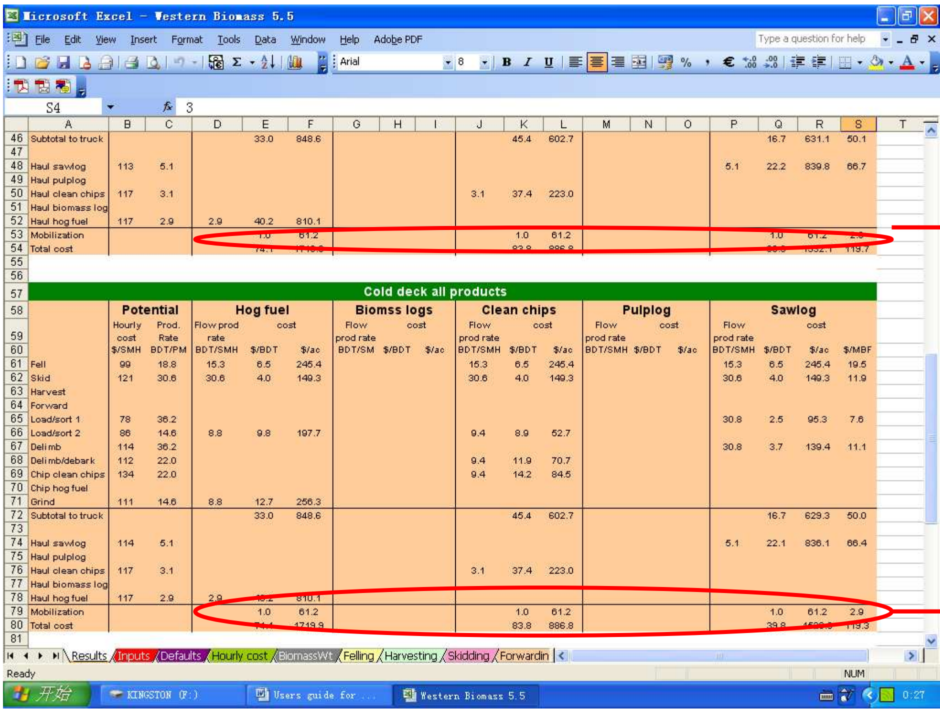


Figure 4-24: Cost prediction results summary worksheet in the Western Biomass model

Within the cost prediction summary section, machine hourly costs ($/SMH) and potential production rates are transferred from the “Inputs” worksheet and listed. Machine flow production rates (BDT/SMH) are also presented to show the actual productivity when individual machines are working in the system.

To facilitate different model users, the Western Biomass model has predicted production cost in terms of dollar per bone dry ton ($/BDT) and dollars per acre ($/ac) for all products. In addition, a production cost in the units of dollar per thousand board feet ($/MBF) is also assigned to the sawlog product as it is the most common unit designation for sawlogs in the western United States.

When multiple products are recovered concurrently, the production cost allocation to different products follows guideline introduced by Hudson et al (1990). These are as follows:

a) All operations which do not produce a product in its final form are charged equally to the products. For example, felling and extraction costs are calculated in units appropriate to the whole tree and charged to each product.

b) An input which produces a product in its final form is charged solely to this product with the by-products not incurring a cost. For example, the total cost of delimbing should be carried by the sawlog, with the residues being considered as a by-product.

<u>Cost Prediction Errors</u>

The prediction errors about the production cost are calculated automatically by the Western Biomass model. The prediction errors are then transformed to a confidence interval (or C.I.) for a point estimate of the production cost. As long as users make a selection about the preferred results (hot operation, cold decking biomass only, or cold decking all the products), the C.I. will appear together with the point estimate of the production cost (Fig. 4-25)

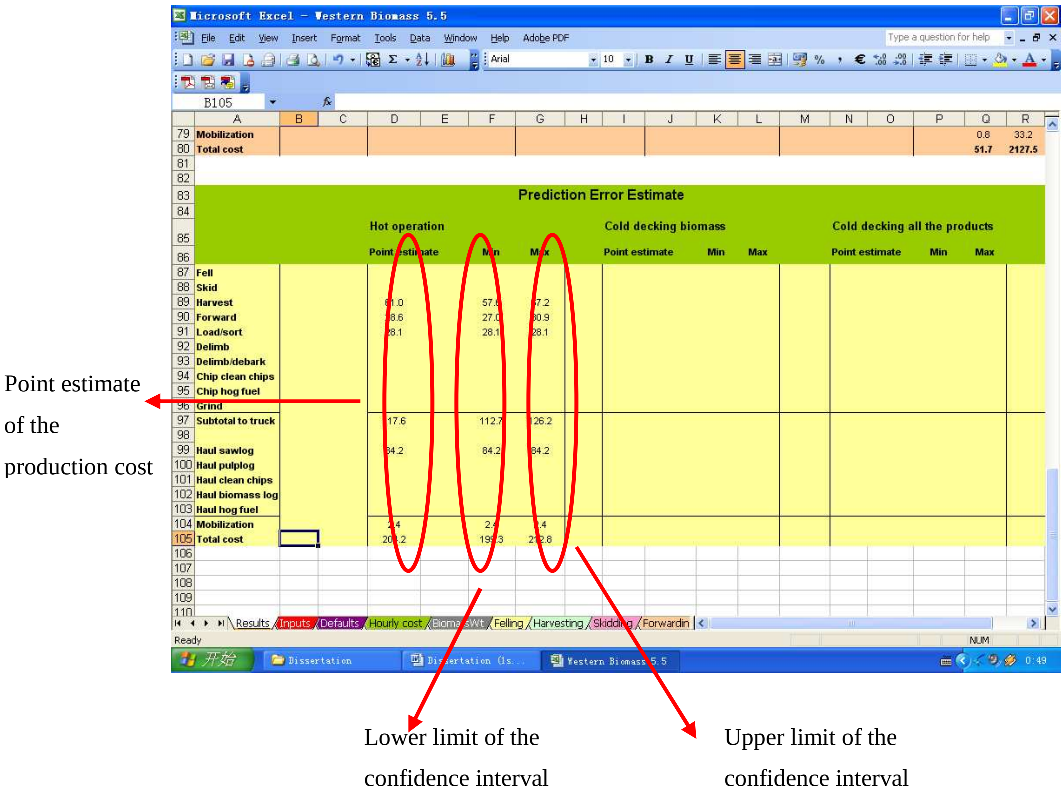


Figure 4-25: Confidence interval (C.I.) of the production cost point estimate

It is important to note here that the confidence interval of the point estimate only accounts for the errors resulting from combining multiple productivity equations. The FVS predicted stand parameters and the machine hourly cost calculations are also associated with prediction errors more or less; however, these errors are difficult to estimate and are not reflected in the confidence interval.

4.3.4 Model Working Summary

Figure 4-26 shows how the different worksheets of the Western Biomass model work together to predict the production costs for fuels reduction treatment operations.

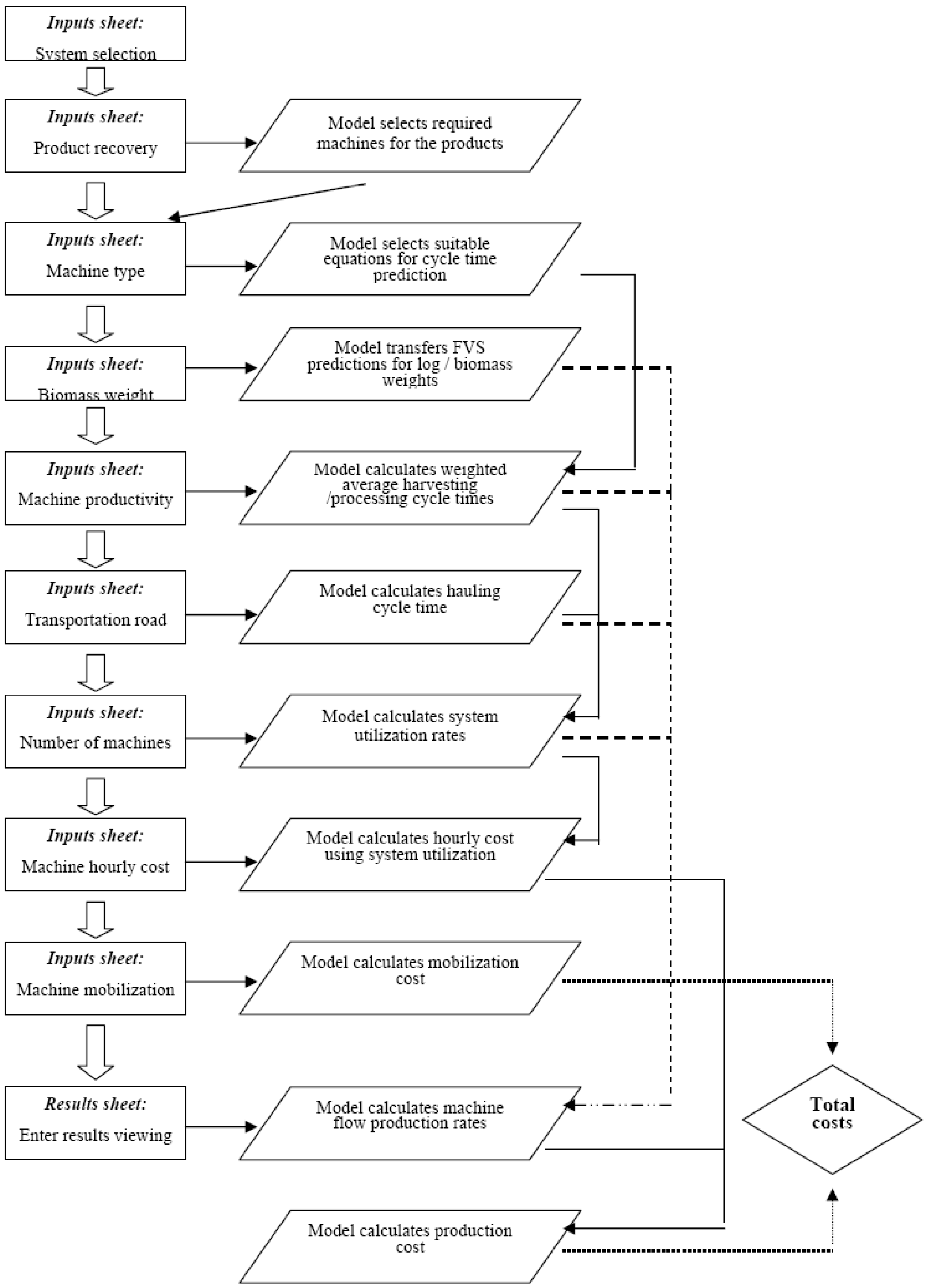


Figure 4-26: Flow chart of the information processing procedures of the Western Biomass mode

4.4 Conclusion

The Western Biomass model is an analytical tool designed and developed for use by forest managers, planners, and project contractors to estimate the costs of fuel reduction treatments through evaluations of harvest prescription, product recovery scenarios, and the machines to be used. Machine operation cycle times are predicted by combining multiple regression equations so that site-specific productivity equations can be adjusted to a point where they are suitable for other regions. The Western Biomass model is also linked with the FVS model output to predict the biomass weight information and to minimize errors often resulting from knowledge-based estimates. The Western Biomass model is a useful valid working tool to help forest managers and planners conduct fuels reduction treatments in a cost-effective way.

Chapter 2

A model application using realistic data

5.1 Introduction

In Chapters 1 and 2, a method using weight generating functions, a relevance network model, and generalized mixed operator was developed to make predictions from multiple regression equations. This method was validated using computer simulations structured in SAS 9.0. The simulation results showed that this method is capable of making reliable predictions that are not significantly different from the true model predictions ($\alpha = 0.05$). Computer simulation offers an opportunity to experiment with the proposed method for thousands of times which is not possible using traditional case studies. However, in the simulation adjustments made in the validation steps, the reality of the system is greatly simplified. There is a need to use a realistic case study as a supplement to the computer simulations to test the validity of the proposed method under the real operation conditions. This model application employs realistic data to demonstrate the use and the accuracy of the Western Biomass model.

5.2 Methodology

5.2.1 Stand description and harvesting prescription

This realistic case involved a fuels reduction treatment to a stand (Swampy TS unit 15A) located in the state of Oregon (Latitude: 43°25’ N, Longitude: 122°25’ W). The total area included in the thinning project was 41 acres. The stand inventory data was taken when the stand was cruised in1987 and a fuels reduction thinning treatment was conducted in 2005.

The silvicultural prescription required the stand to be thinned to 70 trees per acre. Sawlogs were recovered if the removed trees had a DBH greater or equal to 7 inches; other removed trees were hand piled for future burning. There was no specific nutrient management prescription for this particular thinning project, but the thinning was done with a cut-to-length system.

5.2.2 Harvesting operation

A cut-to-length system was contracted to perform the thinning project. The system included a single-grip harvester (Timberjack 1270B) to fell and process the trees prior to forwarding the logs to the landing by a forwarder (Timberjack 1210B) with 15-ton loading capacity. The harvester worked independently for a couple of days before the forwarder came onto the site as the harvester was expected to have a lower production rate than the forwarder. The logs were loaded onto trucks by a large loader and hauled to the mill by three trucks. The total hauling distance was approximately 74 miles. Detailed road types, distances, and grades are summarized in Table 5-1.

Table 5-1: Road types, distance, and slope in the realistic case

Road type	**Road type code in BNG model**	**Distance (miles)**	**Grade (%)**
Highway	2	70	1
Paved road	4	3	4
Gravel road	9	1	0
Spur road	15	0.1	0

5.2.3 Cost prediction and assumptions

The initial stand data was structured to run in the FVS model, and the model was used to project the stand parameters required by the Western Biomass model. The FVS predictions with other operational parameters were then transferred or entered into the Western Biomass model to make a prediction for the production rates and costs.

In addition to the original information provided by the Swampy TS unit 15A project, several basic assumptions were made factors such as recovery distances and transport losses. These assumptions are summarized in Table 5-2.

Table 5-2: Assumptions applied in the realistic case

Parameters	**Assumption**
Harvester move distance per cycle (ft)	15
Number of logs per tree for processing	2
Forwarder intermediate travel distance (ft)	400

Truck unloading & preparation time (min)	25
Forwarding loss (%)	2
Oven dry weight per truck load (BDT)	18

5.3 Results

5.3.1 Stand parameters predicted by the FVS model

Using the Swampy TS unit 15A data from 1987, the FVS model predicted the stand parameters for harvested trees in 2005 (Table 5-3).

Table 5-3: FVS predicted stand parameters for harvested trees

	Harvested trees		
	2.0≤DBH ≤ 5.0	**5.0 <DBH < 7.0**	**7.0≤DBH ≤15.0**
		Inches	
Crown weight (BDT/ac)	0.39	2.15	10.32
Stem weight (BDT/ac)	0.75	4.56	42.02
Stand density	49	83	154
Avg. DBH (inches)	4.12	6.13	10.67
Total volume (ft^3/ac)	57.96	347.23	3138.47
Merch. volume (ft^3/ac)	0	0	3027.57
Tree height (ft)	24.51	36.88	60.48

5.3.2 Cost and production rates predicted by the Western Biomass model

Using the FVS predicted stand parameters and the machine operation information the Western Biomass model predicted that the total cost is 439.70 dollars per thousand board feet (or $/MBF) or 6034.90 dollars per acre ($/ac) if a “hot” operation is utilized; while the total cost is $335.00/MBF or $4597.50/ac if the logs are cold decked at the landing before hauling (Table 5-4). The cost difference between the hot operation and cold decking trees is caused by the loading and hauling productivity increase when the processed logs are cold decked.

Table 5-5 summarizes the point estimates and confidence interval s of the production cost predictions. For this fuel reduction thinning project, the contractor observed stump-to-truck cost was $210/MBF when hot operation was used. The Western Biomass model predicted that the stump-to-truck cost is $240.40/MBF. The Model predicted value is less than 14% of the true, observed value. Further, the model predicted confidence interval for stump-to-truck production cost is [135.5, 345.3], which covers the value of 210 (Table 5-5). This indicates that the Western Biomass model works well in predicting a reliable cost.

Table 5-4: Cost comparison between costs and production for hot operations and cold decking

	"Hot" operation			**Cold decking**		
	Flow production rate	**Cost**		**Flow production rate**	**Cost**	
	(BDT/SMH)	**($/MBF)**	**($/acre)**	**(BDT/SMH)**	**($/MBF)**	**($/acre)**
Harvesting	5.5	72.40	993.80	16.6	26.90	368.90
Forwarding	4.2	83.30	1142.70	15.4	24.10	330.20
Loading	4.2	84.80	1163.50	4.2	84.80	1163.50
Subtotal to truck	N/A	240.40	3300.00	N/A	135.70	1862.50
Hauling	2.0	197.50	2710.10	2.0	197.50	2710.10
Mobilization	N/A	1.80	24.90	N/A	1.80	24.90
Total	N/A	439.70	6034.90	N/A	335.00	4597.50

Table 5-5: Summary of the point estimates and confidence intervals of the production cost.

	"Hot" operation		Cold decking	
	Point estimate	Confidence interval [a]	Point estimate	Confidence interval [a]
	($/MBF)			
Harvesting	72.40	[58.1, 86.7]	26.90	[21.6, 32.2]
Forwarding	83.30	[69.1, 97.4]	24.10	[20.0, 28.2]
Loading	84.80	[84.8, 84.8]	84.80	[84.8, 84.8]
Subtotal to truck	240.40	[135.5, 345.3]	135.70	[44.2, 227.2]
Hauling	197.50	[197.50, 197.50]	197.50	[197.50, 197.50]
Mobilization	1.80	[1.80, 1.80]	1.80	[1.80, 1.80]
Total	439.70	[334.8, 544.6]	335.00	[243.5, 426.4]

[a]: single conservative standard deviation used.

5.3.3 Simulation for a more balanced system

Operational delays have a potential to be minimized by knowing the productivities of system parts. In the realistic case, the system utilization rate could be increased by adding one more harvester, because the potential production rate of the forwarder is more than twice the production rate of the harvester. The number of trucks was assumed to increase to 8 as a result of the increase of the forwarding productivity.

Table 5-6 summarizes the utilization rates for the original system and an assumed balanced system. As a result of employing one more harvester and more trucks, the minimum machine utilization rate was increased from 10% to 24%. The system production cost was reduced to $340.80/MBF (hot operation) and $273.20/MBF (cold decking) (Table 5-7). This represents 78% (hot operation) and 82% (cold decking) of the unbalanced condition.

Table 5-6: Machine utilization rates of the original system and the simulated more balanced system.

	Original system utilization rate (%)		**More balanced system utilization rate (%)**	
	Hot operation	**Cold decking**	**Hot operation**	**Cold decking**
Harvester	31	31	31	31
Forwarder	10	10	25	25
Loader	10	10	24	24
Truck	95	95	95	95

Table 5-7: Production cost of the original system and the simulated more balanced system.

	Original system production cost ($/MBF)		**More balanced system production cost ($/MBF)**	
	Hot operation	**Cold decking**	**Hot operation**	**Cold decking**
Harvesting	72.40	26.90	72.40	26.90
Forwarding	83.30	24.10	34.20	12.10
Loading	84.80	84.80	34.30	34.30
Subtotal to truck	240.40	135.70	140.90	73.30
Hauling	197.50	197.50	197.50	197.50
Mobilization	1.80	1.80	2.40	2.40
Total	439.70	335.00	340.80	273.20

5.3.4 Simulation for biomass recovery

Biomass harvesting, processing, and transportation is often cost prohibitive due to the low production rates when conventional machine systems are used. Biomass recovery, therefore, is often integrated into a conventional sawlog harvest so that the revenue generated from sawlog harvesting can pay for the cost of biomass recovery. Although the case of Swampy TS unit 15A did not include biomass recovery, simulation using the Western Biomass model illustrates how much it would cost if biomass were harvested together with sawlog harvesting.

In addition to the existing harvester and forwarder, a large chipper and three chip trucks (120 cubic yards chip van) were simulated to be in the system. Trees from 2 inches to 6.9 inches in DBH were processed to biomass logs by the harvester. Trees that were too small for the harvester to process were forwarded to the landing as whole trees. These biomass logs were shuttled to the landing by the forwarder prior chipping into hog fuel by the chipper. The chipper then blows the processed hog fuel into the chip van. An energy plant is assumed to be at the same location as the mill so that the chip truck transportation network covers the same route as the sawlog trucks.

The results of the Western Biomass model prediction show that the potential productivities of the harvester and forwarder lead to a low volume of wood delivered at the landing for the other machines to process. The forwarder, chipper, and hog fuel truck are heavily underutilized in the hot operation (Table 5-8), resulting in an extremely high hog fuel production cost of $286.90/BDT (Table 5-9). However, if the biomass logs are cold decked before chipping, the utilization rate of the chipper will increase to 12% (Table 5-8). As a result, the hog fuel production costs are lowered to $187.70/BDT and $150.50/BDT (Table 5-9).

Considering that the potential production rate of the harvester is significant lower than the forwarder, one more harvester is added to the system to better match the productivity of the forwarder. As a result, three more sawlog trucks and three more chip trucks are also added to the system. Under these conditions, the Western Biomass model predictions show that the utilization rates of the forwarder, loader, chipper, and hog fuel trucks are greatly increased (Table 5-10), resulting in much lower production costs for both hog fuel and sawlogs (Table 5-11).

Table 5-8: Potential productivity and utilization rates of the machines.

	Harvester	**Forwarder**	**Loader**	**Chipper**	**Sawlog truck**	**Hog fuel truck**
Potential prod. rate (BDT/PMH)	18.6	46.2	43.2	24.4	1.4	2.1
Utilization - hot system (%)	29	9	10	5	51	95
Utilization - cold decking biomass (%)	29	9	10	12	51	95
Utilization - cold decking biomass and sawlog (%)	29	9	10	12	51	95

Table 5-9: Production costs of biomass and sawlog recovery.

Production cost	Hot operation	Cold decking biomass	Cold decking biomass and sawlog
Hog fuel ($/BDT)	286.90	187.70	150.50
Sawlog ($/MBF)	444.10	444.10	332.60

Table 5-10: Potential productivity and utilization rates of the machines.

	Harvester	Forwarder	Loader	Chipper	Hog fuel truck	Sawlog truck
Potential prod. rate (BDT/PMH)	18.6	46.2	43.2	24.4	1.4	2.1
Utilization - hot system (%)	29	22	24	14	51	95
Utilization - cold decking biomass (%)	29	22	24	29	95	95
Utilization - cold decking biomass and sawlog (%)	95	95	75	24	95	95

Table 5-11: Production costs of biomass and sawlog recovery.

Production cost	Hot operation	Cold decking biomass	Cold decking biomass and sawlog
Hog fuel ($/BDT)	220.70	154.30	130.70
Sawlog ($/MBF)	342.20	342.20	271.50

5.4 Discussion

For this model application, the predictions made through the Western Biomass model were very close to the observed values. This, however, does not indicate that the Western Biomass model has such accuracy for all cases. To ensure model reliability over a large area, long term model maintenance is required. The most important aspect of this case study is that it shows the capability of the Western

Biomass model to work with realistic data, which allows the computer simulation to be validated in the real world.

In this case study, a harvester was added to the system to match the productivity of the forwarder. This, however, is not the only method that can be used to lower system costs. For example, given the long delay time for the forwarder, it could have been used as a loader to load the logs to the trucks. This would eliminate the use of a separate loader and simultaneously increase the utilization of the forwarder. However, the current version of the Western Biomass model is not capable of handling such machine use variability. The next generation of the Western Biomass model will include this feature.

5.5 Conclusion

This model application used a forest stand in the state of Oregon called Swampy TS unit 15A data to illustrate stand parameter predictions using the FVS model and fuels reduction thinning cost predictions using the Western Biomass model. The difference between the Western Biomass model-predicted values and the observed values were less than 3% of the observed value. This suggests a good prediction accuracy of the Western Biomass model. Further simulation cases focused on balancing the system and integrated biomass recovery cost prediction show that Western Biomass model can be used as an effective tool in designing a cost-effective fuels reduction thinning projects.

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Appendix A

Regression Prediction Equations Used in the Western Biomass Model

Felling

1. Pan et al (2008a) – Valmet 603, drive-to-tree

Cycle time (centi min) = 1.3358
+ 0.3785(Move to tree distance in feet)
+ 7.1646(Number of cuts per cycle)
+ 0.3151(Intermediate travel distance in feet)
+ 0.3991(Move to bunch distance in feet)

2. Halbrook and Han (2005) - Timberjack 2628, leveling cab

Cycle time (min) = 0.191
+0.017*(Travel empty distance in feet)
+0.184(# of trees per cycle)

3. Adebayo (2006) – Timbco 445EXL, Swing boom

Cycle time (min) = 0.178
+0.000163(DBH in inches) ^{2}

(For felling one tree per cycle only. Regression equation was redeveloped from original data.)

4. Watson et al (1995) – Hydro Ax121, drive-to-tree

Cycle time (min) = 0.395
+0.0187 (Slope in %)

(For felling one tree per cycle only.)

5. Johnson (1988) – Timbco 2520, leveling cab

Cycle time (min) = 0.078
+0.045 (DBH in inches) (# of trees per cycle)

6. Johnson (1988) – CAT 227, Swing boom

Cycle time (min) = 0.145

+0.0106 (Slope in %)

+0.0086 (Travel empty distance in feet + Intermediate travel distance in feet)

+0.3 (# of trees per cycle)

7. Keatley (2000) – Timbco T445-C, leveling cab

Travel empty time (min) = 0.135

+0.009 (Travel empty distance in feet)

Felling time (min) = -0.078

+0.0116(DBH in inches)

+0.1383(# of trees per cycle)

Move with tree time (min) = 0.0537

+0.0112 (Move with tree dist in feet)

Placing time (min) = 0.1413

(For trees from 4 to 12 inches in DBH)

8. Keatley (2000) – Timbco T445-C, leveling cab

Travel empty time (min) = 0.135

+0.009 (Travel empty distance in feet)

Felling time (min) = 0.186

+0.035(DBH in inches)

+0.125(# of trees per cycle)

Move with tree time (min) = 0.0537

+0.0112 (Move with tree dist in feet)

Placing time (min) = 0.1413

(For trees from 4 to 6 inches in DBH)

9. Largo (2004) - Timberjack 2628, leveling cab

Cycle time (min) = 0.235

+ 0.115 (# of trees per cycle)

Skidding

1. Hartsough et al (1997) – CAT 528, wheeled

Travel empty time (centi min) = 45.7

+0.2617 (Travel dist in feet)

+0.00429 (Favorable slope in %) (Travel dist in feet)

Loading time (centi min) = 80.6

+4.33 (# of trees)

Move time (centi min) = 6.4

+8.4 (# of trees)

Travel loaded time (centi min) = 40.8

+0.2706 (Travel dist in feet)

Unloading time (centi min) = 51.5

(For biomass trees only)

2. Hartsough et al (1997) – CAT 528, wheeled

Travel empty time (centi min) = 45.7

+0.2617 (Travel dist in feet)

+0.00429 (Favorable slope in %) (Travel dist in feet)

Loading time (centi min) = 31.3

+6.03 (# of trees)

+0.178 (Favorable slope in %) (# of trees)

Move time (centi min) = 6.4

+8.4 (# of trees)

Travel loaded time (centi min) = 40.8

+0.2706 (Travel dist in feet)

Unloading time (centi min) = 51.5

(For merchantable trees only)

3. Hartsough et al (1997) – Timberjack 450B, wheeled

Travel empty time (centi min) = 45.7

+0.222 (Travel dist in feet)

+0.00429 (Favorable slope in %) (Travel dist in feet)

Loading time (centi min) = 80.6

+4.33 (# of trees)

Move time (centi min) = 6.4

+8.4 (# of trees)

Travel loaded time (centi min) = 40.8

+0.221(Travel dist in feet)

Unloading time (centi min) = 51.5

(For biomass trees only)

4. Hartsough et al (1997) – Timberjack 450B, wheeled

Travel empty time (centi min) = 45.7

+0.222 (Travel dist in feet)

+0.00429 (Favorable slope in %) (Travel dist in feet)

Loading time (centi min) = 31.3

+6.03 (# of trees)

+0.178 (Favorable slope in %) (# of trees)

Move time (centi min) = 6.4

+8.4 (# of trees)

Travel loaded time (centi min) = 40.8

+0.221(Travel dist in feet)

Unloading time (centi min) = 51.5

(For merchantable trees only)

5. Adebayo (2006) – CAT 518, tracked

Cycle time (centi min) = 393.79

+0.000496 (Travel dist in feet) ^{2}

+4.423 (# of trees)

(Regression equation was redeveloped from original data)

6. Adebayo (2006) – CAT 518, tracked

Cycle time (centi min) = 273.3

+0.000539 (Travel dist in feet) ^{2}

+16.36 (# of trees)

(For biomass trees only. Regression equation was redeveloped from original data)

7. Spinelli and Hartsough (2001) – CAT 528, wheeled

Travel empty time (centi min) = 35.5

+0.299 (Travel dist in meter)

Positioning time (centi min) = 35.3

Loading time (centi min) = -43.3

+45.6 (# of stops during loading)

+13.8 (Cycle weight in wet, metric ton)

Move time (centi min) = -21

+30.4 (# of stops during loading)

Travel loaded time (centi min) = 24

+0.436 (Travel dist in meter)

+0.0379 (Travel dist in meter) (Cycle weight in wet, metric ton)

Unloading time (centi min) = 24.8

8. Halbrook and Han (2005) – John Deere 648E, wheeled

Cycle time (min) = 3.396

+0.006 (Travel dist in feet)

+0.054 (Re-grapple dist in feet)

+0.092 (Favorable slope in %)

9. Pan et al (2008a) – CAT 525B, wheeled

Cycle time (centi min) = 111.9500

+ 0.2132 (Travel dist in feet)

+ 0.6881 (Positioning distance in feet)

– 0.5881 (Number of trees per cycle)

10. Han, H-S. and C. Renzie (2005) – John Deere 748G, wheeled

Cycle time (min) = 4.113

+0.0204 (Travel dist in meter)

11. Han, H-S. and C. Renzie (2005) – CAT 527, tracked

Cycle time (min) = 3.1971

+0.0204 (Travel dist in meter)

12. Johnson, L.R. (1988) – CAT 518, wheeled

Cycle time (min) = 1.068

+0.0056 (Travel dist in meter)

+0.1682 (Favorable slope in %)

13. Coulter, (1999) – CAT 527, tracked

Cycle time (min) = 1.045

+0.0061 (Travel dist in feet)

(For both merchantable and biomass trees)

14. Coulter, (1999) – CAT 527, tracked

Cycle time (min) = 1.356

+0.0042 (Travel dist in feet)

(For biomass trees only, regression equation was redeveloped from original data)

15. Keatley (2000) – CAT 518, wheeled

Travel empty time (min) = 0.329

+0.0028 (Travel dist in feet)

Loading time (min) = 0.0838

+0.399 (# of stops during loading)

Move time (min) = 0.2938

+0.004 Intermediate travel dist in feet)

Travel loaded time (min) = 0.3629

+0.0035 (Travel dist in feet

Unloading time (min) = 1.00

16. Largo (2004) – John Deere 648E, wheeled

Cycle time (min) = 1.75

+0.0056 (Travel dist in feet)

<u>Harvesting</u>

1. Hartsough et al (1997) – Timbco T435

Move time (centi min) = 51.6

+1.01 (Move dist in feet)

Felling time (centi min) = 39.8

+0.114 $(DBH)^2$

Processing time (centi min) = 22.8

+0.2 $(DBH)^2$

2. Adebayo (2006) – Valmet 500T

Cycle time (min) = 0.337

+0.0023 $(DBH)^2$

+ 0.0557 (# of logs per tree)

(For trees from 4 to 24 inches in DBH)

3. Adebayo (2006) – Valmet 500T

Cycle time (min) = 0.428

+0.131 (DBH)

- 0.022 (# of logs per tree)

(For trees from 5 to 8 inches in DBH. Regression equation was redeveloped from original data)

4. Klepac et al (2006) – Timberjack 1270

Cycle time (sec) = 24.796

+0.31419 $(DBH)^2$

5. Schroder (1996) – Timbco T425

Cycle time (min) = [0.48859

+0.04159 (# of logs per tree)

+0.09496 (Vol per tree in ft^3) $^{0.5}$] ^{2}

6. Keatley (2000) – Valmet 500T

Travel time (min) = 0.09

+0.01 (Move dist in feet)

Cut & process time (min) = -0.044

+0.05 (# of logs per tree)

+0.025 (DBH in inches)

Grab & swing time (min) = 0.124

7. Schroder (1996) – Hitachi EX150

Cycle time (min) = -0.022

+0.152 (# of logs per tree)

+0.024 (Butt diameter in inches)

8. Adebayo (2006) – Valmet 500T

Cycle time (min) = 0.275

+0.025 (# of logs per tree)

+0.0046 (DBH) ^{2}

(For trees from 3 to 14 inches in DBH)

9. Turner, D.R. (2004)

LOG (Cycle time (sec)) = 1.4491

+0.0096(Moving dist in meter)

+0.0151(DBH in centimeter)

(Average brush code = 1.5)

Forwarding

1. Hartsough et al (1997) – Timberjack 1010

Travel time (centi min) = 153

+0.498 (Dist in feet)

+ 0.0122 (Dist in feet)(Slope in %)

Load time (centi min) = 642.5+10.7 (# of logs)

Move time (centi min) = 458.9+0.808 (Dist range in feet)

Unloading time (centi min) = 359.7+2.196 (# of logs)

2. McNeel and Rutherford (1994) – No machine model information

Move-in-woods time (min) = 0.2084

+0.0146 (Intermediate travel dist in meter)

Move-at-landing time (min) = 0.1763

+0.0061 (Move at landing dist in meter)

Travel loaded time (min) = 0.2386

+0.0125 (Travel dist in meter)

Travel empty time (min) = 0.3418

+0.0135 (Travel dist in meter)

Sort-at-landing time (min) = 2.1041

Unloading time (min) = 5.3847

Loading time (min) = 9.4284

Sort-in-woods time (min) = 2.0543

3. Adebayo (2006) – Valmet 890

Travel empty time (min) = 0.782

+0.005 (Travel dist in feet)

Loading time (min) = 2.413

+0.113 (# of logs)

Intermediate travel time (min) = 0.204

+0.008 (Intermediate travel dist in feet)

Travel loaded time (min) = 0.814

+0.006 (Travel dist in feet)

Unloading time (min) = 5.388

(For biomass logs only)

4. Adebayo (2006) – Valmet 890

Travel empty time (min) = 0.663

+0.0036 (Travel dist in feet)

Loading time (min) = 3.984

+0.0937 (# of logs)

Intermediate travel time (min) = 0.53

+0.0051 (Intermediate travel dist in feet)

Travel loaded time (min) = 0.374

+0.0036 (Travel dist in feet)

Unloading time (min) = 3.857

(For biomass logs only)

5. Klepac et al (2006) – Timberjack 1010B

Travel time (min) = 1.4657

+0.006102 (Round trip travel dist in feet)

Intermediate travel time (min) = 1.128

+0.02541 (Load volume in ft^3)

- 0.2773 (# of logs)

Loading time (min) = 47.157

-678.01 $(\text{\# of swings during loading})^{-1}$

6. Keatley (2000) – Valmet 892

Travel empty time (min) = 0.008

+0.0052 (Travel dist in feet)

Loading time (min) = -0.8

+0.537 (# of swings during loading)

Intermediate travel time (min) = 0.781

+0.0067 (Intermediate travel dist in feet)

Travel loaded time (min) = 0.539

+0.005 (Travel dist in feet)

Unloading time (min) = 0.227

+0.0147 (# of logs)

7. Schroder (1996) – Timberjack 230-A

Travel empty time (min) = 1.526

+0.0044 (Travel dist in feet)

Loading time (min) = 0.984

+0.537 (# of stops during loading)

+0.083 (% of bunk)

Intermediate travel time (min) = 0.381

+0.214 (# of stops during loading)

+0.0024 (Intermediate travel dist in feet)

Travel loaded time (min) = 1.4

+0.005 (Travel dist in feet)

Unloading time (min) = 0.143

+0.06 (% of bunk)

8. Adebayo (2006) – Valmet 890

Travel empty time (min) = 0.663

+0.0036 (Travel dist in feet)

Loading time (min) = 3.554

+0.103 (# of logs)

Intermediate travel time (min) = 0.53

+0.0051 (Intermediate travel dist in feet)

Travel loaded time (min) = 0.374

+0.0036 (Travel dist in feet)

Unloading time (min) = 3.857

(For sawlogs and biomass logs)

9. Adebayo (2006) – Valmet 890

Travel empty time (min) = 0.782

+0.005 (Travel dist in feet)

Loading time (min) = 2.413

+0.113 (# of logs)

Intermediate travel time (min) = 0.204

+0.008 (Intermediate travel dist in feet)

Travel loaded time (min) = 0.814

+0.006 (Travel dist in feet)

Unloading time (min) = 5.388

(For sawlogs and biomass logs)

10. Hartsough et al (1997) – Timberjack 1010

Travel time (centi min) = 153

+0.498 (One-way travel dist in feet)

+0.0122(One-way travel dist in feet) (Favorable slope in %)

Load time (centi min) = 642.5

+12 (# of logs)

Move time (centi min) = 458.9

+0.808 (Dist range in feet)

Unload time (centi min) = 359.7

+6.69 (# of logs)

<u>Delimbing</u>

1. Halbrook and Han (2005) - Daewoo DH 280, stroke

Cycle time (min) = 0.712

+0.43 (# of logs per tree)

2. Adebayo (2006) – Komatsu PC200, stroke

Cycle time (min) = -0.006

+0.03 (DBH in inches)

+0.36 (# of logs per tree)

3. Hartsough et al (1997) – Timberjack 90, stroke

Cycle time (centi min) = -58.3

+3.8 (DBH in inches)

+78.3 (# of sawlogs per tree)

+27.5 (# of trees per cycle)

4. Johnson (1988) - Rogers-Denis, stroke

Cycle time (min) = -0.13

+0.001 (Butt diameter in inches) ^{2}

+0.5842 (# of logs per tree)

5. Johnson (1988) - Harricana, stroke

Cycle time (min) = 0.118

+0.0117 (DBH in inches)

+0.0532 (# of logs per tree)

6. Keatley (2000) - Kobelco Mark IV SK200 LC, dangle head

Cycle time (min) = 0.118

+0.0117 (DBH in inches)

+0.0532 (# of logs per tree)

7. Coulter (1999) - CAT 320L-Waratah Warrior, dangle head

Cycle time (min) = 0.1106

+0.0038 (Volume in ft ^{3})

+0.2774 (# of logs per tree)

8. Largo (2004) - Daewoo DH 280, stroke

Cycle time (min) = 0.431

+0.49 (# of logs per tree)

Grinding

1. Halbrook and Han (2005) - Vermeer HG6000TX

Cycle time (min) = 14.905

+0.023 (Travel dist in feet)

+0.317 (# of loader grapples per chip van load)

2. Pan et al (2008a) - Bandit Beast 3680

Cycle time (min) = –1133.4000

+ 0.1510 (Hog fuel weight per chip van load in green pounds)

3. Largo (No date) - Bandit Beast 3680

Cycle time (min) = 0.19

+0.16 (# of trees per loader grapple)

<u>Chipping for hog fuel</u>

1. Watson et al (1986) – Morbark 20

Chipping production rate (BDT/hr) = 6.41

+2.57 (DBH in inches)

2. Watson et al (1986) – Morbark 27

Chipping production rate (BDT/hr) = 22.7

+0.211 (DBH in inches)^{3}

3. Hartsough et al (1997) – Morbark 60/36

Cycle time (centi min) = 25

+2.64 (# of logs per loader cycle)

+0.0498 (weight per stem in dry lb)

(For small log length only)

4. Hartsough et al (1997) – Morbark 60/36

Cycle time (centi min) = 25

+2.64 (# of logs per loader cycle)

+0.0498 (weight per stem in dry lb)

(For whole tree with 2-10 inches in DBH)

5. Johnson (1988) – Morbark 18

Production rate (green tons / PMH) = 15.43

– 1.087 (Avg. residue length)

+0.217 (Avg. piece weight in wet lb)

(For limbs and tops only)

6. Westbrook et al (2007) – Conehead 565

Production rate (green tons / PMH) = -0.68

+0.000513 (Avg. piece weight in wet lb)

(For limbs and tops only)

<u>Chipping for clean chips</u>

1. Hartsough et al (2002) - Peterson Pacific DDC5000

Chipping production rate (BDT/hr) = 16.6

-0.63(Chipping hours per cycle)

+0.081(Dry chip weight per tree in lb)

Appendix B

Using the FVS model to calculate the Western Biomass required stand parameters

The Forest Vegetation Simulator (FVS) is a forest growth and yield model. It allows users to make predictions from their own inventory data, while incorporating the effects of various disturbances. With the embedded calculation functions, the FVS model is capable of projecting various parameters for harvested trees, including biomass weights, DBH, volume, tree height, etc. The calculated information can be exported to an external database file (e.g. an Excel or Excess file), allowing the information to be transferred to the Western Biomass model as input.

Step 1 – FVS input files preparation

The FVS model uses three different types of files. The first is a FVS formatted Tree Data file with the format of “<filename>.fvs”. The second and third are the “Suppose” interface Stand List file (<filename>.slf) and Locations file (<filename>.loc), respectively. Most Forest Service Regions have data translators that format regional-specific data into Suppose and FVS formatted files. Save these three files together in one working folder (Fig C-1).

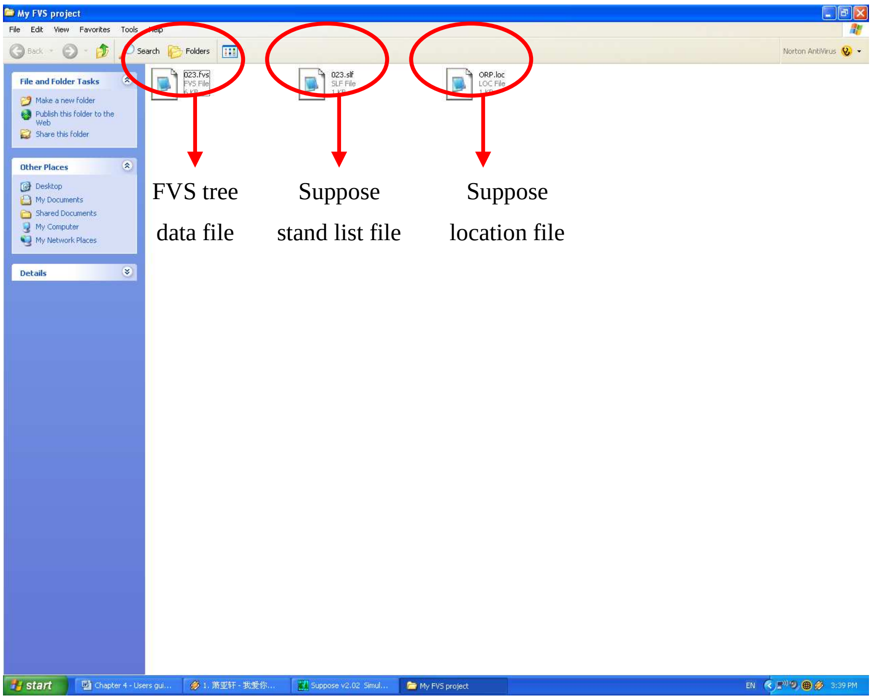


Figure C-1: Three FVS input files in a working folder

Step 2 - Select location file, stand file in the FVS model

2-1 Start the FVS model (Suppose interface).

2-2 From the “File” menu, select “Select Locations file”. The locations file dialog box appears.

2-3 Find the location file in your FVS working folder in the locations file dialog box, then highlight the file, click “Open” (Fig. C-2). A dialog box called “Select Simulation Stands” appears (Fig. C-3)

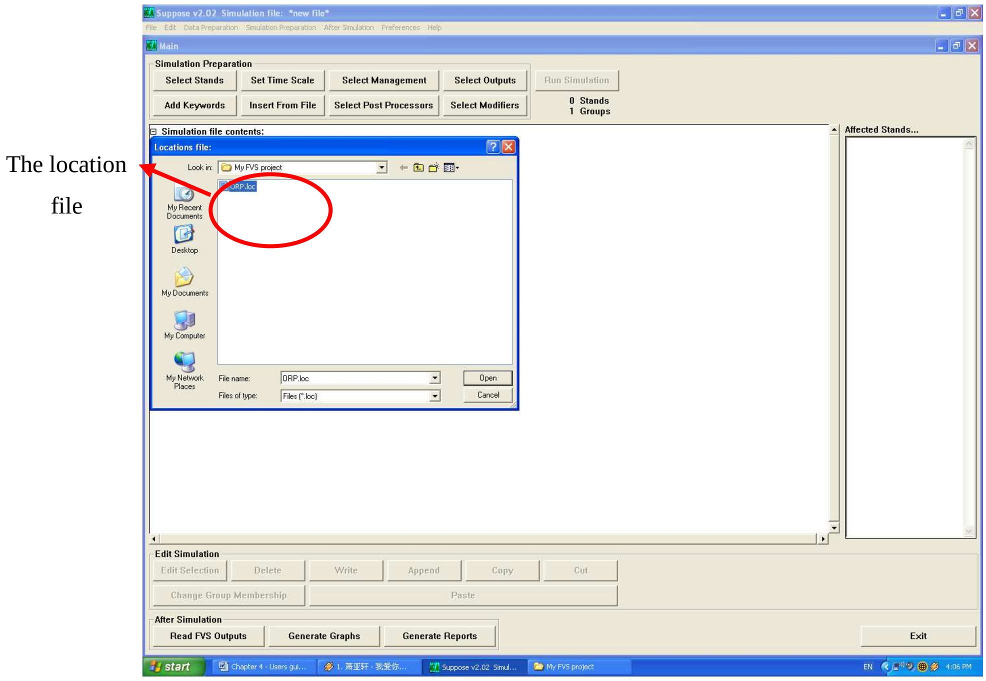


Figure C-2: Find the location file in the Locations File dialog box

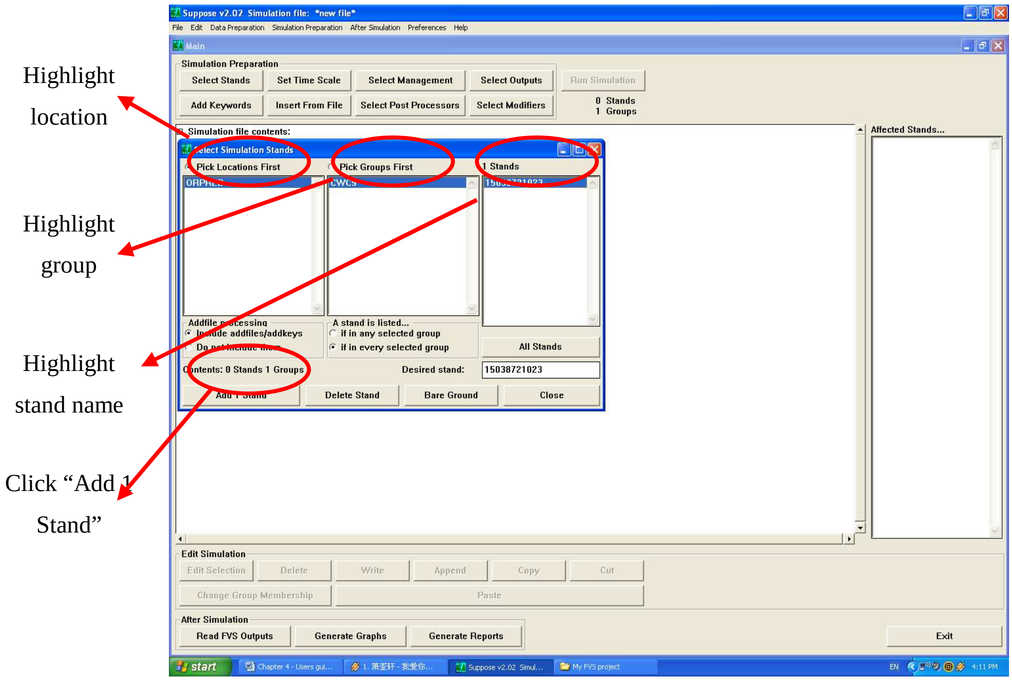


Figure C-3 “Select Simulation Stands” dialog box

2-4 Highlight the location, group, and the stand name. Click “Add 1 Stand”, then click “Close” (Fig. C-3).

2-5 Check the included stand. When a stand is successfully added into FVS for analysis, it will look like Figure C-4.

The stand added to the FVS for analysis

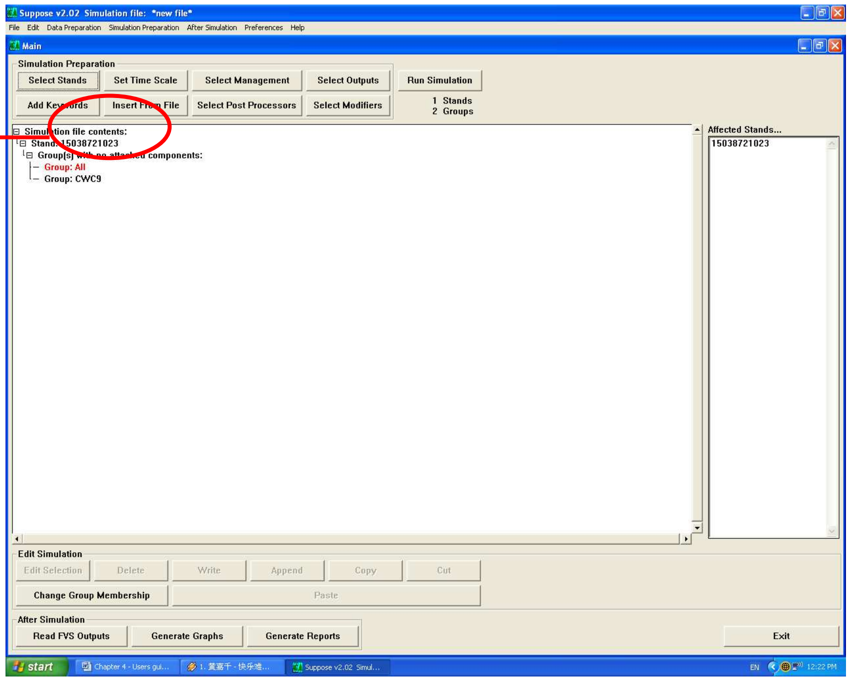


Figure C-4: Add a stand to the FVS model for analysis

Step 3 – Set time scale

For any FVS projection, users are required to choose a projection start and end time, and are required to define a common cycle length.

3-1 Click the “Set Time Scale”, a small dialog window called “Set time scale” will appear (Fig. C-5).

3-2 Manually input projection start time, end time, and cycle length (Fig. C-5).

It is important to note that the FVS default cycle length is 10 years. Setting other user-defined cycle length will make the prediction biased. However, setting cycle length less than 10 years will create less bias than setting cycle length longer than 10 years.

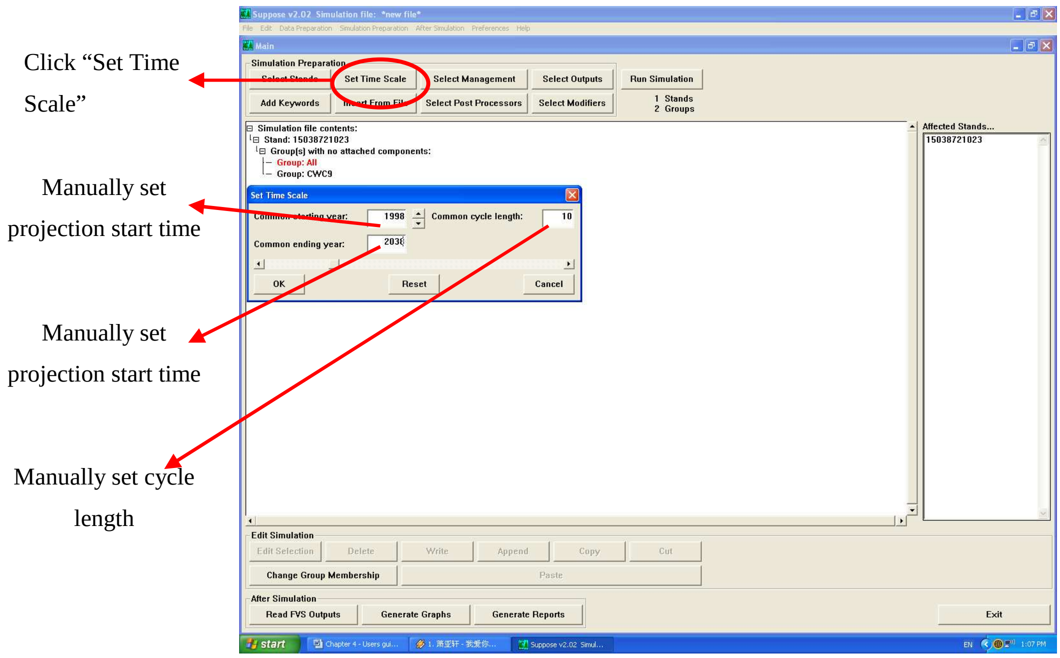


Figure C-5: Set projection start time, end time, and cycle length in the FVS model

Step 4 – Select Management

Since the FVS model is being used to predict the biomass information for mechanical fuels reduction treatments, the management action belongs to "Thinning & Pruning Operations".

4-1 Click "Select Management", a dialog window called "Management Actions" will appear (Fig. C-6).

4-2 Select "Thinning and Pruning Operations" on the left side of the "Management Actions" window, and highlight "Mechanical Thinning" on the right side (Fig. C-6), a sub-window called "Mechanical Thinning" will appear (Fig. C-7).

4-3 Manually input thinning treatment time, residual stand density, DBH range, and species preference, then click "OK"(Fig. C-7).

4-4 Close the "Management Actions" window, a command of "mechanical thinning" will appear in the main FVS interface (Fig. C-8).

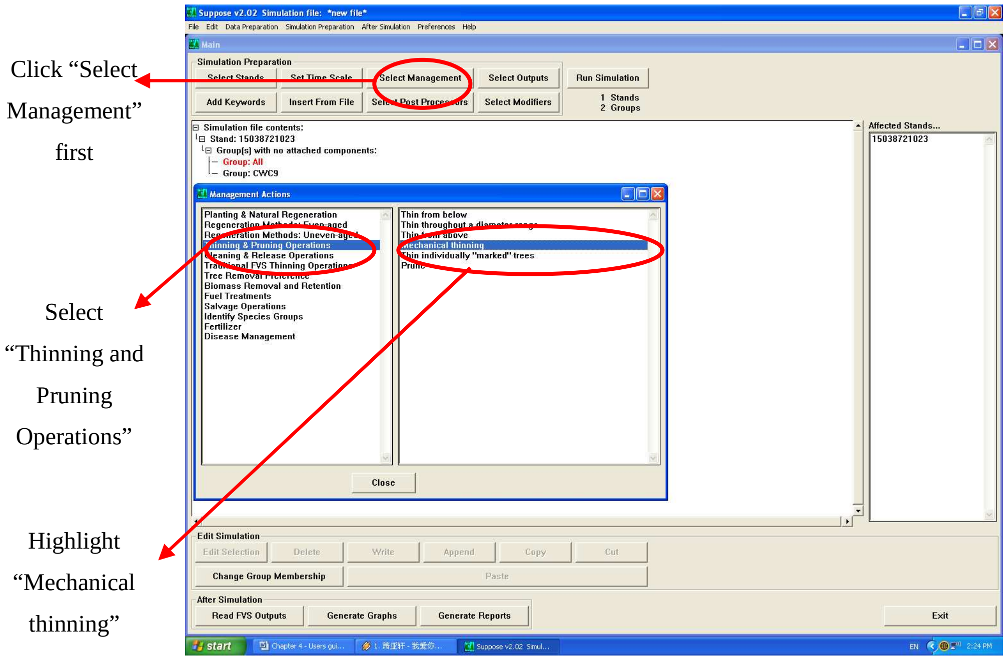


Figure C-6: Select management actions in the FVS model

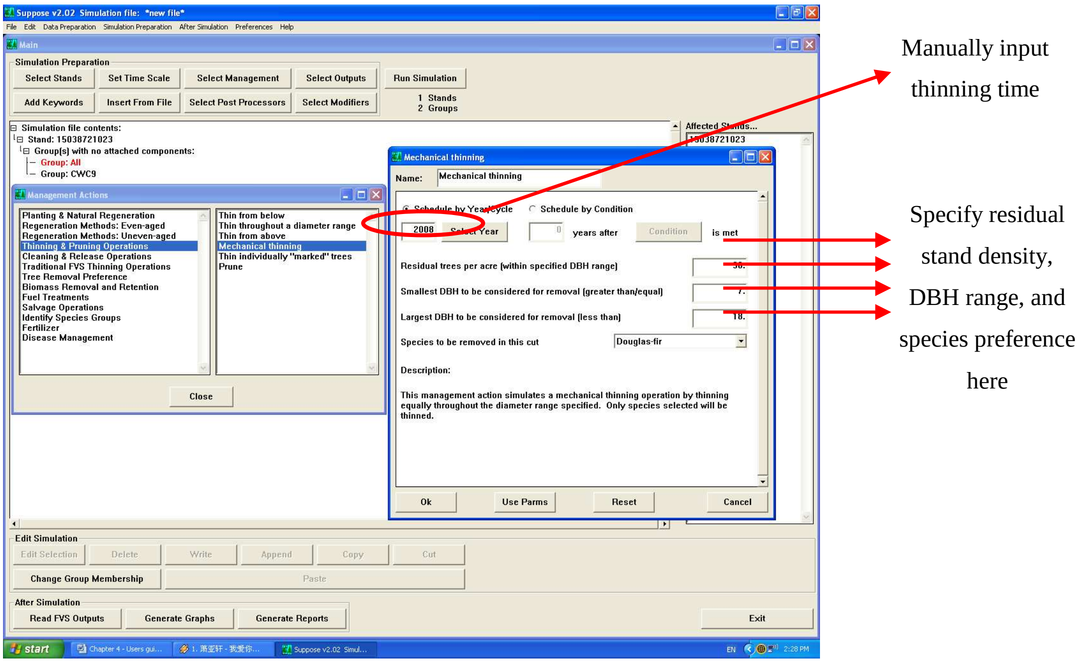


Figure C-7: Manually input thinning time, residual stand density, DBH range, and species preference in the FVS model

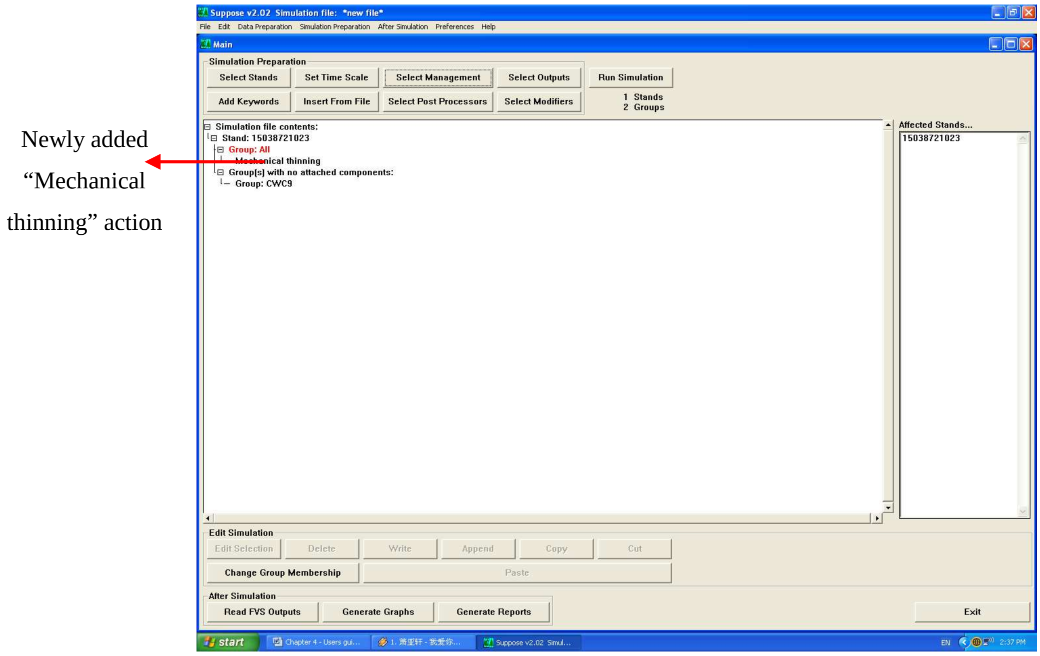


Figure C-8: The FVS interface including the newly added management actions.

Step 5 – Select output

5-1 The Fire and Fuels Extension (FFE) report needs to be included to the output first as it is a prerequisite for calculating the biomass information. Click "Select output", a small window called "Model Outputs" will appear (Fig. C-9).

5-2 In "Model Outputs" window, select "Fire and Fuels Extension (FFE) Reports", and highlight "Select Fire and Fuels Reports" in the right side window. A window about the detailed FFE settings will appear (Fig. C-10).

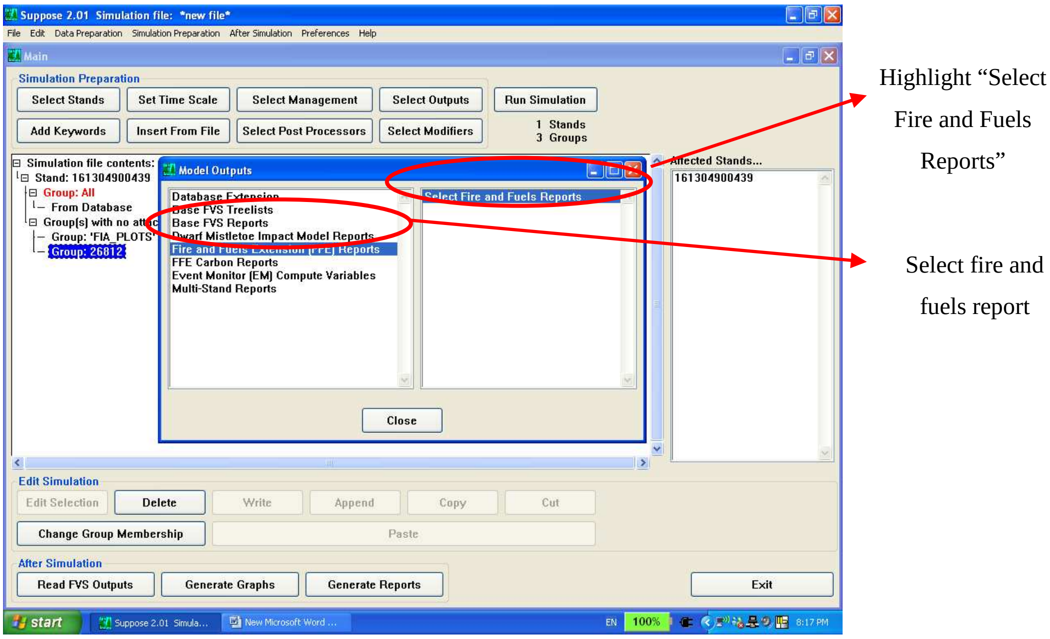


Figure C-9: Select the Fire and Fuels Extension report

5-3 Select “Standard output file only” for any items you want to view. This will ask FVS to transfer the fire and fuels report to the main output file. Then, click “OK”. In the main FVS interface, there will be a command showing “Select Fire and Fuel Reports” (Fig. C-11). Make sure, the “Model Outputs” window is still active at this time.

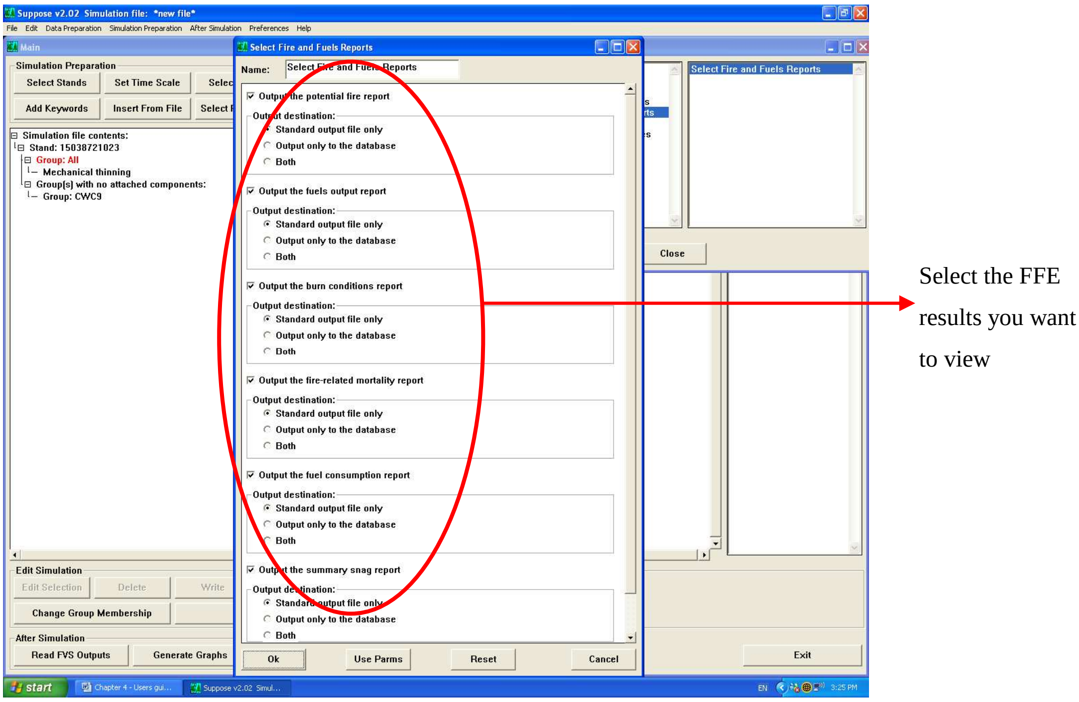


Figure C-10: Select the Fire and Fuels Extension report

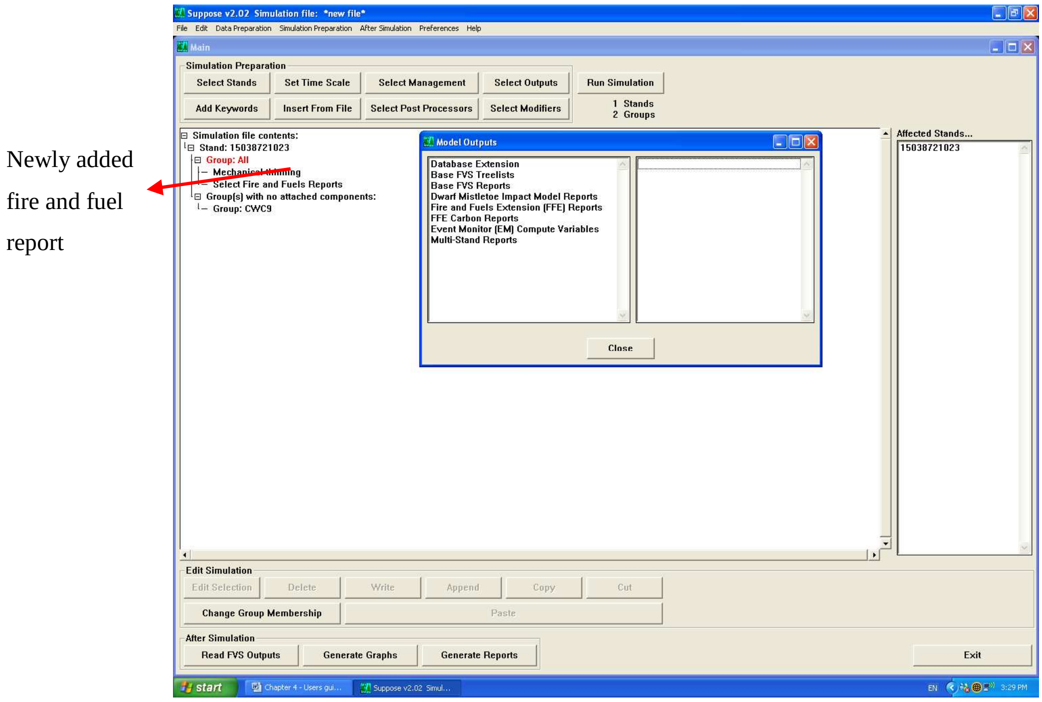


Figure C-11: The FVS interface including the fire and fuels report

5-4 In the “Model Outputs” window, select “Event Monitor (EM) Compute Variable” and in the right side window, highlight “Compute Stand Variables in Editor” (Fig. C-12) , then a dialog window with the name “Compute Stand Variables in Editor” will appear (Fig. C-13).

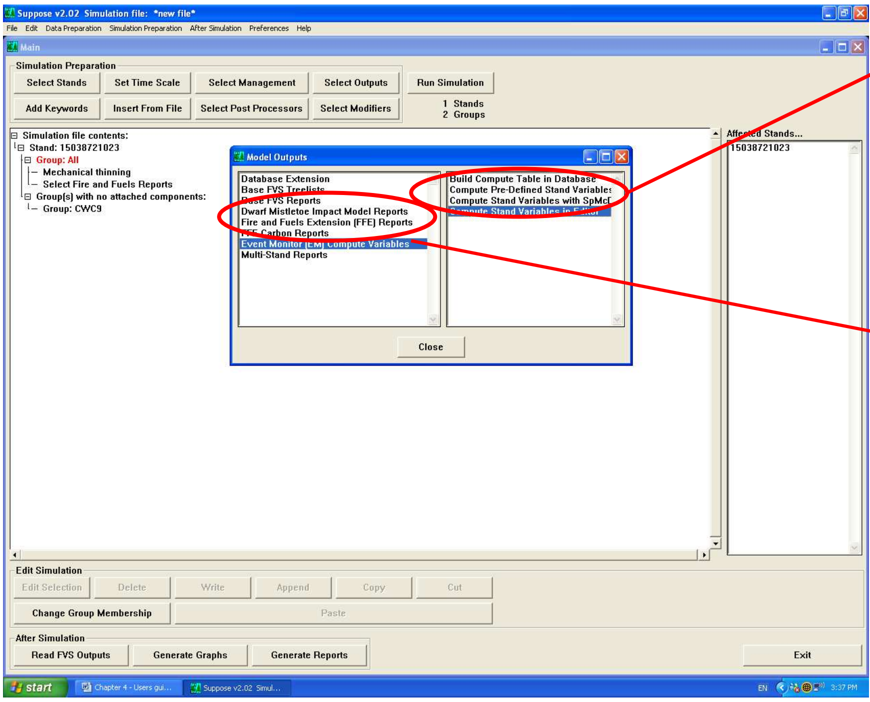


Figure C-12: Using Event Monitor to calculate stand variables in the FVS model

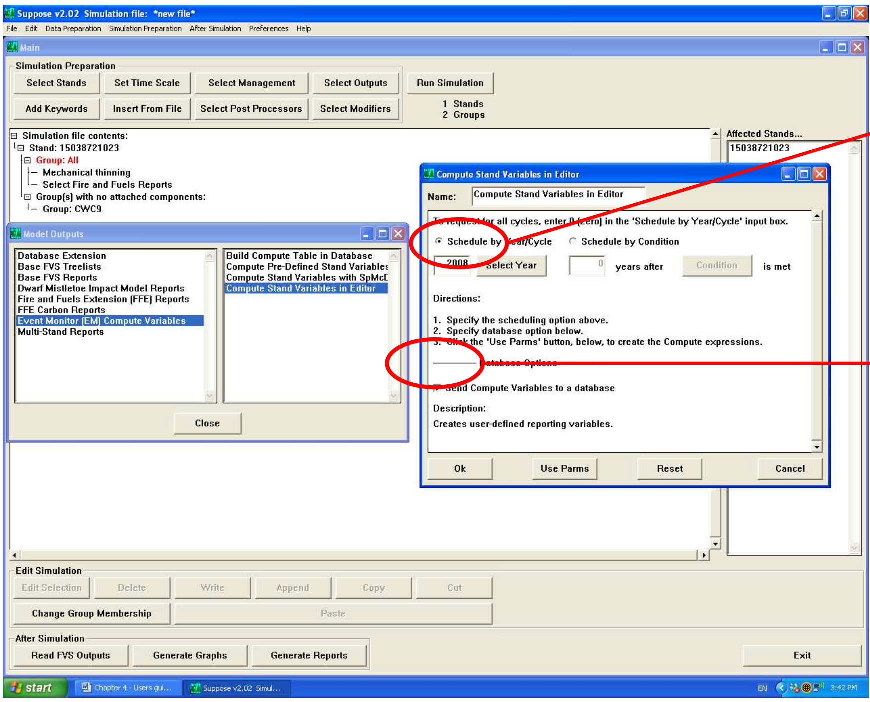


Figure C-13: Compute stand variables in editors

5-5 Manually input thinning operation year again, and check the box before "Send Compute Variables to a data base" (Fig. C-13), then click "Use Parms" and "Proceed" in the follow-up dialog box, a statement editor window will appear (Fig. C-14).

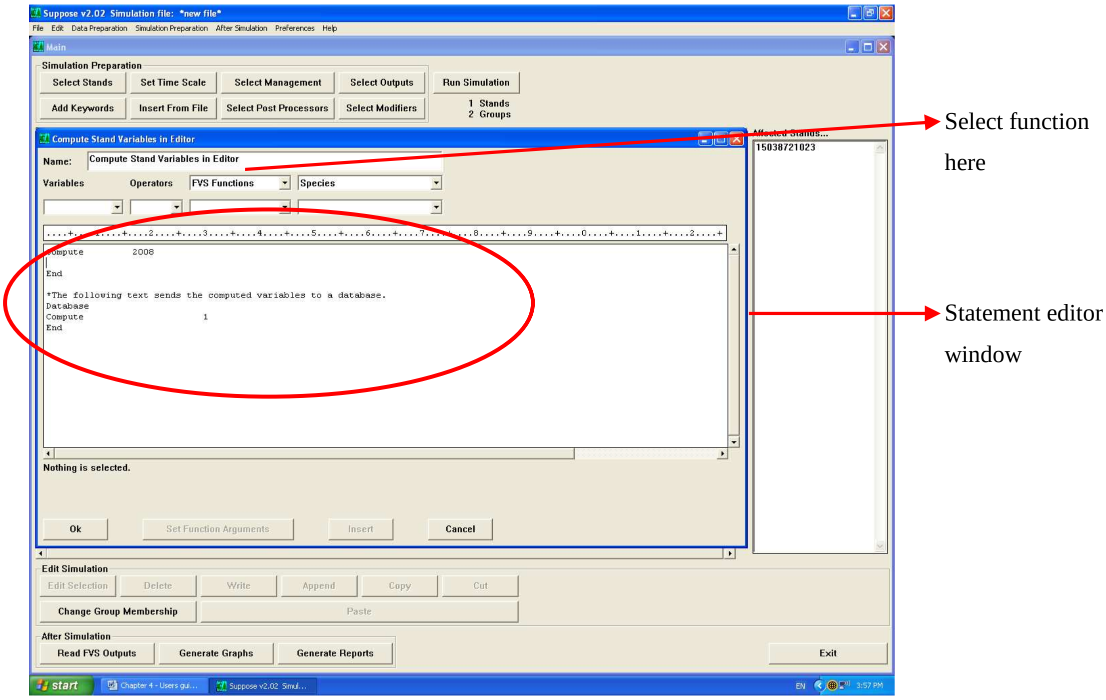


Figure C-14: Statement editor window in the Event Monitor

5-6 In the pull down window beneath the "FVS function", select the function of "TreeBio()" to calculate the biomass weights. Then click "Set function arguments", a dialog window with the name "Compute Stand Variables in Editor" will appear (Fig. C-15).

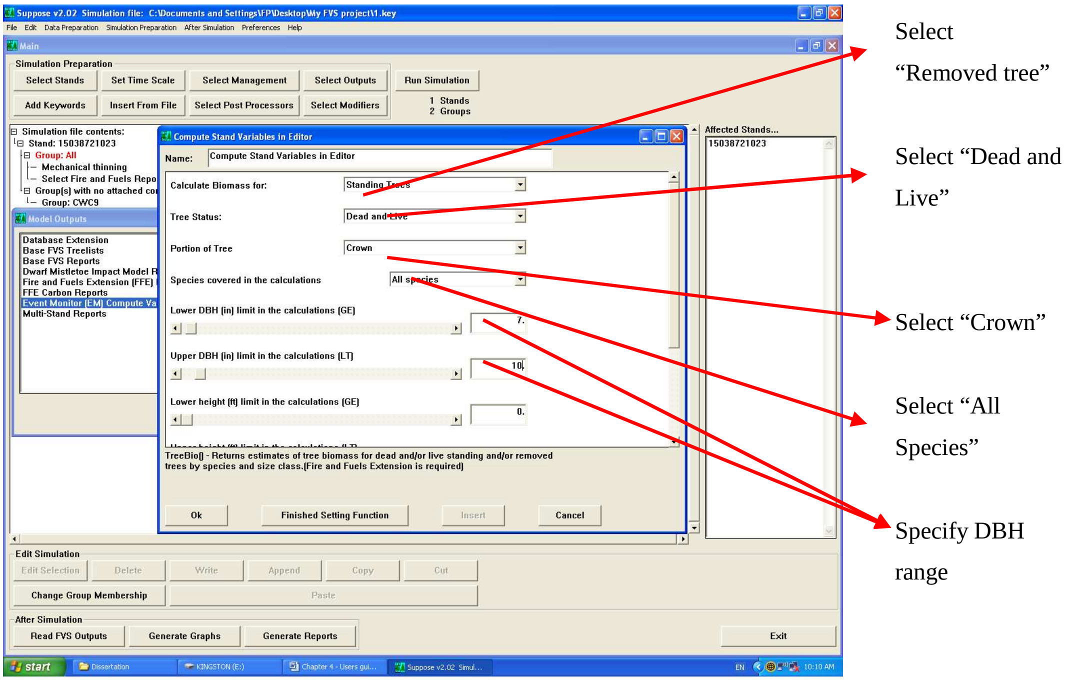


Figure C-15: Set calculation parameter for Event Monitor.

5-7 In the "Compute Stand Variables in Editor" window, select "Removed Trees", "Dead and Live" trees, "Crown", "All species". Manually input numbers for lower DBH limit, upper DBH limit. Then click "Finished setting function" and "Insert". This will result in a statement in the Statement editor window that asks the Event Monitor to calculate the "Removed" "Crown" "Biomass Weight" for harvested "Dead and Live Trees" in a specific DBH range. This specified DBH range should reflect the trees that will be harvested for a product (e.g. trees from 9 to 17 inches in DBH will be harvested for sawlogs). Then, type in a variable name (e.g. BioWt) and a "=" sign in front of this statement. This means you are asking the Event Monitor to calculate the variable value using this statement (Fig. C-16).

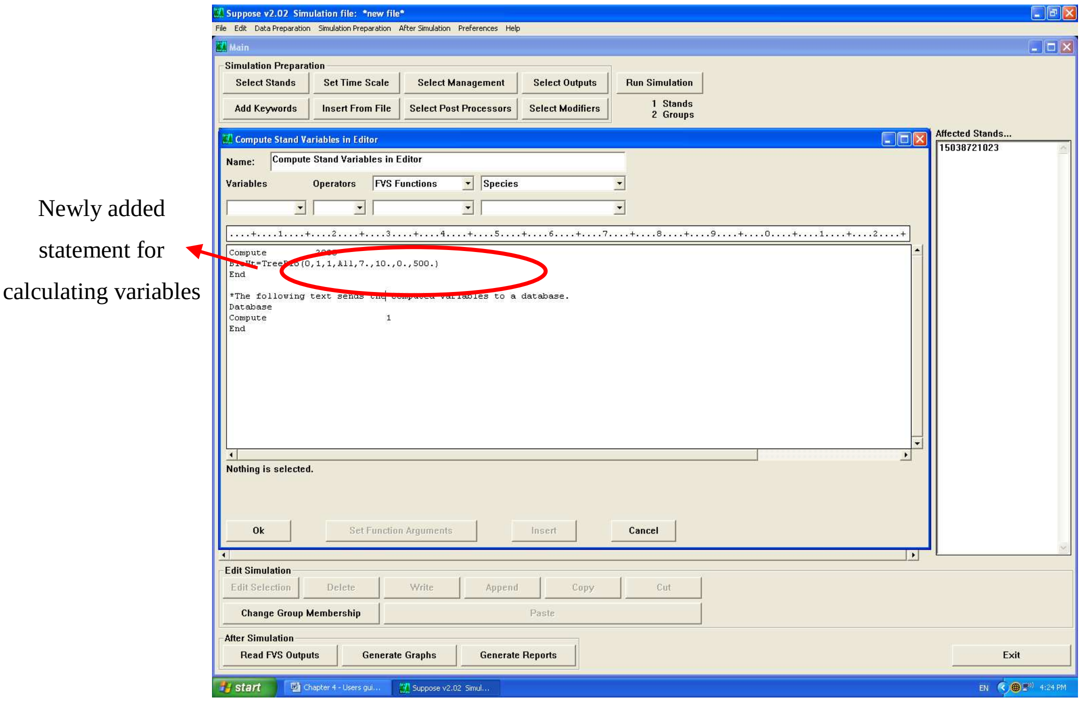


Figure C-16: Edit variable calculation statement in the Event Monitor

5-8 Repeat the procedures from 5-6 to 5-7 to calculate the biomass weight for various products and portions of the removed trees. In order to get the biomass weight information required by the Western Biomass model, the crown and stem biomass weights of the trees for each product need to be projected by the Event Monitor. The Western Biomass model will automatically use the sum of the crown biomass weight and the stem biomass weight as the whole tree biomass weight.

5-9 Repeat the procedures from 5-6 to 5-7 to calculate the following parameters for HARVESTED trees: the stand density, DBH, merchantable volume, total volume, and tree height. All these parameters can be projected using the FVS embedded function SpMcDBH(), and need to be predicted for each recovered product.

5-10 Check the sequence of the Event Monitor statements. In order to transfer the predictions to the Western Biomass model correctly, the sequence of the statements need to be: stem weight, crown weight, stand density, DBH, total volume, merchantable volume, and tree height. Click “OK” after finishing editing the statements. In the main FVS interface, there will be a statement of “Compute Stand Variables in Editor” (Fig. C-17).

Newly added "Compute Stand Variables in Editor"

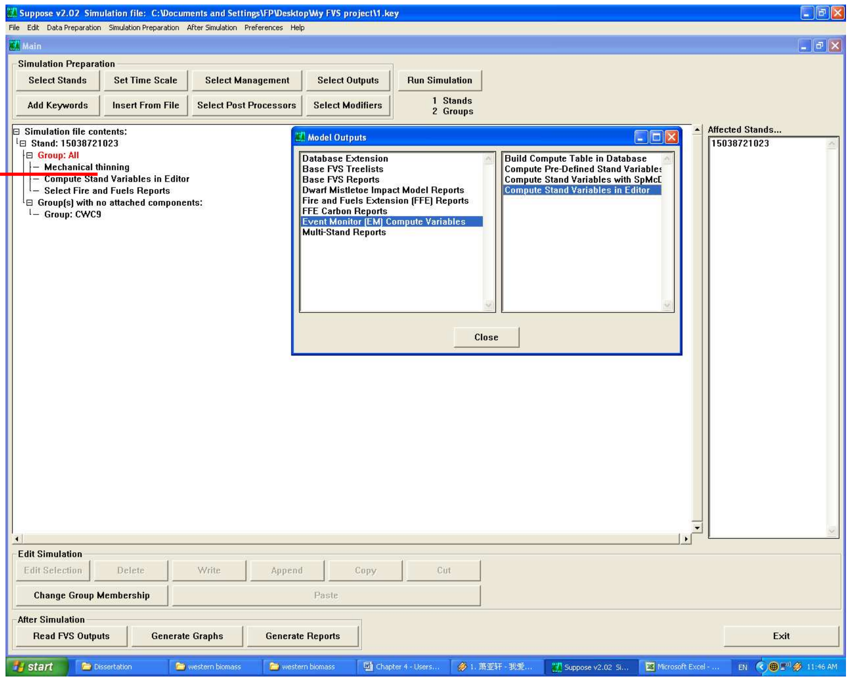
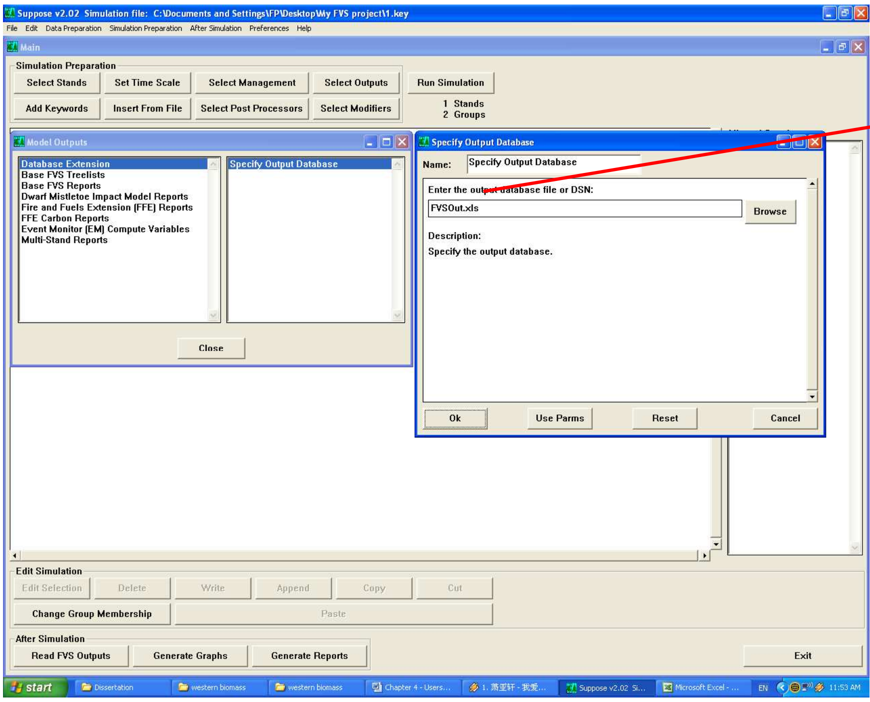


Figure C-17: The FVS interface including Event Monitor calculations.

5-11 Highlight "Database Extension" and "Specify Output Database" in the "Model Outputs" window (Fig. C-17), a dialog window called "Specify Output Database" will appear (Fig. C-18). In this dialog window, make sure the database file name is "FVSOut.xls", which is designated by the Western Biomass model. Then click "OK".



Make sure the file name is "FVSOut.xls"

Figure C-18: Specify output database in the FVS model

5-12 In the “Model output” window, select “Event Monitor Compute Variables” again and highlight “Build compute table in database” in the right side window. A dialog window called “Build compute table in database” will appear (Fig. C-19). Make sure the code for “Add new variables to existing table” is “0=Yes” and the code for “Include variables starting with underscore is “0=No”, then click OK. Close the “Model Outputs” window and return to the FVS main interface.

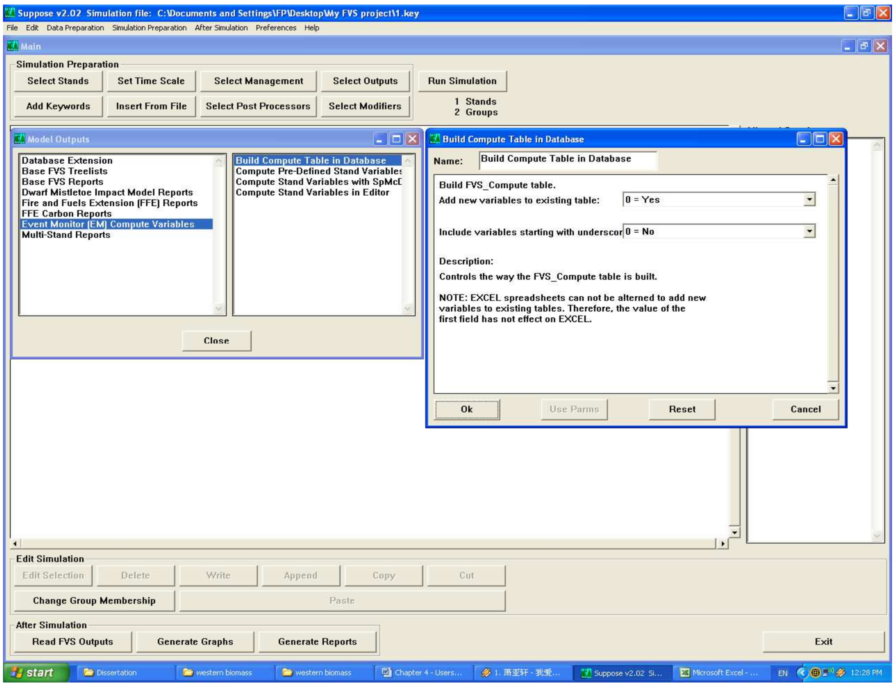


Figure C-19: Build Compute Table in Database in the FVS model

5-13 Check the main interface of the FVS model. Make sure the main interface includes five commands IN SEQUENCE: mechanical thinning, compute variables in editor, select fire and fuels report, specify output database, and build compute table in database (Fig. C-20).

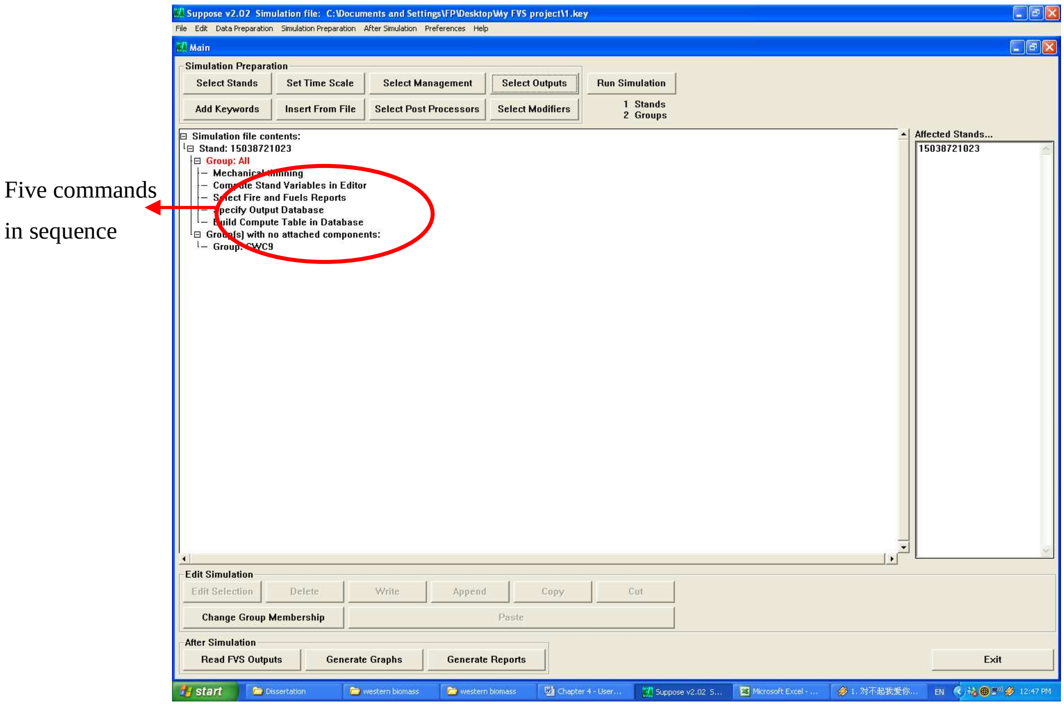


Figure C-20: Five required commands in the FVS main interface.

Step 6 Select Post Processors

Click “Select Post Processors” in the FVS main interface. Select “Compute 1-Table of compute variables (with headers)” and click “Include” (Fig. C-21). Then click “Close”.

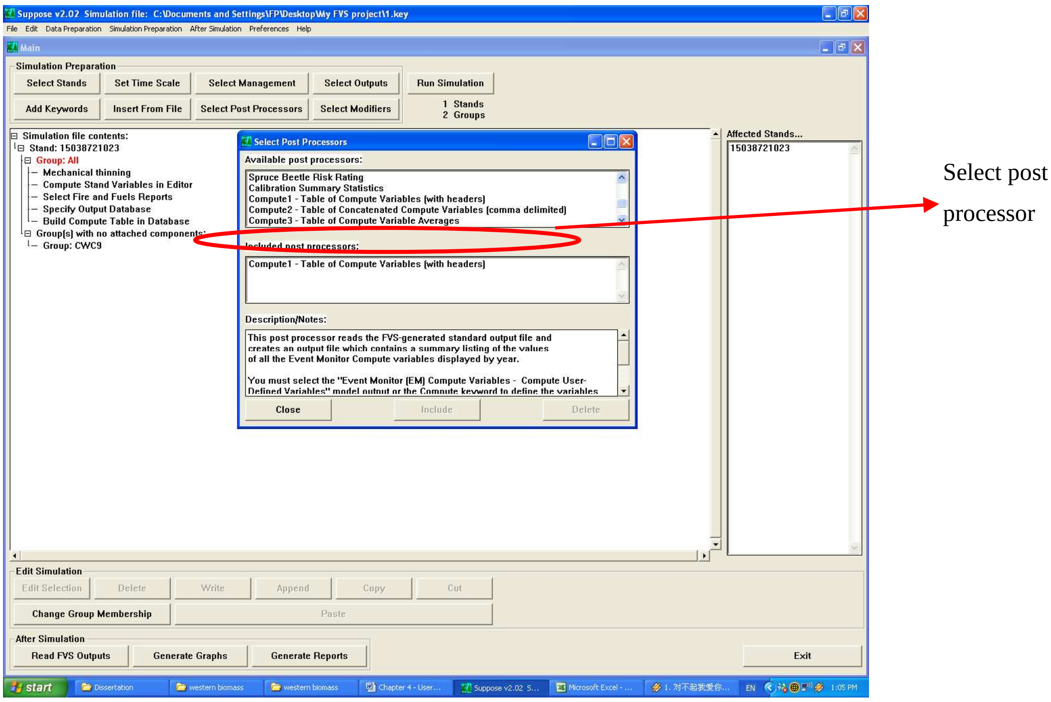


Figure C-21: Select Post Processor in the FVS model.

Step 7 Run simulation

By now, the FVS model has been set to calculate all the stand parameters required by the Western Biomass model. Click “Run simulation”, and input a filename for your project, click “Run” (Fig. C-22).

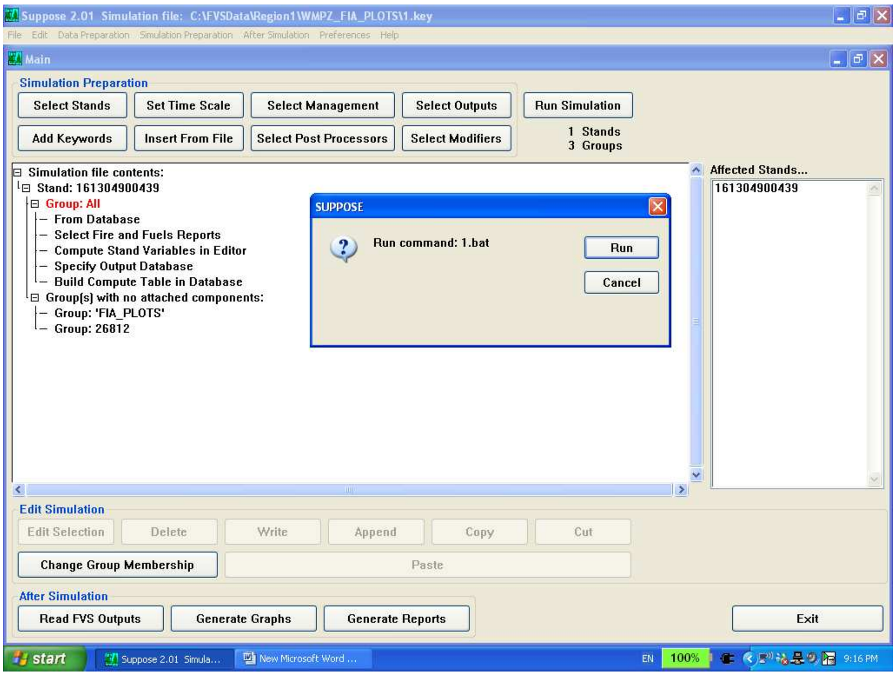
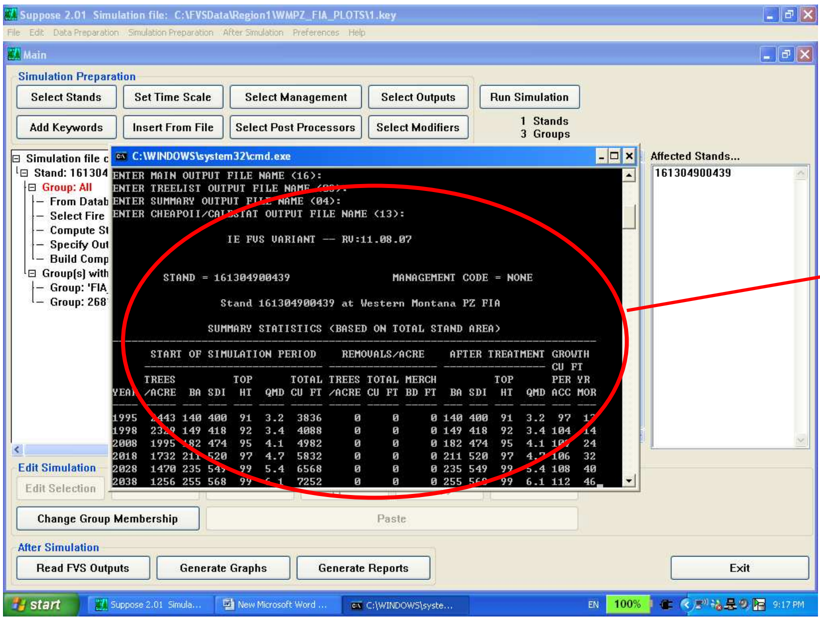


Figure C-22: Run simulation in the FVS model

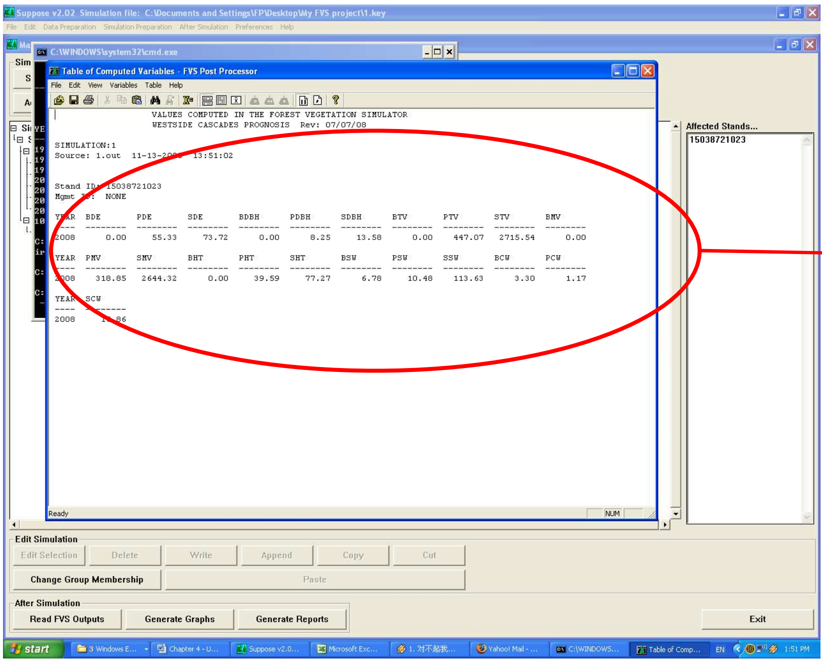
Step 8 Check the Results

The FVS model will run the simulation in a DOS batch file (Fig. C-23). The prediction results will be presented in a “Notepad” file as the main output (Fig. C-24). Meanwhile, an external Excel file will be generated (Fig. C-25), showing the same information as the Notepad file. This Excel database will be transferred to the Western Biomass model as input.



Run simulation in a DOS batch file

Figure C-23: Run simulation in a DOS batch file



Predicted stand parameters required by the Western Biomass model

Figure C-24: Main output of the FVS model

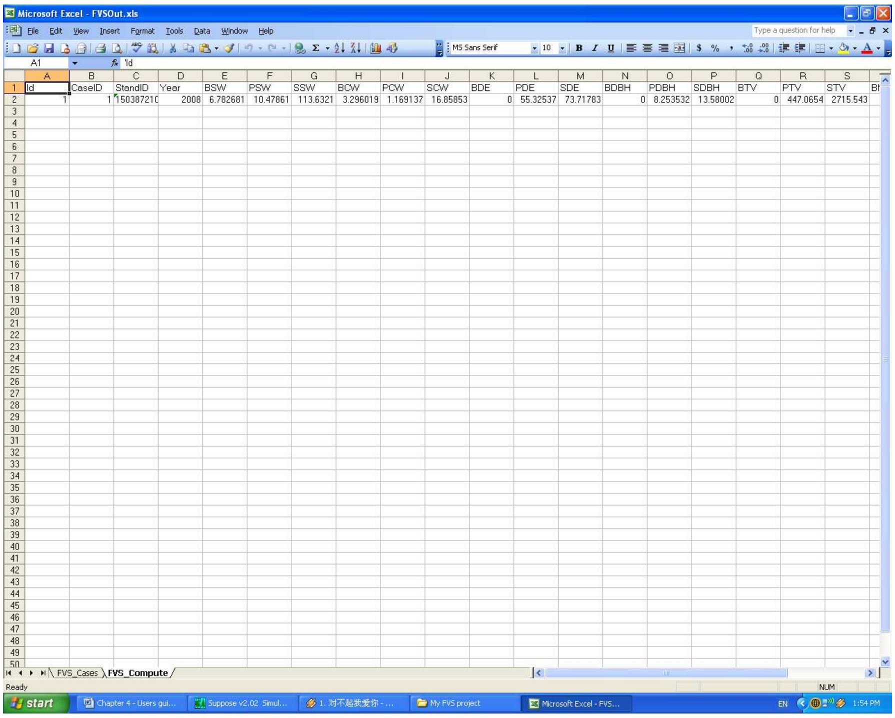


Figure C-25: External Excel database for FVS predictions