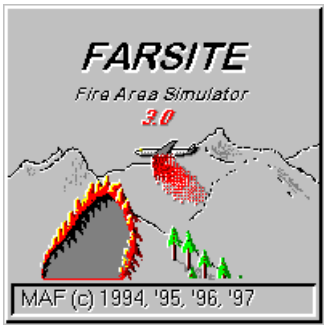
FARSITE [1]TM

Fire Area Simulator

Version 3.0

USERS GUIDE and TECHNICAL DOCUMENTATION

12/1997



(c) 1995, 1996, 1997 Mark A. Finney

Mark A. Finney
Systems for Environmental Management
PO BOX 8868, Missoula MT 59807

---

[1]The *FARSITE* model has been developed with support from the National Interagency Fire Center (National Park Service) in cooperation with the Fire Behavior Research Work Unit of the USDA Forest Service, Intermountain Fire Sciences Laboratory, Cooperative Agreements INT-93854-RJVA and INT-95065.-RJVA., California Department of Forestry and USFS Region 5 Contract 53-91S8-7-AFM61, and USDI National Park Service, AKSO, Contract 1443PX991096278.

CONTENTS

Chapter 1 Introduction **5**

Chapter 2 Overview **9**

Chapter 3 Tutorial **13**

Chapter 4 The FILE Menu **17**

Chapter 5 The INPUT Menu **19**

INPUT | INPUTS 19
INPUT | LANDSCAPE UTILITIES | GENERATE LANDSCAPE FILE 21
Weather Stream Inputs *28*
Wind Stream Inputs *29*
Gridded Weather and Wind Inputs to FARSITE *30*
Fuel File Inputs *33*
INPUT | LANDSCAPE UTILITIES | FILE INFORMATION 38
INPUT TOOL BUTTONS 38
INPUT | LANDSCAPE UTILITIES | MERGE LANDSCAPE FILES 39
INPUT | LANDSCAPE UTILITIES | EXTRACT 40
INPUT | LANDSCAPE UTILITIES | EDIT LANDSCAPE 41
INPUT | DEFINE WEATHER/WIND TYPES 43
INPUT | GENERATE FROM TYPES (WTR/WND) 44
INPUT | CANOPY CHARACTERISTICS 46
INPUT | PROJECT 47
INPUT | BOOKMARK 48

Chapter 6 The OUTPUT Menu **49**

OUTPUT | OUTPUT & EXPORT 49
OUTPUT | COLORS 54
OUTPUT | MAP DISPLAY 55
OUTPUT | ZOOM 56
OUTPUT | THREE D 57
OUTPUT | LEGEND 59
OUTPUT | ELAPSED TIME 60
OUTPUT | CURRENT TIME 60
OUTPUT | GRAPHS 60
Weather Monitoring Stations *60*
Fire Characteristics Chart *61*
Fire Area *62*
Fire Perimeter *62*
OUTPUT | DATA 62
Fire Statistics *62*
Fire Area *62*
Fire Perimeter *63*
Wind Gauge *63*
PRINTING OR SAVING THE CONTENTS OF OUTPUT WINDOWS 63
LANDSCAPE QUERY WINDOW 64
OUTPUT TOOL BUTTTONS 65

Chapter 7 The MODEL Menu **66**

MODEL | PARAMETERS 66
MODEL | FIRE BEHAVIOR 70

MODEL | FIRE ACCELERATION....72

Chapter 8 The SIMULATE Menu 74

SIMULATE | INITIATE/TERMINATE....75
SIMULATE | START/RESTART....75
SIMULATE | RESUME/SUSPEND....75
SIMULATE | STEP THROUGH....76
SIMULATE | RESET....76
SIMULATE | DURATION....76
SIMULATE | MODIFY MAP....77
Simulate | Modify Map | Locate Ignitions....78
Simulate | Modify Map | Import Ignition File....80
Simulate | Modify Map | Export Current Fire Perimeter....81
Simulate | Modify Map | Weather Monitoring & Grid....81
Simulate | Modify Map | Barrier(s)....84
Simulate | Modify Map | Import/Export Barriers....85
Simulate | Modify Map | Change Fuels....85
SIMULATE | OPTIONS....86

Chapter 9 The ATTACK Menu 89

ATTACK | GROUND RESOURCES....89
ATTACK | DIRECT ATTACK....91
ATTACK | INDIRECT ATTACK....93
ATTACK | PARALLEL ATTACK....94
ATTACK | REVISE ATTACK....97
ATTACK | AIR RESOURCES....99
ATTACK | AIR ATTACK....101
ATTACK TOOL BUTTONS....103

Chapter 10 The VIEW Menu 105

VIEW | VIEW LANDSCAPE FILE....105
VIEW | CHANGE VIEW PORT....106
VIEW | VIEW VECTOR FILE....107
VIEW | VIEW RASTER FILE....108
VIEW | REDRAW 2D LANDSCAPE....110
VIEW | REDRAW 3D LANDSCAPE....110
VIEW | ELIMINATE 2D WINDOW....110
VIEW | CLEAR VIEW WINDOWS....110
VIEW | SAVE VISIBLE PERIMETERS....110

Chapter 11 Limitations and Assumptions 111

WINDS, WEATHER, AND FUEL MOISTURES....111
SPREAD PATTERNS....112
MULTIPLE FIRES....116
CROWN FIRE....116
SPOTTING....117
GROUND ATTACK SIMULATION....117
AERIAL ATTACK SIMULATION....118

Chapter 12 Technical Documentation.... 121

INTRODUCTION....121
HUYGENS' PRINCIPLE....123
WIND PROFILES AND REDUCTION BENEATH FOREST CANOPIES....124
WIND-SLOPE VECTOR....125
ELLIPTICAL DIMENSIONS....125

CROSSOVERS 126
MERGERS 129
SLOPE CORRECTION 130
CROWN FIRE 130
SPOTTING 132
FIRE ACCELERATION AND INTERACTION 134
RASTER DATA GENERATION 135
GROUND ATTACK SIMULATION 136
AERIAL ATTACK SIMULATION 138

Literature Cited 140

INDEX 148

Appendix 1 152

Appendix 2 159

Chapter 1 Introduction

Description

*FARSITE (**F**ire **Ar**ea **Si**mula**t**or)* is a model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather. The modeling approach uses an implementation of Huygens' principle of wave propagation for simulating the growth of a fire front. The process is in fact very close to the widely used methods employed manually for the same purpose (Rothermel 1983). The difference being that the process is automated, faster, and more detailed than practical by hand. Furthermore, the projected fire perimeters and behavior are portable numerically and graphically to other PC applications and to GIS applications on other platforms. These advantages, however, come with the requirements for more, and more organized, information on the topography, fuels, and weather.

FARSITE requires the support of a Geographic Information System (GIS to generate, manage, and provide spatial data themes containing fuels vegetation, and topography. Five raster data themes are required to run *FARSITE*; these include elevation slope aspect fuels, and canopy cover and must be downloaded as GRASS ASCII or ARC/GRID ASCII format and combined to a single "landscape" file in *FARSITE* (see **Input**). All themes must be co-registered and be of identical resolution. *FARSITE* simulations also require you to develop files of weather data and wind data.

The basic features of *FARSITE* since version 2.0 have included:

- Adjustable time and space resolutions for fire spread calculations
- Implementation of existing models for surface fire spread, transition to crown fire, crown fire spread, spotting from torching trees, and fire acceleration
- Support for use of custom fuel models
- Control over fuel-specific fire acceleration rates
- Active display of fire perimeters and fire behavior
- 3D rendering of landscape and active fire perimeters
- Zoom windowing
- Graphical and tabular output of fire area and perimeter
- Plotting of frontal fire characteristics on fire characteristics chart
- Multiple ignitions as points, lines, areas
- Printing and file saving of graphical and tabular output
- Adjustable resolution raster output in GRASS ASCII or GRID ASCII format (or alternate format) for fire arrival times, fireline intensity, flamelength, rate of spread, and heat/unit area in metric or English units
- Vector fire and barrier input/output in ARC UNGENERATE and Arcview Shape file formats (or alternate format containing fire behavior at polygon vertices)

- Interactive editing of fuels and fire barriers on the landscape
- Use of weather information for dynamic fuel moisture calculations
- Use of multiple weather and wind streams at adjustable spatial resolutions
- Graphical display of temporal weather variations
- Graphical display of spatially varying wind vectors when using multiple weather stations
- Viewing of raster and vector maps of fire output or GIS themes
- Optional use of GIS themes for crown fuels used for crown fire calculations (crown height, height to live crown base and crown bulk density).
- Utilities for managing landscape files including merging, extracting, and editing.
- Utilities for rapidly generating weather and wind scenarios
- Project and Bookmark files to speed inputs and save simulation progress.

New features added for version 3.0 are:

- Initial Attack capability allows you to simulate ground and aerial attack. You can conduct any number of simultaneous Direct, Indirect, Parallel, and Air attacks on any fires during your simulation. Log files will record your use of air and ground resources (See Chapter 9)

- Support for using gridded weather and/or wind files. This allows grids of temperature, humidity, precipitation, wind speed, wind direction, and cloud cover of arbitrary resolution to achieve spatial variation in weather inputs to *FARSITE* simulations (See Chapter 4).

- Barriers to fire spread, as used in the initial attack and input by the user, are implemented as vectors. This means you can import and export barrier vector files (see **Simulate | Modify Map | Import Barrier File** and **.|.| Export Barriers**).

- Stepping through your simulation one visible timestep at a time is now possible using the **Simulate | Step Through** function.

- *FARSITE* supports Dynamic Data Exchange (DDE) of landscape data themes and ignition information **from** ArcView 3 to *FARSITE* 3 and DDE of vector and raster output **from** *FARSITE* to ArcView 3. You must own the Spatial Analyst add-on to ArcView to fully use these capabilities.

- As part of the ArcView 3 support, *FARSITE* produces shapefiles. See **Output | Export and Output**, and **Simulate | Modify Map**.

- Additional raster output maps for crown fire and fire direction (**Output | Export & Output).**

- Expanded format for custom fuel models to separate live herbaceous and live woody components**.**

- Control over zoom window replay of fire perimeter growth. You can slow-down or speed-up the replay by changing the interval between perimeter displays.

Intended Uses

The *FARSITE* program was originally developed for management support of prescribed natural fires (PNFs). The model was intended for both planning and operational phases of wildland fires. Among the many potential uses for fire growth simulations (Andrews 1989), the most relevant to *FARSITE* are short and long term projections of active and potential fires. The Microsoft Windows interface offers flexibility for office or field prediction of fire growth. Fire growth and behavior scenarios can be developed relatively quickly using short term weather forecasts or long term weather projections.

Active Fires

- short term projections could be used in preparing daily fire situation analyses,
- short and long term projections could help with scheduling fire monitoring activities based on the projected arrival, fire behavior, or fire effects,
- long term projections using weather extremes could help define potential fire variability and range of outcomes,
- short and long term projections could help with assigning priorities to multiple fires

Potential Fires

- Effects of ignition locations, fire weather patterns, and fuel or prescribed fire treatments could be examined for comparing different fire management alternatives,
- Fire spread patterns and behavior under historic weather could help refine prescriptions or define fire management zones,
- Simulating PNFs after suppression becomes necessary. Actual weather records following suppression could be used for simulating the likely burn extent and behavior for planning later prescribed burning of the area at a more suitable time.

Fire Suppression

- Compare the effectiveness of different strategies for containing fires under varying weather scenarios
- Compare suppression efforts for areas with and without fuel treatment programs

- Estimate costs of suppression strategies

Requirements

A user interface has been developed for the Microsoft Windows operating systems to enable the use of *FARSITE* on a personal computer (PC). This version of *FARSITE* is written for the WIN32 Application Programming Interface (API). It requires you to be running Windows NT 4.0 or Windows 95.

The *FARSITE* model is math and data intensive; the minimum and **recommended** PC configurations are:

- Pentium (or equivalent) processor (won't work with 80386 or 80486SX !!),
- 16MB RAM recommended for Windows 95 **(32 MB for Windows NT 4.0)**
- 20MB free hard disk space (for program and files, landscape information, and outputs), **50+ mb recommended**
- VGA monitor (640 x 480 resolution), **super VGA 1024 X 768 recommended**
- Mouse or trackball required

More RAM might be necessary if *FARSITE* is used to simulate large fires (e.g. ~5000 ha) or many smaller fires with high resolution (e.g. <10m). Performance of any Windows program will be enhanced with a Windows accelerated video card and a local bus for video and hard-drive controller.

Chapter 2 Overview

The general procedure for running *FARSITE* consists of:

I. preliminary data acquisition or production,
II. starting *FARSITE* and interactively specifying these data files,
III. selecting options for the simulation and for outputs from the simulation,
IV. running the model,
V. printing/saving any Windows with data of interest.

I. Preliminary data acquisition or production (primarily accomplished outside of *FARSITE, see example files in Appendix 1*):

1. Using the GIS, identify a sub-region of a landscape that you want to simulate fire growth on. Download the 5 required layers in ASCII format from this sub-region (**elevation, slope, aspect, fuels, and canopy cover**). All themes must be **co-registered and of identical resolution**.
2. Transfer the resulting files onto a PC and generate a binary .LCP file with the *FARSITE* program (**Input | Landscape Utilities | Generate**).
3. Produce a weather file containing temperature and humidity data (see **Weather Inputs** or **Defning Weather/Wind Types**).
4. Produce a wind file containing wind and cloud data (see **Wind Inputs** or **Defining Weather/Wind Types**).
5. Produce a file of initial fuel moistures by fuel type (see **Fuel Inputs**). This can be accomplished using the **Input | Inputs** dialog.
6. Verify the .ADJ file containing fuel-specific Rate of Spread adjustment factors. This can be accomplished using the **Input | Inputs** dialog.

II. Start *FARSITE* and interactively specify/edit data files.

1. Begin *FARSITE* by double clicking the *FARSITE* icon.
2. Identify the required input files by selecting the **Input | Inputs** dialog, or select **Input | Project Retrieve** if you have made a project file.

a. LANDSCAPE DATA		(.LCP file)
b. WEATHER		(.WTR file)
c. WINDS		(.WND file)
d. FUELS	- ADJUSTMENT FACTORS	(.ADJ file)
	- FUEL MOISTURES	(.FMS file)

III. Select output and simulation options

1. Set the **Output | Export & Output**. Select (i.e. check) the Raster or Vector file options if you want these data files created or output from the simulation. A file dialog box will open; be sure to specify a directory on your **hard drive** for this output (you should have at least 10MB to safely store output files from the fires).
2. Select the **Output | Map Display** options to change fuel model colors or fire perimeter characteristics. These can be viewed by selecting **Output | Legend**.
3. Set the **Model | Parameters**, including the timestep and perimeter resolution
4. Set the **Model | Fire Behavior** options, calculation methods, and fire behavior options.

IV. Setup the *FARSITE* Simulation.

1. Select **Simulate | Initiate/Terminate** or click on the **"Alpha-Omega"** tool button to initiate the simulation and display the landscape window.
2. Set the spatial resolution of the weather grid and arrangement of weather data (if you have more than 1 weather/wind stream). See Weather/Wind Monitoring and Grid for information on how to set up your landscape to use more than 1 weather/wind stream.
3. **Make a project file. At this point you should create a project file to store the weather/wind stream grid that you just created. This same configuration will be restored when you load this project again.**
4. Set the starting date/time and duration of the simulation by selecting **Simulate | Duration** or clicking on the "**hourglass**" tool button.
5. Input ignitions on the landscape by first selecting **Simulate | Modify Map | Ignition**, or clicking on the **"driptorch"** tool button. The mouse cursor is now in "ignition mode" as indicated at the right of the message bar and by the shape of the mouse cursor when over the landscape window. Ignitions are set onto the landscape using the mouse.
6. Input barrier or fuel modifications on the landscape.
7. Open any output Windows of interest.
8. Start the simulation by selecting **Simulate | Start/Restart** or by clicking the **"checkered flag"** tool button. This indicates the beginning and ending of the active simulation phase.

The simulation should have started running, producing a fire spread map on the landscape and writing to any open output Windows.

9. To temporarily suspend and then resume the simulation, select **Simulate | Resume/Suspend** or click on the **"traffic light"** tool button. This allows intermediate stops and starts during the simulation.

V. Print Windows with data or graphs.

For more information on printing data or graph windows see Printing.

With the cursor on any data or graph window, Click the right mouse button to output the contents to a file, image, or printer. A small dialog box will appear with check-box selections for available output options. The user will be prompted to provide a filename if output is directed to a file. NOTE: When printing from the Landscape window, input mode must be set to “NULL” by toggling off other input modes (ignitions, weather stations, zoom, change fuels, and barriers).

At any time, you can save the visible fire perimeters being generated by the current simulation. Make sure the simulation has been suspended, select **View | Save Visible Perimeters**, and select a filename. The fire perimeters in this file can be viewed on you landscape at any time in this or another simulation by selecting **View | Vector File**.

Chapter 3 Tutorial

An example data set is located in the FARSITE3/EXAMPLES subdirectory of your hard drive. The data set is from the Chagoopa Prescribed Natural Fire of 1992 at Sequoia National Park. Included are 6 files required for simulation and 4 optional files used for examples of their formats:

REQUIRED	
Project File	chagoopa.fpj
Landscape	chagoopa.lcp
Weather stream	chagoopa.wtr
Wind stream	chagoopa.wnd
Initial Fuel Moistures	chagoopa.fms
ROS Adjustment factors	chagoopa.adj
OPTIONAL	
Custom Fuel Model File	example.fmd
Fuel Model Conversion File	example.cnv
Ground Attack Resources	example.crw
Aerial Attack Resources	example.air

The project file contains the names of three files (landscape, weather, and winds) along with other information about your simulation and is useful for saving time when running repeated simulations with the same files. The project file needs to be in the same directory as the landscape, weather, and wind files if it is to be used. Note that the last four files are included only for format examples, they are not needed for the **Chagoopa** simulation. The .fmd file is not needed because all fuel attributes correspond directly with standard 13 Fire Behavior fuel models.

To use the example files in a simple simulation:

1. start *FARSITE* (Windows NT 3.X or Windows 3.1X double click the *FARSITE* icon, Windows 95 single click the *FARSITE* icon)
2. select **Input | Project Retrieve** or press the **File-In** tool button (on far left), find the proper directory, and select the **CHAGOOPA.FPJ** file. This inputs the landscape, weather and wind files.
3. **or** do the following steps (4 through 10) **you don't have to do both**!!!
4. Open the **Input | Input dialog.**
5. **check** the **Landscape** checkbox and then select the **CHAGOOPA**.**LCP** file.
6. in the **Fuel Files group,** check the **Adjustments (ADJ)** checkbox and select the **CHAGOOPA.ADJ** file.
7. check the **Moistures (.FMS)** checkbox and select the **CHAGOOPA.FMS** file
8. **in the Weather Files group** check the **"1" box** and then select the **CHAGOOPA**.**WTR** file.
9. **in the Wind File group,** check the **"1" box** and then select the **CHAGOOPA**.**WND** file.
10. select "OK",

11. select **Model | Parameters** and then press OK. There is no need to make adjustments to these parameters, only verify that you've looked at them.
12. select **Simulate | Initiate/Terminate** or press the **Alpha/Omega** tool button to display the landscape.
13. select **Simulate | Duration** or press the **hourglass** tool button. The **starting** button indicates that the slider bars control input the starting date and time. Click on the "thumb" of each slider bar and set the date and time for 7/17 at 0800. Now click the **ending** button and note that the right-hand boxes are the same date as starting. Set the ending date for 7/18 at 0800 by adjusting only the DAY slider. Press OK when finished.
14. input ignitions on the landscape by first selecting **Simulate | Modify Map | Ignitions** or pressing the **driptorch** tool button. The message bar at the bottom of the screen should say "**Ignition Mode**" on the right. Use the mouse to set a point ignition on the red fuel color (montane chaparral) by clicking the left button once and the right button once.
15. select some output from the simulation, for example, the Current Time, the Elapsed Time, or a graph of fire area. Position these so you can see the entire landscape.
16. start the simulation by selecting **Simulate | Start/Restart** or pressing the **checkered flag**. The simulation will now be running; the message bar will say "Simulation Running".
17. to stop the simulation at any time, press the **traffic light** tool button and wait patiently for the simulation to finish some critical processes and the message bar to say "**Simulation Suspended**". You can change any outputs and then resume the simulation by again toggling the **traffic light**. Instead of using the tool button, you can select **Simulate** from the menu and wait until the menu appears to then select **Simulate | Resume/Suspend**.
18. If a printer is attached to the computer, you can print graph windows to the printer or save to a bitmap file by pressing the right mouse button on the window of interest and making your selection from the print destinations dialog.
19. You can save the visible fire perimeters that are generated by this simulation by selecting **View | Save Visible Perimeters**. The fire perimeters can then be viewed on the current landscape in this or another simulation by selecting **View | Vector File**.
20. To reset the simulation, press the **checkered flag** tool button or **select Simulate | Start/Restart**.
21. To **make a bookmark file** so that you can resume the simulation later from that stopping point, select the **Input | Bookmark Create** and provide a filename. You can then load the bookmark file by selecting **Input | Bookmark Retrieve** or pressing the bookmark tool button.

The following suggestions expand upon this basic simulation procedure and illustrate some of the features that will be helpful in using *FARSITE:*

1. Change the view port using the zoom window (see **View | Change Viewport**).
2. Rerun simulation and make Raster and/or Vector Files (see **Output | Export & Output**) and view these files after the simulation has finished (**View | Raster** and **View | Vector**)
3. Change fuel colors (**Output | Colors**) and redraw landscape (**View | Redraw 2D Landscape**).

4. Change the visible theme (**Output | Map Display**) and redraw the landscape as above.
5. Use the 3D display window (**Output | Three D**).
6. Simulate initial attack with ground crews. First, load the example ground resource file **example.crw** (**Attack | Ground Resource**). Then, after you have a fire growing, assign a direct attack crew to fight the fire (**Attack | Direct Attack**) or . When the attack has finished, use **File | Open** to examine the **grndattk.log** file in the directory where your simulation files are stored (.lcp, .wtr, .wnd, etc.).
7. Simulate aerial attack. Load the example air resources file **example.air** (**Attack | Air Resources**). After you have a fire growing, perform an aerial retardant drop on a portion of the fire (**Attack | Aerial Attack**) or . When finished, use the **File | Open** to examine the **airattk.log** file in the directory where your simulation files are stored (.lcp, .wtr, .wnd, etc.).

To end the simulation completely, press the **Alpha/Omega** tool button or select **Simulate | Initiate/Terminate**.

Chapter 4 The FILE Menu

The File Menu is used to access a built in ASCII editor. This is a convenient way to look at relatively small ASCII data files used for input to *FARSITE*.

Note that the *FARSITE* menu structure changes when you are editing an ASCII file. The menu items "**Edit**" and "**Search**" are inserted after the "File" Menu to access text processing in the ASCII file windows.

File | New

This menu selection opens a new file for editing or creating ASCII inputs to *FARSITE*.

File | Open

This menu selection opens an existing ASCII file for editing or creating ASCII inputs to *FARSITE*. Note that you can search for specific *FARSITE* file **types** with the File Types filters in the **File | Open** dialog box.

File | Save

This menu selection saves your edits to an ASCII file of the same name as the existing file.

File | Save As

This menu selection saves your edits to an ASCII file with a different name that you select.

File | Save Window Positions On Exit

When this selection is checked, all window positions and sizes are saved and restored the next time you use *FARSITE*.

If you change monitor resolutions from higher to lower, you might find that some of your Windows are not visible when you toggle their display. These Windows are probably off the visible portion of the screen. You can move all of these Windows back onto the visible screen by **UNCHECKING** this selection and restarting *FARSITE*. Then **CHECK** this selection again and move your Windows where you want them for subsequent simulations.

File | Exit

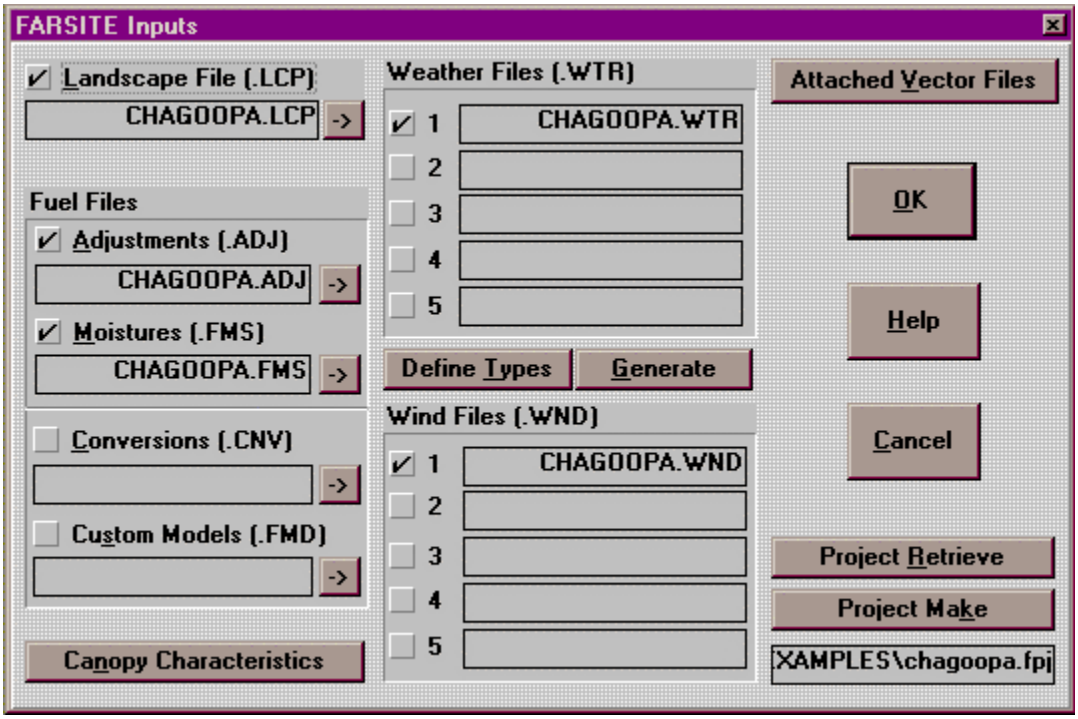
Prompts you with a message box, and then exits the *FARSITE* program if you answer "OK".

Chapter 5 The INPUT Menu

The Input Menu is used to input, edit, and generate all files required for a *FARSITE* simulation. Files not created or loaded here are optional files for setting fire acceleration and initial attack. These must be loaded through their respective menu selections.

Input | Inputs

The **Inputs** dialog displays and accesses the required and optional inputs for *FARSITE*. You can open the **Input** dialog at any time during the simulation to see what files are used in your simulation.



The **checkboxes to the left of each file type description** are used to load individual files. If checked, your selection will load a file; unchecking a box will unload the file and allow you to load another file of that type.

The **(→) button** to the right of each file type brings up the corresponding **dialog box for generating a file of that type**. If you currently have a file of that type open, this dialog will allow you to edit the contents of that file.

Required Input Files

1. a landscape file (.LCP),
2. **at least 1** weather file (.WTR).
3. **at least 1** wind file (.WND),
4. an adjustment file (.ADJ) for spread rate adjustments,
5. an initial fuel moisture file (.FMS)

Optional Input Files:

1. a fuel model conversion file (.CNV),
2. a custom fuel model file (.FMD) that specifies models 14-50.
3. a fire acceleration file .ACL that specifies fuel-specific fire acceleration constants (see **Model | Fire Acceleration** in Chapter 7 for input and editing).

Other buttons on the Inputs dialog **duplicate Input menu selections** and are labeled with their functions:

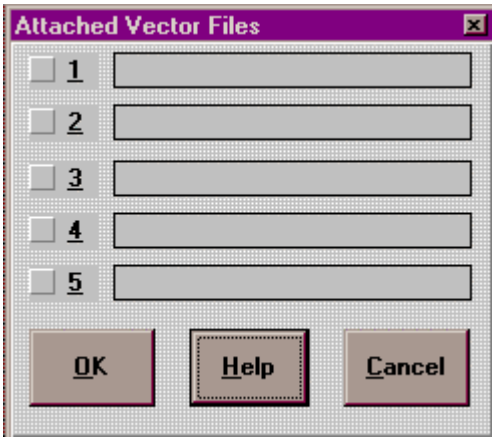
1. The <**Canopy Characteristics**> button brings up the canopy characteristics dialog box.

2. The <**Define Types**> button brings up **the Weather Wind Type Definitions** dialog box.

3. The <**Generate**> button brings up **the Generate from Types (WTR/WND)** dialog box

4. The <**Project Retrieve**> and <**Project Make**> buttons serve the same purpose as their respective menu selections

5. The **Attached Vector Files** button brings up a unique dialog that shows all vector files that are automatically redrawn on the 2D landscape window and are attached to the project file. The checkboxes access the **View | Vector File** dialog and allow you to select a vector file for attaching and customize its display.

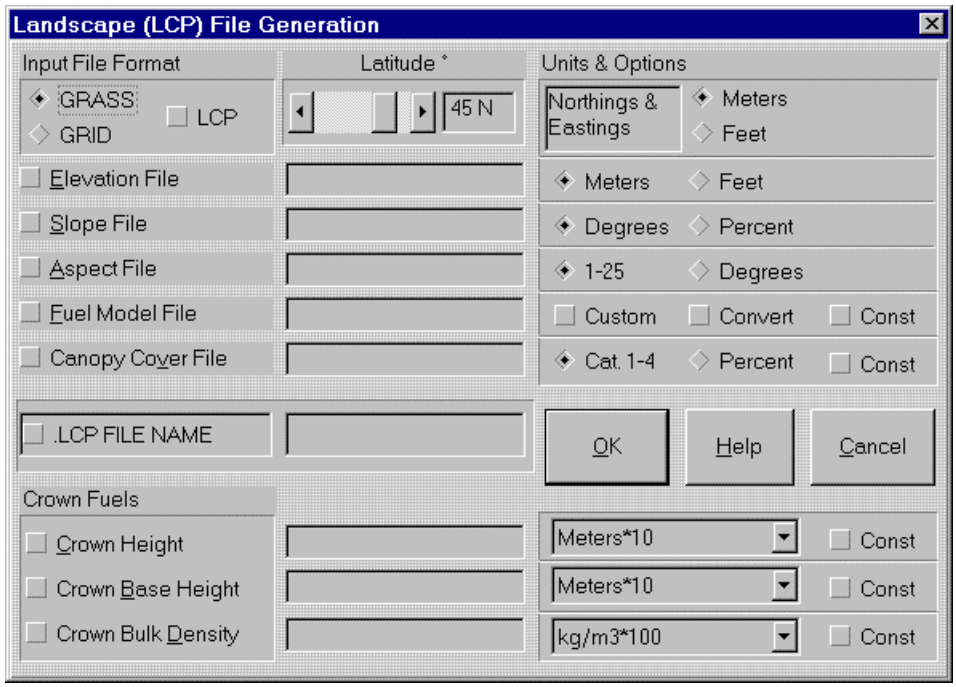


Landscape Utilities

A number of landscape utilities are to manage .LCP file coverages and the scale of these coverages. These include generating .LCP files, reading .LCP file information contained in its header, merging .LCP files, extracting information from .LCP files and Editing .LCP file contents.

Input | Landscape Utilities | Generate Landscape File

The Landscape File (LCP) is generated by importing raster GIS files using this dialog box.



GIS File Formats

FARSITE can import GRASS or ARC GRID ASCII format raster GIS files. Select the checkbox appropriate to your file type. **NOTE: all raster input files must be *co-registered,* and of identical *resolution* and *extent*, and all be the same type (e.g. GRASS or GRID and not mixed for a given .LCP file)**. Be sure that the values in each raster map have the correct units and correspond to the requirements listed below for each map.

Loading GIS Files

Clicking the checkbox to the left of each raster file type will allow you to select each file. The file name selection will be displayed in the center box. All checkboxes for elevation, slope, aspect, fuels, and canopy cover, must be checked

before the specified .LCP file can be created**. These 5 themes <u>are required</u> for every .LCP file; you cannot generate an .LCP file without having all themes**.

All GIS raster themes must have a header to be imported to *FARSITE*. If you are unsure, examine the first 6 lines of one of your raster files. You should see one of the following formats. ARC and GRASS ASCII raster files have different headers:

GRID

NCOLS
NROWS
XLLCORNER
YLLCORNER
CELLSIZE
NODATA_VALUE

GRASS

north:
south:
east:
west:
rows:
cols:

Revising an Existing LCP file

You can import and revise an existing LCP file by checking the "**LCP**" checkbox (upper left Input File Format box). This will prompt you for the name of an existing .LCP file that you want to modify. For example, you could substitute a revised fuels theme for the existing fuels data. Proceed by checking and entering only the new themes you want to subsitute (e.g. the fuels theme). Then select a different output .LCP file name and press OK to generate the new .LCP file.

Optional GIS Files

In addition to the basic 5 themes, you have the option of including raster themes for crown fuels if they are available. You may specify any or all of the 3 crown fuel raster themes (canopy height, height to live crown base, and crown bulk density). Those parameters that are not provided by a GIS theme will be taken from the **canopy characteristics dialog box** and be considered spatially constant for all areas that have canopy cover greater than zero.

Units for GIS Files

The data format options for each file are on the right side of the dialog box**. Be sure these correctly describe the units of your data in each GIS data theme before generating the .LCP file**; these cannot be changed in an existing .LCP file. If your units are something other than listed as an option for that theme, you will have to reclassify or recompute values for that theme on the GIS before generating an .LCP file.

Data Type	**Default**	**Alternate**
REQUIRED THEMES		
elevation	Metric:meters	English:feet
slope	Degrees	Percent
aspect	1-25 *(pre-GRASS v4.0)*	Degrees *(GRID and GRASS post-v4.0)*
fuel	No Custom Models	No Conversions Req.
canopy cover	Categories: 1-4	Percent
OPTIONAL THEMES		
tree height	meters*1.0 or meters*10	feet*1.0 or feet*10
crown base height	meters*1.0 or meters*10	feet*1.0 or feet*10
crown bulk density	kg/m^3*1.0 or kg/m^3*100	lb/ft^3*1.0 or lb/ft^3*1000

Elevation

The elevation theme can have units of meters or feet above sea level. This theme is necessary for adiabatic adjustment of temperature and humidity and for conversion of fire spread between horizontal and slope distances.

Slope

The slope theme should be integers because there is not enough precision to be accurate to fractions of a degree or percentage. Slope can have units of degrees or percent of inclination from the horizontal. The slope theme is necessary for computing slope effects on fire spread and solar irradiance.

Aspect

The aspect theme contains values for topographic aspect that depend on the GIS providing the data. If the aspect data are from a **GRASS ASCII file** all values are oriented **counterclockwise from east**; your choice of units depends on the version of GRASS you are using: more recent versions compute degrees as integer values to the nearest degree, but older versions produced 25 categories of 15 degrees,

with category 25 representing flat terrain. Aspect values from **ARC/INFO** must be azimuth values (**degrees clockwise from north**) and can be integers or decimal values (version 2.0).

NOTE: The units check boxes have no effect on an ARC Grid aspect file because it is assumed that you are using azimuth values for aspect.

Fuel Model

The GIS fuels theme must specify an integer index to a fuel model. Model numbers 1-13 are reserved for standard Fire Behavior fuel models (Anderson 1983). **FUEL MODEL NUMBERS 0, 98, OR 99 CAN BE USED FOR NON FUEL**. Water is assumed represented by number 98 and will display as the color blue. Dark gray will be displayed for numbers 0 and 99.

The default fuels settings to the right of the **Generate dialog box** indicate no optional checks for *Custom* or *Convert*. This means that the GIS fuel theme contains fuel model numbers 1-13 relating directly to the 13 Fire Behavior fuel models (and 0, 98 or 99 for non-fuel). Checking the Custom and/or Convert boxes means the following:

Custom

The Custom checkbox indicates custom fuel models are used (**see .FMD files below**). Any fuel model other than the standard 13 Fire Behavior models (Anderson 1982) are custom fuel models. These must be assigned model numbers 14 through 50 (see description of the custom fuel model file below in the **Fuels** section). The Custom box must be checked if the fuels theme contains any indices relating to custom models.

Convert

The Convert checkbox indicates conversion between fuel indices and fuel model numbers is necessary (**see .CNV files below**). A fuel index is the integer number describing fuel types in the GIS fuels theme. This index must be converted to a fuel model number if:

1. it exceeds 50,
2. it is less than 14 and does not relate to one of the standard Fire Behavior fuel models.

Any combination of check marks may be used to describe a particular fuels theme. For example, a fuels file with all indices less than 14 would require a check only for **Convert** if all of these did not correspond directly to the Fire Behavior model numbers. It would require a check for both **Custom and Convert** if any indices corresponded to custom models. If all indices were between 14 and 50 and corresponded to directly to the custom model number, a check would only be required for **Custom**. **NOTE**: using custom models requires the fuel model color

to be selected in the **Output | Display** dialog otherwise all custom models will display as the color black.

Canopy Cover

The canopy cover theme is necessary for computing shading and wind reduction factors for **all fuel models**. Canopy cover is the horizontal percentage of area covered by tree crowns at the stand level. Coverage units can be categories (1-4) or percentage values (0-100). Categories are assumed to be the following:

1: 1-20%
2: 21-50%
3: 50-80%
4: 81-100%

with zero cover specified by:

0: 0%, **or**
99: 0%

Crown Height

Crown height is an optional spatial data theme that is used for computing wind reduction to midflame height, spotting distances, and crown fire characteristics. It is a stand-level descriptor. The values in the raster theme can be either integers or decimal values. Values can be in meters or feet. The precision of the fire behavior calculations are limited to the nearest 1/10th meter or foot. Thus, if you have integer values and you want greater precision you should use the calculator features of your GIS to multiply the original height units by **10** and select **meters or feet * 10 in this dialog. This conversion is optional for decimal crown height values.**

Crown Base Height

Height to live crown base is an optional spatial data theme that is important for determining transition from surface fire to crown fire. This value should incorporate the effects of ladder fuels (if present) in increasing vertical continuity and assisting transition to crown fire. Values can be in meters or feet. The precision of the fire behavior calculations are limited to the nearest 1/10th meter or foot. Thus, if you have integer values and you want greater precision you should use the calculator features of your GIS to multiply the original crown base units by **10** and select **meters or feet * 10 in this dialog. This conversion is optional for decimal crown base height values.**

Crown Bulk Density

Crown bulk density is an optional spatial data theme that is critical to determining the spread characteristics of crown fires. The values in the raster theme can be

integers or decimal values in either **kg/m^3 or lb/ft^3**. The precision of crown bulk density values are used to the nearest 100th kg/m^3 or 1000 lb/ft^3. Thus, if you have **integer values in your crown bulk density theme, you must use the calculator features of your GIS to multiply the original crown bulk density units by 100 (kg/m^3) or 1000 (lb/f^{t3}). This conversion is optional for decimal bulk density values.**

Multipliers for crown bulk density: If the actual crown bulk density were in metric units (say 0.25 Kg/m^3), the value in the raster map could be multiplied by 100 to give an index of 25 for those cells. Then, you would select Kg/m^3 x 100 as the units for the file. If the actual crown bulk density were in English units (say .015 lb/ft^3), the value in the raster map would be multiplied by 1000 to give an index of 15 for those cells.

IMPORTANT NOTE: You have two options for producing crown bulk density information:

1) Crown Bulk Density can be linked to the canopy cover theme (see **Model | Fire Behavior Options**). Using this method, you would enter only the maximum crown bulk density for each forest type assuming 100% canopy cover. During the simulation, your crown bulk density data will be multiplied by the canopy cover fraction to obtain the actual crown bulk density for each raster cell. You must select the **"Link Crown Density & Cover**" option in the **Model | Fire Behavior** Options dialog.

2) Crown Bulk Density can be independent of the canopy cover. This option would apply if you have already considered canopy cover during development of the crown bulk density theme on the GIS. If your crown bulk density data are like this, **DO NOT** select the "**Link Crown Density & Cover**" option in the **Model | Fire Behavior Options** dialog.

Constant Values

You have the option of using **constant values for any of the non-topographic GIS themes**. By checking the "**Const**" **checkbox** at the far right of each theme, you can use a dialog to insert constant values across the landscape instead of providing a GIS theme. This can be useful for:

1. describing very uniform fuel or vegetation conditions,
2. describing the dominant fuel or vegetation coverage and then using the Landscape Editor to change patches of lesser fuel or vegetation types,
3. providing for later use of the Landscape Editor when fuel or vegetation conditions are better known. For example, Height to Live Crown Base is not typically available on the GIS. It can be observed in the field for critical areas and then edited into the LCP file only if information on HLCB has been provided to the LCP file (using a theme or constant value).

Weather Stream Inputs

A weather file (stream) contains daily observations on temperature and humidity as well as precipitation. These can be automatically generated using the Generate from Types (WTR/WND) dialog once the weather/wind types have been defined.

You can input up to 5 weather streams; this feature allows you to approximate some spatial variation in weather (see **Simulate| Modify Map | Weather Monitoring & Grid**)**). If you use multiple weather stations, you must make sure that the dates in each file overlap**; it will be easier if you use the same starting and ending date for each stream.

Each weather file must contain data in the space delimited ASCII format specified below. The use of a spreadsheet is recommended for producing a weather file; the range of data can then be output or printed to an ASCII file. The weather stream greatly oversimplifies actual variation in weather. However, this format is an attempt to limit to a practical level, the amount of weather information required to simulate fire growth.

All inputs MUST be integers (e.g. NO DECIMALS). Each column must be space delimited (leave a space between columns). See the .WTR example file in the *FARSITE3*\EXAMPLES subdirectory or **Appendix 1.**

METRIC and ENGLISH Units

Version 3.0 of *FARSITE* allows weather inputs in English or metric units. The units are selected by inserting the word ENGLISH or METRIC as the first line of the .WTR file (see Appendix 1). **To ensure backward compatibility with previous versions of *FARSITE*, you don't have to specify ENGLISH.**

Month Day Precip Hour1 Hour2 Temp1 Temp2 Humid1 Humid2 Elevation

Field	Data Type	English Units	Metric Units
Precipitation	integer	hundreths of an inch (1/100 in)	millimeters
Temperature	integer	Fahrenheit (º F)	Celsius (º C)
Elevation	integer	Feet (ft)	Meters (m)

- **Precipitation** is rain amount specified in hundredths of an inch, (**integer**).

- **Hour1** corresponds to the hour at which the **minimum** temperature was recorded (**0-2400**).
- **Hour2** corresponds to the hour at which the **maximum** temperature was recorded (**0-2400**).
- **Temperatures** (Temp1 is **minimum**; Temp2 is **maximum**) are in Fahrenheit (**integer**)
- **Humidities** (Humid1 is **maximum**; Humid2 is **minimum**) are in percent (**0 to 99**), (**integer**)
- **Elevation** is in feet above sea level. NOTE: these units (feet) do not have to be the same as the landscape elevation theme that can be specified in meters or feet, (**integer**).

The weather information in each file is used to interpolate temperature and humidity for hours between the maxima and minima of each day. These data are also extrapolated to different elevations on the landscape using the elevation of the terrain.

Wind Stream Inputs

Wind information is typically input as a stream of data contained in a .WND file. As with weather files, you may load up to 5 .WND files for a given run. This can be important to simulating spatially varying winds (e.g. ridge winds vs. slope winds) on the landscape (see **Simulate | Modify Map | Weather Monitoring/Grid** for directions on how to specify spatial locations for weather/wind streams). A wind file can be automatically generated using the Generate From Types (WTR/WND) utility once you've defined weather/wind types.

Winds are usually variable in space and time. The wind stream however, assumes winds to be constant in space for a given stream but variable in time. In other words there is no vectoring of winds with topography. The input format of winds is similar to that for weather, requiring a space delimited ASCII file that can be created in a spreadsheet or any text editor. Inputs can be at any temporal resolution (e.g. hourly); sub--hourly observation should specify minutes (e.g. 1430). All values must be integers. See the .WND file in the *FARSITE3*\EXAMPLES directory or Appendix 1.

METRIC and ENGLISH Units

Version 3.0 of *FARSITE* allows wind inputs in English or metric units. The units are selected by inserting the word ENGLISH or METRIC as the first line of the .WND file (see **Appendix 1**). **To ensure backward compatibility with previous versions of *FARSITE*, you don't have to specify ENGLISH.**

Month Day Hour Speed Direction CloudCover

- **Hour** is specified as 0-2400, to the nearest minute (**integer**). **It is not necessary to have wind observations at constant intervals.**
- **Windspeed** is the **20ft windspeed** specified in miles per hour, (**integer**)
  ENGLISH Units
  20ft windspeed specified in **miles per hour**
  METRIC Units
  10m windspeed specified in **kilometers per hour**

- **Direction** is specified in degrees, clockwise from north (0-360), (**integer**).
- **Cloud Cover** is specified as a percentage (0 to 100), (**integer**).

Changes can be made to the wind stream after the simulation is running by editing the wind file and re-loading it described above. **Note**: Wind observations do not have to be on a regular interval. You can, for example, enter wind observations every 10 minutes during the afternoon, and only every 2 hours at night.

Gridded Weather and Wind Inputs to *FARSITE*

New to Version 3.0, *FARSITE* can accept gridded inputs for weather and wind variables. The weather/wind variables are separated into two categories: *weather* and *winds*. *Weather* variables include **temperature, humidity, and precipitation**. *Wind* variables include **wind speed, wind direction, and cloud cover**. This separation allows some flexibility in providing gridded inputs or stream inputs. You can provide both gridded weather and wind variables or a combination of the standard weather stream along with gridded wind variables.

Data Units
Data units are the same as those used for weather and wind stream inputs for *FARSITE* to allow compatibility with both GRASS and ARC GRID data:

Temperature	Fahrenheit	(integer)
Humidity	Percentage	(integer)
Precipitation*	Inches X 100	(integer)
Wind Speed	MPH, 20 foot open wind	(integer)
Wind Direction	Azimuth Degrees	(integer)
Cloud Cover	Percentage	(integer)

***Note that the current fuel moisture models can only use precipitation as a single daily value. This means that your gridded Precipitation files should each contain the total precipitation for the day.**

Resolution, Registration, and Extent
Each of the six gridded inputs can be of different resolutions and *do not* need to be co-registered. For example, the resolution for temperature could be 500m but the wind resolution could be 50m. The coverage of each file can also be offset so long as the extent of each grid file covers the landscape on which the fire will be burning.

Input Formats

Accepted formats for the individual grid files are **ASCII** raster outputs from **GRASS** or **ARC GRID**. Depending on the file type, you must have one of these headers:

GRID header

NCOLS	0000
NROWS	0000
XLLCORNER	000000
YLLCORNER	000000
CELLSIZE	00
NODATA_VALUE	-99999

GRASS raster header

north:	000000
south:	000000
east:	000000
west:	000000
rows:	0000
cols:	0000

Specifiying Input Files

The filenames of the gridded input files must be included into an "Atmosphere" file (.ATM) to specify which files are assigned to each date and time. The format for the ATM file depends on if you are using gridded inputs for both *weather* and *wind* variables or just *wind* variables:

To input both weather and wind variables in the gridded format
the following ASCII format is used in the ATM file:

WEATHER_AND_WINDS
METRIC or ENGLISH
MONTH DAY HOUR TEMP HUMID PPT WSPEED WDIR CLDCOVER

For example, if the names of your gridded files are "TESTxx.XXX" your ATM file might look like this for three days beginning 7/15 and ending 7/17:

```
WEATHER_AND_WINDS
ENGLISH
7 15 0200 TEST01.TMP TEST01.HMD TEST01.PPT TEST01.SPD TEST01.DIR TEST01.CLD
7 15 0600 TEST02.TMP TEST02.HMD TEST02.PPT TEST02.SPD TEST02.DIR TEST02.CLD
7 15 1200 TEST03.TMP TEST03.HMD TEST03.PPT TEST03.SPD TEST03.DIR TEST03.CLD
7 15 1600 TEST04.TMP TEST04.HMD TEST04.PPT TEST04.SPD TEST04.DIR TEST04.CLD
7 15 2000 TEST05.TMP TEST05.HMD TEST05.PPT TEST05.SPD TEST05.DIR TEST05.CLD
7 16 0200 TEST06.TMP TEST06.HMD TEST06.PPT TEST06.SPD TEST06.DIR TEST06.CLD
7 16 0600 TEST07.TMP TEST07.HMD TEST07.PPT TEST07.SPD TEST07.DIR TEST07.CLD
7 16 1200 TEST08.TMP TEST08.HMD TEST08.PPT TEST08.SPD TEST08.DIR TEST08.CLD
7 16 1600 TEST09.TMP TEST09.HMD TEST09.PPT TEST09.SPD TEST09.DIR TEST09.CLD
7 16 2000 TEST10.TMP TEST10.HMD TEST10.PPT TEST10.SPD TEST10.DIR TEST10.CLD
7 17 0200 TEST11.TMP TEST11.HMD TEST11.PPT TEST11.SPD TEST11.DIR TEST11.CLD
7 17 0600 TEST12.TMP TEST12.HMD TEST12.PPT TEST12.SPD TEST12.DIR TEST12.CLD
```

```
7 17 1200 TEST13.TMP TEST13.HMD TEST13.PPT TEST13.SPD TEST13.DIR TEST13.CLD
7 17 1600 TEST14.TMP TEST14.HMD TEST14.PPT TEST14.SPD TEST14.DIR TEST14.CLD
```

To input only the wind variables in the gridded format
The ATM file would look like this:

WINDS_AND_CLOUDS
METRIC or ENGLISH
MONTH DAY HOUR WSPEED WDIR CLDCOVER

The .ATM file would look like this with only the *wind* variables in gridded format:

```
WINDS_AND_CLOUDS
ENGLISH
7 15 0200 TEST01.SPD TEST01.DIR TEST01.CLD
7 15 0600 TEST02.SPD TEST02.DIR TEST02.CLD
7 15 1200 TEST03.SPD TEST03.DIR TEST03.CLD
7 15 1600 TEST04.SPD TEST04.DIR TEST04.CLD
7 15 2000 TEST05.SPD TEST05.DIR TEST05.CLD
7 16 0200 TEST06.SPD TEST06.DIR TEST06.CLD
7 16 0600 TEST07.SPD TEST07.DIR TEST07.CLD
7 16 1200 TEST08.SPD TEST08.DIR TEST08.CLD
7 16 1600 TEST09.SPD TEST09.DIR TEST09.CLD
7 16 2000 TEST10.SPD TEST10.DIR TEST10.CLD
7 17 0200 TEST11.SPD TEST11.DIR TEST11.CLD
7 17 0600 TEST12.SPD TEST12.DIR TEST12.CLD
7 17 1200 TEST13.SPD TEST13.DIR TEST13.CLD
7 17 1600 TEST14.SPD TEST14.DIR TEST14.CLD
7 17 2000 TEST15.SPD TEST15.DIR TEST15.CLD
```

These ATM files are input to *FARSITE* using the **Input | Inputs** dialog. If you are supplying both weather and wind variables in the ATM file, then the ATM file should be selected as a "**Weather File (.WTR)**". In this case you will not need to supply any wind files. If you are supplying only the wind variables in the ATM file, the ATM file should be selected as a "**Wind File (.WND)**" and you will need to also supply a weather stream in the standard format (.WTR). You cannot specify more than one ATM file for gridded *weather* or *wind* variables. You also cannot specify more than one .WTR file if an ATM file has been selected for gridded *wind* variables.

Fuel File Inputs

Some fuel inputs are required and some are optional. Below is a description of the file formats and contents of these files.

(Required Files)

Initial Fuel Moistures (.FMS)

The fuel moistures at the beginning o f the simulation must be set for each fuel type. These fuel moistures are required to begin the process of calculating site specific dead fuel moistures at each time step throughout the simulation. The following ASCII integer space-delimited format is used (see example file in *FARSITE3*\EXAMPLES or Appendix 1):

FuelMod 1Hour 10Hour 100Hour LiveH LiveW

- Fuel Model (1-50) corresponds to a fuel model specified 1) on the landscape if no conversions are used, or 2) the fuel model conversion file if conversions are used (see below for description of **fuel conversions**). Fuel models 1-13 must relate to the Fire Behavior 13 standard fuel models (Anderson 1982). Fuel models numbered from 14 to 50 are for custom models as described in the custom fuel model file (.FMD). **NOTE**: **if custom models are used, all models must have initial fuel moistures specified in this file !!!**

- Fuel moistures for each category are in percent, and may exceed 100 (**integers**). LiveH and LiveW indicate "live woody" and "live herbaceous" fuels, just like BEHAVE. **Unlike dead fuels, live fuel moistures remain constant throughout the simulation unless you manually change them.**

  The initial fuel moistures can be changed by fuel type after the .FMS file is loaded. This can be done three ways. **Reselecting** the **Input | Moistures** item in the **Input | Inputs** dialog will display a message box asking if you want to edit the existing fuel moistures:

  YES will bring up a fuel moisture dialog box allowing interactive editing of fuel moistures by fuel model. NOTE: if fuel conversions are used, these are the fuel model numbers (1-50), not the indices converted from the GIS fuel theme. You can save your settings to a new file if you want to.
  NO will allow you to select another initial fuel moisture file for input.

  Lastly, you can push the **(→)** button in the **Input | Inputs** dialog to edit and save initial fuel moistures.

Adjustment Factors (.ADJ)

Rate of spread adjustment factors allow the user to use experienced judgment or local data to tune the simulation to observed or actual fire spread patterns (see spread patterns **Limitations and Assumptions**). These factors have the same purpose as adjustments for BEHAVE predictions (Rothermel and Rinehart 1983). Factors are fuel type specific and are **multiplied by the rate of spread** to achieve the specified adjustment. For example, spread rate for a given fuel type would be reduced by half with an adjustment factor of 0.5, and a quarter with a factor of 0.25. Similarly, spread rate would be doubled using a factor of 2.0. Keeping the adjustment factors at 1.0 maintains the original spread rate.

As described in Limitations and Assumptions, simulating fire spread over long spaces and times may tend to overpredict fire spread because of the coarse spatial and temporal scale of data used for the calculations. This coarse scale does not

reflect the finer-scale heterogeneities that 1) prevent fire from reaching an equilibrium spread rate, or 2) change fire shape (e.g fluctuating wind direction). Spread rate may also be underpredicted because of errors in fuel typing, inaccurate fuel moistures, or improperly represented local winds, etc.

The following ASCII space delimited format is used for the .ADJ file (see example .ADJ files in *FARSITE3*\EXAMPLES subdirectory or Appendix 1):

FuelMod AdjustmentFactor

- Fuel model is an **integer** value (1-50). As always, model numbers 1-13 are restricted in reference to the 13 standard Fire Behavior fuel models (Anderson 1982). Models 14-50 are for custom models specified in the fuel model file (.FMD). **NOTE: an adjustment factor must be specified for each custom model used**.
- The Adjustment factor can be a **floating point number** (decimal) specifying the multiplier for rate of spread adjustment (see above). It must be greater than zero.

After loading an .ADJ file, **reselecting** the **Adjustments** item in the **Input | Inputs** dialog will allow you to modify the existing adjustment factors in one of two ways. A message box will ask if the user wants to modify the existing factors:

YES will allow individual adjustment factors to be changed interactively through a dialog box.

NO will allow a new .ADJ file to be selected and loaded.

Lastly, you can push the **(→)** button in the **Input | Inputs** dialog to edit and save adjustments.

(Optional Files)

One or more of the optional fuel input files are required if : 1) custom fuel models are used, and 2) if the fuel attribute of the fuel theme on the landscape (.LCP file) does not correspond to the fuel model (thus requiring a conversion). **NOTE**: custom fuel models and conversions can be used even if they are not required for a given .LCP file.

Fuel Conversion File (.CNV)

A conversion file is necessary if the fuel model numbers in the GIS fuels theme do not correspond directly to the fuel numbers in the fuel model file or the standard 13 fuel models. **It is recommended that you reclassify your fuels theme to make the fuel attributes correspond directly to fuel models** (e.g. use the

GRASS command **r.reclass**). If you don't want to reclassify the fuel attributes, you'll have to use a conversion file. For example, fuel types 68, 74, and 86 on the fuels theme may actually correspond to Fire Behavior fuel models 2, 5, and 8, respectively. Without reclassifying them to the Fire Behavior numbers, the conversion file would contain the following entries:

68 2
74 5
86 8

Perhaps a better use for a conversion file is for changing the fuel model that a particular fuel attribute represents. For example, your fuel map may contain Fire Behavior fuel models 5 and 8 that you decide should really be 6 and 9, respectively (or custom models). You would then create and load a conversion file that contains:

5 6
8 9

The format for the conversion file is:

ConvertFrom FuelModel

- Convertfrom is the index or attribute of a fuel type in the fuels theme converted to a fuel model number 1-99, (**integer**)
- Fuel Model can be any fuel model 1-50, (**integer**), or rock (0,99) or water (98).

NOTE: you can create a fuel conversion file by pressing the **(→)** button next to the "Conversions (CNV) item in the Input Input dialog and saving your settings to a new file. You will then have to load this file by checking the "Conversions" selection.

Custom Fuel File (.FMD)

NOTE: The contents of the custom fuel model file have changed for version 3.0 to include separate live herbaceous and live woody fuel components and their surface area/volume ratios. You must change your inputs from v2.0 to use this feature.

The use of custom fuel models is supported in *FARSITE*. Models other than the standard 13 Fire Behavior models (Anderson 1982) must be supplied in a custom fuel model file. Custom models must be produced independently of the *FARSITE*

program (e.g. the NEWMODL module of BEHAVE). The file must be an ASCII file with the following space delimited format, and have model numbers between **14 and 50** (see sample .FMD file in *FARSITE3*\EXAMPLE subdirectory or **Appendix 1**):

METRIC and ENGLISH Units

Version 3.0 of *FARSITE* allows wind inputs in English or metric units. The units are selected by inserting the word ENGLISH or METRIC as the first line of the .FMD file (see **Appendix 1**). **To ensure backward compatibility with previous versions of *FARSITE*, you don't have to specify ENGLISH**.

FMod 1H 10H 100H LiveH LiveW 1HSAV LiveHSAV LiveWSAV Depth XtMoist DHt LHt

Field	Data Type	English Units	Metric Units
Fuel Loading	decimal	tons/acre (2000 lb/ac)	metric tonnes/hectare (1000 kg/ha)
Surface Area/Volume	integer	1/ft	1/cm
Fuel Bed Depth	decimal	ft	cm
Heat Content	integer	BTU/lb	kJ/kg

- FMod is a fuel model number 14-50, (**integer**).
- Loadings of 1, 10, 100hr, **live herbaceous**, and **live woody** fuels in tons/acre, (**decimal**).
- Surface area to volume ratios (ft^{-1}) for 1-hour, **live herbaceous**, and **live woody** fuels, (**integer**).
- Depth of the fuel bed (ft), (**decimal**)
- Extinction moisture percent, (**integer**)
- Heat contents of dead (***DHt***) and live (***LHt***) fuels (BTU/lb), (**integer**)

NOTE: for each custom fuel model, you must specify an initial fuel moisture in the .FMS file AND an adjustment factor in the .ADJ file.

NOTE: you can create a custom fuel file by pressing the **(→)** button next to the "Custom Models (FMD) item in the Input Input dialog and saving your settings to a new file. You will then have to load this file by checking the "Custom Models" selection.

Input | Landscape Utilities | File Information

This utility reads the header information in an LCP file and displays it. Information consists of:

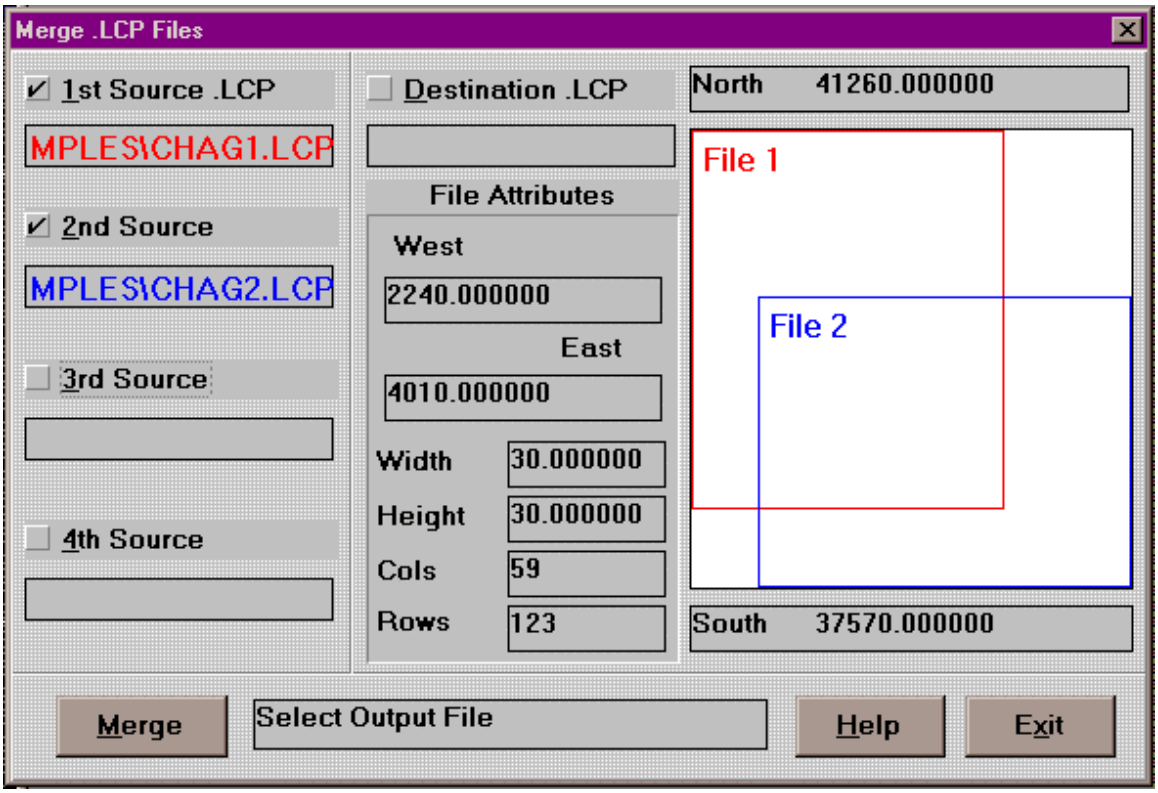
1. North, South, East, West boundaries,
2. rows, cols, and cell resolutions,
3. Units for landscape themes,
4. optional landscape themes included,
5. optional files included (fuel model conversion files, custom fuel model files

Input Tool Buttons

LOAD PROJECT LOAD BOOKMARK

Input | Landscape Utilities | Merge Landscape Files

This utility is used for **merging 2 to 4 existing LCP files** into a single output LCP file.



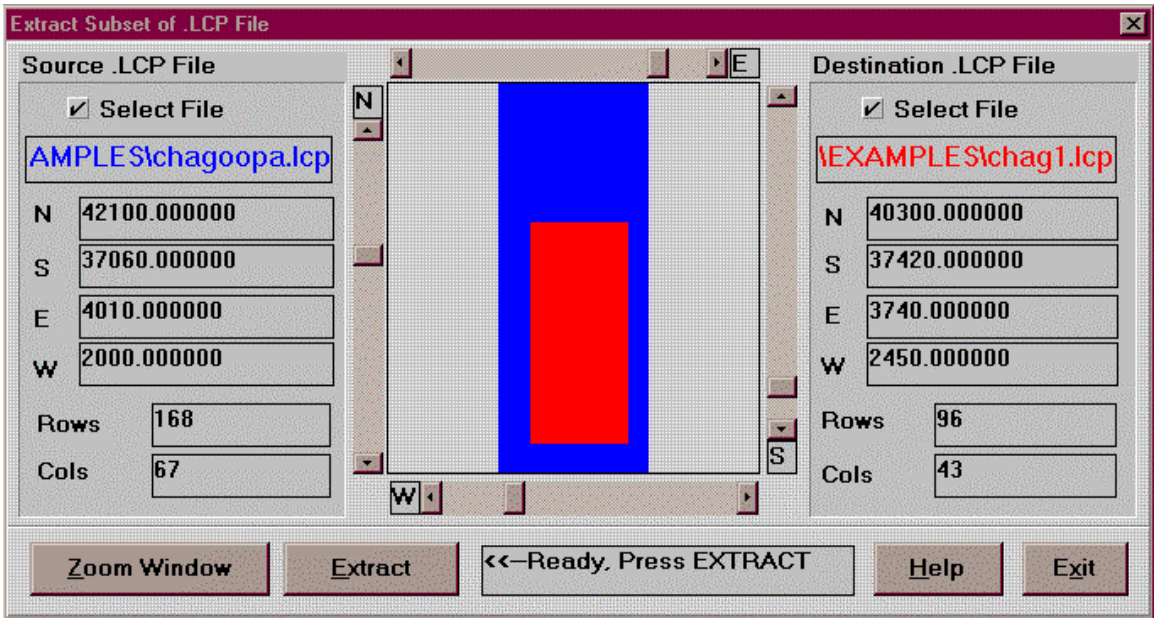
To use this utility:

1) Use the checkboxes on the left for each file you want to merge. **Merging files does not affect the input files**. You will see the juxtaposition of these file boundaries displayed on the right. **Files to be merged must contain the same themes and have the same units for these themes**.
2) Choose the destination LCP file for output
3) select the "**Merge**" button to begin the merging process.

NOTE: Brief instructions are displayed in the message window at the bottom of the dialog. The Merge utility combines files in priority order. Values for a given raster cell will be taken from the first source map containing a positive attribute.

Input | Landscape Utilities | Extract

This utility is used to extract a rectangular portion from an existing LCP file into a new .LCP file.



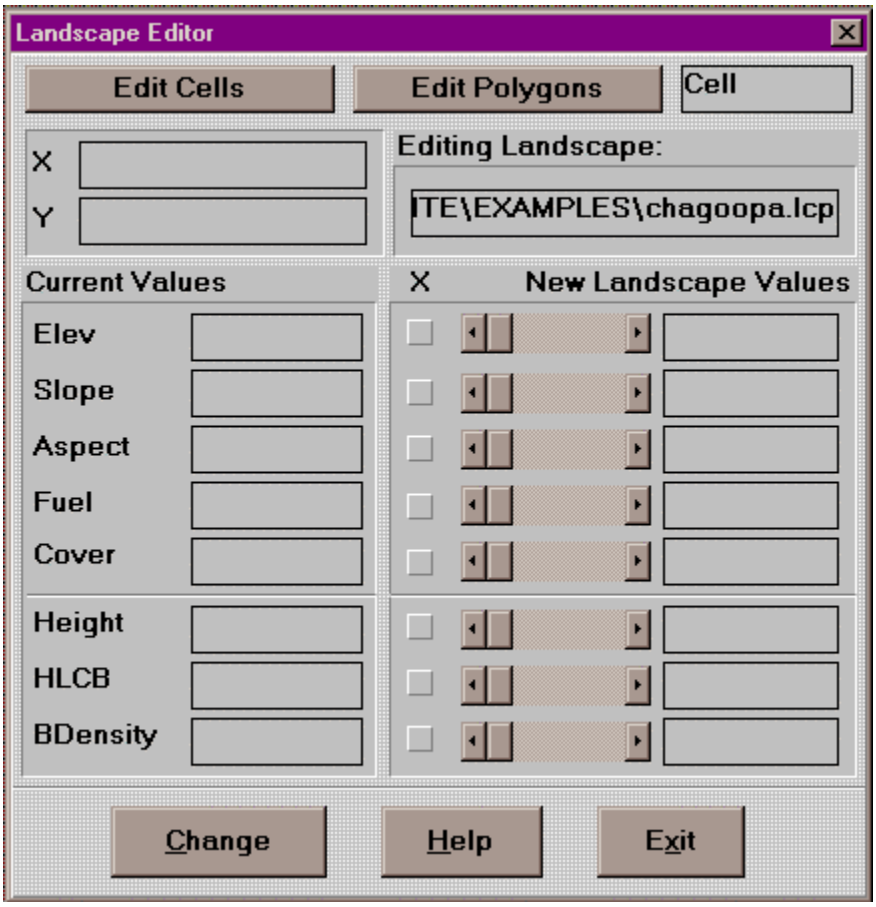
To use this utility:

1) First, you must select the LCP file from which to extract the region. You can transfer the coordinates of **the existing 2-D zoom window** to the extraction region if the input file is the same as the currently displayed LCP file. This is achieved by pressing the "Zoom Window" button.
2) If you are extracting from a different LCP file, haven't opened a zoom window, or want to make adjustments to the zoom boundaries, you can also adjust the North, South, East, and West boundaries of the extraction region using the slider bars.
3) Last, you need to select an output file for your extracted region.
4) Selecting the "**Extract**" button will start the extraction process.

NOTE: Brief instructions are displayed in the message window at the bottom of the dialog.

Input | Landscape Utilities | Edit Landscape

The edit utility is used to **permanently change** landscape attributes **directly in an LCP file**.



To use this utility:

1) a landscape window must be displayed. This can be achieved after a simulation has been initiated or using the **View | Landscape File** selection.

2) You are prompted by a message box that encourages you to make a **backup file** that you can rely on if you make a serious mistake**. It is strongly recommended that you make a backup file** before you begin to edit. This can be achieved automatically by *FARSITE* (by answering **YES** to the message box) or you can do this yourself.

3) Editing can be accomplished 1) cell by cell, or 2) within a polygon. These options are selected using the buttons at the top of the edit landscape dialog.

For both **Cell and Polygon** editing, the **left mouse button selects** a coordinate from the landscape window and the **right button makes the changes** to the landscape. For Cell editing, clicking the left button on the landscape outlines a cell to be edited and displays the current landscape attributes of that cell on the left of the edit dialog. For polygon editing, clicking the left mouse button on the landscape window secures a coordinate for defining a polygon; a series of left clicks on the landscape window will define a polygon with a temporary white line. If you have checked one or more attributes for changing to a New Landscape Value, the right mouse button will change the cell(s) but not change unselected attributes.

No changes will be made to the landscape if a polygon contains less than 3 points, or if no "New Landscape Values" are checked.

If you make a mistake when defining a polygon, you can cancel the existing polygon before you click the right button by switching to cell editing and back again to polygon editing (**press the "Edit Cells" button and then the "Edit Polygon" button**).

NOTE: Cell by cell editing may require you to enlarge your view in the landscape window by changing the View Port.

NOTE: Using a fuel conversion file when editing fuels attributes in the landscape file can have confusing and unintended results. This happens because the fuel values in the LCP file are reclassified according to the table in the fuel conversion file. It is recommended that you edit your landscape file without a conversion file or using a **"neutral" fuel conversion file** (e.g. one that converts all fuel models to their original fuel model number).

NOTE: When editing an LCP file, the "**Link Crown Density and Cover**" option in the Model | Fire Behavior Options menu will be temporarily turned off. This allows you to see and change the attributes for crown bulk density in the LCP file as they exist unmodified by the cover attribute.

Edit Cells

This button allows you to change individual cells of an LCP file. A LEFT BUTTON click selects the cell and displays the current attributes on the right of the dialog. Clicking the "Change Button" on the edit dialog or a RIGHT BUTTON click changes the attributes to the New Landscape Values that you've selected.

Edit Polygons

This button allows you to change LCP attributes within polygons that you define. A series **of LEFT BUTTON** clicks secures vertices of a polygon on the landscape. You don't have to close the polygon. Clicking the RIGHT MOUSE BUTTON or the "Change Button" will change the attributes of cells inside the polygon to the New Landscape Values.

New Landscape Values

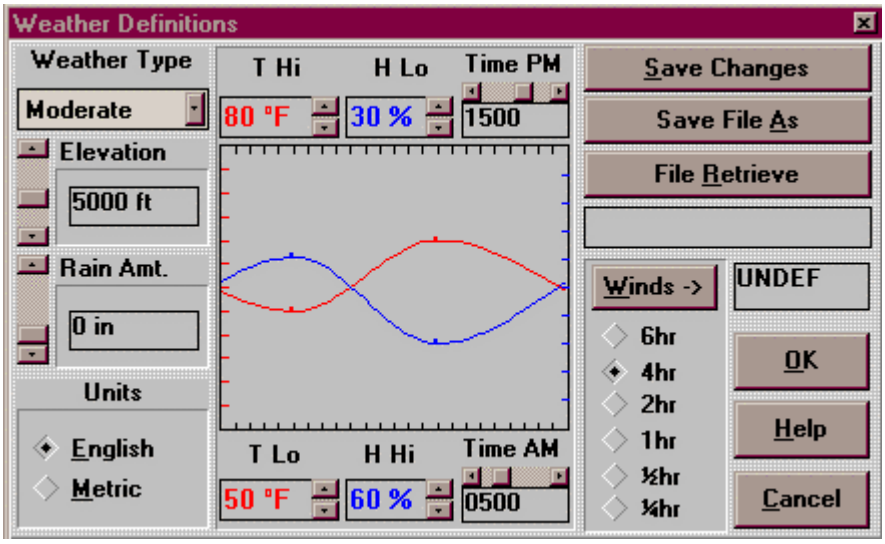
New Landscape values are those that are indicated by checking the box to the right of the attribute. Only those attributes checked will be changed to the new value. You set the new value using the slider.

Change

The change button can be used to make your changes to the landscape in both **Cell** and **Polygon** modes. An easier way to do this however, is to click the **RIGHT MOUSE BUTTON**.

Input | Define Weather/Wind Types

The purpose of this utility is to define weather/wind types associated with different types of fire activity. These definitions can then be pieced-together for a series of dates that will automatically generate the required WTR and WND files for a *FARSITE* simulation.



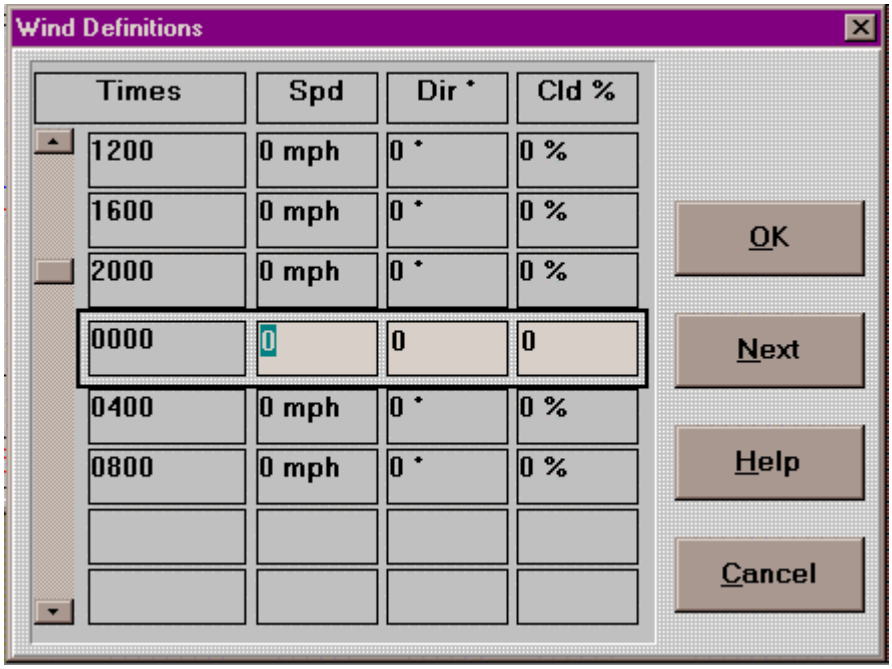
The idea is to characterize fire weather as it pertains to fire activity. Your options are **None, Low, Moderate, High, Extreme, and Other**. These will be specific to your location, elevation, the time of year, and perhaps topography. You will then use these "types" to generate a complete stream of weather and wind inputs for a range of calendar dates by just indicating a weather/wind "type" for each day. Of course, **you can always edit the .WTR and .WND files in any ASCII editor, like in version 1.x of *FARSITE***.

For each weather type (selector in the upper left):

1. adjust the **high and low temperature** and the **high and low humidity**.
2. adjust the **times** at which these maxima and minima occur,
3. adjust the **elevation** and **rain** amount,

4. select the **wind observation interval** (ie. 6hr, 4hr, 2hr....) and press the "**Winds →**" button to open the wind definition dialog. You will notice that a time template will be created with your specified intervals.

   After pressing the **'Winds →'** button, the following dialog allows you to define the wind observations at the intervals specified above (#4):



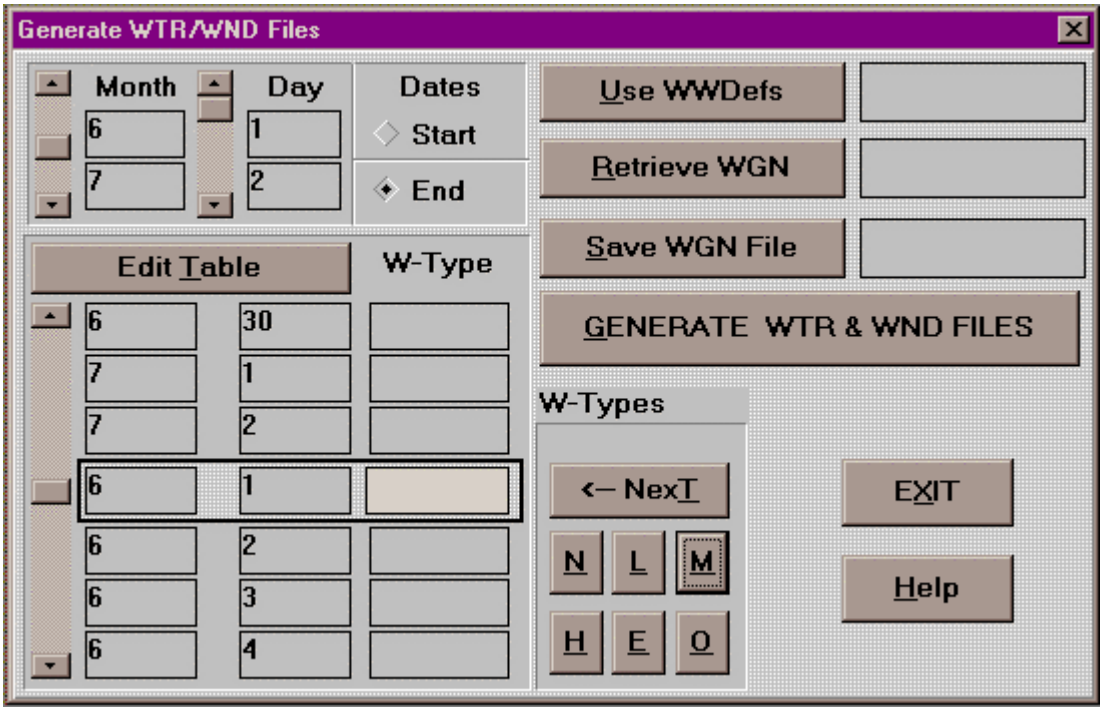
For each wind observation time:

1. Input the **speed, direction, and cloud cover** (Use the **TAB** key to switch among these input Windows).
2. Type "**N**" or click the "**Next**" button to advance the row of wind observation times. You can also use the vertical slider to the left of the date range.
3. When finished press "**OK**",
4. when you return to the weather definition dialog, verify that the wind definitions have been "**defined**" for that weather type.

Make sure that you save this file. You will need this file for generating the WTR and WND files.

Input | Generate From Types (WTR/WND)

This utility uses the weather and wind type definitions to automatically generate the required **WTR** and **WND** files for a *FARSITE* simulation. After setting up a range of dates, you will designate what "type" of fire weather occurred on each date (Low, Mod, High etc.). **Once generated, you can edit the .WTR and .WND files in any ASCII editor, like in version 1.x of *FARSITE*.**



To use this utility:

1) Press the "Use WWDefs" button to load the weather and wind type definitions produced earlier. You cannot generate WTR and WND files without having defined weather/wind types.

2) Next, select the starting and ending dates for your weather and wind streams. **Remember, a *FARSITE* simulation requires weather and wind streams to contain 1 Full Day before and 1 Full Day After the dates you want to simulate. For example, if you want to start your simulation on August 10th and end on September 15th, the minimum range of dates would include August 9th and September 16th.**

3) Then, select the "**Edit Table**" button. This will fill out the range of dates to be filled below.

4) You can now use the keyboard to put in the first letters of the weather types or use the "type buttons" (N, L, M, H, E, O) to fill in the types for each day. These correspond to the weather/wind types you have defined. NOTE: you can only use weather/wind types that you have defined. For example, if you have not defined the "None" type, you cannot use it in this dialog.

5) The "**Next**" button enters your change and advances the rows of dates either up or down depending on which end of the date range you are situated. You can also use the vertical slider bar on the left side of the date table to edit the weather/wind type for any of the dates.

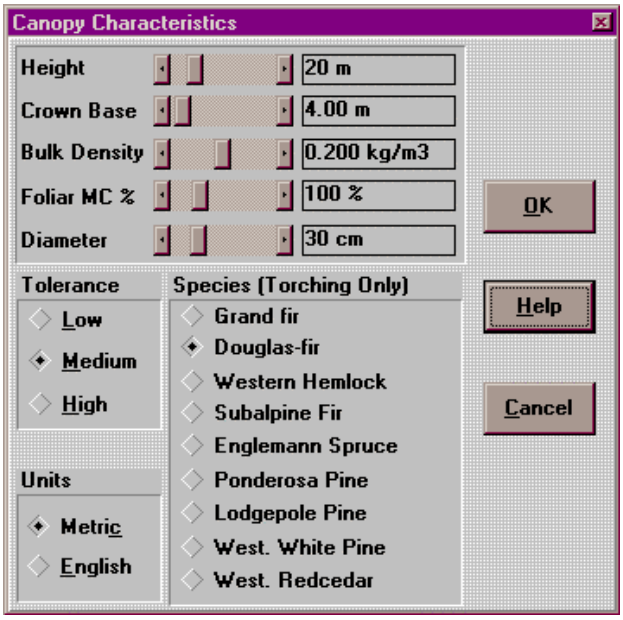
6) Once you have filled in all weather/wind types for the range of dates, you can select the "GENERATE WTR & WND FILES" button. **This will prompt you for a**

filename. The **WTR** and **WND** extensions will be appended to this file name for the **weather** and **wind** files that will be generated.

You should save this file (.WGN) by pressing the "Save WGN File" button if you think you might want to make changes to this calendar template.

Input | Canopy Characteristics

Canopy characteristics except cover are considered uniform across the landscape except where crown fuel characteristics have been specified in a GIS data theme



(see **Input | Landscape Utilities | Generate Landscape File**). This is unrealistic of course, but **to simulate crown fires** without spatial canopy data themes on height, height to live crown base, crown bulk density, you would have to provide a constant map theme for each of these variables anyway.

The canopy characteristics dialog box allows you to select these uniform canopy characteristics used for crown fire calculations (tree height, height to live crown base, crown bulk density, and foliar moisture content). These values will be used for any crown fire parameter not contained in the landscape (.LCP) file.

IMPORTANT NOTE: **For calculating crown fire spread**, you have the option of using the spatial canopy cover theme to modify the constant crown bulk density value in this dialog (see **Model | Fire Behavior Options**)

Parameters that affect spotting from torching trees (if torching occurs) are tree diameter and species. These parameters only determine the characteristics of trees that torch and

produce embers if torching occurs (see **Limitations and Assumptions**, and **Technical Documentation**).

Input | Project

A project file contains most of the inputs and customizations that you've made for a simulation. A project file is used to speed up the process of loading files and setting the customizations for subsequent simulations. You are encouraged to make a project file after you are satisfied with the look and customized appearance for a particular simulation. The project file can be made using either the **Input | Project Make menu selection** or the **Project Make button** on the **Input | Inputs** dialog.

After loading the required files you can make a project file at any time during a simulation. You must make a project file before you can make a bookmark file (**Input | Bookmark Create**)

A project file contains:
1) the names of all of the required and optional input data files for *FARSITE*.
2) display customizations set at the time the project file was made:
   - →changes to fuel model colors (**Output | Colors**),
   - →the weather and wind grid (**Simulate | Modify Map | Weather/Wind Monitoring & Grid**),
   - →the resolution of the map gridlines (**Output | Map Display**),
   - →the names of up to 5 vector files drawn on your landscape (see **Input | Inputs** or **View | Vector Files**).
   - →the current viewport coordinates.

When using **multiple** weather/wind streams, you should make a project file after you finish customizing a weather/wind grid so that these tedious changes are saved for your next simulation.

The next time you want to do a simulation with those settings, you can load the project file instead of loading all of the input files individually. A project can be loaded using the **Input | Project Retrieve menu selection**, the **Load Project** tool button (see diagram at end of chapter) or the **Project Retrieve button** on the **Input | Inputs** dialog box.

Once a project is loaded, you can substitute individual project components such as the landscape file, weather file(s), or visible vector files using the **Input | Inputs** dialog box and resave the project if desired.

Input | Bookmark

A bookmark file is used just like a bookmark: to bring you back to the point where you left the simulation. It contains almost all settings for all dialogs and files you have already loaded. It also restores all fire perimeters and fire data from the state of the simulation at the time it was created. A number of possible uses for this include:

1. performing multiple simulations from the same starting point (e.g. with and without control lines, with and without fuel modifications, different weather scenarios etc.).
2. reducing time required for repeated simulations and
3. for demonstrations, for saving and reviewing a past simulation with the 2D, 3D, and printing features of *FARSITE*.

A bookmark file is created using the **Input | Bookmark Create** menu selection. It can be made any time after a project file is made or loaded.

A bookmark file is retrieved using the **Input | Bookmark Retrieve** menu selection or the bookmark tool button. A bookmark file cannot be retrieved when another project or bookmark file is loaded or when a simulation is initiated or active.

Chapter 6 The OUTPUT Menu

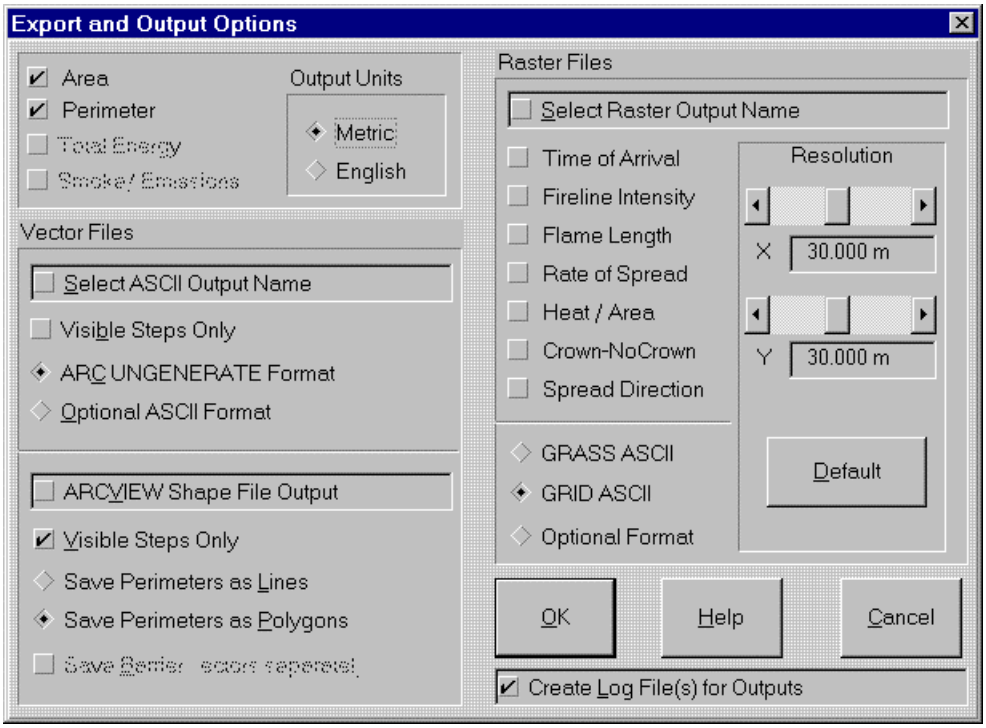
The Output Menu contains options for generating output from the simulation. GIS **Export** files must be selected before the simulation begins because these are created progressively at run time. Many of the output options are also accessed using tool buttons on the tool bar (see toolbar diagram at end of chapter).

NOTE: Most of the output windows can be printed or saved. See Printing or Saving Output Windows.

Output | Output & Export

The output dialog contains options for calculations by the simulation. Area and Perimeter are calculated by default. Selecting **Raster** or **Vector** file output brings up a **file selection dialog**. Entering or selecting an output file enables selections for the type of fire behavior data input into the files.

NOTE: YOU MUST SELECT YOUR OUTPUT FILES BEFORE STARTING THE SIMULATION -- ALL OUTPUT FILES (VECTOR AND RASTER) ARE OPTIONAL AND WILL ONLY BE PRODUCED AFTER YOU MAKE YOUR OUTPUT SELECTIONS !!



Vector Files

A vector file contains the vertices of each fire polygon. Beginning with *FARSITE* v3.0 you can output vector files in ASCII format **and** in ArcView shapefile formats. Using the above dialog box you can select either or both types of output files. In both cases the fire perimeter vectors can be produced at all timesteps or just the visible time steps (see **Model | Parameters**). A check mark in the "**Visible Steps Only**" box is the default; unchecking this box causes vector output at all time steps.

To output ASCII fire perimeter data first check the **Select ASCII Output Name** checkbox to enter an output filename. Then select the output format and other options below.

ARC Ungenerate Format

The output file extension for ASCII format files is **.VCT** with a default output format of ARC UNGENERATE ASCII (indicated by the checked **ARC ungenerate checkbox** in the **output dialog**). These can be imported to GRASS using the ***v.in.arc*** command. Note that this is a "LINES" file; no polygon labels are created.

NOTE: The **identifier** for each line or polygon in the ARC file has information on the **Time (2 digits each for DAYS, HOURS, MINUTES, after ignition and Fire Number (5 digits) for the fire perimeter in the simulation**. The following are examples of the format used in version 3.0:

00003000001 (30 minutes, Fire 1)
00020000002 (2 hours, Fire 2)
01143000003 (1 day, 14 hours, 30 minutes, Fire 3)

Optional Format

An optional vector file format can be selected by checking the **Optional** checkbox. This file will contain for each X and Y fire perimeter coordinate (Easting and Northing) the time of arrival. Optional fire characteristics selected for output (**using the checkboxes for raster output files**) will also be included as additional columns. A blank row will be inserted between the data block of each polygon. The following column format and order is used, although the actual columns contained in a data file will depend on your selections (**see Raster Files below for data units**):

East North ArrivalTime FLIntensity FlameLength SpreadRate Heat/Area Crown Direction

ArcView Shapefile Format

Shapefiles are the native data format used by ArcView. The format consists of 3 files (.SHP, .SHX, and .DBF). They are binary files but are completely portable

between MS Windows and UNIX operating systems, meaning that they can be created and viewed by ArcView running on each system.

To output your fire perimeters as a shapefile, check the ArcView Shape File Format checkbox and enter a filename. You can select to output only the visible timesteps or all timesteps determined by your **Model | Parameters**.

You can select to output fire perimeter features of the shapefile as lines (arcs) or polygons.

Raster Files

A rasterRaster file will be produced for each fire spread parameter selected in the dialog box. **You must make your raster selections before you run the simulation; the rasterizing is done progressively during the simulation (see Technical Documentation) and cannot be performed afterward.**

The default output format is GRASS ASCII (indicated by the checkmark in the GRASS checkbox of the output dialog) for import to GRASS using the ***r.in.ascii*** command. You can also select an ARC/GRID ASCII file for import to ARC/INFO.

A fire time-of-arrival raster file will always be produced for GRASS and GRID ASCII output. Raster themes containing fire behavior characteristics can be produced by checking the appropriate boxes. These raster themes are distinguished by the extension added to the filename (see Resolution below). All attributes are computed for the center point of each cell (see Technical Documentation).

Resolution

The **resolution** of the raster file can be set between 1 and 200 meters using the resolution slider. The default setting when the **Output | Export & Output** dialog is first opened is set to the resolution of the .LCP file.

The **resolution** of the raster output files **does not have to be the same as the original landscape resolution**. Finer resolutions require more calculation time and produce larger data files.

The **Default button** will reset the resolution to the original landscape resolution.

The **X and Y Resolution** can be set **independently for GRASS** files but must be **identical for GRID files.**

Files with the following extensions will be produced:

Raster Theme	**DOS Filename Extension**
Time of Arrival	.TOA
Fireline Intensity	.FLI
Flamelength	.FML

Rate of Spread	.ROS
Heat per Unit Area	.HPA
Crown-NoCrown	.CFR
Spread Direction	.SDR

Default raster values are set to -1. **NOTE:** All raster outputs are natural precision decimal values. Use the optional "**mult=**" specifier for the ***r.in.ascii*** command if increased precision is required when importing to GRASS. **(i.e. *r.in.ascii input=testdata.toa output=testdata mult=10*).**

Optional File Format

The **Optional File Format** checkbox selects an ASCII file format that contains columns of fire behavior values (depending on your selections) by raster coordinate (East, North):

East North ArrivalTime FLIntensity FlameLength SpreadRate Heat/Area Crown Direction

NOTE: the easting and northing for each attribute in the optional format above is the coordinate of the **"lower left**" or "**southwest**" corner of each cell.

The following table shows the units for each of the output parameters:

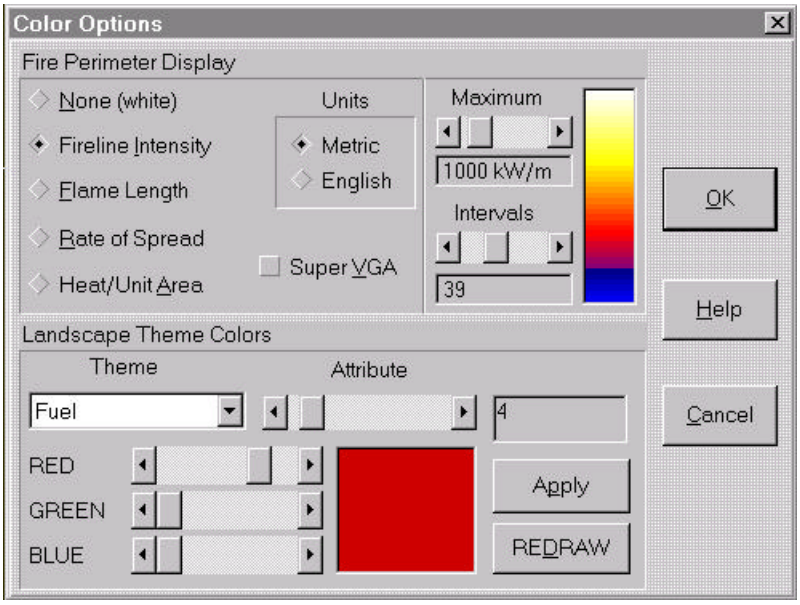
	Metric	**English**
Time of Arrival	hours	hours
Fireline Intensity	kW/m	BTU/ft/sec
Flamelength	m	ft
Rate of Spread	m/min	ft/min
Heat per Unit Area	kJ/m^2	BTU/ft^2
Crown-No Crown	1=surface, 2=passive, 3=active	1=surface, 2=passive, 3=active
Spread Direction	0-359 º Azimuth	0-359º Azimuth

Log Files

Checking the "**Create Log File(s) For Outputs**" box will generate log file for your raster and vector file outputs. A different extension will be appended onto the base file name for vector files (LGV), shapefiles (LGS), and raster files (LGR). These files contain information on the simulation inputs, parameters used, and start/end times. Log files are useful for documenting the contents and simulation background for each raster or vector output file you've created.

Output | Colors

The Colors dialog allows you to select colors for displaying the fire perimeter and the visible landscape theme.



Fire Perimeter Display

The screen output of fire perimeters at the specified visible timestep can be color-coded by fire behavior characteristics. The default is **No Fire Behavior**, with perimeters drawn in white. The range of values and color intervals can be selected using the sliders to the right of the check boxes. The range and depth of colors will be displayed to the right and changed according to the number of intervals you select. Color availability will depend on your monitor; super VGA will allow a wider range of colors for fire perimeter characteristics.

If the fire perimeter colors are difficult to discern on your fuel color background, you can either:

1. select the **No Fire Behavior** option (default) to display solid white fire perimeters,
2. re-run the simulation after changing fuel colors (see below), or
3. alter the **maximum** and **interval** settings for the fire perimeter display (this will reduce the sensitivity to differences in fire behavioralong the fireline however).

Super VGA

The super VGA option is available to enhance screen output if your monitor and/or graphics card offers this support. This version of *FARSITE* contains a logical palette of 256 pure colors used with the super VGA option. Support will be determined automatically and you will be notified if your computer will not be capable of this graphics mode. NOTE: you will get more apparent color combinations without using super VGA

mode because Windows dithers the basic colors to approximate color variation. You may select super-VGA mode at any time. For example, after the landscape is drawn, selecting the superVGA option along with one of the fire characteristics for perimeter coloration will draw only the fire perimeters using the super-VGA palette.

Landscape Theme Colors

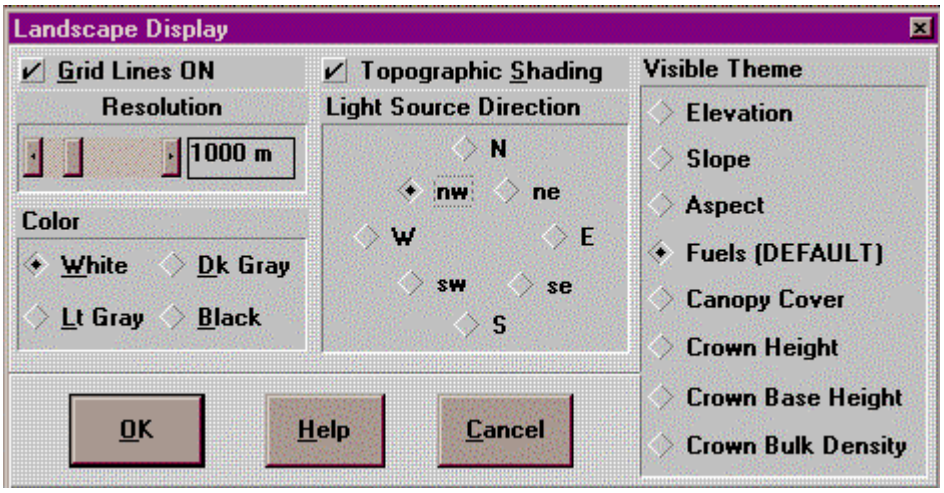
The color of the visible landscape theme attributes can be changed by adjusting the mix of red, green, and blue. The visible landscape theme is selected in the Output Map Display dialog. Press the **Apply button** once the desired color for the selected fuel model is displayed in the color box. If the landscape window is currently displayed, press the **redraw button** to redisplay it with new fuel colors.

NOTE: redrawing the screen may take some time for large or high resolution landscapes because all colors are re-assigned by reading the landscape filefrom disk. **NOTE**: Redrawing the landscape during an active simulation will erase all fire perimeters and other designations on the old landscape.

Fuel model colors can be previewed by displaying the **Legend window** (**Output | Legend**).

Output | Map Display

The Map Display dialog controls options for displaying the landscape window.



Grid Lines

Grid lines can be toggled on/off with using the **Grid Lines ON** checkbox. If you choose to have grid lines displayed, you can select the resolution and color of these lines. The gridlines slider selects the resolution of the grid lines in either meters or feet depending on the distance units of your LCP file.

Topographic Shading

This option enables/disables shading of each fuel model color by topographic aspect. The light source direction can be selected from 8 options.

NOTE: You may want to disable the topographic shading with very diverse fuelscapes. If you are not using the Super VGA setting (**Output | Colors**) the dithered topographic shading tends to confuse the spatial definition of fuel types. If you are using the Super VGA setting the shading may confuse the distinct fuel types that have the same basic color.

HINT: If topographic shading is displayed, avoid defining fuel colors that are "dark"; the shading method uses the defined fuel model color for the "light facing slopes" and darkens that color for slopes of other aspects. (see **Output | Colors** for color definitions)

Visible Theme

The landscape theme visible in the landscape window can be selected by checking the appropriate box. You can only select themes that you have provided to your LCP file during generation (**Input | Landscape Utilities | Generate .LCP**). For example, you can't display tree height if you haven't included tree height in the LCP file. Once you've selected the visible theme, you can change the colors associated with the attributes in this theme using the **Output | Colors** dialog. You can redraw the landscape window using the **View | Redraw 2D Window** selection.

NOTE: Only fuel model color changes can be saved to a project file. Changes to colors of the other themes are not saved.

Output | Zoom

Selecting the **Output | Zoom** function or corresponding tool button activates a zoom window for the **landscape** and/or the 3D window.

Operation

After selecting the zoom window function, position the cursor at the upper left corner of the sub-region of the window that you want to enlarge. While holding down the left mouse button, drag the cursor and the rubberband box down to the lower right corner of your target region and release the left mouse button. A new window will be placed in the

upper left of the client region of your screen. You can resize this zoom window by grabbing the frame and stretching to the desire size.

The image shown in the zoom window is an enlargement of a portion of the original bitmap. You should resize the zoom window to the desired size, realizing that you can change the scaling of the "X" and "Y" axes. Once the zoom window is established, its scroll bars can be used to maneuver the position of the window over the landscape.

Right Mouse Button Functionality

Fire perimeters shown in the zoom window of the main landscape window and the 3D window can be **redrawn at the enlarged scale** in the zoom window by pressing the right mouse button on the zoom window. Resizing or scrolling of the zoom window will erase the redrawn perimeters. Fire perimeters are drawn without coloration of fire characteristics.

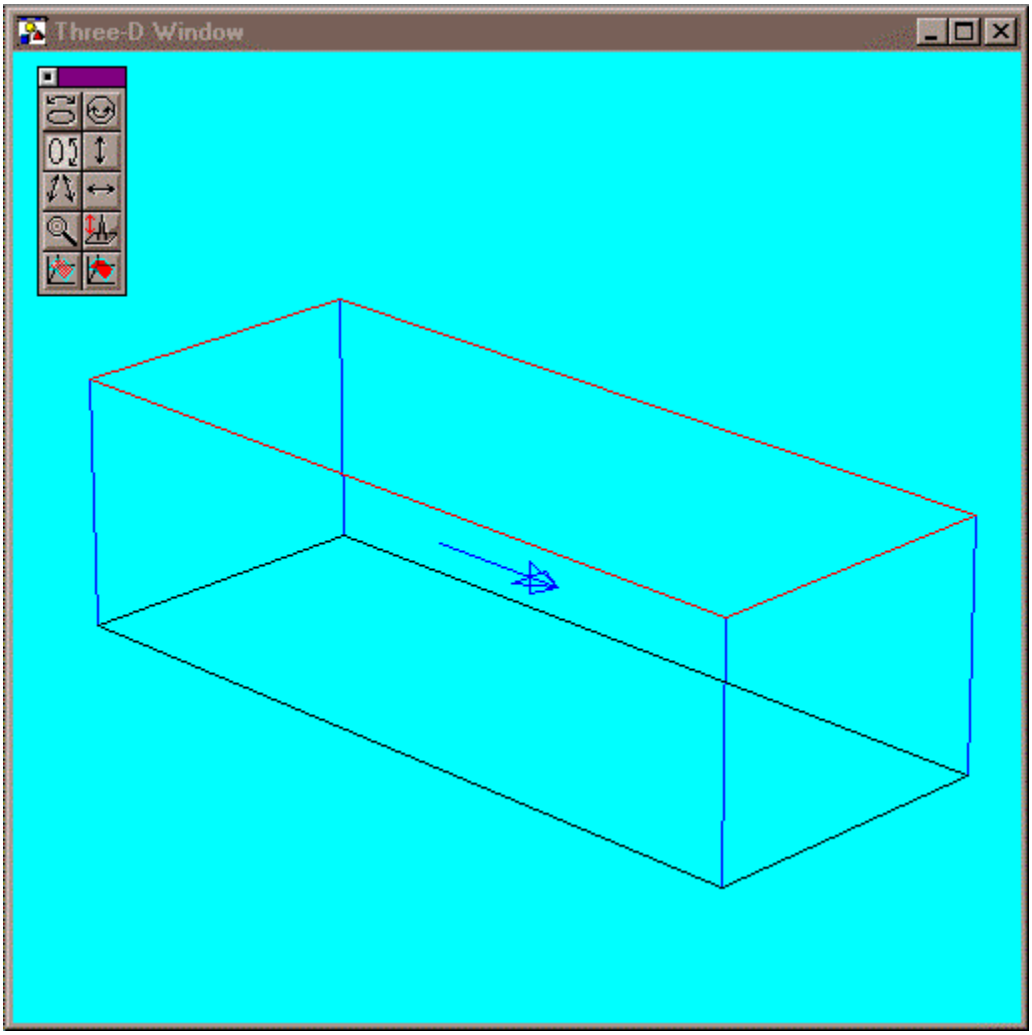
Replay Delay

You can control the speed at which the fire perimeters are redrawn in the zoom window (see **Right Mouse Button Functionality** above). Use the **Output | Zoom | Replay Delay** dialog to adjust the *milliseconds* between redrawing the visible perimeters. This is useful for demonstrations and for examining in an animated fashion how fire growth changed over time.

Output | Three D

This function allows you to produce a three dimensional view of the landscape. Selecting the 3D menu item or the corresponding tool button will open a window and a floating toolbox containing tool buttons for manipulating the orientation of the landscape:

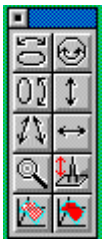
When first opened, the 3D window displays a wire-frame box**. The starting view is always from the South.**



1. move the toolbox outside the Three-D window,
2. use the mouse cursor to select a given tool button for repositioning the viewing angle,
3. move the mouse cursor **back into the Three-D window**, and
4. click the left or right button on the window to position the bounding box for the landscape, **the left and right buttons perform opposite operations**.
5. once you have done most of the manipulations, you can check your perspective by selecting the “skeleton landscape” button, and again clicking the left mouse button in the 3D window.
6. you can remove the skeleton landscape by clicking the right mouse button on the 3D window when the “skeleton landscape” button is on.

7. when you have the desired viewing angle, select the “final landscape” button and click the left mouse button on the 3D window; it will take a few minutes to complete the drawing.

Rotate in XY direction
Rotate in YZ direction
Move In/Out
Magnify
Skeleton Landscape

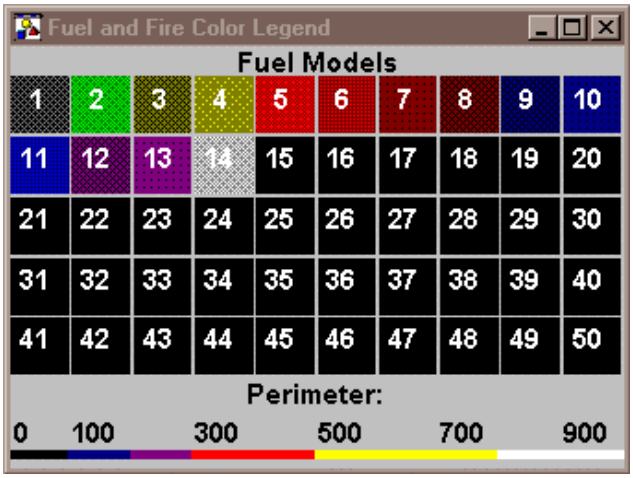


Rotate in XZ Direction
Move Right/Left
Move Up/Down
Vertical Exaggeration
Final Landscape

- the **direction arrow** in the middle of the bounding box is **pointing NORTH.**
- You can display both vector and raster files on the 3D window using the **View | Vector** and **View | Raster** menu selections.
- this window can be **saved to a bitmap file** by pressing the **right mouse button** on the Three-D window after it is done with the final landscape drawing. See Printing and Saving Output Windows.

Output | Legend

This menu item toggles the display and removal of the fuel color legend window.



The legend displays the colors of the visible **fuel models** as well as the color of the fire perimeter. **NOTE**: changes to the fuel model colors or to the range or units of fire perimeter characteristics that are initiated through the **Output | Colors** dialog will not be updated on the legend window until the Legend window is resized or otherwise redrawn.

Output | Elapsed Time

The elapsed simulation time is displayed by selecting this menu item or the "stop watch" tool button. Elapsed time is displayed in the following format (24 hour format):

Days Hours:Minutes

Output | Current Time

The current simulation time is displayed by selecting this menu item or the "clock" tool button. The current time will not display before the duration of the simulation has been set (**Simulate | Duration**). The display format for the current time is (24 hour format):

Month/Day Hours:Minutes

Output | Graphs

A number of graph Windows can be displayed to show data changes over time. Graph Windows can be opened at any time, resized, minimized, and printed. The fire area and perimeter are calculated as a horizontal projection as well as with a topologic correction. The **topologic** value or slope value represents the surface area (for fire area) or surface distance (for fire perimeter).

Right Mouse Button Functionality

All graph Windows can be printed to a file or printer by clicking the right mouse button on the window of interest and checking the desired output. Graph Windows can be displayed during an active simulation so that run-time changes can be monitored. Graph Windows can be opened using the menu commands or their corresponding tool buttons.

Weather Monitoring Stations

Two graph Windows are displayed from each weather station: **fuel moisture** and/or a combined **temperature and humidity** graph. One or both graphs can be displayed using the dialog that is activated with the **Output | Data | Weather Station**

selection or tool button. **NOTE**: Stations are placed using **Simulate | Modify Map** or the corresponding tool button.

Fire Characteristics Chart

A Fire characteristics chart can be displayed for automatic plotting of fire front characteristics. A fire characteristics chart (Andrews and Rothermel 1982) is useful for visualizing fire behavior in terms of **spread rate** and **heat per unit area**. The product of these axes yields values of **fireline intensity** that is related to **flamelength** (Byram 1959). Fire behavior values are plotted in **red** from all active fire fronts (if there are more than one fire) in the current time-step; these black markers are replaced by **yellow** markers as time progresses. This feature allows you to visualize an "envelope" of fire behavior resulting from temporal and spatial changes for each fuel type involved at the fire edge. For example, fuel moisture fluctuation throughout a diurnal cycle results in movement along the X-axis; windspeed and slope affects spread rate and position along the Y-axis. Different fuel types will result in distinct clusters of points and have their own envelope of fire response to environmental conditions.

Left Mouse Button Functionality

The fire characteristics chart in *FARSITE* has adjustable X and Y axes. By moving the mouse-cursor to the edges of the chart, a left button click will increase or decrease the length of the axis depending on which side you're nearest. For example, the range of the X-axis can be increased decreased by moving the mouse cursor to the far right or far left of the window, respectively, and clicking the left button. The Y-axis can be adjusted by moving to the top or bottom of the window.

Interpreting Crown Fire Characteristics

The fire characteristics chart will reflect a transition from surface to active crown fire by increasing both the heat/unit area and spread rate. Heat/Unit Area increases because fine crown fuels are added to the combustion zone. Spread rate increases because the crown fire becomes influenced by the open windspeed not an understory wind. Thus, points on the fire perimeter that are burning as a crown fire will plot on the chart to the right of those points burning only in surface fuels. The flamelength values for crown fire are more difficult to interpret than for surface fire because much of the flame is emanating from burning crown fuels that are elevated considerably above the ground surface.

Fire Area

Graph of total fire area over time (from all fires) is toggled using this menu item or the area tool button. Horizontal and topologic values of fire area are displayed as a function of time. The topologic value will always be greater than the horizontal projection on sloping ground. The difference between horizontal and topologic values of fire area can become greater or stay the same, but cannot decrease over time.

Fire Perimeter

Graph of total fire perimeter length (from all fires) over time is toggled using this menu item or the perimeter tool button. Unlike fire area, the horizontal and topologic values for perimeter may diverge and converge over time as the fire edge spreads to new terrain.

NOTE: these windows can be **saved to a bitmap file or printed directly to a printer** by pressing the **right mouse button** on the window. See Printing and Saving Output Windows.

Output | Data

Scrolling data Windows are available to monitor fire area, perimeter, and fire statistics as they change over time. Data are displayed by elapsed and current simulation times. Data corresponding to visible timesteps will be colored **RED or YELLOW** (depending on your monitor); those corresponding to other timesteps will be **BLUE**.

Fire Statistics

The fire statistics include the numbers of total fires, new spot fires, and enclaves at each time step. The total number of fires is calculated as:

Total Fires=previous total+new spots+enclaves-merged fires.

Fire Area

Displays a scrolling window containing combined fire areas by elapsed and actual time. Fire area units will be in hectares or acres depending on your selection of output units in the **Output | Export & Output** dialog. The horizontal fire area is displayed along with an estimate of the topologic or surface area of the fire.

Fire Perimeter

Displays a scrolling window containing combined fire perimeters (from all fires) by elapsed and actual time. Perimeter units are miles or kilometers depending on your selection of units in the **Output | Export & Output** dialog. The horizontal fire perimeter length is displayed along with the surface distance of the perimeter.

Wind Gauge

The wind gauge option will display as a circular wind gauge window if you have only one weather/wind stream specified. An array of wind gauge needles will be overlaid on your landscape window if you have **specified multiple weather/wind streams** in the **Input | Inputs** dialog. In both cases, the length of the needle indicates the open windspeed (mph at 20 ft above the vegetation) in the direction it is pointing.

The color of the needle indicates the scale of the windspeed on the circular wind gauge:

→ If the needle is **yellow**, each concentric ring on the gauge represents **a 5 mph** increment in open wind speed.

→ If the needle is **red**, each concentric ring on the gauge represents **a 10 mph** increment in open wind speed.

The midflame windspeed is reduced from the open windspeed depending on the canopy information and fuel characteristics.

NOTE: most of these windows can be **saved to file** by pressing the **right mouse button** on the window. See Printing and Saving Output Windows.

Printing or Saving the Contents of Output Windows

Most of the output windows visible in *FARSITE* can be saved without using third party software. Depending on the contents of the window, the window can be:

1) printed directly to a printer,
2) saved as a bitmap, or

3) the data stored to a file.

All of these options are accessed by clicking the **right mouse button** on the window of interest. If these options are available, a small **Print Destinations dialog** will appear showing several valid selections. Proceed by selecting one or more options and pressing **<OK>.**

Printing to a printer

The contents of the window will be printed to the selected printer that is connected to the Windows operating system. All printing is done at the size of a full page.

NOTE: The purpose of printing the 2-D landscape window is to generate rapid output from the simulation that can be photocopied, FAXed, or resized and photocopied onto a transparency for overlay onto topographic maps.

Saving a bitmap image

A color bitmap file (BMP) will be created with this option. These files can be read and modified by most paint and graphics programs or converted to other raster graphics formats (e.g. TIFF). They can be pasted into most word processing programs (for Windows operating systems). They can also be printed in color if a color printer is connected to Windows.

Saving data to a file

The contents of data windows (fire area, perimeter, and statistics) can be saved to an ASCII text file. This will allow you to later import and graph the data using the graphics software of your choice.

Landscape Query Window

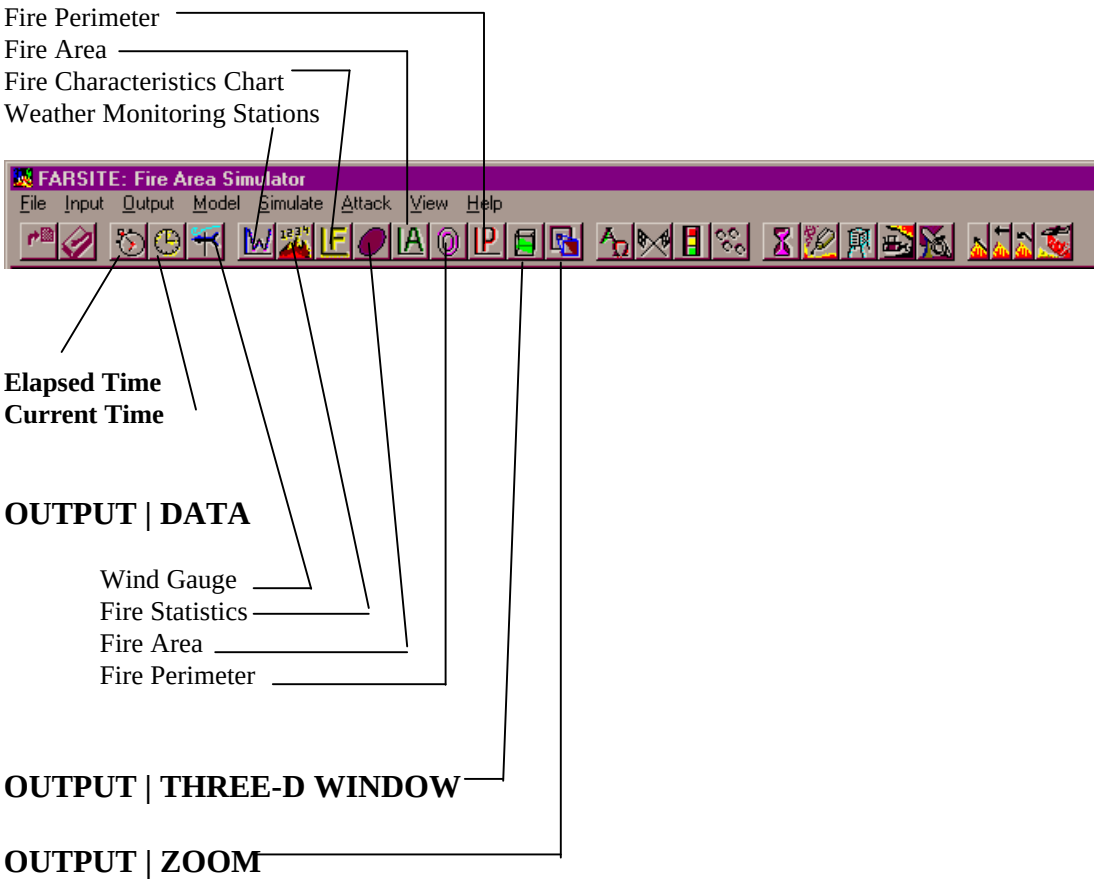
The landscape query feature works when the input mode **to the landscape is "NULL".**

Clicking the **left mouse button** anywhere on the **visible 2D landscape window** will display a resizeable window with all spatial data attributes from that raster cell.

NOTE: the values for **fuels displayed in the query window** are subject to the contents of a fuel conversion file that you may have loaded but not to temporary changes to the landscape made with the Simulate | Modify Map options.

Output Tool Butttons

OUTPUT | GRAPHS

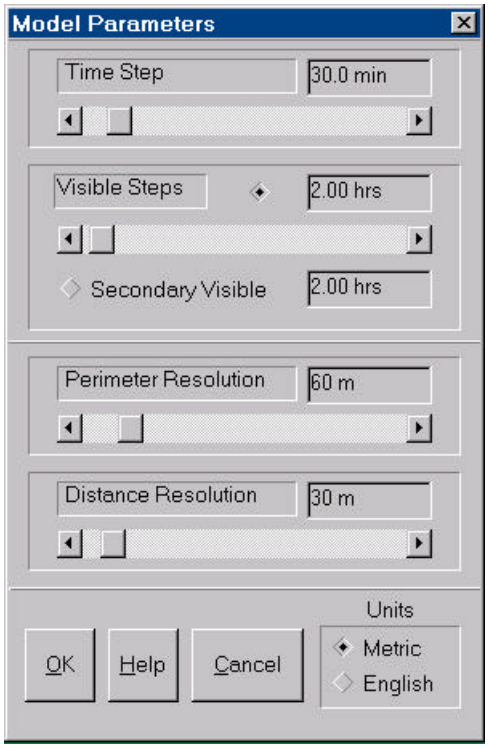


Chapter 7 The MODEL Menu

The Model menu contains selections for controlling operation of the simulation in terms of space and time resolution as well as fire behavior calculations.

Model | Parameters

The model parameters control the temporal and spatial resolution of the simulation. Greater computer processing time is required for shorter time steps and finer distance resolutions. More RAM is also required for finer resolutions. **NOTE**: These parameters must be set for each simulation.



Timestep

Definition
The timestep is the maximum amount of time that the conditions at a given point are assumed constant so that the position of the fire front can be projected. The positions of all fires will be projected over this timestep so that possible mergers can be computed.

Usage
A shorter time-step becomes more appropriate with faster fire spread rates. The heading portion of the fire should be used as the determining factor. However, the following table may be a useful starting point:

TYPE OF FIRE	FUELS	TIMESTEP
surface	timber	~30 to 120+ minutes
surface	brush, dry grass	~10 to 20 minutes
surface extreme or torching/crowning	all	~5 to 10 minutes

The timestep is really of secondary importance compared with the spatial resolution of the calculations (as determined by the perimeter and distance resolutions below). The internal timestep used by the simulation is constantly changing according to the minimum time required for the fire to spread the distance equaling the distance resolution. The actual timestep is thus, only used as a consistent period during which all fires will be projecting to a coincident time before mergers and spotting are computed. Thus, many fires burning in close proximity where spotting is likely should have a shorter timestep. This however, will increase processing time.

Visible Timesteps

Definition
The visible timestep is always a multiple of the actual timestep; it cannot be shorter than the timestep. The fire front will be drawn to the output screen at these intervals. The visible timestep is often set many times longer than the actual timestep to avoid unnecessary temporal detail in fire perimeter positions displayed on the monitor. The visible fire perimeter may be color-coded to reflect various frontal fire characteristics (see Output | Colors).

Usage
The setting for the visible timestep is dependent on the purpose of the simulation in terms of graphically representing fire spread and fire behavior. For example, 1-day visible intervals may provide adequate temporal detail for long simulations (e.g.

weeks); these fire perimeter isochrons however will not reveal diurnal patterns of fire behavior or spread. Shorter simulations or those intended to spatially depict varying fire spread rates throughout a burning-period would likely require timesteps no longer than several hours. **NOTE:** the visible time-step can affect the time resolution of the vector output from the simulation depending on your selections in the **Output | Export & Output** dialog.

FARSITE v.2.0 introduces a **primary** and **secondary** visible time step. The primary visible step must always be set. The secondary visible time step is optional and is set as a multiple of the primary visible step. This is useful for distinguishing fire growth at two meaningful time periods (e.g. hours and days). The secondary visible step will be displayed differently depending on your settings in **Output | Colors** they will be displayed in red if the visible fire perimeter is set to "white" and displayed as "white" if the fire perimeter is color coded by frontal fire characteristics.

Perimeter Resolution

Definition

The perimeter resolution determines the maximum distance between points used to define the fire perimeter. It is a resolution of a fire front in the direction tangential to the fire perimeter at each point. As fire perimeters expand, new points must be inserted between existing vertices along convex portions to maintain the definition of the fire front. The line segments are lengthening between these vertices. By contrast, segments between vertices of concave portions of a fire front become shorter over time and are eventually removed from the front as the vertices cross-over into previously burned areas (see **Technical Documentation**).

Usage

Setting of the perimeter resolution must consider its "importance" in both a relative and absolute sense. Relative to the resolution of the raster landscape, the perimeter resolution determines the amount of landscape information used in the simulation. In an absolute sense, the perimeter resolution defines the scale of possible curvature and detail of the fire front. Both must be weighed in the context of the simulation purpose.

A coarse perimeter resolution will decrease the use of spatial information in computing fire spread. Less information will remain unused, however, for perimeter resolutions shorter than the raster resolution. Using a perimeter resolution that is several times longer than the raster resolution would allow the fire to skip-over variations in fuels or topography that have a finer scale. This can be acceptable where the perimeter resolution matches a scale of interest much coarser than the raster landscape; for example if *FARSITE* is used to simulate fires say 30000ha using a raster resolution 30m resolution.

The perimeter resolution controls the detail of the fire front, both in curvature and in the ability of a fire perimeter to respond to heterogeneities occurring at a fine scale. Finer resolution is necessary to make a spreading fire sensitive to small scale variations in spatial variables (e.g. fuels or topography varying on the scale of a few cells) as well as temporal changes in wind directions. Coarse resolution compared to the raster resolution would limit the potential for fire to spread through narrow corridors of fuel when surrounded by larger areas of non-fuel. Note that there is no gain in meaningful precision when setting the perimeter resolution much lower than about half the native raster resolution.

Setting a meaningful perimeter resolution can be based on the practical knowledge gained through mapping of actual fire fronts. Most fire maps have an implicit resolution, either determined by lack of data or often by the observer's threshold for irrelevant detail. This limit of relevant detail translates directly to a useful perimeter resolution. Until sensitivity analyses have been conducted for known fires or experience suggests otherwise, a logical perimeter resolution would be no more than about twice the raster resolution of 30m.

Distance Resolution

Definition

The distance resolution is the maximum projected spread distance from any perimeter point. This distance cannot be exceeded in a timestep before new fuels, weather, and topography data are used to compute the spread rate (see **Distance Checking** in **Technical Documentation**). It is the resolution in the radial or spreading direction for each point. The values of the distance resolution cannot be greater than the perimeter resolution because of the methods used for detecting and eliminating crossovers. The *FARSITE* program automatically adjusts the distance resolution to a working internal value for each fire that cannot exceed this maximum value. This adjustment is necessary for very small fires that require a fine perimeter resolution and thus a fine distance resolution.

Usage

The distance resolution is somewhat dependent on the perimeter resolution because it cannot exceed that distance because of the potential for complex crossovers on the fire perimeters (see Crossovers Technical Documentation). However, the distance resolution can be set shorter than the perimeter resolution. This would give a greater radial than tangential resolution. Considerations for deciding the distance resolution are similar to those pertinent to the settings for the perimeter. The most logical value for distance resolution would be approximately the same as that for the perimeter.

Model | Fire Behavior

This dialog allows you to modify fire behavior calculations and other options for the simulation.

Crown Fire Calculations

This option enables a surface fire to make the transition to some form of crown fire depending on the crown fuel conditions and surface fire behavior. Selecting this option does not force a crown fire, but allows the *FARSITE* model to determine if transition occurs (see **Technical Documentation**) and adjust fire rate of spread accordingly.

Link Crown Density and Cover

Crown bulk density is critical to determining crown fire spread. This option forces the simulation to use the crown cover attributes for each cell to modify the crown bulk density values for that cell. This will be important to crown fire behavior if you are using constant crown bulk density information for the landscape (see **Canopy Characteristics**) or have specified only the maximum crown bulk densities a spatial GIS theme in the LCP file. DO NOT check this option if your crown bulk density theme in your LCP file contains site specific bulk densities that are already representing actual variability of crown fuels.

Embers From Torching Trees

If the crown fire calculations are enabled, embers may be lofted by torching trees. Embers of a given size class are lofted and their contact points with the landscape are computed by iterating their descent through a modeled wind field.

Growth of Spot Fires

This option will enable a variable percentage of embers that land on receptive fuel to ignite new fires. The simulation will grow each of these as new point ignitions. The slider changes the percentage of live embers that cause ignitions. This option was added beginning with *FARSITE* version 1.1 to allow you to simulate spotting more efficiently. The simulation takes too long for most purposes with the many spot fires started when the ignition probability is 100%.

NWNS Backing ROS

This option forces the use of the No-Wind No-Slope rate of spread for the spread rate of backing fires (Rothermel 1983). This has been proposed as a solution to problems of fire area with increasing windspeed if the origin of fires assumed to coincide with the rear focus of an ellipse (Bilgili and Methven 1990); if not selected, the backing spread rate is computed as a product of elliptical dimensions (see **Limitations and Assumptions**, and **Technical Documentation**).

Expansion Correction

This option attempts to eliminate illogical expansions of the fire perimeter at each timestep. These illogical expansions are caused by small local concavities involving a series of 3 perimeter points; the orientation off these points forces them to cross over previously burned areas. Enabling this option will not affect the fire shape at the scale of the whole fire, but will affect some localized concave portions of the perimeter. These operations also increase the processing time for the simulation.

Burn Methods

Future versions of *FARSITE* will likely permit some options for methods to determine how the simulation controls the spatial and temporal precision of the calculations.

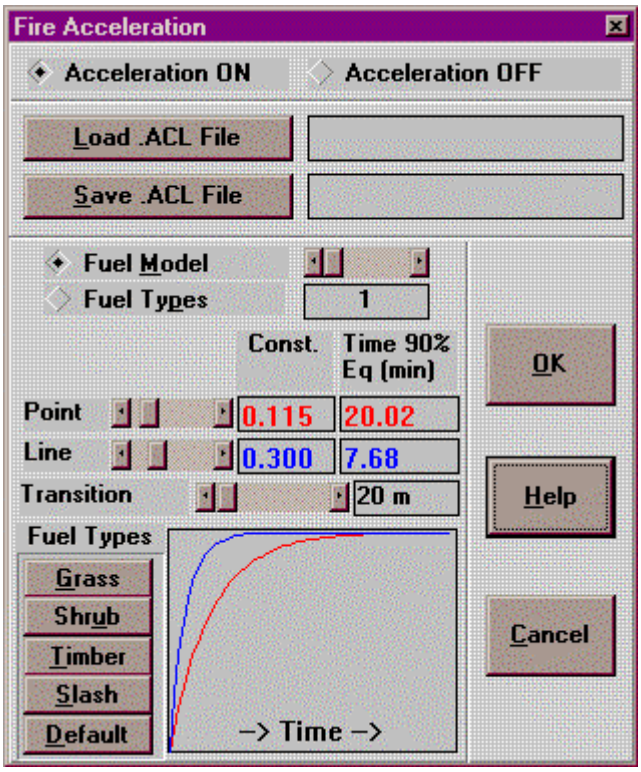
There is currently only one option available in this release of *FARSITE*.

Model | Fire Acceleration

Fire acceleration for each fuel type can be controlled for point and line fires using this dialog. Fire acceleration is defined as **the rate of increase in spread rate/fireline intensity from a given source**.

Point and Line Source Acceleration

Fire acceleration from a point source fire will be slower than from a line fire (see **Technical Documentation** and **Limitations and Assumptions**). The present version of *FARSITE* allows acceleration constants for each "type" of fire to be selected. A point fire is one with a perimeter length shorter than the threshold for **transition** to a line fire. This is an improvement over not using any fire acceleration at all, because changing wind or fuel conditions that create new equilibrium spread rates do not cause immediate changes in fire spread rates.



Fuel Model vs. Fuel Types

This dialog can be used to adjust fire acceleration constants for fuel models individually as well as by "fuel types". A fuel type refers to **grass, shrub, timber, or slash** as the dominant fuel contributing to fire spread. Once defined, these types can be used to quickly assign approximate acceleration constants to the actual fuel models. All acceleration definitions can be saved and retrieved as a binary .ACL file.

To define a fuel "type" click on the fuel type button. Then adjust the **point** and **line** source acceleration constants until you are satisfied with the **90% equilibrium time** for that constant and fuel type. You can also define a "**default**" value in the same way.

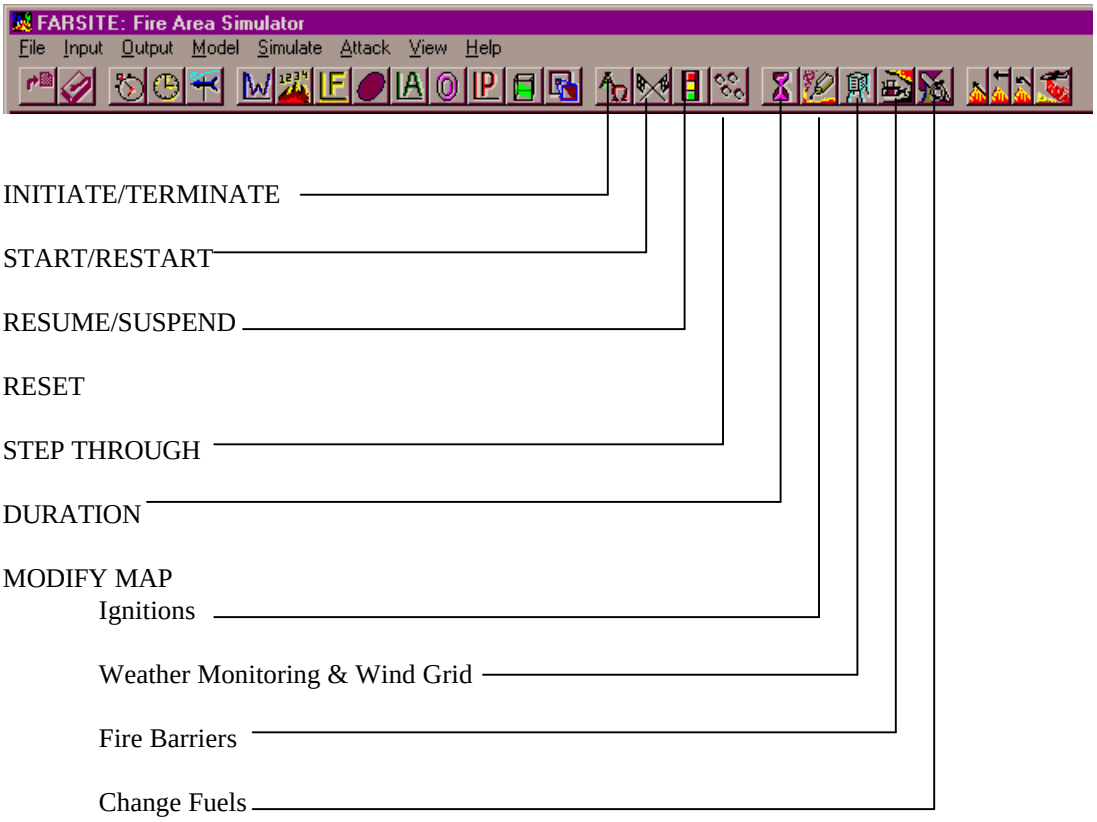
To apply these types to actual fuel models, click on the **fuel model button**. For each fuel model that you select with the slider, click once on the appropriate fuel type buttons on the lower left of the dialog (<GRASS>, <SHRUB>,. <TIMBER>, <SLASH>, <DEFAULT>). Notice that your previously defined values for these fuel types now appear in the constant and 90% equilibrium box.

At any time, you can adjust the values of point and line source acceleration for a fuel model. The intent of the fuel type definitions is to speed the process of assigning of acceleration constants to similar fuel types.

You can **save and retrieve** your settings for fire acceleration using the appropriate buttons on the dialog box. The default extension for these files is **.ACL**.

Chapter 8 The SIMULATE Menu

The Simulate menu contains selections for hierarchically toggling the **starting** and **stopping** of the simulation, setting its **duration**, and locating **ignitions** and **modifications to the landscape**. Note that all of these selections have corresponding tool buttons. The concept of starting and stopping the simulation is hierarchical in a way similar to the organization of an automobile race. A simulation and a race event must be initiated and terminated and have a beginning and ending; during the run the simulation may be suspended and resumed repeatedly depending on actual operating conditions (as with an automobile race). The tool buttons depict these hierarchies as:



Simulate | Initiate/Terminate

A simulation is initiated once and terminated once. After specifying all the required data (landscape, winds, weather, fuels), the landscape is displayed by toggling the **Simulate | Initiate/Terminate** item or by pressing the **Alpha/Omega** tool button. Toggling this selection again will erase the fuelscape, erase all simulation data, and require the entire process of data specification to be repeated. A message-box warns the user that terminating the simulation will have these results and force all data files to be input a new project file to be retrieved, or a new bookmark file to be retrieved.

Simulate | Start/Restart

Once the required run-time parameters have been selected (**Model | Parameters**, **ignitions**, **duration**) the **Simulate | Start/Restart** menu item or **Checkered Flag** tool button will toggle the beginning the simulation. Toggling this selection again will reset all run-time simulation parameters and output specification, and re-display the original fuelscape. **NOTE**: all of your selections for output vector and raster files will be closed and **new output files must be specified after resetting**. A message box advises of these consequences before resetting the simulation. This selection duplicates the Simulate | Reset selection once the simulation has been started.

NOTE: If you want to have your **ignitions restored after toggling restart**, select the simulation option "**Restore Ignitions At Reset**" (see **Simulate | Options**),

Simulate | Resume/Suspend

At any time during the running simulation, the **Simulate | Resume/Suspend** item or **Traffic Light** tool button can be toggled to suspend the simulation. The operating status of the simulation will be displayed on the message bar at the bottom of the output screen (SIMULATION RUNNING or SIMULATION SUSPENDED). Suspending the simulation is recommended before performing modifications to the landscape or to the output features of *FARSITE* once the simulation is underway. Although it is possible to make selections and changes without suspending an active simulation, delays with screen output and message response can make feedback to the user difficult. Toggling the **Simulate | Resume/Suspend** item or tool button again will resume the simulation.

NOTE: it may take up to a few minutes for the simulation to be suspended after selecting the suspend option. Some *FARSITE* processes cannot be interrupted to allow user input and must be completed before the user can make changes to the inputs, outputs, or parameters of the simulation. **DO NOT MAKE REPEATED TOGGLES** as an attempt to elicit a simulation response. Successive toggles cancel each other!!!

Simulate | Step Through

The "step through" feature will advance the simulation one visible timestep at a time. This is easier than having to repeatedly reset the duration (see **Simulate | Duration**) for short time increments and then resume the simulation.

The step through feature is useful when you are using the Attack features of *FARSITE* and you need to make or change the tactical suppression decisions on a regular basis.

Simulate | Reset

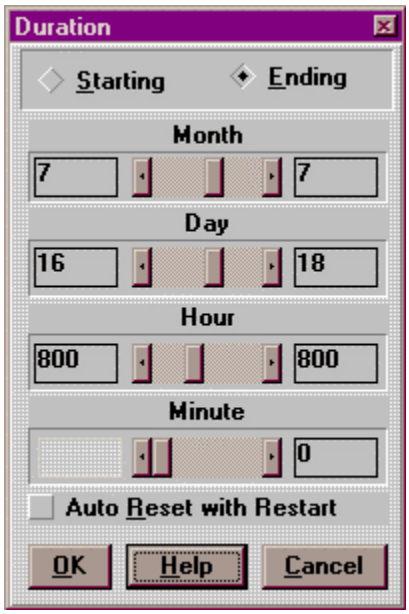
Using the **Simulate | Reset** selection instead of **Simulate | Start/Restart** may be necessary if the simulation has been initiated (e.g. landscape displayed) but modifications or input to the landscape need to be reset before the simulation has been started. **NOTE**: all of your selections for output vector and raster files will be closed and **new output files must be specified after resetting**. A message box advises of these consequences before resetting the simulation.

NOTE: This option does not have a corresponding tool button.

NOTE: Resetting the simulation will erase all ignitions, even if you have selected the "Restore Ignitions at Reset" option in the **Simulate | Options** dialog. This is different than toggling restart (**Simulate | Start\Restart**).

Simulate | Duration

The Start time and Duration of the simulation are set with the Duration dialog. The start date and time are set by selecting the **Start** button and using the sliders to enter the desired values for Month, Day, and Hour into the boxes on the left side of the dialog. The same sliders control the **End** date and time when the Ending button is selected.



These are selected using the radio buttons on the duration dialog. You cannot set the starting or ending times of the simulation before the first day of your wind stream or weather stream or after the last day of these data streams. For this reason, the wind and weather stream file must be loaded before the duration can be set.

The **optional** check box "**Auto Reset With Restart**" indicates that the dates will be reset if you restart or reset the simulation. This will force you to reenter the simulation duration for the next simulation. **NOTE**: This is the same option as listed as "**Reset Duration at Restart**" in the **Simulate | Options** dialog.

Simulate | Modify Map

The Modify Map selection accesses options that are used to input changes to the Landscape window. Most of these selections also have corresponding tool buttons on the tool bar. All of these selections are toggles and change the "Input Mode" displayed on the message bar at the bottom of your screen. "NULL MODE" indicates that no inputs to the landscape are possible.

The landscape map can be modified in terms of:

1. ignitions (mouse located, or imported ignition file)
2. weather monitoring stations/weather-wind grid
3. fire barriers, and
4. fuel changes

Selecting any of these modifications will change:

1. the input status displayed in the message box at the bottom of the screen,
2. the shape of the cursor (when over the landscape window) to reflect the type of input,
3. display Easting and Northing coordinates of the cursor on the landscape (upper left)

NOTE: toggle all modifications to the off position to avoid unintended inputs to the landscape when resizing or moving the landscape window. Inputs are automatically toggled off when the simulation is started or resumed.

Simulate | Modify Map | Locate Ignitions

Ignitions are a **required** input to the landscape before the simulation can be started (no kidding).

The mouse cursor is used to point to an ignition location. The left button is used to click the coordinate of the ignition location. The way you end the input for a given fire determines the type of ignition. Three types of ignitions can be set on the landscape depending on the pattern of mouse-button clicks:

Point Ignition

One <**left button click**> followed by one <**right button click**>. All point ignitions have a starting rate of spread of 0.0.

Area Ignition

A series of <**left button clicks**> ending the polygon with a <**right button click**>. This will create a closed polygon defining an active outward burning fire perimeter. You should not try to close the polygon; this is done automatically after the right button click.

Line Ignition

A series of <**left button clicks**> ending with a <**double click>** with the **left** mouse button. The number of left button clicks determines the number of segments of the line ignition.

When setting an area or line ignition, you have the option of setting the current rate of spread for each perimeter point. This affects the starting value of spread rate for fire acceleration in the subsequent time step. You can adjust the initial spread rate by

selecting the "**Adjust Ignition Spread Rate**" checkbox in the **Simulate | Options** dialog. Then, your line and polygon ignitions can be set to any percentage of the calculated equilibrium spread rate when the simulation is started or resumed. The inputs are made using the slider in a spread rate window that appears after the second input point. The rate of spread for **line and polygon ignitions** is assumed to be at **100% of the equilibrium spread rate** if this option is disabled.

NOTE: Unless the "**Rotation Sensitive Ignition Patterns**" option is CHECKED in the **Simulate | Options** dialog, all of your ignitions will be outward burning fires (e.g. expanding in area). **Otherwise, polygon ignitions oriented clockwise will burn inward (such as around an island or enclave) and those oriented counter-clockwise will burn outward**. Be sure of the options settings before locating ignitions.

COMMENTS ON IGNITION PATTERNS

It is important to realize that not all ignition patterns possible in a *FARSITE* simulation are logical or will result in logical fire spread and behavior. Results can be misleading if the assumptions of the simulation are ignored (see **Limitations and Assumptions**). A few considerations are listed here:

Multiple spot ignitions, **line ignitions**, or **area ignitions**

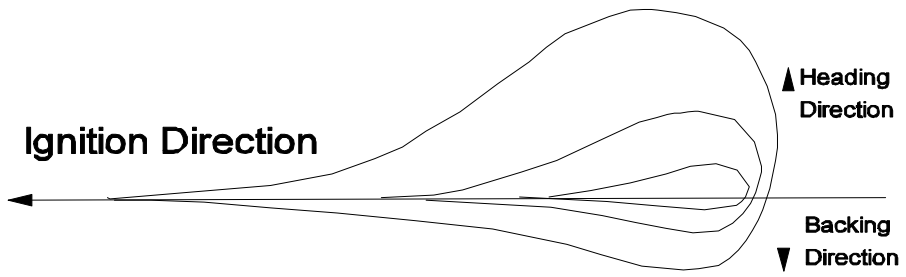
These will not interact as individual fires merge. In prescribed fire situations for example, mass-fire behavior from multiple spot ignitions results because of the interaction between the fire and weather (winds and temperature) and fuels (heating and moisture). Another example would be strip head fires or "back" fires normally placed and timed to take advantage of fire interactions. None of these interactions or the resulting fire behavior are addressed by *FARSITE*.

Line Ignitions

Line ignitions are often really area ignitions as represented at a given instant in time. A true line ignition could only occur if an entire line were lit instantaneously. If fire acceleration and spread rates are slow, a continuous line ignition may look linear for a few minutes. However, as line ignition proceeds with a torch for example, the "line" becomes a somewhat triangle-shaped area being extended in a straight line from one apex. The actual shape of the above fire is determined by the acceleration of the fire front that probably depends on the length, shape, and time since ignition at a given point along the perimeter, assuming fuels, slope, and winds are constant.

Avoid **line or area ignitions** with crossing lines. Area and line ignitions that form crossovers (e.g. a "figure-8") may not have the intended results depending on your selection of "**Rotation Sensitive Ignition Patterns**" in the **Simulate | Options** dialog. With typical ignition procedures in prescribed fire

situations, these ignition patterns would be extremely unlikely. The *FARSITE* program analyzes each fire for crossovers in order to preserve the meaningful outer perimeter (see **Technical Documentation**). *FARSITE* version 3.0 is capable of finding the outer fire perimeter even with very complex knots on a fire polygon ignition. You can override this feature by selecting the "Rotation Sensitive Ignition Patterns" option to force enclaves or "inward burning" fire fronts.



Mistaken Ignition Inputs

If you make a mistake before terminating your ignition input, you can have your input **ignored** by *FARSITE* by **re-selecting any of the tool buttons or menu selections**. Continue your map modifications and your mistake will be "grayed" and ignored by the simulation. You can also use the **Simulate | Reset** selection to reset all of your landscape inputs.

Simulate | Modify Map | Import Ignition File

Ignition points, lines, or polygons may be imported to a *FARSITE* landscape from:

- a GRASS ASCII file,
- an ARC/INFO UNGENERATE ASCII vector file, and
- an ARCVIEW shapefile

NOTE: both GRASS and ARC ASCII vector files must be **in single precision format, no double precision values!!**

This feature allows you to use existing fire perimeters from GIS data as starting locations for a fire simulation. Selecting the **Simulate | Modify Map | Import**

Ignition File will bring up a file selection dialog. You can only select one file at a time, but can repeat the procedure to bring in ignitions from multiple files.

See COMMENTS ON IGNITION PATTERNS in Locate Ignitions

Simulate | Modify Map | Export Current Fire Perimeter

Your current fire perimeters can be exported to two types of vector files:

- ARC UNGENERATE ASCII vector file (default), or
- an ARCVIEW shapefile (polygons) by specifying a **.SHP extension** on the filename

You can export your fire perimeters at any time during the simulation. You can then use the **Simulate Modify Map | Import Ignition File** selection to import this file as polygon ignition sources. For example, you might want to export your ignitions before you start the simulation so that you can import and use them for later simulations.

NOTE: Only outward burning fire perimeters will be exported (e.g. expanding in area); your inward burning fires (e.g. around enclaves) will not be exported or imported into *FARSITE*. Use the bookmark feature (**Input | Bookmark**) to save your entire simulation (including all fire perimeters), or use the "**Restore Ignitions at Restart**" option in the **Simulate | Options** dialog.

Simulate | Modify Map | Weather Monitoring & Grid

This selection is Optional for running *FARSITE*.

This selection has two functions:
1) to allow you to set the location for "weather monitoring stations" that monitor weather at a particular location, and
2) to enable you to make use of multiple weather/wind streams by customizing the resolution and spatial location of those streams on the landscape.

When you first activate this selection, you'll notice that a second window appears with the landscape image; this window has the caption "Weather/Wind Stream Grid". **NOTE**: the cursor will acquire the shape of a weather station when placed over the landscape window, but not the Weather/Wind Stream Window.

Locating a Weather Station:

A **weather monitoring station** is a location you specify from which weather and fuel moisture information is to be collected and displayed graphically **(these are NOT the locations of weather stream inputs!!)** . These graphs display cumulative strip-charts of temperatures and humidities on one graph, and fuel moistures on another graph.

Up to 5 stations can be located on the landscape. **A weather station is located by positioning the mouse cursor over the desired spot on the landscape and clicking the left mouse button.** This will result in a numbered marker being placed at that location in the landscape window. You can display the weather and fuel moisture information from each weather station by pressing the **"W"** tool button or selecting the **Output | Graphs | Weather** menu item. The resulting dialog contains checkboxes for displaying fuel moisture and/or temperature graphs by weather station.

Customizing a Weather/Wind Grid:

Customizing a weather/wind grid only works in the **Weather/Wind Stream Grid** window.

BEFORE YOU BEGIN: You must have already loaded more than 1 weather stream AND more than 1 wind stream; you also must have the same number of weather and wind streams to use multiple weather/wind stream indexes.

Right Mouse Button Controls the Grid Resolution

Use the right mouse-button to change the resolution of the grid, depending on where the mouse cursor is located in the window**.** To adjust the resolution of the grid in the North-South direction, i.e. to make it finer, move the cursor to the top of the window and click the right mouse button until the grid is of the desired dimension. Move the cursor to the far right of the window and click the right mouse button to make it finer in the East-West direction. Placing the mouse at the bottom or left of the window when you make a right-click will have the opposite effect on resolution in the respective directions.

NOTE: You can only change the Grid Resolution when the viewport is set at **maximum** (e.g. the full extent of the LCP file). You can however, change the Weather/Wind stream index for any cell at any viewport extent.

Left Mouse Button Controls the Weather/Wind Stream Index

To change the weather/wind stream index of a given grid cell, position the cursor in that cell and press the left mouse button. This will increment the index number of the weather/wind stream corresponding to that grid-cell. Incrementing beyond the number of available weather/wind stations will reset the index to 1. **NOTE:** all cells will reset to weather/wind stream 1 when the resolution is adjusted with the right mouse button.

Toggle the Weather Station Button or menu selection to erase the weather/wind stream Grid Window

Once you are satisfied with the way a grid is customized, you should make or save the project file so that these settings will be retained in that project for future uses.

Simulate | Modify Map | Barrier(s)

Barriers are an Optional input to *FARSITE*.

New to *FARSITE* version 3.0, barriers will NOT be erased if you change the viewport (see **View | Change View Port**).

The fire barriers option and tool button (**bulldozer**) can be used to place an absolute fire barrier on the landscape. This barrier is impermeable to a surface or crown fire, but not to spot fires. Embers may be transported over the barrier. A barrier can be useful for stopping a fire along pre-determined routes (e.g. ridges or stream channels). It may also be useful for inactivating a portion of a fire perimeter that has, would, or should become extinguished; this may be done by stopping the simulation and tracing outside that portion of the perimeter with the dozer. **NOTE**: this may not work if the current fire position is beyond the most recent visible fire perimeter.

The mouse cursor is used to locate the fire barrier and **left mouse-button clicks** are used to secure points along the barrier. The barrier will show up as a **white** line until terminated with a **right mouse button click** when it will be redrawn in **black** with the calculated width. **BE SURE TO terminate the Barrier with a right button click** before inputting any further map modifications, otherwise the barrier won't work.

Mistaken Barrier Inputs

If you make a mistake before terminating the barrier, you can have your input ignored by *FARSITE* by re-selecting any of the tool buttons or menu selections. Continue your map modifications and your mistake will be "grayed" and ignored by the simulation. You can also use the **Simulate | Reset** selection to reset all of your landscape inputs.

Simulate | Modify Map | Import/Export Barriers

This feature allows you to import/export vector files to serve as barriers. Two file formats are supported:

- ARC UNGENERATE ASCII files, and
- ARCVIEW **shapefiles** (polylines)

NOTE: ARC ASCII vector files must be **in single precision format, no double precision values !!**

When imported, these files will be buffered as fire barriers. The width of the fire barrier will be set according to the distance resolution you've specified in **Model | Parameters,** thus you must set the parameters first, before you can import on of these files. You can use any vector attribute as the basis for a fire barrier (e.g. streams, roads etc).

Simulate | Modify Map | Change Fuels

Fuel Changes are an Optional Input to *FARSITE*

This selection allows minor **temporary** modifications to the fuel map. These are not permanent modifications to the .LCP file (see **Input | Landscape Utilities | Edit Landscape** for permanently editing landscape files).

These changes will be erased if you change the view port.

This feature is only intended to provide some flexibility in adjusting the distribution of fuel types when small inaccuracies in the GIS fuel theme are found. Wide disparities between actual fuels and GIS fuels data need to be rectified on the GIS, not in *FARSITE*. You can also use a fuel conversion file to reclassify fuel models in the landscape file for use during the simulation.

Fuel changes are made by defining polygons for a specific fuel type. Polygons are defined with the mouse cursor, using a **left mouse button click** to establish vertices of the polygon. A **right button click** closes the polygon and fills it with the color for the specified fuel type. A fuel type dialog will appear after the first **left button click**. **Make sure this dialog is moved outside the landscape window when changing fuels otherwise the dialog will be hidden by the landscape during input**. This dialog contains a slider to select the fuel model (this model corresponds to the fuel model in the fuel model file not the GIS theme (if conversion has been necessary), and a **CHANGE** button to select that fuel type as the intended type for the fuel polygon. The **CHANGE** button must be pressed to change the fuel type. No more than 12 fuel models can be changed, although any number of polygons can be changed per fuel model. **NOTE**: a fuel model must exist prior to the changes, else the polygon will be filled with the color black indicating "NO FUEL". This can be used to force the formation of enclaves.

Mistaken Fuel Inputs

If you make a mistake before terminating the fuel input, you can have your input ignored by *FARSITE* by re-selecting any of the tool buttons (or menu selections). You can then continue your map modifications and your mistake will be "grayed" and ignored by the simulation. You can also use the Simulate | Reset selection to reset all of your landscape inputs.

Simulate | Options

This selection allows you to change some settings that affect the way your simulation works. The follow options are available:

Reset Duration At Restart

This option is identical to that in the Simulate | Duration dialog. When UNCHECKED, it allows you to restart or reset a simulation without changing the start and end times for the simulation. Checking this option will always reset the duration parameters when you restart or reset the simulation-- you will then provide new start and end times for subsequent simulations.

Restore Ignitions At Restart

When checked, this option will restore your ignitions when the simulation is **RESTARTED** (not **RESET**) See **Simulate | Start/Restart** or **Simulate | Reset**. The ignitions will be restored as they existed at the beginning of the simulation. If left unchecked, you must enter new ignitions for subsequent simulations.

Rotation Sensitive Ignition Patterns

When this option is **UNCHECKED**, all of your ignitions will produce outward burning fires (e.g. fires increasing in area or expanding outward). Your ignitions of fire polygons are screened for the rotation direction (clockwise or counterclockwise) and reversed if found to be oriented clockwise. This screening and correction process is bypassed when this option is **CHECKED** and allows you to produce inward and outward burning fire polygons. **COUNTERCLOCKWISE** polygons will burn **outward**, and **CLOCKWISE** polygons will burn **inward**.

Display Fire Growth as Completed

This option only affects the **display** of fire growth not the simulation process. When this option is checked (default) the simulation will draw fire perimeter growth as it is calculated (i.e. when more than one fire is simulated, fires will appear to grow one-at-a-time). Unchecking this option will display growth of all fires simultaneously by delaying drawing until a timestep is completed.

Adjust Ignition Spread Rates

This option allows you to adjust the initial spread rate for **line and polygon ignitions.** This option will open a small dialog box when you attempt to input a line or polygon ignition using the **Simulate | Modify Map | Locate Ignition** selection. This dialog can then be used to adjust, on a point-by-point basis, the percentage of the equilibrium spread rate assigned to the vertices of the point or line fire.

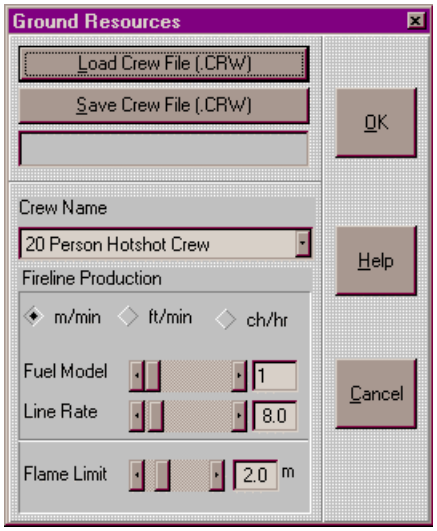
Chapter 9 The ATTACK Menu

The Attack Menu contains selections for loading ground resource files (.CRW) and air resources files (.AIR) and for assigning these resources to perform suppression activities.

Attack | Ground Resources

Ground resources are stored in files with the default extension .CRW. These files describe the capabilities of different crews that you can use for fire fighting operations such as Direct, Indirect, and Parallel attacks. The crew capabilities include:

1. Name/description of crew,
2. Rate of line building by fuel model,
3. Flame length limitations for direct attack



The easiest way to develop the crew profile above is to use an ASCII editor to create a crew file as shown in **Appendix 1**. This crew file can then be loaded into the simulation.

For each crew type, you need to define a name by which you will identify that crew when you assign resources for initial attack. For example, you might define a crew type as a "*20-person hotshot*" crew, "*5-person squad*", or a "*Tractor Crew*". You can use any name to describe the attack capabilities of that crew. The crew name must begin and end with # signs but OTHERWISE DO NOT USE '#' SIGNS IN THE CREW NAME.
The format for the .CRW file is:

Format	**Comments**
#Name of 1st Crew#	(bracket the "name" with #
units	(see below)
FLAME_LIMIT 0.0	(meters or feet depending on "units" above)
fuel_model line_production_rate	(fuel_model **integer** & line_production_rate **decimal**)
fuel_model line_production_rate	
fuel_model line_production_rate	
99	(end with 99 for no fuel, **don't specify line rate**)
#Name of 2nd Crew#	(append other crew descriptions at the bottom...)
etc.	

You have 3 choices for units of line production that also imply how the flame limit is interpreted. These units are constant for all inputs in a given crew. Your units must be specified in one of the following ways:

units for *line_production_rate*	**units for FLAME_LIMIT**
METERS_PER_MINUTE	meters
FEET_PER_MINUTE	feet
CHAINS_PER_HOUR	feet

For each fuel model on your landscape you will need to define the ***flat terrain*** **rate of line production**. *FARSITE* assumes that the rate of **line production is constant along the ground surface**, meaning that horizontal rate of line production on sloping terrain will be slower than on flat land. To acquire realistic numbers for line production in your fuel types you will need to use your experience and/or consult some of the research literature that reports these rates (see below). *FARSITE* assumes no decrease in line building rate resulting from crew fatigue (see **Limitations and Assumptions**).

Another way of defining crew information is to edit the values directly in the Ground Resources dialog and then save the file. Do this by selecting the "**Define New Crew**" item from the "crew name" list box. You will be prompted for a name/description of the crew. After entering the crew name, you will need to define the flamelength limit for direct attack and the line production rate for each fuel model in your simulation.

The following references might be useful for determining the rate of line production for your fuel models:

Barney, R.J., C.W. George, and D.L. Trethewey. 1992. Handcrew fireline production rates -- some field observations. USDA For. Serv. Res. Pap. INT-457.

Fried, J.S. and J.K. Gilless. 1989. Expert opinion estimation of fireline production rates. For. Sci. 35(3):870-877.

Haven, L., T.P. Hunter, and T.G. Storey. 1982. Production rates for crews using hand tools on firelines. USDA For. Serv. Gen. Tech. Rep. PSW-62.

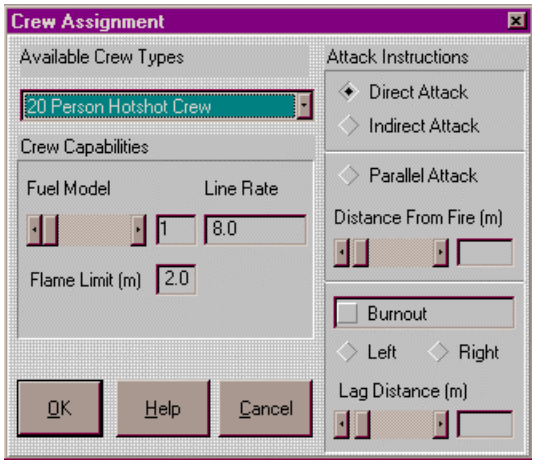
Perry, D.G. 1990. Wildland Firefighting: Fire behavior tactics & command, 2nd Edition. Fire Publications Inc, Bellflower CA.

Phillips, C.B. and R.J. Barney. 1984. Updating bulldozer fireline production rates. USDA For. Serv. Gen. Tech Rep. INT-166.

Quintilio, D., P.J. Murphy, and P.M. Woodard. 1988. Production guidelines for initial attack hotspotting. Fire Management Notes 43(2) 6-9.

Attack | Direct Attack

Direct attack is defined as the building of impermeable fireline directly along an actively burning fire front. **NOTE: you must have loaded or defined your Ground Resources (.CRW file) before you can perform a direct attack.** You can initiate as many attacks per fire or during the simulation as you want to.



To initiate a direct attack you need to do the following:

1. Assign a crew to perform the attack,
2. Identify the location on a specific fire perimeter that you want to start building fireline, and
3. Identify the direction along the perimeter that the line is to be built

These steps are accomplished as follows:

Assign a crew to perform the attack

1. Select the **Attack | Direct Attack** menu item or click the appropriate tool button,
2. On the "**Crew Assignment**" dialog, select the crew from the list box of "**Available Crew Types**", you will be able to review the crew's capabilities with the controls on the dialog. To change these capabilities however, you must cancel and return to the "**Ground Resources**" dialog,
3. Press **<OK>**, the follow the directions below.....

Identify the location to start building fireline

(note that the cursor shape should change when moved to the landscape window to reveal a "pulaski and shovel")

4. Use the mouse to **locate a point just inside a visible fire perimeter**,
5. **<Left Click>** to secure that point, then...

Identify the direction to build line around the fire perimeter

6. Move the cursor **outside the fire perimeter in the direction you want to build line,**
7. **<Left Click> to make a line segment and <Right Click>** to end the input. Successful input will be identified by 1) a change in the cursor shape, and 2) the placement of an arrow on the starting point that you've identified that points in the direction the attack will proceed.

Interpreting a Direct Attack

A direct attack will extinguish successive portions of a fire perimeter. These will be displayed as stationary black segments along the perimeter. You can assign any number of attacks to a given fire perimeter going any direction around the fire front. Once a direct attack encounters an inactive portion of a fire perimeter (e.g. along a barren area, fire barrier, or perimeter segment that has already been suppressed) the attack will automatically proceed along that fire perimeter looking for active fire perimeter segments to suppress.

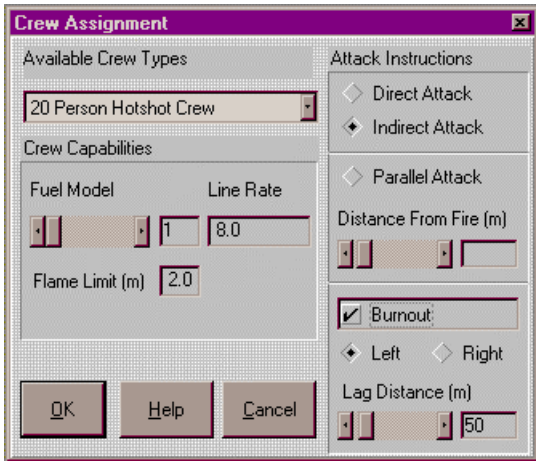
Once an attack has begun, you can revise the tactics for it by selecting **Attack | Revise Attack**. For example you might want to suspend it, change it to indirect, or cancel the attack altogether.

Log File of Ground Attack Activities

When any attack is finished or the simulation is restarted or reset, a log file (GRNDATTK.LOG) is written in the current directory and lists the **crew type, the type of suppression tactics used, the duration of the attack, and the length of line built**. This information can be useful for estimating costs associated with suppression activities.

Attack | Indirect Attack

An indirect attack is defined as the building of impermeable fireline along a pre-determined route, independent of the direction or pattern of fire growth. This line is not meant to contact the active fire front until after line construction is finished. **NOTE: you must have loaded or defined your ground resources before you can perform an indirect attack.** You can initiate as many attacks per fire or during the simulation as you want to.



To initiate an indirect attack you need to do the following:

1. Assign a crew to perform the attack,
2. Identify the route that the crew will follow in building line.

These steps are accomplished as follows:

Assign a crew to perform the attack

1. Select the **Attack | Indirect Attack** menu item or click the appropriate tool button. Note that the "**Indirect Attack**" button is selected as one of the "Crew Instructions".
2. On the "**Crew Assignment**" dialog, select the crew from the list box of "**Available Crew Types**", you will be able to review the crew's capabilities with the controls on the dialog. To change these capabilities however, you must cancel and return to the "**Ground Resources**" dialog,
3. Decide if you want the crew to conduct **a burnout operation** from the newly constructed fireline by checking the "Burnout" checkbox. If so, you need to decide **carefully** which side of the fireline you want to burnout (from the crews perspective, either left or right). You also need to specify the distance behind the advancing fireline that burnout should begin.
4. Press **<OK>**, the follow the directions below.....

Identify the route the crew will follow in building fireline

(note that the cursor shape should change when moved to the landscape window to reveal a "pulaski and shovel")

5. Use the mouse cursor to **locate the starting point** of the indirect line by making a **<Left Click>**
6. Continue making a series of **<Left Clicks>** to draw the route of line construction,
7. Finish by making a single **<Right Click>.** When finished, an arrowhead will be drawn at the starting point showing the direction that the crew will move.

Interpreting an Indirect Attack

An indirect attack will proceed in increments along the predetermined route. You will see progressive lengthening of a gray colored bar. Its width will be automatically determined by your choice of distance resolution. If burnout is enabled, you will see a line of fire ignited progressively along the side of the indirect line, and lagged by the distance selected in the Crew Assignment dialog.

Once an attack has begun, you can revise the tactics for it by selecting **Attack | Revise Attack.** For example you might want to suspend it for a while, eliminate burnout operations, or cancel the attack altogether.

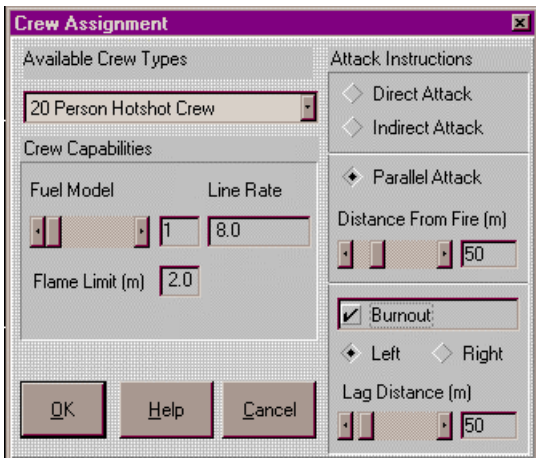
Log File of Ground Attack Activities

When any attack is finished or the simulation is restarted or reset, a log file (GRNDATTK.LOG) is written in the current directory and lists the **crew type, the type of suppression tactics used, the duration of the attack, and the length of line built**. This information can be useful for estimating costs associated with suppression activities.

Attack | Parallel Attack

A parallel attack involves building fireline at a fixed distance from an active fire front and in a direction parallel to it (i.e. tangential). You must have loaded or defined your ground resources before you can assign a parallel attack. Parallel attack is

implemented to minimize the horizontal length of fireline produced. This is accomplished by preventing the attack crew from entering concave portions of the fire perimeter (**Technical Documentation**). Instead, it proceeds around the fire front always maintaining a convex fireline shape.



The procedure for initiating a parallel attack is similar to that used for direct attack except for some additional **attack instructions**:

1. Assign a crew to perform the attack and specify **attack instructions**,
2. Identify the location on a specific fire perimeter that you want to start building fireline, and
3. Identify the direction along the perimeter that the line is to be built

These steps are accomplished as follows:

Assign a crew to perform the attack

1. Select the **Attack | Parallel Attack** menu item or click the appropriate tool button,
2. On the "**Crew Assignment**" dialog, select the crew from the list box of "**Available Crew Types**", you will be able to review the crew's capabilities with the controls on the dialog. To change these capabilities however, you must cancel and return to the "**Ground Resources**" dialog,
3. Select the distance from the active fire front to be maintained by the parallel attack.
4. Decide if you want the crew to conduct burnout operations as it proceeds (check the Burnout Checkbox). If so, you need to decide **carefully** which side of the fireline you want to burnout (from the crews perspective, either left or right). You also need to specify the distance behind the advancing fireline that burnout should begin.

5. Press **<OK>**, the follow the directions below.....

Identify the location to start building fireline

(note that the cursor shape should change when moved to the landscape window to reveal a "pulaski and shovel")

6. Use the mouse to **locate a point just inside a visible fire perimeter**, **NOTE** you will not be able to conduct a parallel attack against an inward fire front!! Use Direct Attack for this task.
7. **<Left Click>** to secure that point, then...

Identify the direction to build line around the fire perimeter

8. Move the cursor **outside the fire perimeter in the direction you want to build line,**
9. **<Left Click> to make a line segment and <Right Click>** to end the input. Successful input will be identified by 1) a change in the cursor shape, and 2) the placement of an arrow on the starting point that you've identified that points in the direction the attack will proceed.

Interpreting a Parallel Attack

A parallel attack builds increments of fireline parallel to the existing fire perimeter at some fixed horizontal distance. As with the indirect attack, parallel fireline construction is represented as a progressively longer gray bar. You can assign any number of parallel attacks to a given fire perimeter going any direction around the fire front. If a parallel attack encounters an inactive portion of a fire perimeter (e.g. along a barren area, fire barrier, or perimeter segment that has already been suppressed) the attack will rapidly advance along that line looking for active fire perimeter segments to suppress. If the parallel attack encounters a locally concave region of the fire perimeter, it will digress to intercept the opposite side of the concavity and thus minimize the amount of fireline produced. If you have selected the burnout option, a line of fire will be ignited on one side of the advancing fireline.

Once an attack has begun, you can revise the tactics for it by selecting **Attack | Revise Attack**. For example you might want to suspend it, change it to direct or indirect, or cancel the attack altogether.

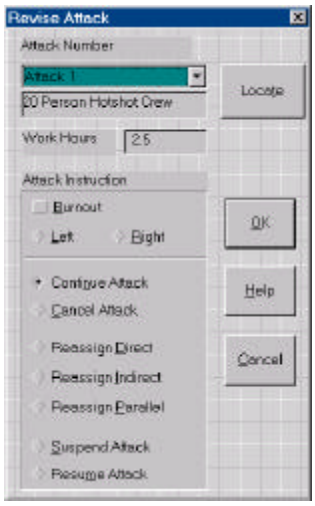
Log File of Ground Attack Activities

When any attack is finished or the simulation is restarted or reset, a log file (GRNDATTK.LOG) is written in the current directory and lists the **crew type, the type of suppression tactics used, the duration of the attack, and the**

length of line built. This information can be useful for estimating costs associated with suppression activities.

Attack | Revise Attack

After an attack is underway, you may want to revise the tactics associated with it. The Revise Attack feature allows you to change a number of the attack instructions.



Select the "**Locate**" button to see the current location of your attack crews. Crews are identified by an **Attack Number** that is unique to each attack. Selecting an attack in the listbox will redraw that attack number in the landscape window on top of other attacks. **Work Hours** are the number of hours that the crew has been actively building fireline.

- **Direct Attack** crew locations are identified by **red** circles.
- **Indirect Attack** crew locations are identified by **blue** circles.
- **Parallel Attack** crew locations are identified by **purple** circles.

You can then **select the Attack Number** to revise by the number shown on the landscape window. The following changes can be made to the attack instructions:

Burnout

You can enable or disable the burnout option for indirect attack and change the side of the line on which burnout is conducted.

Continue

This is the default option.

Cancel

When checked this option cancels the selected attack.

Reassign Direct

You can reassign any attack (direct, indirect, parallel) to become a direct attack. After leaving this dialog you must follow the procedure for locating a direct attack **starting from steps 4-7** in the **Attack | Direct Attack** dialog.

Reassign Indirect

You can reassign any attack (direct, indirect, parallel) to become an indirect attack. After leaving this dialog you must follow the procedure for locating an indirect attack **starting from steps 4-6** in the **Attack | Indirect Attack** dialog.

Reassign Parallel

You can reassign any attack (direct, indirect, or parallel) to become a parallel attack. After leaving this dialog you must follow the procedure for locating a parallel attack **starting from steps 6-9** in the **Attack | Parallel Attack** dialog.

Suspend Attack

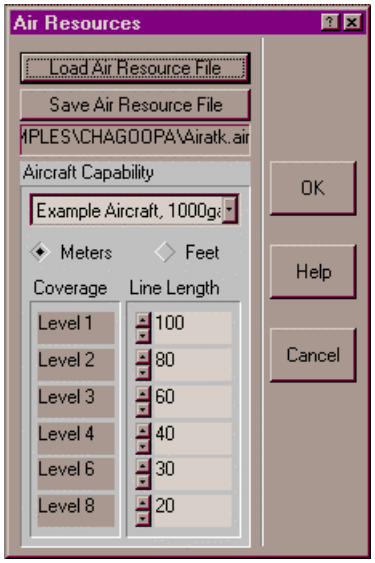
You can suspend any attack and then resume it later.

Resume Attack

After suspending an attack you can resume it from its current location.

Attack | Air Resources

Air resource file (.AIR) contains information on the aircraft name and its capabilities. The capabilities include only the retardant line length by coverage level (see the example file in **Appendix 1**).



The format for the .AIR file is as follows:

Format		**Comments**
#Name of 1st Aircraft #		(bracket the "name" with #
units		(see below)
1	*Line Length*	(coverage level 1 & line length **decimal**)
2	*Line Length*	(coverage level 2 & line length **decimal**)
3	*Line Length*	(coverage level 3 & line length **decimal**)
4	*Line Length*	(coverage level 4 & line length **decimal**)
6	*Line Length*	(coverage level 6 & line length **decimal**)
8	*Line Length*	(coverage level 8 & line length **decimal**)
#Name of 2nd Aircraft #		(append other crew descriptions at the bottom...)
etc.		

For each aircraft type, you need to define a name by which you will identify that aircraft when you assign resources for an air attack. For example, you might define an aircraft as a "*DC-6, 2000 gal*". You can use any name to describe the attack capabilities of that aircraft. The aircraft name must begin and end with # signs but OTHERWISE DO NOT USE '#' SIGNS IN THE AIRCRAFT NAME.

You have 2 choices for units of line length. These units are constant for all inputs for a given aircraft. You can have different units for aircraft in a given file. Your units must be specified in one of the following ways:

Units

METERS *or* meters
FEET *or* feet

Coverage Level and Line Length

For each coverage level you will need to define the length of the effective retardant pattern. Coverage levels need to be higher to be effective in heavier fuels. *FARSITE* simply assumes that the length of the pattern is independent of topography because of the variety of tactical approaches used by pilots for retardant application. To acquire realistic numbers for line length in your fuel types you will need to use your experience and/or consult some of the research literature that reports these rates (see below).

You can define new aircraft information directly in the Air Resources dialog by selecting the "**Define New Aircraft**" item from the "aircraft name" list box. You will be prompted for a name/description of the aircraft. After entering the crew name, you will need to define the effective pattern length for each coverage level (1-8). You can the save the file.

The following references might be useful for determining the length of effective retardant pattern for your aircraft type:

George, C.W. 1975. Fire retardant ground distribution patterns from the CL-215 air tanker. USDA For. Serv. Res. Pap. INT-165.

George, C.W. 1981. Determining airtanker delivery performance using a simple slide chart-retardant coverage computer. USDA For.Serv. Gen. Tech. Rep. INT-113.

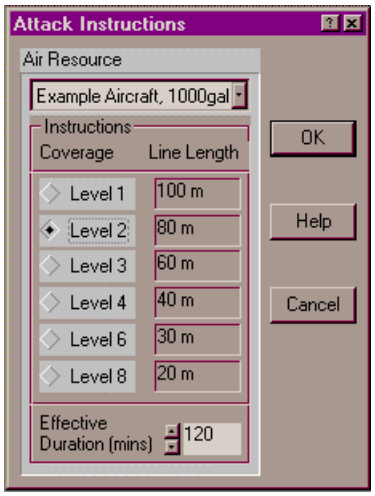
George, C.W. and A.D. Blakely. 1973. An evaluation of the drop charaacteristics and ground distribution patterns of forest fgire retardants. USDA For. Sev Res Pap. INT-134.

George, C.W. and G.M. Johnson. 1990. Determining aair tanker performance guidelines. USDA For. Serv. Gen. Tech. Rep. INT-268.

Swanson, D.H., C.W. George, and A.D. Luedecke. 1976. Air tanker performance guides: general instruction manual. USDA For. Serv. Gen. Tech. Rep. INT-27.

Attack | Air Attack

The Air Attack dialog allows you to select and apply the air resources you've loaded using an .AIR file or defined in the **Attack | Air Resources** dialog. You can use as many of the defined resources as you want (see Limitations and Assumptions).



The procedure for using air resources is to:

1. Select the aircraft and specify attack instructions,
2. Locate the line along which the retardant will be dropped.

These steps are accomplished as follows:

Select the aircraft and its instructions:

1. Select the aircraft you want to used from the list box of available aircraft. Only those aircraft that have been loaded or defined in the Attack | Air Resources dialog will appear hear. You cannot edit the description or its capabilities here.
2. Specify the coverage level for the site-specific fuel type and canopy cover characteristics at the drop site (use the Landscape Query function to look at the site descriptors).
3. Specify the effective duration of the retardant and click <**OK**>

Locate the line along which the retardant will be dropped

1. Move the "bomber" cursor to the start point for the retardant pattern and **<Left Click>** to secure that point,
2. Move the cursor in the direction you want to drop the retardant and <Left Click> to identify a line along which the retardant will be applied. If you don't like the line location, repeat steps 1 and 2 until you are satisfied, and then

3. <**Right Click**> to end the application. You'll notice that at least part of the white line has been replaced by a thick black line segment that indicates the exact length dimensions of the retardant. You cannot change your attack instructions at this point.

Interpreting a retardant drop

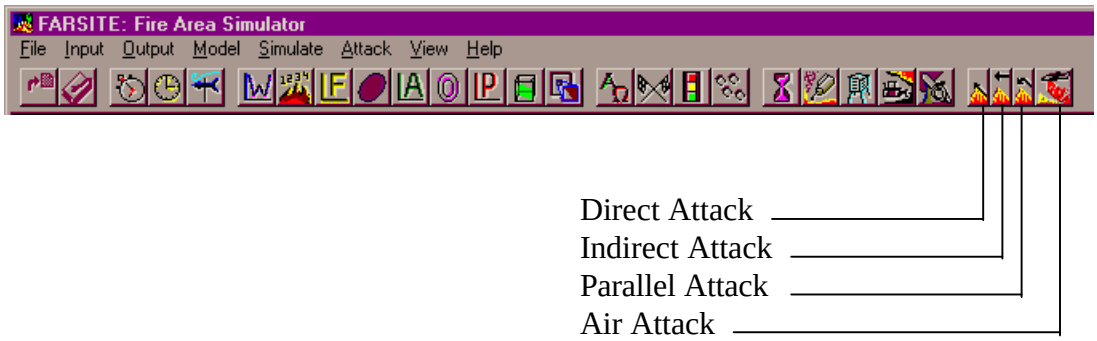
After selecting the drop characteristics, the cursor will change appearance to a "bomber". You'll often notice a faint gray fire perimeter has been drawn around the previously visible fire fronts on the landscape window. This gray line indicates the current position of the fire front that you need to consider when targeting the location for the retardant drop. This gray perimeter can appear to suggest the fires have burned beyond their previous positions. This occurs if you've interrupted the simulation before it has completed drawing or calculating fire growth for all fires in a timestep. Thus, the gray line is drawn temporarily to facilitate accurate air attack before the new fire position is officially updated in the landscape window.

Retardant treated areas will appear gray when they are active and can be distinguished from other barriers by the pointed shape of its ends. After the effective duration has expired, the color of the drop area will change to green, indicating no remaining effect on fire spread. While effective, the drop area will be impermeable to fire spread (surface and crown fire) but the fire can spot over the treated area.

Log File of Air Attack Resource Use

When any Air attack is finished or the simulation is restarted or reset, a log file (AIRATTK.LOG) is written in the current directory and lists the **aircraft type, the coverage level and line length selected, and the effective duration of the retardant**. This information can be useful for estimating costs associated with air attack.

Attack Tool Buttons



Chapter 10 The VIEW Menu

The View Menu contains options for viewing landscape files (.LCP), ASCII vector files, and ASCII raster files.

View | View Landscape File

An .LCP File can be viewed without loading it for simulation. This selection allows you to view a landscape file in 2 Dimensions and in 3 Dimensions. Only one landscape file can be viewed at once.

2 D Window

After selecting the file for viewing, a landscape window will be displayed. You can change the theme that is displayed using the **Output | Map Display** selection.

3 D Window

After selecting the file for viewing, the 3D window will appear for you to adjust the viewing angle (**Output | Three D**).

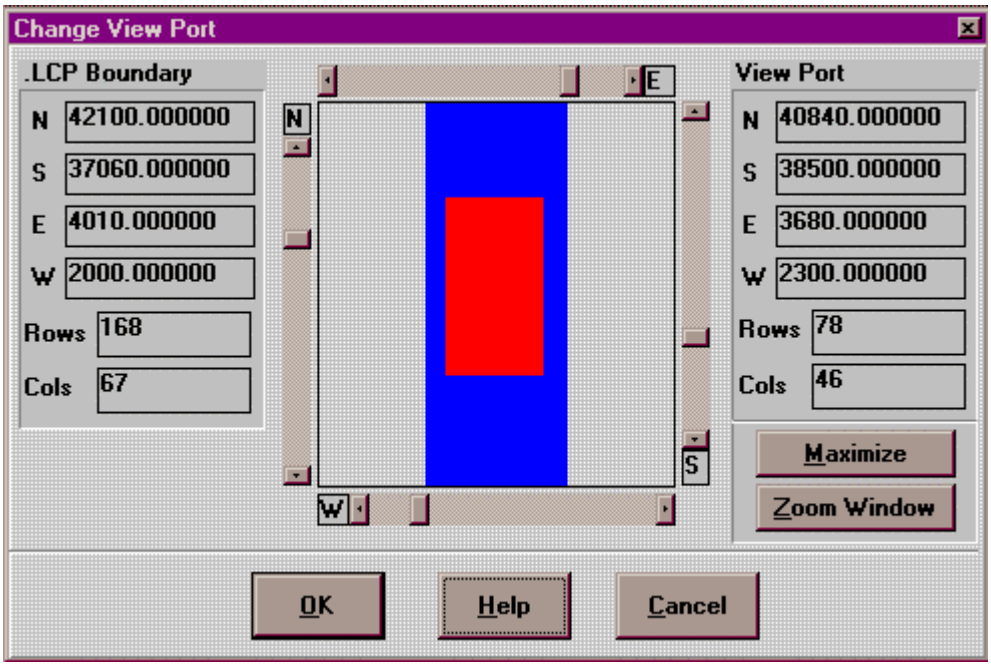
Both

This menu item will activate both 2D and 3D Windows for the selected landscape.

View | Change View Port

The View Port can be changed using the dialog activated with this menu item. Changing the view port is achieved for the current Landscape File (.LCP) by:

1. Using the Zoom Window, and/or
2. Using the sliders to adjust the North, South, East, and West borders on the illustration window on the Change View Port dialog.



To use the **Zoom Window** to adjust the view port, first open the zoom window on the visible landscape window. Then select **View | Change View Port**. Click once on the **Zoom Window button** or type "**Z**". This will transfer the coordinates for the zoom window to the view port. The illustration window in the middle of the dialog will graphically show this change along with the numerical coordinates for the North, South, East, and West boundaries of the view port.

The sliders located on all sides of the illustration window can be used to adjust, cell by cell, the boundaries of the viewport on all sides of the landscape.

The **Maximize** button will maximize the viewport to the original extent of the .LCP file.

Click "OK" or <return> to change and redraw the view port.

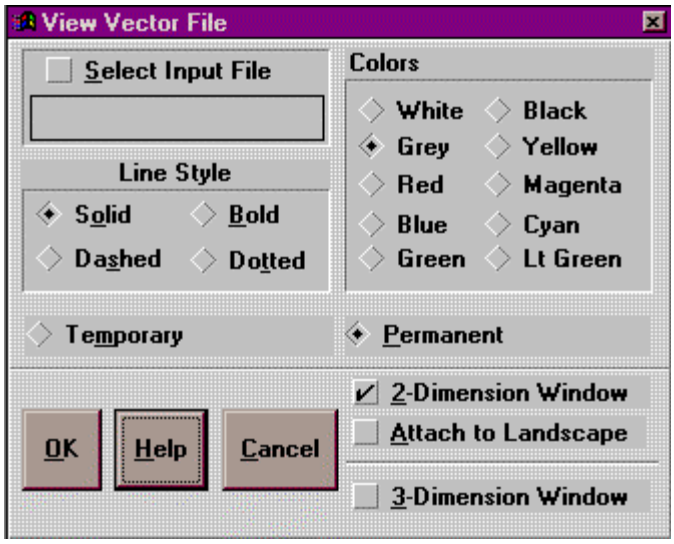
View | View Vector File

The **View | Vector** selection opens the "View Vector File" dialog box. This allows you to overlay vector files on the currently visible 2-D landscape. Vector files can be of the following formats:

- ARC UNGENERATE ASCII,
- GRASS ASCII,
- ARCVIEW shapefile format (.SHP), and
- *FARSITE* .VIS file (see **View | Save Visible Perimeters**)

and contain **points, lines, or polygons**. For ARC files, you will be prompted for information the confirms the input file as containing points, lines or polygons. **ASCII vector vertices from GIS vector files must NOT be in scientific notation (recommend exporting vectors from the GIS in single precision).**

A file is selected by checking **Select Input File** on the **View Vector File** dialog box. You can choose the following display options:



Line Style

Line styles for the vectors can be solid, dashed, dotted, or bold. You should choose solid lines if you are importing a points file.

Colors

The color selection determines the color of the imported vectors as drawn on the landscape. Lines and polygons will be drawn in this color. If the import file is a point, a small circle will be drawn around each point in this color.

Temporary vs. Permanent

The temporary selection draws the vectors only in the visible landscape window not on the permanent bitmap that replaces the image in the landscape window when it is refreshed (e.g. after resizing or covering by another window). Select **temporary** if you will want to be able to erase the vector file later in the simulation. **Note: you must move the dialog box off of the landscape window if temporary is selected, otherwise the window will be refreshed after closing and erase the vector display.** Select **permanent** if you want the vectors to remain visible on the landscape throughout the simulation or until you reset the simulation.

2D Window

The selected vector file will be drawn to the visible landscape window in the color and style chosen above.

Attach to Landscape

Attaching the selected vector file will allow it to be restored when you reset the simulation or clear the window if this is checked. This will also allow up to 5 vector files to be saved to a *FARSITE* project file (.FPJ) if 1) this selection is checked, and 2) if you make a project file after viewing the vector files. Projects saved with these vectors will redraw the vectors automatically when the project is loaded and landscape displayed. You can review all of the attached files in the **Input | Inputs | Attached Vector File** dialog.

3D Window

The selected vector file will be drawn to the visible 3 D Window. No hidden line removal is attempted. Thus, depending on the viewing angle, you could see fire perimeters or other vectors that would be hidden by the topography.

View | View Raster File

The **View | Raster** selection opens a file input dialog and allows you to overlay a raster file onto the currently visible landscape. The purpose of this feature is to allow you to view the fire behavior raster files created by *FARSITE* simulations. However, any raster file in GRASS ASCII or GRID UNGENERATE format can be viewed.

Raster files can be of any resolution. A rainbow color scheme is used to display the range of values.

A **raster legend window** will automatically appear showing the range of colors and the numerical scaling for the most recently displayed raster file in both the 2D and 3D window.

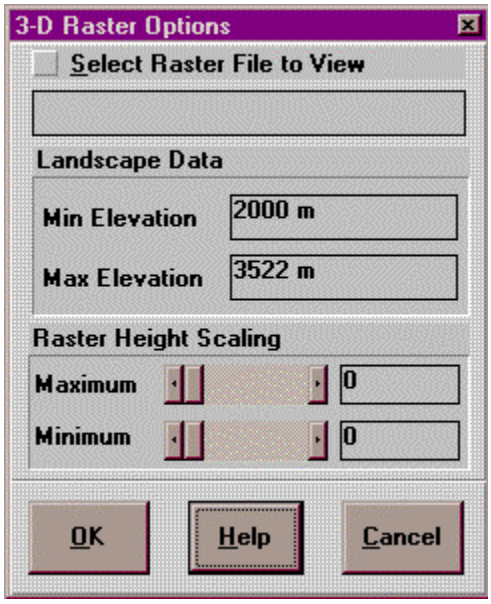
2D Window

The selected raster file will be drawn to the visible landscape window.

3D Window

The selected raster file will be drawn to the visible 3 D Window. The entire 3D window is redrawn. If the 3D window is currently visible, it is drawn in the same perspective. If it is not visible, the 3D window is initiated for you to position before drawing.

The 3-D Raster Options dialog allows you to select the file to display along with height scaling. **Height Scaling** of the raster file allows you to adjust the relief of your raster values as displayed on the 3D landscape. For example, a map of fireline intensity might be displayed with taller cells for higher intensities.



Both

This option allows your selection to be displayed on both the 2D landscape window and 3D window.

View | Redraw 2D Landscape

This selection will redraw the 2D landscape window. You should use this after you change settings for displaying the landscape such as theme colors (**Output | Colors**) or grid resolution, topographic shading, or visible theme (**Output | Map Display**).

View | Redraw 3D Landscape

This selection will redraw the 3D landscape window. You should use this after you change settings for displaying the landscape such as theme colors (**Output | Colors**) or grid resolution, topographic shading, or visible theme (**Output | Map Display**).

View | Eliminate 2D Window

This selection is the only way to remove the 2D landscape window in View Mode. This will not eliminate the landscape window during an active simulation.

View | Clear View Windows

After viewing vector files or raster files, the view Windows (2D and 3D) can be cleared of vector or raster information using this menu item.

View | Save Visible Perimeters

Fire perimeters that are currently drawn on the landscape can be saved at any time during a simulation to a (.VIS) file by selecting **View | Save**. A (.VIS) file stores the screen coordinates of the fire perimeters to facilitate rapid comparisons between results of different simulations. **NOTE: this file is not compatible with an ARC UNGENERATE or GRASS ASCII vector file.**

Chapter 11 Limitations and Assumptions

Fire arrival and behavior at a given point on the landscape is dependent on the behavior and time of travel *en route* to that location. This means that fire growth projections should generally worsen with time and spread distance because errors will be compounded, regardless of the accuracy or resolution of temporal or spatial data. That is, unless errors to one extreme are compensated by equal errors to the opposite.

Logically, however, a fire growth simulation should be most accurate when using accurate data at high spatial and temporal resolution. An "optimum" resolution for each landscape parameter, fire behavior type, and simulation purpose, probably exists so that the pertinent variability is preserved without irrelevant detail. The sensitivity of spatial fire simulation to the resolution and qualities of different fire input parameters on the landscape, however, remains to be tested.

Winds, Weather, and Fuel Moistures

The present version of *FARSITE* uses only simplified weather and wind inputs. Open-winds are assumed parallel to the terrain and spatially constant but can vary in speed and direction over time. Spatial variability in winds is accomplished only through use of multiple data streams. Wind speeds are adjusted for mid-flame height based on canopy characteristics and fuel model. The weather streams specify daily maximum and minimum temperatures and humidities and the elevation of the observations. The time of the maximum temperature is assumed to be coincident with the minimum humidity. This will probably not be accurate for the period where thunderstorms occur or during frontal passage.

Temperature and humidity observations are interpolated with a sine-curve (sensu Rothermel et al. 1986) to acquire temperatures and humidities throughout the day. A sine-exponential interpolation (Beck and Trevitt 1989) may be an improvement, but this will have to be tested. A lapse-rate (3.5F/1000ft) is used to adjust these observations to other elevations on the landscape. Daily precipitation amounts are included in the weather stream and assumed constant across the landscape. Solar radiation at the ground surface is computed using canopy coverage and terrain information; in this version of *FARSITE*, all other canopy characteristics (height, height to live crown base, crown bulk density, and foliar moisture content) are assumed spatially constant except where optional spatial data themes have been provided (height, height to live crown base, and crown bulk density).

Dead fuel moistures are calculated using the procedures implemented in BEHAVE (Rothermel et al. 1986, Hartford and Rothermel 1991). The calculations for daily fine dead fuel moistures (at 1400 hours) are different from the calculations for hourly fuel moistures at

other times of the day. This results in an abrupt shift in the fuel moistures at 1400 hours. It is not known how critical this inconsistency is to the results of long term fire behavior spread simulations. Live fuel moistures are assumed to remain constant throughout the simulation unless manually changed. There are currently no general models for all species of live fuels that describe moisture variation, either diurnally or seasonally.

The limitations to fire spread projections of the simplified weather data are not really known. Obviously, model results would be expected to suffer where strong interactions of wind and terrain are present. Furthermore, calculations that depend on fuel temperature and moisture may not be accurate where shadows are cast by topography, precipitation varies elevationally or spatially, or water availability is significantly is altered (e.g. higher fuel moistures near streams) .

Spread Patterns

Fire spread patterns generated using Huygens' principle with an elliptical wave have been found to agree reasonably well with observed surface fire spread under relatively simple conditions (Anderson et al. 1982, French 1992). Wind changes produced fire spread shifts close to those observed for fires spreading in grass fuels with essentially no influence of topography. It is not yet confirmed how well Huygens' principle itself simulates fire growth on complex landscapes. Sanderlin and Sunderson (1975) were apparently the first to apply a "radial" perimeter expansion technique, now generally referred to as Huygens' principle, to simulating wildland fire spread. From a comparison of predictions with observed perimeters of the Potrero wildfire (September 1973) in Southern California, they concluded that their technique was acceptable for fire growth modeling in complex situations. The only other indications from complex circumstances are from some preliminary validations of *FARSITE* in which observed fire spread patterns were compared against surface fire spread predicted by the model (Finney 1994, Finney and Ryan 1995, Finney and Andrews 1996). These early comparisons were promising but the many potential sources of error in the observed data (fuel maps, perimeter maps, weather data etc.) preclude definite conclusions. More validations are planned and will be necessary before the "window" of applicability might be defined.

For practical purposes, the most important result of the *FARSITE* tests to date has been that spread rates for all fuel models tended to be overpredicted by the Rothermel spread equation (Rothermel 1972). Sanderlin and Sunderson (1975) made a similar observation and ascribed the cause to problems relating windspeed to elliptical dimensions. Some problems may be a result of inaccurate data on fuel moistures, fuel descriptions (e.g. models), and weather. Also, wind reduction factors for forested areas and lee-side topographic sheltering can undoubtedly cause errors for spread rate calculations on some parts of a landscape.

However, given all input data to be accurate, the problem with overprediction may persist; the scale of time and space-averaged winds (e.g. hourly) and spatially homogenized fuels within rasters may be too coarse to reflect fine-scale variability in fire environment (temporal or spatial) that keeps fire actually spreading at variable rates. This could force the average fire

spread rate over large areas and long time spans to be overpredicted. The nonlinear relationship between windspeed, fire acceleration, and fire spread rate means that the average windspeed cannot be expected to predict the average spread rate (Richards 1993). Fluctuating wind directions also cause overprediction of spread in the heading direction because they reduce the eccentricity of the fire shape compared to the ellipse (see #6 below).

The simple approach to correcting the spread rates, perhaps too simplistic for complex landscapes, is to assign rate of spread adjustment factors to each fuel type (Rothermel and Rinehart 1983). These factors must be based on empirical observations of previous fires, or of phases of growth of the existing fire, in patches of homogeneous fuels. They should be based on the heading portion of the fire, given that spread in other directions is dependent on the elliptical dimensions. It would be possible however, to compute the spread rate for one fuel type in a mixture of fuels if the following were known: 1) the fractional distance occupied by fuel type, 2) the average spread rate for the fuel mixture, and 3) the individual spread rates of other fuel components of the mixture. Then the equation for the harmonic mean (Martin 1988, Fujioka 1985) can be solved for the unknown spread rate. The adjustment factors, however, may not be constant throughout the duration of a fire. Average spread rates may change if wind variations change frequency compared to the conditions used to obtain the adjustment factor. For example, adjustment factors determined from fire spread before a cold front may be not be adequate during and after the front passes because there may be more variability in wind speed or direction than before. The *FARSITE* model provides a means to apply and change fuel-specific adjustment factors throughout the simulation (see **Fuel Inputs, Adjustments**).

A number of assumptions are critical to modeling fire growth using Huygens' principle. As discussed below, some of these assumptions are probably violated by current modeling methods. The degree to which a technical violation limits the practical application of a model, however, is not yet known. This is the critical question, because models will never be fully valid at all scales or for all purposes, but may be useful nonetheless if the scope of the assumptions are clearly understood by the user. The following paragraphs present a discussion of some major assumptions of the modeling method used for *FARSITE*. A detailed treatment of the subject was also written by Andre and Viegas (1994).

1. Fire spread is elliptical. This is probably not strictly true. The shapes of fires are assumed to be elliptical under uniform conditions because this is mathematically convenient (Van Wagner 1969). Fire shapes under different conditions have variously been described as ovoid (Peet 1967), as a pair of ellipses (Albini 1976, Anderson 1983) or as fan-shaped (Byram 1959). Green et al. (1983) found the ellipse fit as well as more complex shapes, given its simplicity and the absence of more definitive data. An analysis of fire shapes by Richards (1993) suggested that neither ovoid, double ellipse, or fan-shaped fires can be explained simply from variations in windspeeds or directions acting on an otherwise elliptical spread pattern. Richards' methods however, made the assumption that fire spread was independent of the shape of the fire front which may not be supported (see #2 below). Even if the assumption of elliptical fire shapes in continuous fuels is true, however, fire shapes in fuels that are not continuous at the scale relevant to mechanisms of fire propagation will not be

elliptical or intuitive (Green 1983). For example, a fire may spread only in the heading direction because of wide spacing between fuel patches and would have the shape of a rectangular strip. Fire shapes resulting from discontinuous fuels will not be adequately modeled by *FARSITE*.

2. Fire spread in any direction is independent of the shape of the fire front (i.e. points along a fire front can be considered independent sources of wavelets). Recent studies suggest that this is not correct (Weber 1989, Cheney et al 1993). Radiative heat transfer ahead of a spreading fire has long been known to depend on the shape and length of the fire front (Byram 1959). Radiation from a continuous line fire decreases as the distance from it, but as the square of the distance from a point source fire. The violation of the shape independence assumption limits the extent to which Huygens' principle can be simply applied to spreading fire and distinguishes fire spread from the travel of light; portions along light waves do not interact as can portions of a fire front. For fire growth modeling, this means that the existing shape and length of the fire front along any segment should affect the nature of heat transfer and spread rate along that segment. Therefore, a broad flank of a fire that becomes a heading fire as a result of a wind direction shift should assume a different shape than predicted by a Huygens' algorithm. This will not be reflected in the current *FARSITE* model. The practical effects of these problems on fire growth patterns produced in a simulation are however, not yet known.

3. Fire acceleration is **fuel dependent** but **independent of fire behavior**. Fire acceleration is defined as the rate of increase in spread rate from the current rate to an equilibrium spread rate under constant environmental conditions. Since version 2.0 of *FARSITE* you have been able to adjust the fire acceleration constants for each fuel type. The fire acceleration equations (Alexander et al. 1992) in *FARSITE* compute the average and ending rate of spread for a timestep. These are likely to be important where the simulation uses small time-steps (<10min), where fuels and topography are very heterogeneous (spatially), and winds are variable. The incorporation of acceleration means that fire spread rates will not immediately adjust to the equilibrium spread rates when conditions change. The rate of fire acceleration is dependent on a rate factor. The default rate for all fuel types in *FARSITE* is subjectively set at 0.115 (Alexander et al. 1992) to allow acceleration to 90% of equilibrium rates after 20 minutes from a point source fire. Line source fires are known to accelerate much faster (Johansen 1987). These factors can be adjusted in *FARSITE*, but there are no data to guide settings for these factors. Although the equilibrium spread rate is dependent on fuel conditions, the buildup or acceleration rate has been found to be fuel independent for a variety of fuel types (excelsior, pine needles, conifer understories). A single acceleration rate may not be accurate for all fuel types (McAlpine and Wakimoto 1991), especially between very different fuel conditions. Fire in grass fuels is expected to accelerate more rapidly than in slash fuels, but there are few data to guide these settings. Acceleration is presumed to be independent of the fire behavior or eventual spread rate. Thus, the same time is required in a given fuel type to achieve a steady-state spread rate regardless of the environmental conditions.

4. Fires will instantly achieve the expected elliptical shape when burning conditions change (e.g. wind speed or slope steepness). This assumption is probably acceptable for simulations with a time step longer than a few minutes. Laboratory experiments (McAlpine 1989) suggest that shape changes occur relatively rapidly compared to the time required for buildup in spread rate or intensity.

5. The elliptical shapes are fuel independent; shape (not size) is only determined by the resultant wind-slope vector. This assumption is probably acceptable because 1) empirical relationships between windspeed and elliptical dimensions suggest shapes are common to a variety of fuel types over a wide range of ambient windspeeds (Alexander 1985), and 2) the empirical coefficients for wind and slope effects on fire spread rates used in the Rothermel spread equation are dependent of fuel bed characteristics (Rothermel 1972). These coefficients are the unit vectors used to obtain the resultant wind-slope vector.

6. Variation in windspeed and directions at a higher frequency than the wind stream resolution do not affect the elliptical fire shape. This is not correct, but the importance of its effect on fire growth patterns is not yet clear. Fluctuating wind directions decrease the length to breadth ratio of an otherwise elliptical fire (see **Technical Documentation**). This has the effect of overpredicting the heading spread of a fire at the expense of flanking spread. Some compensation for the overpredicted heading spread will be achieved through use of rate-of-spread adjustment factors.

7. The origin of an elliptical fire is located at the rear focus of the ellipse. The focus is assumed as a starting point because it provides an implicit means to calculate backing spread rates (see **Technical Documentation**). Alexander (1985) reports that using the origin as the focus may underpredict the backing spread. At present, *FARSITE* allows the user to select a constant backing spread rate calculated from the spread rate under zero slope and wind for the given fuel type (Rothermel 1983).

8. The spread of a continuous fire front can be approximated using a finite number of points. The adequacy of this assumption is dependent on the spatial resolution required by the user and the resolution specified for the simulation (see **Technical Documentation**). It is assumed that a resolution can be specified that preserves the "important" features of fire growth but ignores irrelevant spatial detail. This is dependent on the purpose and requirements for the simulation. The same concept is implicit in maps of fire growth made by direct observation; minor variations in fire position that result from rocks or small discontinuities in fuel are ignored. The relevant resolution probably decreases as the fire gets larger.

9. The *FARSITE* model is not designed to determine ***if*** a fire will spread or not. It is also not technically designed for modeling fire spread only by smoldering or by the rolling of burning debris, even though the resulting spread rate may be approximated by judicious use of the adjustment factors for a given fuel type (see fuel inputs). The *FARSITE* model cannot determine where or if a fire will cross a barrier (e.g. a creek or a vertical cliff) unless the resolution of the data are fine enough to reflect the "bridges" etc. on which fire may cross.

Multiple Fires

Although *FARSITE* will handle up to 5,000 simultaneous fires, the fire spread patterns of neighboring fires will not necessarily be accurately represented because fire interaction with weather and fuels is not accounted for. For example, behavior resulting from “back fires“ set for suppression purposes, or a prescribed fire ignition pattern that is applied to “draw” the fire together at different times, places, or stages of build-up will not be addressed by *FARSITE*. Extreme fire behavior, e.g. plume dominated fires, that are affected by feedback between the weather and fire behavior are not intended to be simulated by *FARSITE*. Users should not assume that ignition patterns used for prescribed burning will result in correct simulation of fire behavior!!

Crown Fire

The crown fire models of Van Wagner (1977, 1993, and Alexander 1988) have been implemented in *FARSITE*. This approach requires information on crown fuels and the forest canopy, including:

- Effective height to live crown base,
- Crown bulk density
- Tree height
- Foliar moisture content

Although *FARSITE* presently requires a canopy cover theme, the above crown-fuel characteristics must be constant for areas having canopy coverage, unless the optional crown fuel themes have been provided to the .LCP file.

Van Wagner (1993) notes that the height to live crown base is a difficult parameter to measure. The height to live crown base is really an "effective" number that incorporates ladder fuels (see Fahnestock 1970) and understory fuels such as small trees that assist the transition to crown fire. Thus, height to live crown base will not be a simple measurement in multi-storied stands.

Heat required to ignite the crown is based only on fuel sizes on the 100hr timelag and smaller (<3” diameter). This limitation may underestimate the potential for crowning or torching because larger woody fuels (1000 hr+) and their contributions to radiative and convective heating of overstorey fuels are ignored. Rothermel (1991, 1994) discusses the contribution of large woody fuels to the development of convection columns and consequent crown fire behavior.

The wind-slope vectoring for crown fire has not been tested and may not be realistic. *FARSITE* presently uses the wind-slope vector direction from the understory surface fire with midflame winds. The reason is that transition to crown fire in Van Wagner's (1977, 1993) model is dependent first on the surface fire behavior that is determined by midflame winds. The problem with later combining an open-wind vector with the surface slope effect is that the range of data used to develop the slope coefficient in the Rothermel (1972) model may not be applicable to crown fire. The slope coefficient depends on fuel bed parameters not accounted for by the canopy fuels in which the fire is then burning. This situation needs further work and testing.

Spotting

The existing spotting models (Albini 1979, 1981, 1983a, 1983b, Morris 1987) were originally devised to predict the maximum distance burning embers would travel over flat and regularly undulating terrain. The maximum spotting distance is determined by the balance between particle size, burnout rate, and time or distance traveled. Smaller particles are lofted higher and transported further, but burnout sooner than larger particles. Thus, as published, Albini's equations for the maximum spotting distance cannot be implemented for complex topography because winds, terrain, and forest canopy can all vary.

At present only the model for spotting from torching trees (Albini 1979) is present in *FARSITE*. The purpose of the spotting capability of *FARSITE* is to compute the maximum distances that particles of different sizes would travel over complex landscapes. These indicate the potential distances ahead of the fire that spotting could be found, assuming winds vary only as a function of height above ground or as specified spatially by the weather/wind grid. Nevertheless, this greatly oversimplifies reality in mountainous terrain.

Depending on topography, Albini's equations may suggest the farthest spotting distances are produced by larger particles that aren't transported over deep ravines. The spotting model in *FARSITE* does not intend to predict the number of embers produced, or exact locations that embers will land, only the direction and distance embers might land.

Spotting is produced whenever some form of crown fire develops (torching and running crown fire). You must recognize, however, that the torching tree model of ember lofting was not intended for representing ember lofting from a running crown fire. It will likely **underestimate** both the ember sizes, lofting height, and ultimate spotting distances under conditions of running crown fire.

Ground Attack Simulation

The mechanics of simulating direct and indirect tactics are described in the **Technical Documentation**. As with fire growth simulation, the techniques used here assume that variations in the fire environment in time or space at scales finer than those specified by the model parameters will not necessarily have influence over the progress of fire suppression.

Thus, fuel variations or fire characteristics that normally would affect suppression efforts cannot be simulated at finer scales than the fire growth simulation. There are no slope limitations to the operation of mechanized equipment such as dozers.

Fire suppression activities are not affected by areas of non-fuel (barren, rock, lakes etc) in terms of travel time across them or in changing decision tactics when they are encountered. If indirect line is routed across a lake, the crew will merely skip to the other side of the water when it encounters the lake (resuming suppression along the remaining part of the route) and not count the travel time required to circumnavigate the lake.

Line production rates are maintained independently when more than one crew is assigned to direct attack on the same portion of a given fire. Two crews that attack the same part of an active fireline will essentially "leap frog" each other, attacking alternating segments of the active fire perimeter. For example, if a slow crew and a fast crew are working on the same portion of the perimeter, the suppression line will alternate between fast and slow segments. This leap-frogging will result in unrealistic increases in line production and should be avoided.

Users are responsible for providing their own line production rates. The values in the example file (Appendix 1) are for **demonstration only**.

A direct attack will continue on the original fire front until finished or until the user reassigns it. For example, if an attack is initiated against an outward burning fire front it will always remain on the outside of the fire front even if it begins attacking a concave portion of the fire perimeter that then becomes isolated as an enclave. This keeps the direct attack faithful to its original intent, that of limiting the expansion of the fire. You can however, attack an inward burning fire front (enclave).

A parallel attack cannot be assigned to an inward-burning fire front (e.g. an enclave). Instead, the direct attack can be used to suppress inward fire fronts.

Aerial Attack Simulation

It is assumed by the simulation that a retardant pattern will always be impermeable to an approaching fire front until its user-defined effectiveness has expired. In reality, most applications of retardant are supported by ground crews to ensure fire doesn't breach the treated area. Furthermore, the effectiveness of a retardant drop is not sensitive to fire behavior, although spot fires can be initiated beyond the fire line.

The user is responsible for selecting realistic performance parameters for the aircraft, the coverage level and line length, and the effective duration. Furthermore it is the user's responsibility to consider the time of day (e.g. nighttime restrictions on flying) and the local weather conditions that would otherwise affect the ability to fly into the fire area. No explicit consideration is given for factors affecting retardant longevity such as air temperature,

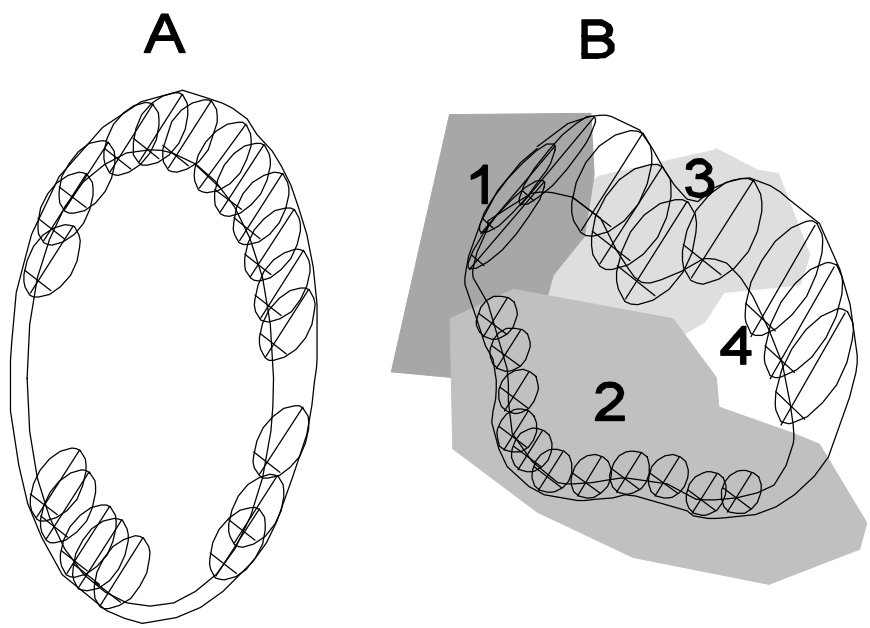
shading, or fuel type. The user can however, implicitly incorporate such elements into the setting for effective duration.

Chapter 12 Technical Documentation

Introduction

The *FARSITE* model (***Fi***re ***Ar***ea ***Si***mula***t***or) simulates fire growth as a spreading elliptical wave. The fire is propagated over a finite time step using points, that define the fire front, as independent sources of small elliptical wavelets. These small ellipses can be thought of as forming an envelope around the original perimeter, the outer edge representing the new fire front. This process has been referred to as Huygens' principle (Anderson et al. 1982). Huygens' principle is named for the 17th century Dutch mathematician Christian Huygens who proposed it for describing the travel of light waves.

The reliance on an assumed fire shape, in this case an ellipse, is necessary because the spread rate of only the heading portion of a fire is predicted by the present fire spread model (Rothermel 1972). Fire spread in all other directions is inferred from this forward spread rate using the mathematical properties of the ellipse. An elliptical shape would not have to be assumed if the spread rate in all directions could be computed independently from the fuels, weather, and topography.



Two examples of Huygens' principle with elliptical fire shapes. Winds are uniform from the southwest. A. homogenous fuels, and B. mosaic

of four cover types (fuel, windspeed) that change the size and shape of the ellipses.

The depiction of a fire front spreading as a wave is intuitively attractive for several reasons:

1) The fire front at most scales of perception is continuous along its active portions in time and space and can naturally be represented as a series of iso-chrons (time contours),
2) The wave propagation technique is distinct from the data resolution or data type used for its solution (e.g. not limited to raster-type or vector-type landscape information).
3) Radiation from flames is an important means of fire propagation and is itself a wave,
4) Existing models of surface fire behavior (Rothermel 1972), crown fire behavior (Van Wagner 1977), and spotting (Albini 1979) are formulated as point-vectors (giving rates and distances of spread from a given location) that translate naturally to the vector fire perimeters produced by Huygens' principle.

This approach differs considerably in concept from the cellular models, or cellular automata, that simulate fire spread as a contagion process between cells (Kourtz and O'Regan 1971, Kourtz et al. 1977, Green 1983). Cellular models solve for ignition times of cells at known regular spacing. The position of the fire front at a given time must be interpreted from cells having similar arrival times. This type of model has some inherent difficulties. Among the most critical, appear to be the distortion of fire shapes caused by the gridded landscape geometry (Ball and Guertin 1992), and absence of information on spread between cells; the latter becomes vital to synchronizing effects of temporal changes in weather or fuel moisture around the fire perimeter. None of the cellular models adequately simulated fire spread under test conditions with spatial and temporal heterogeneity (French 1992). Techniques recommended by (French 1992) for reducing geometric distortion have included enlarging the "search radius" for interacting cells (increasing the number of "adjacent cells"), and decreasing the time step (depending on the specific cellular algorithm in use). Cellular models may be deterministic, or have probabilistic or fractal modifications (Clark *et al*. 1994) to spread rates and/or directions. Non-deterministic models would require multiple runs to generate a risk map (event-probability map) for a given scenario because outputs change between individual simulations having identical input parameters.

The concept of applying Huygens' principle to model fire growth simply involves using the fire environment at each perimeter point to dimension and orient an elliptical wave around each point on a fire front at each time step. The shape and direction of the ellipse is determined by wind-slope vector while the size (e.g. spread rate) is determined by the fuel conditions. The implementation of this in a practical fire growth model is, however, considerably more complex.

Huygens' principle has been applied to fire growth modeling in various forms. The earliest published application was the "radial fire propagation model" by Sanderlin and Sunderson (1975). This was a computerized method for projecting fire perimeter growth over complex landscapes. It used a 3 dimensional wind field, a rasterized landscape of fuels and topography,

and provided reasonable projections of fire growth (Sanderlin and Sunderson 1975, Sanderlin and Van Gelder 1977). The essential mathematics and many of the complications of this approach were first identified here. Anderson *et al.* (1982) brought the terminology and concept of Huygens' principle to the fire literature. They described the mathematics and applied Huygens' principle to perimeter data from a test fire, finding it suitable as a fire growth model. French *et al*. (1990) and French (1992) employed a graphical technique which used computer graphics block-copy techniques to produce fire fronts. The "four-point" technique (Beer 1990, French 1992) uses 4 points on an elliptical perimeter that correspond to its major and minor axes as the propagation points that form the new fire perimeters. Richards (1990) analytically derived a differential equation that propagates any point using an elliptical fire shape. Richards (1990) technique is employed in the *FARSITE* model and uses the vertices of the fire perimeter polygon as the propagation points. The same result is achieved by the method of Roberts (1989; discussed by French 1992) in which the line segments between the vertices are the objects of propagation. Knight and Coleman (1993), Dorrer (1993), and Wallace (1993) also developed procedures for computing fire perimeter positions based on Huygens' principle of wave propagation. Recently, Richards (1995) has extended his equations to expand fire shapes different from the simple ellipse (lemniscate, double ellipse etc).

Essential as it is, the method chosen to implement Huygens' principle really becomes a minor part of the whole simulation process. The outline of the process control used in *FARSITE* illustrates this (Appendix 2); Richards' (1990) equation is used only in step 6 of the surface fire calculations and step 10 of the crown fire calculations.

Huygens' Principle

The method chosen for implementing Huygens' principle in *FARSITE* was developed by G.D. Richards (1990). His differential equation solves for the spread vector (rate and direction) of each point knowing its orientation on the fire perimeter and the heading, flanking, and backing dimensions of an elliptical fire originating at that point. The elliptical dimensions are obtained from empirical models for the length to width ratio determined by the wind-slope vector (Anderson 1983, Alexander 1985). These dimensions are given units of fire spread rate from the predicted rate of forward spread (Rothermel 1972). The calculated spread rates are then multiplied by the time-step to obtain the positions of all points on the fire front at the end of the time-step.

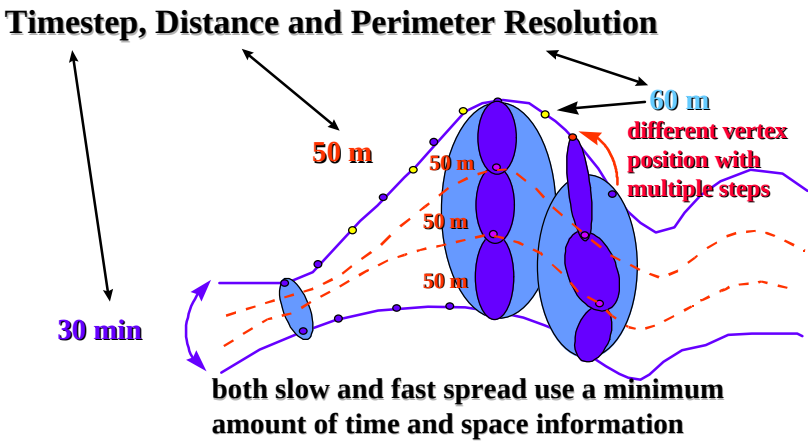
Several modifications to this procedure are used in *FARSITE* to increase control over the simulation. The most important change is the concept of a dynamic time-step that is implemented through distance checking. Distance checking ensures the spread distance of any point on a fire is less than the maximum distance in a given timestep. Without this procedure, there would be no control over the amount of spatial information used by the simulation. Faster moving heading portions of a fire would automatically use a coarser scale of landscape information than slower portions of a fire; important landscape information within a timestep

such as a river or change in fuel type could be ignored. Distance checking allows control over the minimum level of spatial detail used in a simulation.

During distance checking, the working value or internal value of the timestep is constantly changing. If during a timestep the distance check is exceeded by any point on a fire, the minimum time from all points to spread that distance is used as the new timestep. The original timestep is then decreased by that amount, and the process repeated until the original timestep is consumed. The timestep then becomes important only as a consistent interval for:

1) computing and displaying fire perimeters at meaningful time periods,
2) merging of multiple fire fronts, and
3) iterating the descent of embers.

Relationship between the timestep, distance resolution, and the perimeter resolution.



In Richards (1990) application of his differential equation, he uses a single correcting iteration to compensate for the changing orientation of each point after a given timestep. The orientation of each point on the fire front is a required input to the equation, but is changed as a result of the solution. Thus, an average orientation from the two timesteps is used for each point in a second and final round of computations. This process can be repeated more often within a timestep if greater averaging of the orientation is desired. At present, no correcting iterations are performed in *FARSITE*. This will be an area of further investigation as an option for the simulation.

Wind Profiles and Reduction Beneath Forest Canopies

Wind speed is input to *FARSITE* at the reference height of 20 feet above the vegetation. Speed is assumed to vary with height above the vegetation according to a logarithmic wind profile (Albini and Baughman 1979). Wind direction is assumed to remain constant with height. Beneath the canopy, winds are greatly reduced depending on the canopy cover and stand height (Albini and Baughman 1979). Recommended wind reduction factors, e.g. multipliers for the 20ft wind to obtain representative midflame winds, are 0.1-0.2 for sheltered fuels, but 0.4-0.6 for fully exposed fuels (e.g. no canopy) (Rothermel 1983). In *FARSITE*, the

wind reduction factors are calculated at each location based on the canopy cover and the canopy height (Albini and Baughman 1979), irrespective of the surface fuel model. Thus, brush fuels (fuel model 4 or 5), that are normally exposed, can be sheltered if the canopy cover and height are both high. Timber understory fuels (8, 9, 10) can be exposed in the canopy cover and height are low. No accounting is made for topographic variation in wind exposure (e.g. ridgetop vs. valley vs. slope).

Wind-Slope Vector

The easiest way to vector the mid-flame wind speed and effect of slope on fire spread was to compute and vector the dimensionless wind and slope coefficients in the Rothermel model. This method was used by Sanderlin and Sunderson (1975). The resultant vector is dimensionless, and can be converted to an effective mid-flame windspeed by solving for windspeed in the wind coefficient equation.

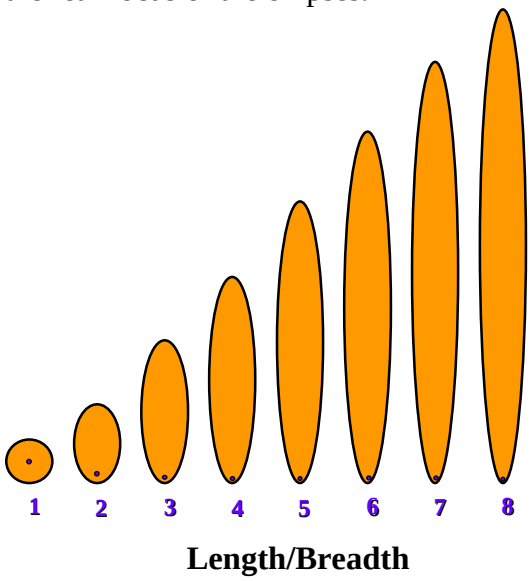
Elliptical Dimensions

A number of empirical relationships between fire shape and wind speed have been developed (Alexander 1985). Some of the relationships use midflame windspeed and others an open windspeed at 20ft or 10m above the vegetation. At present, *FARSITE* employs Anderson's (1983) model for length to width ratio of the ellipse because it uses mid-flame windspeed and because of its stated applicability to any fuel type. A simple ellipse is used, however, rather than the double ellipse. The midflame windspeed is a simpler value to obtain in the simulation because the wind-slope vector (above) is a midflame value. The appropriate open wind vector would have to be inferred from this midflame value.

Anderson's model does not yield a circular fire with zero wind and slope. Thus, as implemented in *FARSITE*, the length to breadth ratio from Anderson's model is adjusted by subtracting 0.397 from the predicted length to width ratio. This is not seen as a serious problem. Variation in wind direction at higher frequencies than represented in the wind stream will decrease the eccentricity of an elliptical fire. Simard and Young (1978) developed a model of fire shapes that accounted for Gaussian variation in wind direction. They recommended using a standard deviation of 10 degrees for all windspeeds (Alexander 1985). Their model has recently been found to agree reasonably well with a theoretical analysis of effects of wind variation on elliptical fire shape (Richards 1993). All other models assume windspeed and direction to be constant. However, the empirical nature of some of these relationships suggests that wind variation must have affected the original field data to some degree.

Elliptical Fire shapes expressed in terms of the "length to breadth ratio". Note that the

ignition point is assumed to be located at the rear focus of the ellipses**.**



Most of the work using elliptical fire shapes assumes the origin of a fire is at the rear focus of an ellipse (Anderson 1983, Alexander 1985, Andrews 1986). This provides an implicit means to calculate the backing fire spread rate. Catchpole et al. (1982), Alexander (1985), and Bilgili and Methven (1990) suggest however, that this assumption has not been adequately examined; using the focus as the ignition point may underpredict backing fire spread. It also appears to produce a temporary decrease in fire area for small length to breadth ratios as windspeed increases (Bilgili and Methven 1990). On the other hand, using the no wind-no slope spread rate as the backing rate may overpredict spread with increasing slope or winds (Byram 1959). Van Wagner (1988) and Cheney (1981) show that backing spread decreases as slope inclines to about 20+ degrees. In effect, spread may be faster down steeper slopes because of ignition by rolling or sliding debris.

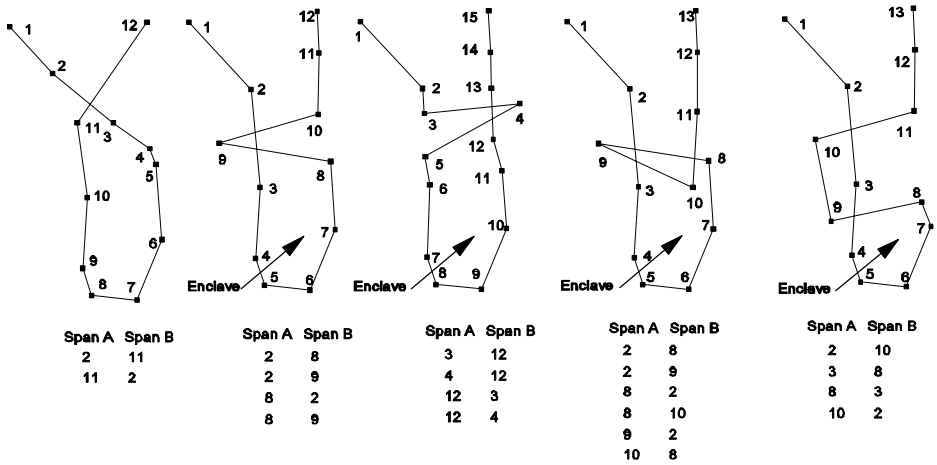
Crossovers

After a fire has burned for a given timestep the fire perimeter is processed for crossovers. Crossovers are formed when locally concave portions of the fire perimeter intersect during a given timestep (Sanderlin and Sunderson 1975, Richards 1990, Knight and Coleman 1993, Wallace 1993, Richards and Bryce 1995). This happens because the spread directions of points in a concavity are oriented inward; spread from unburned fuel to burned fuel is not automatically detected by the perimeter expansion algorithms. These crossovers must be removed to preserve the meaningful exterior portions of the fire front. Sometimes, an enclave or island is formed by a crossover. This represents a region of the perimeter in which the points are ordered in an opposite rotation. These enclaves essentially become separate fire fronts burning inward as a natural result of their orientation in Richards' (1990) differential equation.

Regardless of the methods chosen, the process of crossover removal is expensive of time and computing power. A number of ways of removing illogical artifacts of the perimeter expansion have been proposed. Richards (1990) used a clipping strategy that excised the illogical portions of the fire perimeter from the fire polygon. Knight and Coleman (1993) and Wallace (1993) describe similar methods. Most recently, Richards and Bryce (1995) describe an algorithm that leaves intact the offending perimeter vertices but renders them inert. The methods described below are more similar to the clipping routines. This approach is used in *FARSITE* because it enables orderly storage of only meaningful fire perimeter information and facilitates export of fire polygons for GIS uses.

Version 1.x

The algorithm used for clipping loops and crossovers in *FARSITE* versions 1.x, processes the order of segment crosses to find enclaves and correct the outer fire front.



Five examples of crossovers occurring along concave portions of a fire front. Enclaves are formed by crossovers in the last four configurations.

The simplest example is the first diagram in Figure 10.2. that involves crossing of segments 2 and 11 (identified by the first vertex on the span). If crosses are computed for each span with each other span on the fire perimeter, the number of crosses would be 2, resulting in the order of intersections listed below the diagram (segment 2 crosses segment 11, and segment 11 crosses with 2). Knowing the number of intersections to be 2, and finding the match between segment 2 as Span A for the first intersection and segment 2 as Span B for the second intersection, the algorithm would clip all points from 3 through 11, replacing them with the intersection point.

Other general types of crossovers have a pattern that is recognizable regardless of other crosses within the bounds of these intersections. Some of these are shown above. Enclaves are identified in each of these patterns and written to separate arrays as separate fires. These enclaves may still contain crossovers themselves and must be processed through the same algorithm to clean these perimeters. This process may again result in enclaves being divided to form separate inward burning perimeters.

A limitation of this technique involves the spread distance possible within any given timestep. Too much spread relative to the resolution of the fire perimeter will produce a spaghetti-like fire front or create complex knots that cannot be resolved logically by the above algorithms. Hence the need for a dynamically adjustable distance check that depends on the average resolution of a given fire. This feature attempts to limit the spread so that the crossovers fall within the limits of complexity solvable by the algorithms.

Since Version 2.0

A new algorithm was developed for version 2.0 to process crossovers on fire perimeters. It appears to more accurately determine enclaves. It is also tolerant of complex fire perimeter knots or “spaghetti ignitions” that are input by the user or arise naturally on complex landscapes.

The new algorithm corrects a fire polygon by following the outer edge starting from an extreme point. An extreme point is defined as one of the polygon vertices that is the farthest west, east, north, or south, and thus determines the bounding rectangle of the polygon. For an outward burning fire it proceeds with each perimeter segment (pair of vertices) counterclockwise until an intersection with another segment is encountered (clockwise if processing an inward fire). Vertices are written to a separate array containing the corrected fire polygon. If the process finds an intersection, the algorithm decides the rotation direction produced by the intersection with the new perimeter segment and whether the intersection produces a locally convex or concave region. These criteria are used to determine the next vertex to be processed (either in the original direction around the fire polygon or in the reverse direction). The intersection point is written as the next point on the new fire polygon. The process is continued until the algorithm arrives back at the starting point. This determines the vertices that now define the outermost fire perimeter.

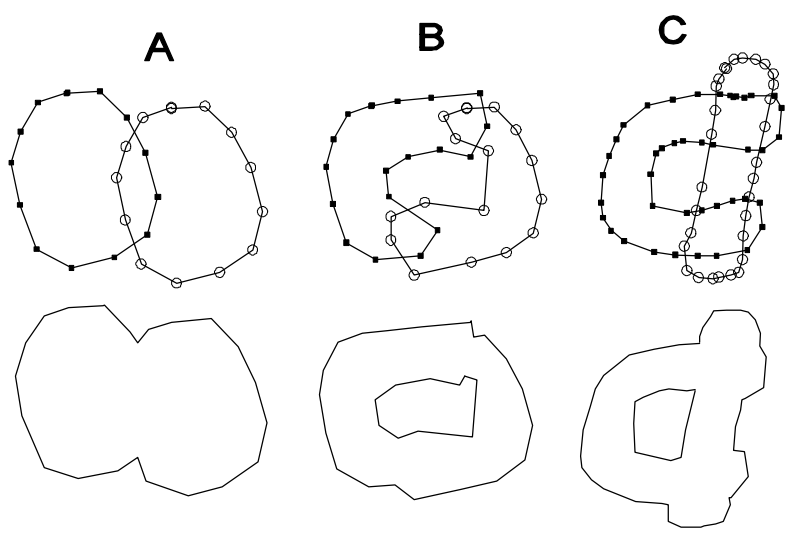
After processing the vertices for the outermost fire polygon, the algorithm looks for perimeter segments that have crossed but not yet been processed. These will occur if an enclave is formed. If one of these intersections is found, the new intersection serves as the starting point for the same algorithm to again follow the edge of the fire polygon. This process determines if a new inward fire has been created within the original fire perimeter polygon (an enclave). Each enclave is written as a separate fire if it has more than 2 vertices and is oriented

clockwise. This process is repeated until there are no more unprocessed crosses on the original fire perimeter polygon.

Mergers

Searching for fire mergers is accomplished at the end of a timestep after all fires have spread and crossovers removed. This is a computationally intensive process that first compares the bounding rectangles for each fire. If rectangles for two fires overlap, it examines within the overlapping region, segments of the first fire for intersections with those of the second fire.

As with crossovers, the intersection coordinates and average fire characteristics of the intersecting segments are stored, as well as the order of segments in each fire that cross.



Examples of fire mergers. Mergers “B” and “C” form enclaves and thus one outward burning fire and one that burns inward.

This information is used by one of two algorithms. If there are only 2 crosses between fires, then no enclaves can be formed and the simpler, faster algorithm merges these fires (diagram “A” in Figure 10.3). Merging fires with more than two intersections uses the comparatively complex algorithm to write segments alternately from each fire between intersection points. There can be only one outward burning fire perimeter, so all subsequent fire perimeters must be inward burning enclaves (diagrams “B” and “C” above).

The algorithms for merging fires will perform mergers between 1) two separate outward burning fire polygons, and 2) between an inward burning fire polygon and an outward burning

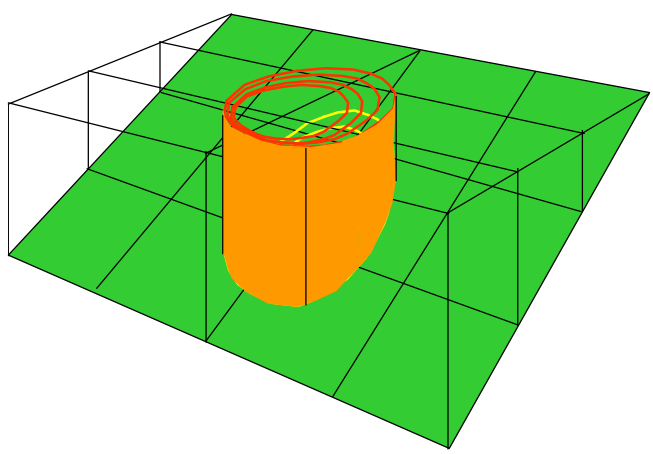
polygon. The latter situation develops where spot fires are burning within an inward burning polygon (that defines the fire front around an enclave). The spot fires will burn as independent fires until they merge with each other or with the wall of the enveloping inward burning fire. No situation can logically develop where two inward burning fire polygons could merge.

The process of merging fires proceeds first with mergers among all outward burning fires, and then for mergers between enclaves and outward burning perimeters. This sequence eliminates illogical overlaps between outward burning fires that could influence how enclaves are processed when they contain spot fires.

Slope Correction

In sloping terrain, the topographic slope and direction of spread on that slope are used to translate the surface coordinates of the fire front to horizontal coordinates. This step is necessary because all fire spread calculations (e.g. for surface fire and crown fire) produce fire spread rates along the ground surface. As modified by the wind-slope vector, the forward spread rate is used in the acceleration functions to produce an average spread rate for a given timestep. This in turn is used to produce the elliptical dimensions in units of surface spread rate that input to Richards' differential equation. The resulting time derivatives for the X and Y coordinates are applied to give the spread of a particular point in units of surface spread distance. These must be converted to the horizontal coordinates.

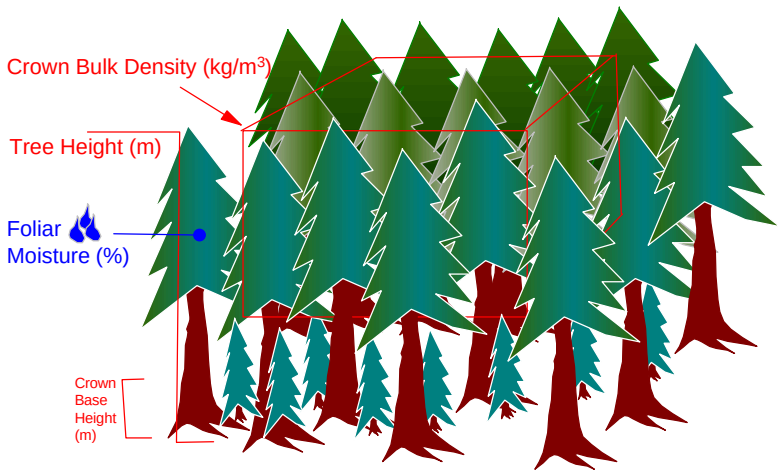
Transformation of fire coordinates from a sloping ground surface to a horizontal plane will flatten the fire shape in the uphill direction.



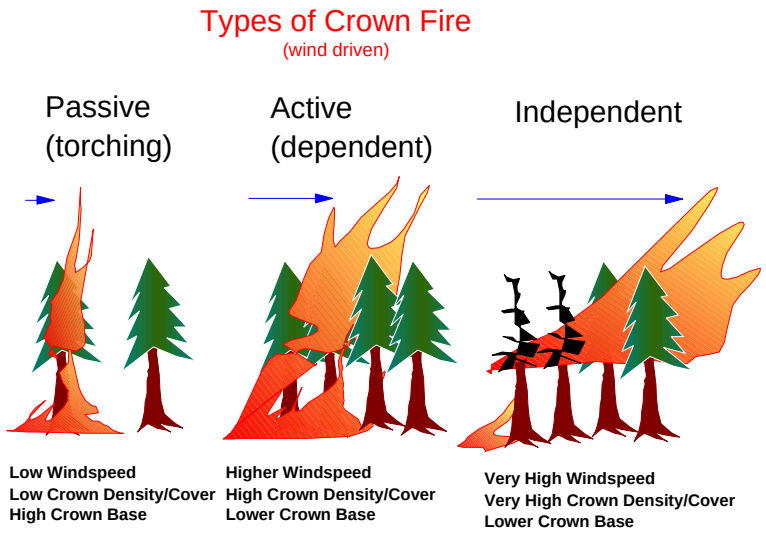
Crown Fire

A surface fire may make the transition to some form of crown fire depending on the surface intensity and crown characteristics (Van Wagner 1977, 1993) . The crown characteristics that are used to compute crown fire activity are: crown base height, crown height, and crown bulk density. Lower crown base height (including ladder fuels) facilitates ignition of the crown fuels by the surface fire and thus, transition to some form of crown fire. Crown bulk density is used determine threshold values for active crown fire, which spreads much faster than a surface fire. Crown height is used as the upper level of the crown space for determining crown fuel loading and the starting height for lofting embers.

Crownfire Model Inputs



After determining the surface spread characteristics, the fireline intensity is compared with the intensity threshold that is critical to involving the overlying crown fuels. If the threshold is met or exceeded, some form of crown fire has occurred. To determine what “type” of crown fire (Van Wagner 1977), the equilibrium rate of crown fire spread is computed for the current spread direction (Rothermel 1991), modified by the “crown fraction burned” (Van Wagner 1993) and compared with the critical rate of spread required for an active crown fire. If this threshold is not met or is exceeded, the crown involvement is assumed limited to torching trees (and passive crown fire), else it becomes an active crown fire.



Some method was required for linking the numbers of trees torching at once to the fire and canopy characteristics. It was assumed that more trees would torch as a group when both the "crown fraction burned" factor and canopy cover increased. The numbers of trees torching in a group affects the flame height and duration important to lofting of embers (Albini 1979). The above rules were subjectively assigned.

Number of Trees Torching at Once

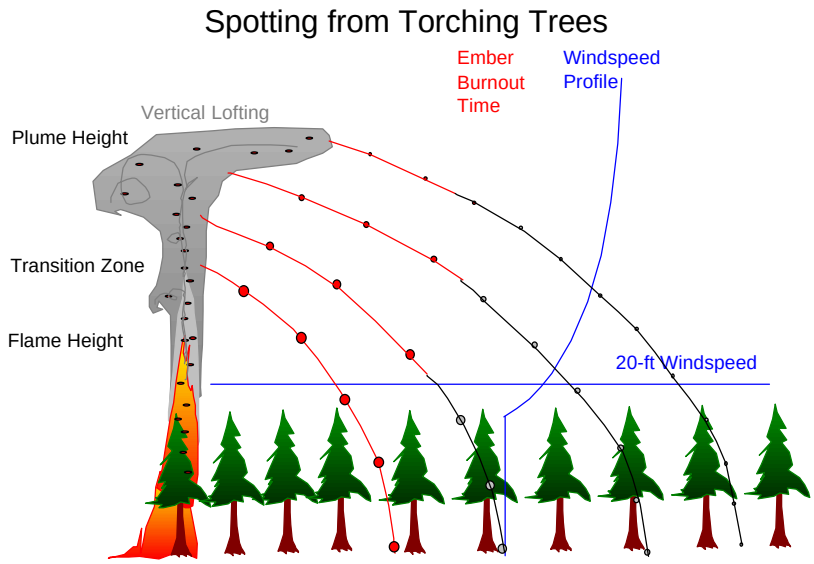
	Crown Fraction Burned		
Canopy Cover	<50%	50% to 80%	80%+
<50%	1	2	3
50% to 80%	2	3	6
80%+	3	6	10

Spotting

At present, spotting in *FARSITE* is simulated only from torching trees (Albini 1979). Maximum spot distances of embers from burning slash piles (Albini 1981), and line fires (Albini 1983a, 1983b, Morris 1987) are calculated in BEHAVE, but are not present in *FARSITE*. As originally implemented in BEHAVE, the spotting component of *FARSITE* is intended to compute the maximum spotting distance from a given point on a fire front if

torching occurs. It is not intended to simulate the numbers of embers, exact locations embers would land, or locations of resulting spot fires.

Spotting is achieved as a 3 step process. The first step determines the maximum lofting height of cylindrical embers of 16 size classes (1/16" to 1 inch) that originate at the top of a tree or group of trees (see above). Some embers may be too heavy to be lofted by the given plume generated by the tree(s). The burning characteristics of a tree (flameheight and duration) are determined by size and species of the trees (Albini 1979). For all lofted embers, the position, size, and time of lofting are stored until the end of a timestep.



After embers from all portions of all fire fronts are lofted in a given timestep, each ember is iteratively descended until it is extinguished or contacts the ground. The iteration assumes that each ember falls at its terminal velocity determined by diameter and the time since it began falling. Using 50ft steps for vertical drop, the iteration accounts for change in the ground elevation, windspeed as a function of height above ground, and time of flight. Embers are assumed to follow the ambient wind direction. An ember will be extinguished if it is airborne longer than the burning duration determined by its size (Albini 1979). Above the canopy height, a logarithmic wind profile is assumed. This may overestimate spot distance if the terrain is not forest covered (Albini 1981). Below the canopy, the midflame windspeed is assumed vertically constant.

The third step involves ignition of spot fires and checking for impact of the embers within existing fire perimeters. At present, all embers burning at impact are considered ignitions. The probability of ignition (Bradshaw et al. 1984) is present, but not activated in this version of the simulation, given the intent to show locations of potential ignitions rather than their result.

Fire Acceleration and Interaction

Fire acceleration is defined as the rate of increase in fire spread rate. It affects the amount of time required for a fire spread rate to achieve the theoretical steady state spread rate given 1) its existing spread rate, and 2) constant environmental conditions. This usage only applies to fire spread under constant environmental conditions (e.g. fuel moisture constant, winds constant, fuel availability constant). Other definitions of acceleration also exist (e.g. Cheney and Gould 1997) but these don't separate effects of changing fire environment from physical process of build-up rate. Changes in the fire environment that lead to increases in available fuel and spread rate are simulated explicitly as separate fire behavior processes by the simulation.

Fire acceleration rates are distinguished simply by "ignition type". Point source fires have slower acceleration than line source fires (Johansen 1987). These ignition types are used in *FARSITE* for convenience, although both types are really elements of a continuum of fire spread from a 1-dimensional source. Even this is simplistic, however, for most fires have 2-dimensional curving fronts with alternating convex and concave regions; small concave regions would be expected to have more rapid acceleration than convex regions as a result of different heat transfer ahead of the front. Similarly, fire acceleration from multiple separate fires with nearby fronts would also be increased. No 2-dimensional effects of fire shape on acceleration are addressed in *FARSITE*.

The lack of independence between portions of a fire front technically violates this assumption of Huygens' principle. Unlike light waves interfere little among sources, fire propagation can interact along curving fronts and between multiple sources. It is not known what, if any, corrections are required to model fire growth and behavior for the practical applications intended for *FARSITE*.

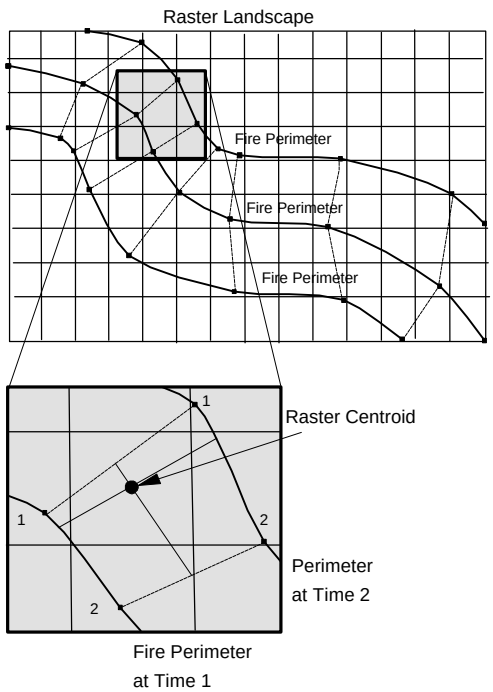
Fire acceleration is currently implemented as a two step process using the model of the Canadian Forest Fire Behavior Prediction System (Alexander et al. 1992). The first calculation is always performed. It computes the final forward spread rate by accelerating the fire from its current rate toward the new equilibrium over the given timestep. The average spread rate is computed from the distance traveled divided by the timestep.

A second calculation becomes necessary only if the distance check was used to truncate the fire spread distance within the timestep. Here, the average and final spread rates are calculated using the actual spread distance (the distance check) and initial rate of spread. This is done numerically using Newton's method to iterate travel time over the check distance.

Fire acceleration rates can be adjusted for each fuel type. Grass fuels are expected to have more rapid acceleration rates (shorter time to reach equilibrium) than fuel types will larger woody material (slash etc).

Raster Data Generation

Because the fire front and its characteristics are computed as a vector, raster representation of fire growth must be obtained by interpolation. *FARSITE* contains a routine for generating variable resolution raster information from the fire perimeters. The routine is tightly integrated with the control structure of the simulation; rasterizing is performed between distance checks (sub-time steps). This increases the proximity of vector information used for interpolating the fire behavior and arrival time at each raster. The raster algorithm interpolates the value for arrival time and fire behavior characteristics for the center point of each raster cell falling within two successive fire perimeters.



Method for interpolating fire behavior and time of arrival for raster centroids.

The interpolation for fire arrival time is a simple inverse-distance weighted average of the radial distance between a given raster centroid and the corresponding fire perimeter segments. The fire behavior interpolation uses an inverse-area weighted average to obtain a value for fireline intensity, flamelength, spread rate, or heat per unit area for each raster. Each raster centroid is contained within a quadrilateral defined by four perimeter points, 2 successive points on perimeters at each timestep. Each point has values for fireline intensity and spread rate in their respective spread directions. The interpolation computes the inverse proportional areas of 4 component quadrilaterals formed between each corner and the raster centroid. The

fire behavior value for the raster centroid is calculated as the weighted average of fire behavior at each corner.

Ground Attack Simulation

A number of analyses have shown the effects of fire supression on fire growth where the fire shape remains constant (Albini et al. 1978, Bratten 1978, Mees 1985, Anderson 1989, Fried and Fried 1996). Direct attack and parallel attacks that start at the head of a fire reduce burned area more than an attack from the back and can result in different fire shapes depending on the rate of line production compared to fire spread rate. Direct attack occurs at the flaming front whereas parallel attack maintains a constant distance from the active fire front. Although none of the analytical models can be applied to fire shapes that arise under non-uniform environmental conditions, they do give ready comparisons for results of simulations of suppression with uniform fire conditions.

Many factors are known to affect the rate of fireline production. Fuel type, soil type, topography, weather influences on working conditions, crew size, equipment, fatigue, and crew experience have been related to line production rates of hand crews (Hirsch and Martell 1996). Of these factors, most of the variation in line costruction rate can probably be explained from fuel type, crew size, and equipment. Theses effects on line production have also been the most consistently documented compared to other possible factors (Haven et al. 1982, Phillips and Barney 1984, Phillips et al. 1988, Quintilio et al. 1988, Fried and Gilless 1989, Barney et al. 1992, Hirsch and Martell 1996). Simulation control over line production rate was thus, restricted to these factors.

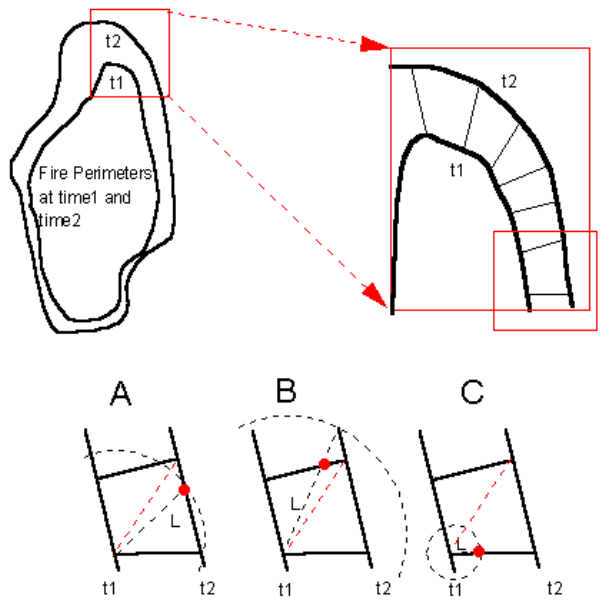
The simulation of horizontal rate of fireline production is assumed only to be a function of fuel type and slope for an arbitrary crew type and size. On sloping terrain the horizontal rate is computed as the product of the horizontal rate and the cosine of slope in the direction of travel. This assumes that the horizontal rate is constant in a plane parallel with the slope but that less line will be produced on steep slopes in the horizontal plane.

Direct Attack

The effect of direct attack on an active fire front is calculated using the known fire perimeter positions at two successive timesteps t_1 and t_2. The idea is to compute the position at t_2 of an attack crew building line at a given rate from its position on the fire perimeter at t_1 (see Figure below). The computation assumes that the range of possible solutions is defined by a quadrilateral of perimeter vertices (two successive points at and t_1 and their new positions at t_2). The fire perimeter points will move to their respective positions at t_2 without suppression. Because this quadrilateral is obtained while adhering to the time and space resolutions set for the simulation, the suppression effects on the fireline will also be calculated within those tolerances.

The effect of suppression can be most easily visualized for the simplest case on flat terrain where identical fire spread rates from each vertex form a symmetric quadrilateral. The effect

of suppression can then be represented as an circle of potential solutions with a constant radius L determined simply as the product of the line construction rate and the time difference between t_2 and t_1. Solutions to the suppression problem occur where the circle of suppression intersects the legs of the quadrilateral. Some potential solutions are illogical. Different methods are required to obtain some solutions depending on the length of the suppression line L relative to the dimensions of the quadrilateral. More complex solutions are required for sloping terrain, where the circle is eccentric along the fall-line of the slope, given the above assumption of constant horizontal line production. Furthermore if fire spread rates and directions from each vertex are not the same, then the length of line construction in a given timestep must be computed as the arc distance along a circular path rather than the straight line used for the simple case. The arc's radius and angle are a function of the difference between fire spread distances away from t_1 in a direction perpendicular to the horizontal fire perimeter at t_1, and horizontal distance between vertices of the t_1 perimeter.



Method for constructing fireline during direct attack. Pairs of vertices on a fire perimeter at time 1 and time 2 form a quadrilateral as shown in items A, B, and C. Fireline is shown as line L (radius of the arc, dotted black line) and is the product of the timestep and the line production rate in a particular fuel type. Item A shows the solution if fireline production is less than the diagonal of the quadrilateral (dotted red line) but greater than the spread distance between t1 and t2. Item B shows the solution if fireline is greater than the diagonal. Item C shows one possible solution when line production is much less than the spread distance between t1 and t2.

The first case occurs when the potential suppression circle intersects the fire perimeter segment of t_2 within bounds of the quadrilateral (L is smaller than the diagonal of the quadrilateral but greater than the spread distance). Solving for this point is done iteratively (item **A** in Figure). The second case occurs if the potential suppression circle exceeds the bounds of the quadrilateral without intersecting it. This happens when the line production rate

is large compared to the spread rate and larger than the diagonal of the quadrilateral. The solution in this case is to incrementally compute the progress of line building over shorter timesteps such that the length L falls within the quadrilateral (item B in Figure). The third case occurs when the rate of line production is much slower than the fire spread rate. In reality, a flanking action would be taken by a fire crew. The simplest way to "flank" the fire spread is to compute the point at which the line production parallels the route of the suppression starting point from t_1 to t_2 (item C in Figure).

Indirect Attack

Indirect attack is simulated by the incremental lengthening of an impermeable fireline along a predetermined route. The length of line produced is determined by 1) the rate of line production in a given fuel type, 2) the slope in the direction of travel, and 3) the timestep. The distance resolution set for the simulation will interrupt the line production, forcing it to sample the landscape for information on fuel type and topography, if the length of the line in a given timestep exceeds that resolution. The distance resolution also determines the width of the fireline that can't be breached by the fire spread distance in a given timestep. The constructed fireline is represented as a closed stationary polygon for which mergers with active fire fronts are computed as described above (see **Mergers**). When a merger is detected, the vertices from the fire that have entered the interior of the fireline polygon are "turned off".

Burnout, "firing out", or "back firing" is simulated on one side of the indirect line by adding a line fire incrementally to the simulation, but behind the advancing edge of the fireline by an adjustable distance. Each incremental line fire is then merged with the existing fire fronts.

Parallel Attack

A parallel or tangential attack is simulated using a combination of the direct and indirect methods discussed above. Since a parallel attack is designed to maintain line production at a fixed distance from the fire front, the algorithm from the **Direct Attack** methods is used to calculate the fireline path. As described by Fried and Fried (1996), this tactic has the same theoretical solution as for direct attack. The path taken by the parallel attack in *FARSITE* is however, computed along the **convex hull** of a fire perimeter. A convex hull is the ordered set of vertices that defines the globally convex outermost edge of a polygon. The convex hull will be the same as all or part of a fire that is convex (eg. an ellipse or circle). This feature has the benefit of minimizing the horizontal length of fireline constructed and it allows for automatic burnout of unburned fuels in concave regions. Once the route for fireline production is computed, the fireline is constructed the same way as for the **Indirect Attack**. Burnout is accomplished in the same fashion as with the Indirect Attack methods described above.

Aerial Attack Simulation

The effectiveness of a retardant drop depends on density of the retardant applied to a specific fuel type (Rothermel and Philpot 1975, George 1981). Heavy fuels such a timber or slash require higher retardant densities or coverage levels than uniformly fine fuels such as grass. George (1981, 1992) classifies retardant densities by coverage level. Coverage levels 1-6+ correspond to 1-6+ US gallons per 100 ft^2 of ground surface (George 1981).

Both simulations and field trials have shown that the length of a drop pattern is dependent on the volume of retardant and the density of its application (George 1981, George and Johnson 1990, George 1992). Aircraft with multiple tanks or compartments can choose to open all tanks at once and apply a high concentration of retardant onto a short pattern, or use different combinations of sequential tank openings for lesser coverage and a longer pattern. For a given volume of retardant, higher densities are found toward the middle of the drop pattern and have substantially shorter length of coverage. The relationships between retardant volume, drop height, air speed, aircraft type, and other parameters have been incorporated into simple slide calculators (George1981).

All retardant applications have a limited duration of effectiveness regardless of the type (water, gum thickened, or foam). As retardant dries, it becomes less effective in stopping fire spread. The limited duration is an important tactical consideration in scheduling retardant drops. Drops too far ahead of the fire may evaporate or dry before the fire gets there. Retardant applied to timber fuels with holdover potential may not be effective without subsequent attention from ground crews.

Obviously many factors actually affect the application and effectiveness of air attack. Air temperature, wind speed and direction, angle of aircraft approach, drop height, aircraft speed, flow rate of retardant from the tanks, and fire behavior are all noted effects (George and Blakely 1973, George 1975, George 1981, George and Johnson 1990). None of these factors are considered explicitly in this simulation.

The *FARSITE* implementation of air attack requires the user to input aircraft-specific information on effective line length by coverage level (see George 1981, 1992). The responsibility is on the user to provide realistic information and implement the aircraft capabilities in a realistic manner. *FARSITE* simulates a retardant drop as a line of the specified length/coverage level that is impermeable to a fire for the specified duration. After the effectiveness expires, fire may burn across the drop pattern as if the retardant was never applied.

Literature Cited

Albini, F.A. 1976. Estimating wildfire behavior and effects. USDA For. Serv. Gen. Tech. Rep. INT-30.

Albini, F.A. and R.G. Baughman. 1979. Estimating windspeeds for predicting wildland fire behavior. USDA For. Serv. Res. Pap. INT-221.

Albini, F.A. 1979. Spot fire distance from burning trees- a predictive model. USDA For. Serv. Gen. Tech. Rep. INT-56.

Albini, F.A. 1981. Spot fire distance from isolated sources-- extensions of a predictive model. USDA For. Serv. Res. Note INT-309.

Albini, F.A. 1983a. Transport of firebrands by line thermals. Comb. Sci. Tech. 32:277-288.

Albini, F.A. 1983b. Potential spotting distance from wind-driven surface fires. USDA For. Serv. Res. Pap INT-309.

Albini, F.A. and R.G. Baughman. 1979. Estimating windspeeds for predicting wildland fire behavior. USDA For. Serv. Res. Pap. INT-221.

Albini, F.A., G.N. Korovin, and E.H. Gorovaya. 1978. Mathematical analysis of forest fire suppression. USDA For. Serv. Res. Pap. INT-207.

Alexander, M.E. 1985. Estimating the length-to-breadth ratio of elliptical forest fire patterns. pp. 287-304 Proc. 8th Conf. Fire and Forest Meteorology.

Alexander, M.E. 1988. Help with making crown fire hazard assessments. in Fischer, W.C. and S.F. Arno (compilers), Protecting people and homes from wildfire in the interior west. USDA For. Serv. Gen. Tech. Rep. INT-251. pp. 147-156.

Alexander, M.E., B.D. Lawson, B.J. Stocks, and C.E. Van Wagner. 1992. Development and structure of the Canadian forest fire behavior prediction system. Forestry Canada Fire Danger Group, Inf. Rep. ST-X-3.

Anderson, D.G, E.A. Catchpole, N.J. DeMestre, and T. Parkes. 1982. Modeling the spread of grass fires. J. Austral. Math. Soc. (Ser. B.) 23:451-466.

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122.

Anderson, H.E. 1983. Predicting wind-driven wildland fire size and shape. USDA For. Serv. Res. Pap. INT-305.

Anderson, D.H. 1989. A mathematical model for fire containment. Can. J. For. Res. 19:997-1003.

Andre, J.C.S. and D.X. Viegas. 1994. A strategy to model the average fireline movement of a light to medium intensity surface forest fire. Proc. 2nd Intl. Conf. Forest Fire Research, Coimbra 1994. pp 221-242.

Andrews, P.L. and R.C. Rothermel. 1982. Charts for interpreting wildland fire behavior characteristics. USDA For. Serv. Gen. Tech. Rep. INT-131.

Andrews, P.L. 1986. BEHAVE: fire behavior prediction and fuel modeling system- BURN subsystem, Part 1. USDA For. Serv. Gen. Tech. Rep. INT-194.

Andrews, P.L. 1989. Application of fire growth simulation models in fire management. Proc. 10th Conf. Fire and Forest Meteorology, Ottawa Canada. pp 317-321.

Ball, G.L. and D.P. Guertin. 1992. Improved fire growth modeling. Intl. J. Wildl. Fire 2(2):47-54.

Barney, R.J. 1983. Fireline production: A conceptual model. USDA For. Serv. Res. Pap. INT-310.

Barney, R.J., C.W. George, and D.L. Trethewey. 1992. Handcrew fireline production rates -- some field observations. USDA For. Serv. Res. Pap. INT-457.

Beck, J.A. and C.F. Trevitt. 1989. Forecasting diurnal variations in meteorological parameters for predicting fire behavior. Can. J. For. Res. 19:791-797.

Beer, T. 1990. The Australian National Bushfire Model Project. Math. Comp. Mod. 13(12):49-56.

Bilgili, E and I.R. Methven. 1990. The simple ellipse: A basic growth model. 1st Intl. Conf. on Forest Fire Research, Coimbra 1990. pp B.18-1 to B.18-14.

Bradshaw, L.S, J.E. Deeming, R.E. Burgan, and J.D. Cohen. 1984. The 1978 National Fire-Danger rating system: Technical Documentation. USDA For. Serv. Gen. Tech. Rep. INT-169.

Bratten, F.W. 1978. Containment tables for initial attack on forest fires. Fire Tech. 14(4):297-303.

Burgan, R.E. 1988. 1988 revisions to the 1978 National Fire-Danger Rating System. USDA For. Serv. Res. Pap. SE-273.

Byram 1959. Chapter Three, Combustion of Forest Fuels. *in* Davis, .K.P., Forest Fire: Control and Use. McGraw-Hill. New York.

Catchpole, E.A, N.J. DeMestre, and A.M. Gill. 1982. Intensity of fire at its perimeter. Aust. For. Res. 12:47-54.

Cheney, N.P. 1981. Fire Behavior. *In* Gill, A.M., R.H. Groves, and I.R. Noble (eds.) Fire and the Australian biota. Aust. Acad. Science. Canberra.

Cheney, N.P., J.S. Gould, and W.R. Catchpole. 1993. The influence of fuel, weather, and fire shape variables on fires-spread in grasslands. Intl. J. Wildl. Fire 3(1):31-44.

Cheney, N.P. and J.S. Gould. 1997. Letter to the Editor: Fire growth and acceleration. Intl. J. Wildl. Fire 7(1):1-6.

Clarke, K.C. and J.A. Brass, and P.J. Riggan. 1994. A cellular automton model of wildfire propagation and extinction. Photogrammetric Eng. and Remote Sensing 60(11):1355-1367.

Dorrer, G.A. 1993. Modelling forest fire spreading and suppression on basis of Hamilton mechanics methods. in G.A. Dorrer (ed). Scientific Siberian A: special issue Forest Fires Modelling and Simulation. pp 97-116.

Fahnestock, G.R. 1970. Two keys for appraising forest fire fuels. USDA For. Serv. Res. Pap. PNW-99.

Finney, M.A. 1994. Modeling the spread and behavior of prescribed natural fires. Proc. 12th Conf. Fire and Forest Meteorology, pp138-143.

Finney, M.A. and K.C. Ryan. 1995. Use of the *FARSITE* fire growth model for fire prediction in US National Parks. Proc. The International Emergency Mgt. and Engineering Conf. May 1995 Sofia Antipolis, France. pp 186-192.

Finney, M.A. and P.L. Andrews. 1996. The *FARSITE* fire area simulator: fire management applications and lessons of summer 1994. Proc. Intr. Fire Council Mtg. November 1994, Coer D'Alene ID. *in press*

Fons, W.T. 1946. Analysis of fire spread in light forest fuels. J. Agric. Res. 72(3):93-121.

French, I.A., D.H. Anderson, and E.A. Catchpole. 1990. Graphical simulation of bushfire spread. Math. Comput. Model. 13(12):67-71.

French, I.A. 1992. Visualisation techniques for the computer simulation of bushfires in two dimensions. M.S. Thesis University of New South Wales, Australian Defence Force Academy, 140 pages.

Fried, J.S. and J.K. Gilless. 1989. Expert opinion estimation of fireline production rates. For. Sci. 35(3):870-877.

Fried, J.S. and B.D. Fried. 1996. Simulating wildfire containment with realistic tactics. For. Sci 42(3):267-281.

Fujioka, F.M. 1985. Estimating wildland fire rate of spread in a spatially nonuniform environment. For. Sci. 31(1):21-29.

George, C.W. 1975. Fire retardant ground distribution patterns from the CL-215 air tanker. USDA For. Serv. Res. Pap. INT-165.

George, C.W. 1981. Determining airtanker delivery performance using a simple slide chart-retardant coverage computer. USDA For.Serv. Gen. Tech. Rep. INT-113.

George, C.W. 1992. Improving the performance of fire retardant delivery systems on fixed-wind aircraft. USDA For. Serv. Res. Note INT-400.

George, C.W. and A.D. Blakely. 1973. An evaluation of the drop charaacteristics and ground distribution patterns of forest fire retardants. USDA For. Sev Res Pap. INT-134.

George, C.W. and G.M. Johnson. 1990. Determining aair tanker performance guidelines. USDA For. Serv. Gen. Tech. Rep. INT-268.

Green, D.G. 1983. Shapes of simulated fires in discrete fuels. Ecol. Mod. 20:21-32

Green, D.G., A.M. Gill, and I.R. Noble. 1983. Fire shapes and the adequacy of fire-spread models. Ecol. Mod. 20:33-45.

Hartford, R.A. and R.C. Rothermel. 1991. Moisture measurements in the Yellowstone Fires in 1988. USDA For. Serv. Res. Note INT-396.

Haven, L., T.P. Hunter, and T.G. Storey. 1982. Production rates for crews using hand tools on firelines. USDA For. Serv. Gen. Tech. Rep. PSW-62.

Hirsch, K.G. and D.L. Martell. 1996. A review of initial attack fire crew productivity and effectiveness. Intl. J. Wildl. Fire 6(4):199-215.

Knight, I. and J. Coleman. 1993. A fire perimeter expansion algorithm based on Huygen's wavelet propagation. Int. J. Wildl. Fire 3(2):73-84.

Kourtz, P. and W.G. O'Reagan. 1971. A model for a small forest fire.. to simulate burned and burning areas for use in a detection model. For. Sci. 17(2):163-169.

Kourtz, P, S. Nozaki and W. O'Regan. 1977. Forest fires in the computer- A model to predict the perimeter location of a forest fire. Fisheries and Envioronment Canada. Inf. Rep. FF-X-65.

Johansen, R.W. 1987. Ignition patterns and prescribed fire behavior in southern pine forests. Georgia For. Comm. For. Res. Pap. 72.

Martin, R.E. 1988. Rate of spread calculation for two fuels. West. J. Appl. For. 3(2):54-55.

McAlpine, R.S. 1989. Temporal variations in elliptical forest fire shapes. Can J. For. Res. 19:1496-1500.

McAlpine, R.S. and R.H. Wakimoto. 1991. The acceleration of fire from point source to equilibrium spread. For. Sci. 37(5):1314-1337.

Mees, R.M. 1985. Simulating initial attack with two fire containment models. USDA For. Serv. Res. Note PSW-378.

Morris, G.A. 1987. A simple method for computing spotting distance from wind-driven surface fires. USDA For. Serv. Res. Note INT-374.

Peet, G.B. 1967. The shape of mild fires in Jarrah forest. Austr. For. 31(2):121-127.

Perry, D.G. 1990. Wildland Firefighting: Fire behavior tactics & command, 2nd Edition. Fire Publications Inc, Bellflower CA.

Phillips, C.B. and R.J. Barney. 1984. Updating bulldozer fireline production rates. USDA For. Serv. Gen. Tech Rep. INT-166.

Phillips, C.B., C.W. George, and D.K.Nelson. 1988. Bulldozer fireline production rates -- 1988 update. USDA For. Serv. Res. Pap. INT-392.

Quintilio, D., P.J. Murphy, and P.M. Woodard. 1988. Production guidelines for initial attack hotspotting. Fire Management Notes 43(2) 6-9.

Richards, G.D. 1990. An elliptical growth model of forest fire fronts and its numerical solution. Int. J. Numer. Meth. Eng. 30:1163-1179.

Richards, G.D. 1993. The properties of elliptical wildfire growth for time dependent fuel and meteorological conditions. Comb. Sci. Tech. 92:145-171.

Richards, GD. 1995. A general mathematical framework for modeling two-dimensional wildland fire spread. Int. J. Wildl. Fire. 5(2):63-72.

Richards, GD. and R.W. Bryce. 1995. A computer algorithm for simulating the spread of wildland fire perimeters for heterogeneous fuel and meteorological conditions. Int. J. Wildl. Fire. 5(2):73-80.

Roberts, S. 1989. A line element algorithm for curve flow problems in the plane. CMA-R58-89. Centre for Mathematical Analysis, Aust. Nat. Univ. (Cited from French 1992).

Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115.

Rothermel, R.C. 1983. How to predict the spread and intensity of forest and range fires. USDA For. Serv. Gen. Tech. Rep. INT-143.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the northern Rocky Mountains. USDA For. Serv. Res. Pap. INT-438.

Rothermel, R.C. 1994. Some fire behavior modeling concepts for fire management systems. *in* Proc. 12th conf. Fire and Forest Meteorology, pp164-171.

Rothermel, R.C. and C.W. Philpot. 1975. Reducing fire spread in wildland fuels. In Experimental Methods in Fire Research. Proc. of the meeting to honor Clay Preston Butler, Stanford Research Institute. pp369-403.

Rothermel, R.C. and G.C. Rinehart. 1983. Field procedures for verification and adjustment of fire behaviorpredictions. USDA For. Serv. Gen. Tech. Rep. INT-142.

Rothermel, R.C, R.A. Wilson, G.A. Morris, and S.S. Sackett. 1986. Modeling moisture content of fine dead wildland fuelsinput to the BEHAVE fire prediction system. USDA For. Serv. Res. Pap. INT-359.

Sanderlin, J.C. and J.M. Sunderson. 1975. A simulation for wildland fire managment planning support (FIREMAN): Volume II. Prototype models for FIREMAN (PART II): Campaign Fire Evaluation. Mission Research Corp. Contract No. 231-343, Spec. 222. 249 pages.

Sanderlin, J.C. and R. J. Van Gelder. 1977. A simulation of fire behavior and suppression effectiveness for operation support in wildland fire amangement. In: Proc. 1st Int. Conv. on mathematical modeling, St. Louis, MO. pp 619-630.

Simard, A.J. and A. Young. 1978. AIRPRO and airtanker productivity simulation model. Environ. Can., Can. For. Serv., For. Fire Res. Inst. Info. Rep. FF-X-66.

Swanson, D.H., C.W. George, and A.D. Luedecke. 1976. Air tanker performance guides: general instruction manual. USDA For. Serv. Gen. Tech. Rep. INT-27.

Van Wagner, C.E. 1969. A simple fire growth model. Forestry Chron. 45:103-104.

Van Wagner, C.E. 1977. Conditions for the start and spread of crownfire. Can. J. For. Res. 7:23-24.

Van Wagner, C.E. 1988. Effect of slope on fires spreading downhill. Can. J. For. Res. 18:818-820.

Van Wagner, C.E. 1993. Prediction of crown fire behavior in two stands of jack pine. Can. J. For. Res. 23:442-449.

Wallace, G. 1993. A numerical fire simulation mode. Intl. J. Wildl. Fire 3(2):111-116.

Weber, R.O. 1989. Analytical models for fire spread due to radiation. Combust. Flame 78:398-408.

INDEX

—A—

ARC/INFO GIS, 5, 6, 21, 22, 24, 30, 50, 51, 108
ArcView, 6, 50, 51
Attached Vector Files, to Landscape, 20
Attack, Air, 99
Attack, Air Resources, 15, 97, 99
Attack, Direct, 15, 89, 90, 96
Attack, Ground Resources, 87
Attack, Indirect, 91, 96
Attack, Log Files, Air Attack, 100
Attack, Log Files, Ground Attack, 90, 92, 95
Attack, Menu, 87
Attack, Parallel, 93, 96
Attack, Revising, 90, 92, 95

—B—

Backing Spread, 70, 113, 121, 124
BEHAVE, 33, 36, 109, 130, 140, 144
Bookmark File, 14, 46, 47, 80

—C—

Canopy, 5, 9, 20, 22, 23, 25, 26, 45, 46, 99, 109, 114, 115, 130, 131
Cellular Models, 120, 141
Colors, Fire Perimeters, 15, 46, 53, 55, 56, 59, 66, 67, 108
Colors, Landscape Themes, 15, 46, 53, 55, 56, 59, 66, 67, 108
Colors, Super VGA, 54, 55
Conversion File, Fuel Models, 24, 25
Crossovers, 68, 124
Crown Fire, 60, 69, 114, 129, 158
Cursors, 10, 11, 56, 57, 60, 77, 81, 82, 84, 90, 92, 94, 99
Custom Fuel Models, 13, 23, 24, 25, 36, 37, 153

—D—

Data, Output, 60, 61
Distance Resolution, 68
Duration, 10, 14, 59, 75, 76, 84
Duration, Reset at Restart, 84

—E—

Editing, Landscape Files (.LCP), 40, 83
Ellipse, 123
Elliptical Dimensions, 123
Embers, 69, 82, 131
Examples, 9, 27, 29, 32, 34, 36, 87, 116, 151
Extracting, Landscape Files (.LCP), 39

—F—

FARSITE, Description, 5
FARSITE, Features, 5, 6, 15, 25, 26, 47, 51, 74, 113
FARSITE, File Menu, 17
FARSITE, Input Menu, 19
FARSITE, Intended Uses, 7
FARSITE, Introduction, 5, 119
FARSITE, Overview, 9
FARSITE, Requirements, 8
FARSITE, Tutorial, 13
FARSITE, Use on Active Fires, 7
FARSITE, Use on Potential Fires, 7
File Information, .LCP Files, 37
Fire Acceleration, 20, 71, 132
Fire Behavior Options, 0, 10, 13, 24, 25, 26, 32, 34, 35, 36, 41, 46, 53, 54, 69, 132, 141
Fire Behavior Options, Backing Spread Rates, 70
Fire Behavior Options, Embers from Torching Trees, 69
Fire Behavior Options, Enable Crown Fire, 69, 158
Fire Behavior Options, Growth of Spot Fires, 70
Fire Behavior Options, Link Crown Density, 41, 69
Fire Spread, Backing, 70, 113, 121, 124
Fire Spread, Flanking, 112, 113, 121, 136
Fire Spread, Heading, 66, 111, 112, 113, 119, 121
Fire, Area Data and Graphs, 0, 5, 61, 62, 64, 119
Fire, Fire Characteristics Chart, 60, 64
Fire, Front, 5, 60, 61, 66, 67, 68, 78, 79, 89, 90, 91, 93, 94, 109, 112, 113, 116, 119, 120, 121, 122, 124, 125, 126, 128, 130, 131, 132, 133, 134, 136, 144
Fire, Perimeter Data and Graphs, 53, 61, 62, 64, 80
Fireline Intensity, 6, 52, 60, 71, 107, 129, 133
Fires, Interaction, 132
Fires, Mergers, 127, 136
Fires, Multiple, 114
Fires, Spot, 115, 130, 131
Flame Length, 52
Flanking Spread, 113, 121, 136
Fuel File Inputs, 32
Fuel File Inputs, Fuel Conversion File, 24
Fuel Models, Conversion Files, 24
Fuel Models, NFFL, 13, 24, 25, 32, 34, 35, 36

—G—

GIS Files, ARC/INFO, 5, 6, 21, 22, 24, 30, 50, 51, 108

GIS Files, Aspect, 24
GIS Files, Canopy Cover, 25, 130, 157
GIS Files, Crown Base Height, 25
GIS Files, Crown Bulk Density, 26
GIS Files, Elevation, 23, 28
GIS Files, Exporting From FARSITE, 7, 10, 15, 51, 62, 67
GIS Files, Fuel Model, 13, 24, 32, 35, 71, 153
GIS Files, GRASS, 5, 6, 21, 22, 23, 24, 30, 31, 35, 50, 51, 52, 72, 107, 108
GIS Files, headers, 21, 22, 30, 31, 37
GIS Files, Importing to LCP File, 9, 19, 33, 34, 46, 47, 62, 106
GIS Files, Slope, 23, 70, 123, 128, 157, 158
GIS Files, Tree Height, 25
Graphs, Output, 59, 81
GRASS GIS, 5, 6, 21, 22, 23, 24, 30, 31, 35, 50, 51, 52, 72, 107, 108

—H—

Heading Spread, 66, 111, 112, 113, 119, 121
Heat/Unit Area, 60, 133

—I—

Ignitions, 77
Ignitions, Area, 78
Ignitions, Importing, 79, 80
Ignitions, Line, 78
Ignitions, Point, 70, 77
Ignitions, Restoring at Restart, 85
Ignitions, Rotation Sensitive, 78, 85
Initial Attack, Air, 99
Initial Attack, Air Resources, 15, 97, 99
Initial Attack, Direct, 15, 89, 90, 96
Initial Attack, Ground Resources, 87
Initial Attack, Indirect, 91, 96
Initial Attack, Parallel, 93, 96
Input, Bookmark File, 6, 14, 46, 47, 80
Input, Inputs Dialog, 9, 19, 33, 34, 46, 47, 62, 106
Input, Optional, 34
Input, Project File, 6, 9, 13, 20, 46, 47, 140
Input, Required, 32

—L—

Landscape Display, Options, 10, 15, 47, 55, 103, 108
Landscape File, Constant Values, 27
Landscape Files, Editing, 40, 83
Landscape Files, Extracting, 39
Landscape Files, File Information, 37
Landscape Files, Merging, 38
Landscape Utilities, 9, 21, 37, 38, 39, 40, 46, 55, 83
Landscape, Query Window, 64
Legend, Fuel Model Colors, 10, 54, 58

—M—

Map Display, Grid Lines, 55
Map Display, Topographic Shading, 55
Map Display, Visible Theme, 55
Mergers, 127, 136
Mistakes, Barriers, 83
Mistakes, Fuels, 84
Mistakes, Ignitions, 79
Mode, Fire Behavior, 10, 26, 41, 46, 69
Model , Fire Acceleration, 20, 71
Model, Fire Behavior, 10, 26, 41, 46, 69
Model, Parameters, 10, 14, 51, 65, 74
Multiple Fires, 114

—N—

NFFL, Fuel Models, 13, 24, 25, 32, 34, 35, 36

—O—

Output, Export Files, 7, 10, 15, 51, 62, 67
Output, Raster Files for Export to GIS, 51
Output, Vector Files for Export to GIS, 15, 20, 47, 50
Outputs, Shapefiles, 51

—P—

Parameters, Model, 10, 14, 51, 65, 74
Parameters, Model, Distance Resolution, 68
Parameters, Model, Perimeter Resolution, 67
Parameters, Model, Timestep, 66
Parameters, Model, Visible Timestep, 66
Perimeter Resolution, 67
Prescribed Natural Fire (PNF), 7, 141
Printing, Window Contents, 5, 11, 49, 58, 61, 62, 63
Project File, 9, 13, 46, 47

—Q—

Query Window, 64

—R—

Raster Data Generation, 133
Raster Files, 51
Rate of Spread, 6, 20, 33, 34, 60, 66, 67, 68, 69, 70, 71, 77, 78, 110, 111, 112, 113, 119, 120, 121, 124, 128, 129, 132, 133, 136, 142, 157, 158
Redrawing Fire Perimeters, in Zoom Window, 56
Redrawing Landscape Windows, 15, 108

—S—

Saving, Window Contents, 49, 58, 61, 62, 63
Simuate, Resetting, 74, 75, 79, 83, 84, 85
Simulate, Duration, 10, 14, 59, 75, 84
Simulate, Ignitions, 77
Simulate, Ignitions, Importing, 79, 80

Simulate, Initiate/Terminate, 10, 14, 15, 74
Simulate, Modify Map, 6, 10, 14, 29, 46, 60, 64, 76, 77, 79, 80, 82, 83
Simulate, Options, 74, 75, 76, 78, 79, 80, 84
Simulate, Resume/Suspend, 10, 14, 74
Simulate, Start/Restart, 10, 14, 74, 75, 85
Simulate, Temporarily Changing Fuels, 83
Simulate, Weather Monitoring & Grid, 80
Slope Correction, 128
Spot Fire, 115, 130, 131
Spotting, 115, 130, 131

—T—

Three D Window, 15, 57, 103
Three D Window, Tool Bar, 58
Time, Current Display, 59
Time, Elapsed Display, 59
Timestep, 66
Tool Buttons, 49, 57, 59, 73, 76, 79, 83, 84
Topography, 5, 29, 43, 67, 68, 98, 106, 110, 112, 115, 119, 121, 134, 136, 157

—V—

Vector Files, 15, 20, 47, 50
Vector Files, Attached to Landscape, 20
Vectoring Wind & Slope, 123
View Port, Changing, 104
View, Changing View Port, 104
View, Clearing View Windows, 108
View, Eliminating 2D Windows, 108
View, Landscape File, 103
View, Redrawing Landscape Windows, 15, 108
View, Saving Visible Perimeters, 11, 14, 108
View, Viewing Raster Files, 106
View, Viewing Vector Files, 105
Visible Theme, from .LCP File, 10, 15, 47, 55, 103, 108
Visible Timestep, 66

—W—

Waves, 5, 110, 119, 120, 121
Weather Files, Generate Dialog, 29, 44
Weather Inputs, 9, 27
Weather Station, Locating, 81
Weather, Gridded, 30
Weather, Monitoring Stations, 60, 64
Weather/Wind Definition Dialog, 42
Weather/Wind Grid, Customizing, 81
Wind Direction, 6, 30, 34, 68, 111, 112, 113, 123, 131
Wind Files, Generate Dialog, 29, 44
Wind Inputs, 9, 29, 30
Wind, Gauge Display, 62, 64
Winds, Gridded, 30
Windspeed, 29, 60, 62, 70, 110, 111, 113, 120, 123, 124, 131

—Z—

Zoom Window, 56
Zoom Window, Redrawing Fire Perimeters, 56
Zoom Window, Use in Change View Port, 15, 104
Zoom Window, Use in Extracting .LCP, 39

Appendix 1

Printout of example input files

The following are printouts (complete or partial) of the example CHAGOOPA files, in the \FARSITE3\EXAMPLES\ subdirectory.

Weather Input File (.WTR)

```
ENGLISH
7 15  30  500 1300  49  70  98  38 8400
 7 16   0  400 1300  53  77  91  26 8400
 7 17   0  500 1300  56  77  62  25 8400
 7 18   0  500 1400  54  75  59  20 8400
 7 19   0  400 1400  52  76  60  16 8400
 7 20   0  400 1500  49  77  63  10 8400
 7 21   0  500 1400  53  75  66  24 8400
 7 22   0  500 1500  43  74  92  30 8400
 7 23   0  500 1300  46  71  68  18 8400
 7 24   0  500 1300  49  73  56  15 8400
 7 25   0  500 1500  45  74  44  24 8400
 7 26   0  500 1400  53  76  55  18 8400
 7 27   0  400 1400  53  79  57  18 8400
 7 28  20  500 1600  53  77  52  22 8400
 7 29   0  500 1400  56  79  48  16 8400
 7 30   0  500 1300  56  68  51  22 8400
 8  1   0  500 1300  57  81  34  20 8400
 8  2   0  400 1600  57  76  45  23 8400
 8  3   0  500 1300  59  81  39  19 8400
 8  4   0  400 1300  54  77  42  20 8400
 8  5   0  300 1400  54  71  50  30 8400
 8  6   0  500 1300  52  75  53  27 8400
 8  7   0  500 1300  54  75  40  20 8400
 8  8   0  500 1300  48  79  55  19 8400
 8  9   0  500 1300  54  79  50  19 8400
 8 10   0  500 1400  56  82  45  22 8400
 8 11   0  400 1300  59  76  49  29 8400
 8 12  10  400 1300  59  78  52  28 8400
 8 13  50  500 1000  58  75  59  39 8400
```

Wind Input File (.WND)

```
ENGLISH
7 15     0    2  359   0
7 15   100    2    3   0
7 15   200    5  346   0
7 15   300    3  340   0
7 15   400    0  292   0
7 15   500    1  338   0
7 15   600    2  358   0
7 15   700    3   37   0
7 15   800    5  158   0
7 15   900    9  170   0
7 15  1000    8  157   0
7 15  1100   10  158   0
7 15  1200    9  165   0
7 15  1300    4  172   0
7 15  1400    7  163   0
7 15  1500   11  164   0
7 15  1600   12  171   0
7 15  1700   10  172   0
7 15  1800    8  163   0
7 15  1900    5  176   0
7 15  2000    4  191   0
7 15  2100    2  204   0
7 15  2200    3  329   0
7 15  2300    2  326   0
7 15     0    4  347   0
7 16   100    3  352   0
7 16   200    5  327   0
7 16   300    4  350   0
7 16   400    7  342   0
7 16   500    5  334   0
7 16   600    4  355   0
7 16   700    4   16   0
7 16   800    7  166   0
7 16   900    8  169   0
7 16  1000   14  162   0
7 16  1100    6  176   0
7 16  1200   13  171   0
7 16  1300   10  166   0
7 16  1400   12  168   0
7 16  1500   14  168   0
7 16  1600   14  171   0
```

Initial Fuel Moisture File (.FMS)

```
 1 100 19 20 125 125
 2 10 19 20 125 125
 3 10 19 20 125 125
 4 10 19 20 125 125
 5 10 19 20 125 125
 6 10 19 20 125 125
 7 10 19 20 125 125
 8 10 19 20 125 125
 9 10 19 20 125 125
10 10 19 20 125 125
11 10 19 20 125 125
12 10 19 20 125 125
13 10 19 20 125 125
```

Rate of Spread Adjustment File (.ADJ)

```
1 0.5
2 0.5
3 0.5
4 0.25
5 0.25
6 0.25
7 0.25
8 0.5
9 0.5
10 0.5
11 0.5
12 0.5
13 0.5
```

Custom Fuel Model File (.FMD)

```
ENGLISH
14 4.0 5.0 5.0 1.0 8.0 2500 2000 1800 0.5 35 8000 9000
15 4.0 5.0 5.0 1.0 12.0 2000 2000 1800 1.5 35 8000 9000
16 4.0 5.0 5.0 0.0 18.0 1500 2200 1800 1.5 35 8000 9000
17 4.0 5.0 5.0 0.0 20.0 2900 2200 1800 2.5 35 9000 9000
```

Ground Resource File (.CRW) for Attack simulation

```
#20 Person Hotshot Crew#
METERS_PER_MINUTE
FLAME_LIMIT 2.0
1	8
2	7
3	7
4	0.5
5	0.8
6	 0.8
7	1.1
8	4
9	4
10	 2
11	0.3
12	0.5
13	0.5
99
#5 Person Squad#
METERS_PER_MINUTE
FLAME_LIMIT 2.0
1	2
2	2
3	2
4	.1
5	.1
6	.1
7	.2
8	1
9	1
10	.5
11	.05
12	.05
13	.05
99
#Tractor Crew, 4 person#
METERS_PER_MINUTE
FLAME_LIMIT 3.0
1	25
2	25
3	25
4	15
5	15
6	15
```

```
7       15
8       5
9       5
10      5
11      3
12      3
13      3
99
```

Air Resource File (.AIR) for Attack simulation

```
# Bomber  1, 1000 gal#
METERS
1       100
2       80
3       60
4       50
6       40
8        35
# Bomber  2, 3000 gal#
METERS
1       250
2       190
3       150
4       100
6       80
8       60
# Bomber  3, 500 gal#
METERS
1       60
2       40
3       35
4       30
6       25
8       20
```

Appendix 2

FARSITE Process Control

```
For each timestep (date and time specified)
{       For each fire
        {       For each vertex (X, Y)
                {       Get the fire environment (fuels, weather, topography)
                        Calculate fuel moistures from initial conditions
                        Calculate vertex orientation angle
                        Calculate surface fire (below)
                        if (Canopy Cover >0)
                                Calculate crown fire (below)
                }
                Perform Direct and Parallel Attacks
                Update Raster Output Maps (arrival time, fire intensity etc.)
                Correct crossovers
                Compute area and perimeter
        }
}
Ember flight, ignition, growth from time of contact
Perform Indirect and Aerial Attacks
Merge all fires
```

Surface fire Calculations

```
{       Compute forward equilibrium spread rate
        Vector wind and slope
        Compute elliptical dimensions using resultant wind-slope vector
        Compute spread rate R by accelerating fire over timestep
        Compute average spread rate of fire over timestep
        Compute spread differentials
        Slope transformation
        Compare fire spread with distance resolution
        if (fire spread is truncated to distance resolution)
        {       Compute time to spread distance resolution with acceleration
                Adjust spread distance to distance resolution
                Reduce time elapsed to accomplish distance resolution
        }
}
```

Crown Fire Calculations

```
{       Calculate Critical Surface Fire Intensity Io
        if (actual surface intensity>= Io)
        {       Compute crown fraction burned
                Compute acceleration constant for crown fire spread
                Compute maximum crown fire spread rate
                Vector open wind and slope
                Compute elliptical dimensions using resultant wind-slope vector
                Compute critical crown fire spread rate
                Compute actual crown fire spread rate
                if (actual crown fire spread >= critical crown fire spread rate
                {       Accelerate crown spread rate
                        Compute crown spread differentials
                        Slope Transformation
                        Compare fire spread to distance resolution
                        if(crown fire spread is truncated to distance resolution)
                        {       Fire acceleration as a function of distance resolution
                                Adjust spread distance to distance resolution
                                Reduce time elapsed because of increased spread rate
                        }
                        Compute Crown Fire Intensity
                        Ember Lofting from Active Crown Fire
                }
                else
                {       Compute Crown Fire Intensity
                        Ember Lofting from Torching Trees
                }
        }
}
```

Spot Fire Calculations

```
{       Lofting
        {       Determine plume characteristics (for torching tree)
                Loft embers
        }
        Flight
        {       Iterate horizontal and vertical ember flight path
        }
        Ignition
        {       Determine if ember lands inside existing fires
                Ignition Frequency
        }
}
```