

# **Help for the User Interface for VSMOKE-GIS and VSMOKE**

**Version 2.2.1  
February 23, 2009**

**Simple smoke dispersion model for prescribed and wildland fires  
in flat to gently rolling terrain**

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## **Introduction**

Resource managers in the United States use prescribed fire for a variety of purposes, such as to control vegetation, or reduce fuels that have accumulated in the forest. There is an interest to increase the amount of acres treated with prescribed fires to promote healthy forests. This includes using fire to improve habitat for threatened and endangered species, and reduce heavy fuel loads since wildfires in these areas can be catastrophic under the certain environmental conditions. Though there are benefits to treating forests with prescribed fires, there is also a potential impact from smoke to human health and public safety. Prescribed fires release small particles (2.5 micrometers or less in size) that can penetrate deep into human lungs and increase the risk of serious health problems. Furthermore, smoke plumes with a high ground-level particulate matter concentrations increase the likelihood for traffic accidents to occur along highways, or reduce visibility in scenic areas.

Two simple screening models have been developed by the USDA Forest Service to determine what impact smoke emissions may have on visibility and people's health in flat to gently rolling terrain. The VSMOKE (Lavdas 1996) and VSMOKE-GIS smoke dispersion models are classified as Gaussian models among people who are involved in estimating air pollution impacts. VSMOKE and VSMOKE-GIS are unique when compared to other point source (i.e. smoke stack models) Gaussian models in allowing the user to control what percentage of the smoke is dispersed at ground level, and how the remaining smoke rises to maximum height in the atmosphere.

VSMOKE-GIS is a tool to help people visualize where specified particulate matter concentrations are likely to occur downwind of a fire. The VSMOKE-GIS model uses many of same calculation as VSMOKE (Lavdas 1996), but the output is displayed in the geographic information system (GIS) software called ArcMap or ArcView

(developed by Environmental Systems Research Institute® (ESRI)). This allows a person to see if the smoke concentrations may reach unhealthy concentrations, reduce visibility along a highway, and/or negatively impact other smoke sensitive targets (such as a hospital or school). The VSMOKE-GIS model predicts the maximum downwind distance a PM2.5 (fine particle) concentration may occur. The user of VSMOKE-GIS can enter up to 10 particulate matter concentrations to evaluate, or choose the 5 fine particle concentration that relate to the Environmental Protection Agency's (EPA) 1-hour air quality index (AQI ) for particulate matter.

VSMOKE is a model that estimates downwind concentrations of particulate matter and carbon monoxide at 31 fixed distances, and how far and how well a person may see through the smoke plume at each distance. The pollution concentration results are color coded according to the 1-hour AQI index for fine particulate matter, or carbon monoxide. VSMOKE also provides estimates on the dimensions of the smoke plume above the ground, provides an estimate of the atmosphere's ability to disperse smoke (called Dispersion Index (DI)) from multiple fires, and the likelihood of the smoke contributing to a highway accident (called Low Visibility Occurrence Risk Index (LVORI)). A GIS software package does not need to be used to perform a VSMOKE analysis. Instead, a person can access the model through the user interface software (found at c:\vsmkgs\smoke.exe).

This version (2.2.1) of the user interface software provides a way to use the two smoke dispersion models and has added an interface to easily retrieve the Fire Emission Production Simulator (FEPS) results in comparison to version 2.1.0. The FEPS model produces hourly estimates of PM2.5, carbon monoxide, and heat release rates, which are then used by VSMOKE and VSMOKE-GIS.

Occasionally, you should visit the VSMOKE website (<http://webcam.srs.fs.fed.us/vsmoke/>) to see if a new version or update of the software, this manual, or help files is available for downloading.

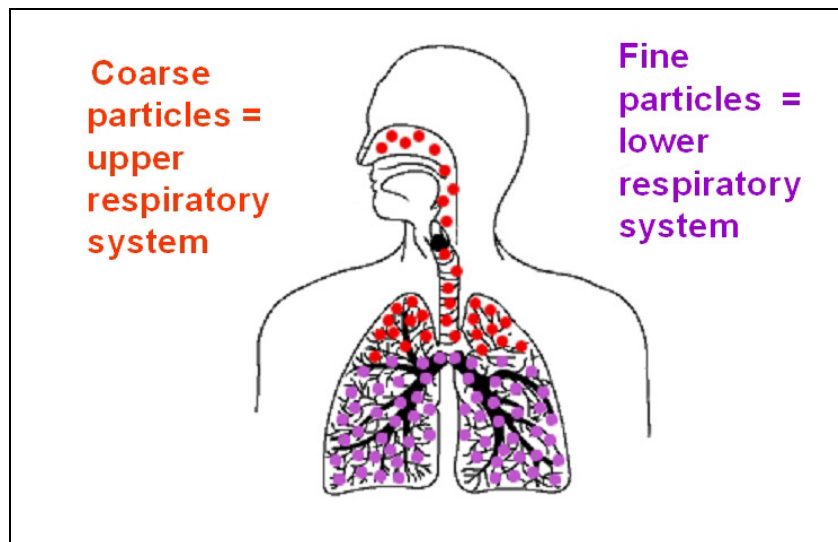
This manual is divided into the following sections (also found under the "Help Topics" tab in the software application):

1. Background information on the health and visibility impacts of smoke from prescribed and wildfires
2. VSMOKE and VSMOKE-GIS model assumptions
3. Information on FEPS (Fire Emissions Production Simulator)
4. The steps that need to be taken by GIS software users to allow them to interface with the data input forms and models.
5. The six steps necessary to complete a smoke analysis.
6. A description of all the variables used in VSMOKE and VSMOKE-GIS; and some helpful hints on how to acquire the data, and reasonable values to use as inputs.
7. Two ways to estimate the stability of the atmosphere.
8. Suggested websites and other documents for further reading.

## **Background Information on Health and Visibility Impacts of Smoke**

### **Health Effects of Fine Particles**

Particulate matter is a mixture of solids and liquid droplets suspended in air. A number of compounds can be found in particulate matter, such as: sulfates, nitrates, volatile organic compounds, elemental carbon, metals, soil or dust, and fragments of pollen or mold spores. The size of particles is directly linked to their potential for causing health problems. Coarse particles less than 10 micrometers in diameter do pose a health risk, because they can penetrate into your lungs. Fine particles 2.5 micrometers and smaller in diameter are of greatest health concern since they can penetrate deep into the lungs and some fine particles may even get into your bloodstream. Exposure to fine particles (PM<sub>2.5</sub>) can affect both your lungs and your heart. Larger particles (greater than 10 micrometers in size) are of less concern, although they can irritate your eyes, nose, and throat.



Smoke produced from burning wood, other vegetation, and organic matter is made up of a complex mixture of water, gases, and particulate matter. When a person views a smoke plume from a fire they are seeing a large amount of water vapor being released. However, mixed among the water vapor are gases (such as carbon monoxide) and fine particles produced when wood and other organic matter are consumed. About 70 percent of the particulate matter released from smoke contains fine particles; primarily in the form of volatile organic compounds or elemental carbon.

Smoke from prescribed and wildfires can irritate the eyes and airways causing stinging eyes, a runny nose, coughing, a scratchy throat, irritated sinuses, or headaches. A person with heart or lung disease might have their symptoms become worse with the increase in pollution from the fires. The biggest health threat from

smoke comes from the fine particles since they can penetrate deep into the lungs or get into the bloodstream, where they can cause illnesses such as bronchitis. Fine particles can aggravate chronic heart and lung diseases - and even are linked to premature deaths in people with these conditions.

People with heart disease might experience chest pain, palpitations, shortness of breath, or fatigue. People with lung disease may not be able to breathe as deeply or as vigorously as usual, and they may experience symptoms such as coughing, phlegm, chest discomfort, wheezing and shortness of breath. When smoke levels are high enough, even healthy people may experience some of these symptoms.

Usually, **older adults** are more likely to be affected by smoke, possibly because they are more likely to have heart or lung diseases than younger people, and the amount of air that can be taken into their lungs with each breath decreases with age. **Children** also are more susceptible to smoke than healthy adults for several reasons, including: their respiratory systems are still developing, they breathe more air (and air pollution) per pound of body weight than adults, and they're more likely to be active outdoors.

Most people working at prescribed fires and wildfires are considered healthy, but that can have reactions to the particulate matter released from the fires. Fire fighters should not be exposed to fine particulate concentration averaging greater than 5,000 micrograms per cubic meter during an 8-hour work shift.

Some other websites that have useful information on the effects of fine particles to people's health are:

1. Forest Fire Smoke: <http://cfpub.epa.gov/airnow/index.cfm?action=smoke.main>
2. Human Health Impacts of Forest Fires in the Southern United States: A Literature Review: [http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja\\_fowler001.pdf](http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja_fowler001.pdf)
3. The AirNow website showing recent fine particulate matter concentrations measured in the atmosphere: <http://www.epa.gov/air/data/geosel.html>
4. Particle Pollution and Your Health: <http://www.airnow.gov/index.cfm?action=particle.airborne>
5. Smoke Management Guide for Prescribed and Wildland Fire Chapter 3, Section 3.1 – Public Health and Exposure to Smoke: <http://www.nwccg.gov/pms/pubs/SMG/1-58.pdf>

## Fine Particulate Matter Air Quality Index

The Environmental Protection Agency (EPA) has developed the Air Quality Index (AQI) for fine particulate matter (PM<sub>2.5</sub>). The VSMOKE model results use the values for the 1-hour average concentrations (see table below) to color code the results.

Visit the [AirNow](http://www.airnow.gov) website to learn more about the AQI for fine particles.

PM <sub>2.5</sub> 24-hr Avg. Concentration (ug/m <sup>3</sup> )	PM <sub>2.5</sub> 1-3 hr Avg. Concentration (ug/m <sup>3</sup> ) *	Index Values	Visibility (Miles)	Level of Health Concern	Cautionary Statements
0.0 – 15.4	0.0 – 38	0-50	> 11	<b>Good</b>	None
15.5 – 35.4	39 – 88	51 – 100**	6 – 10	<b>Moderate</b>	None
35.5 – 65.4	89 – 138	101 - 150	3 – 5	<b>Unhealthy for Sensitive Groups</b>	People with respiratory or heart disease, the elderly, and children should limit prolonged exertion.
65.5 – 150.4	138 – 351	151 – 200	1.5 – 2.75	<b>Unhealthy</b>	People with respiratory or heart disease, the elderly and children should avoid prolonged exertion, everyone else should limit prolonged exertion.
150.5 – 250.4	352 - 526	201 – 300	1 – 1.25	<b>Very Unhealthy</b>	People with respiratory or heart disease, the elderly and children should avoid any outdoor activity, everyone else should avoid prolonged exertion.
250.5 +	>526	301 - 500	< 1	<b>Hazardous</b>	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.

\*An AQI of 100 for PM<sub>2.5</sub> corresponds to a PM<sub>2.5</sub> level of 35.4 micrograms per cubic meter (24-hr avg.). Information taken from "Wildfire Smoke: A Guide for Public Health Officials", July 2008 revision. <http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf>



Many fires occur in areas where there is not fine particulate matter monitors. The table above provides an estimate of the fine particulate matter concentrations based upon the distance you can see a distant object. Please note these are only estimates since there are numerous factors that influence visibility conditions. Use the following procedure when estimating the AQI value in the field (Therriault 2001):

1. Face away from the sun.
2. Determine the range in visibility by trying to locate several distant objects (such as a sign, tall building, or mountain) where you know how far away the objects are located from your current position. You may not be able to see some objects due to background atmospheric conditions and/or the smoke in the atmosphere.
3. Once you know the distances of the furthest object you can see then use the table above to estimate the AQI category.

### **Health Effects of Carbon Monoxide**

Carbon monoxide (CO) is an odorless, colorless gas that is formed when carbon in fuel is not burned completely, which is the case with prescribed and wildfires. Carbon monoxide is highly reactive and can contribute to an increase in ground-level ozone, or convert to carbon dioxide (a gas thought to contribute to global climate change). Once inside a person's blood stream it will bind to the hemoglobin (a protein carried by red blood cells) instead of oxygen, and can lead to oxygen deprivation, damages to body tissue, and coughing and cold-like symptoms. Typically, fire fighters can be at risk to carbon monoxide poisoning since they are working within and near the burn areas. Something to know about carbon monoxide is:

1. Carbon monoxide is poisonous to healthy people at high concentrations in the air and at extremely high levels can cause death.
2. Can affect people with heart disease such as angina, clogged arteries, or congestive heart failure. A single exposure of carbon monoxide at sufficient levels may result in chest pain and cause a reduction in a person's ability to exercise. Repeated exposure may lead to other cardiovascular impacts.
3. Can affect a person's central nervous system and people who breath high concentrations may develop dizziness, nausea, vision problems, reduced ability to work or learn, reduced manual dexterity, and impaired mental function, and/or difficulty performing complex tasks.
4. Typically, the body recovers quickly from short-term exposure during smoke-free periods and the person can breathe "clean air."

Firefighters working on prescribed burns are often exposed to more carbon monoxide and particulate matter than firefighters on wildfires. Currently, the recommendation is to keep the time weighted average for an 8-hour shift to 50 part per million (ppm), and firefighters should never be exposed to more than 200 ppm.

A useful website resource to read: How Carbon Monoxide Affects the Way We Live and Breathe (<http://www.epa.gov/air/urbanair/co/>)



### Carbon Monoxide Air Quality Index

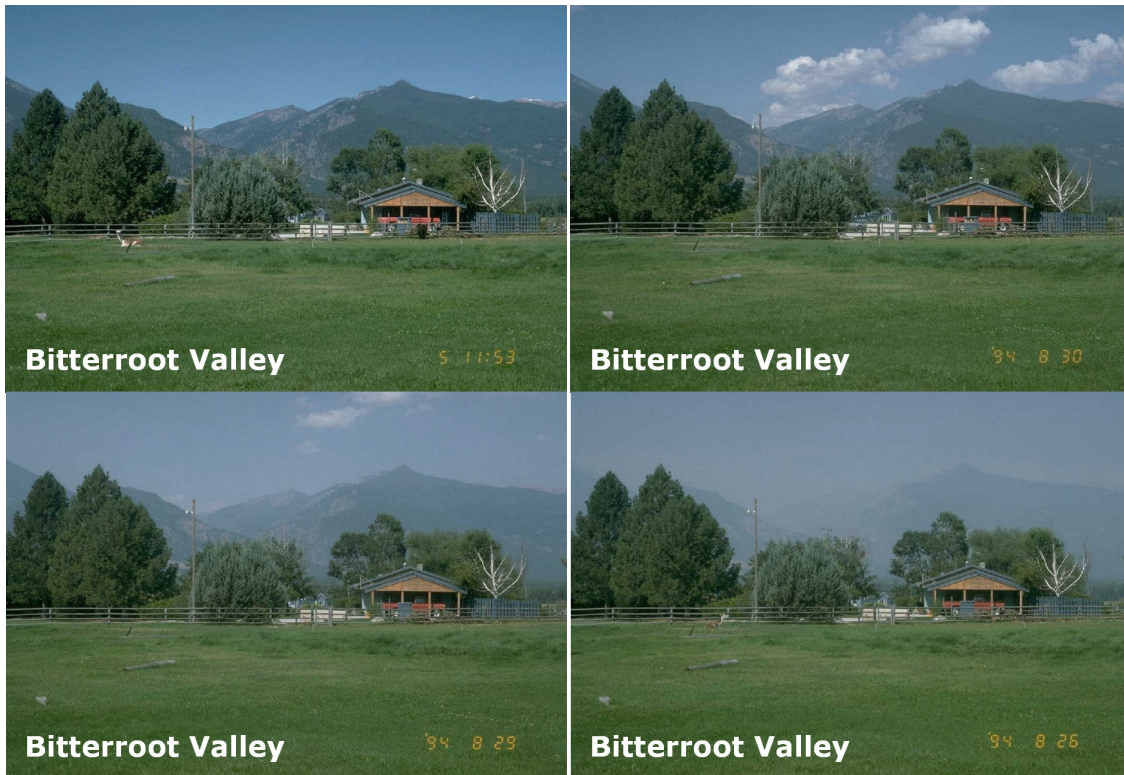
The Environmental Protection Agency (EPA) has developed the Air Quality Index (AQI) for carbon monoxide (CO). The VSMOKE model results use the values for the 1-hour average concentrations to color code the results. Visit the AirNow website to learn more about the AQI for carbon monoxide.

CO 1-hr Avg. Concentration (ppm)	Index Values	Level of Health Concern	Cautionary Statements
0.0 - 4.4	0 - 50	Good	None
4.5 - 9.4	51 - 100	Moderate	None
9.5 - 12.4	101 - 150	Unhealthy for Sensitive Groups	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion
12.5 - 15.4	151 - 200	Unhealthy	People with heart disease, such as angina, should reduce moderate exertion and avoid sources of CO, such as heavy traffic.
15.5 - 30.4	201 - 300	Very Unhealthy	People with heart disease, such as angina, should avoid exertion and sources of CO, such as heavy traffic.
30.5 +	301 - 500	Hazardous	People with heart disease, such as angina, should avoid exertion and sources of CO, such as heavy traffic. Everyone else should reduce heavy exertion.

## Visibility

Typically, when people talk about visibility they are concerned with both how far and how well a distant object can be seen. Anything that causes the sun's light (photons of energy) to be absorbed or scattered can reduce visibility conditions. The initial reduction in the amount of sunlight occurs from the gases (like nitrogen) naturally occurring in the atmosphere. Additional reductions in visibility conditions occur from fine particles due to air pollution released from people's activities, especially the combustion of fossil fuels. The types of fine particles measured in the atmosphere are sulfates, nitrates, volatile organic compounds, elemental carbon, and soil. In the eastern United States sulfates are the primary fine particle responsible for visibility impairment.

Smoke from prescribed and wildfires release fine particles (PM<sub>2.5</sub>) and very large quantities of water vapor. The primary fine particles released from fires are volatile organic compounds and elemental carbon. These pollutants are released and mix with the other air pollutants present in the atmosphere. In sufficient quantities the fine particles can exacerbate visibility conditions along highways and a scenic view. The four photographs taken at the Bitterroot Valley (below) show how smoke has reduced the visibility of an area with good visibility (upper left) to poor visibility (lower right). The VSMOKE program does provide visibility estimates when the relative humidity is below 70 percent.



At times the relative humidity in the atmosphere can exceed 70 percent, especially in the southeastern United States during the night or early morning. There are

times when the atmospheric conditions have little wind movement (stagnation) and the water vapor released from the smoke can cause the relative humidity to increase for brief periods above 100 percent (Achte-meier et al. 1998). During periods of high humidity the water vapor acts as a nucleating particle and the fine particles present can increase in size and they become more efficient at scattering light. The result is that visibility can be reduced significantly (to a few feet) for people driving on highways that had been experiencing no visibility impairment from smoke and/or fog. Situations where motor vehicle drivers have experienced this situation have resulted in multiple vehicle accidents because the driver's visibility was severely impaired. The VSMOKE model provides an estimate of the likelihood of a vehicle accident occurring (called the Low Visibility Occurrence Risk Index (LVORI)) based upon the calculated Dispersion Index and the relative humidity (see Lavdas 1996).

Three useful websites providing information on visibility and fine particles are:

1. The Smoke Dilemma: A Head-on Collision?:  
[http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja\\_achte-meier010.pdf](http://www.srs.fs.usda.gov/pubs/ja/uncaptured/ja_achte-meier010.pdf)
2. Introduction to Visibility : [http://199.128.173.141/intro\\_to\\_visibility.pdf](http://199.128.173.141/intro_to_visibility.pdf)
3. The Visibility Information Exchange Web Site (VIEWS) provides estimates of visibility conditions from mainly rural sites near wildernesses, wildlife refuges, and national parks designated as Class 1 according to the Clean Air Act Amendments of 1977.  
<http://vista.cira.colostate.edu/views/>

Further reading: Smoke Management Guide for Prescribed and Wildland Fire Chapter 3, Section 3.2 – Visibility Chapter 3, Section 3.3 – Problem and Nuisance Smoke

## **VSMOKE and VSMOKE-GIS Model Assumptions**

Consult the Program VSMOKE–Users Manual (Lavdas 1996) to read a thorough description of the modeling assumptions for VSMOKE. The modeling assumptions described in the VSMOKE manual for predicting the downwind concentrations of particulate matter would also apply to the VSMOKE-GIS model.

Both VSMOKE and VSMOKE-GIS are classified as Gaussian plume atmospheric dispersion models. Gaussian models are widely used to provide an initial examination of pollution impacts downwind of the source (for example, a fire). Usually, if the Gaussian model estimates there will be no pollution impacts then a more complex model analysis is not needed. The mathematics used in a Gaussian model is easily understood and the model assumptions are consistent with meteorological theory. Furthermore, the inputs required by the model are relatively easy to acquire. Studies that have examined Gaussian model predictions with measurements in the field have found the model predictions agree reasonably well with field measurement of pollution concentrations. If an error is made by the Gaussian model then it is mostly likely to over-predict the downwind pollution concentrations.

Gaussian models begin by predicting downwind pollution concentrations in the center of the plume. The model assumes the average wind field is uniform and steady. Next, the model will superimpose small, random fluctuation in the wind at right angles to the plume centerline. These random fluctuations are assumed to cause the pollutants (i.e. smoke) to be displaced from the plume centerline and produce a normal distribution (Gaussian) in pollution concentration from the plume centerline to the outer edge of the plume.

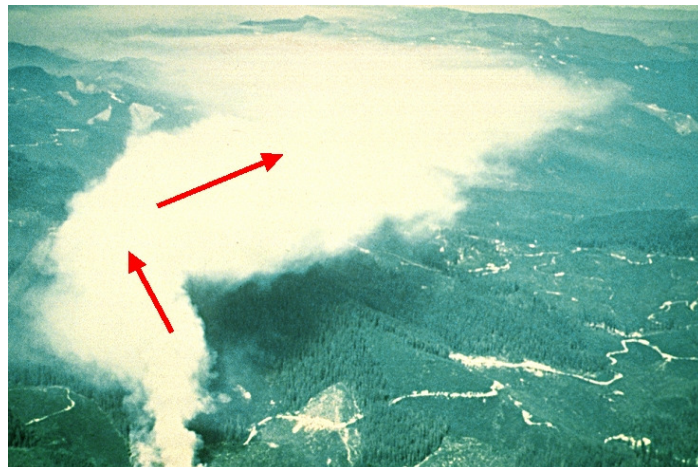
The model results from VSMOKE and VSMOKE-GIS are providing a snap shot of the highest pollution concentrations and worst visibility conditions during the time period of simulation (typically 1-hour). During the time period being analyzed it is assumed the meteorological conditions and emissions rates are constant and do not change significantly. A separate modeling analysis should be conducted if there are significant changes.

VSMOKE and VSMOKE-GIS will work best in weather map terms if:

1. Fair weather afternoon conditions exist under a well-established mixing layer.
2. The presence of a ground based nocturnal surface inversion that is typical of clear, light wind conditions at night in rural areas.
3. The weather map isobars (lines of equal pressure) are straight or form slowly sweeping arcs.

VSMOKE and VSMOKE-GIS also assumes the terrain is flat to gently rolling as is typical in most of the eastern United States. Sea breezes from the ocean or large lakes are not accounted for in the models and the results may be unreliable adjacent to coastal areas.

Gaussian models are used in mountainous terrain, but the results must be interpreted cautiously. For example, if a fire is occurring in a valley or the side slope of a mountain then the smoke movement will be influenced by the terrain (see figure below) until the smoke is well above the mountains. The use of a VSMOKE and VSMOKE-GIS may provide useful information beyond using just smoke screening criteria and can supplement a person's experience of smoke dispersal in rugged terrain.



# FEPS (Fire Emissions Production Simulator)

## Quick Overview of FEPS

The hardest values to provide reasonable estimates to the VSMOKE and VSMOKE-GIS models are the "Total Source Emission Rate of Particulate Matter (gm/sec)", "Total Source Emission Rate of Carbon Monoxide (gm/sec)" and the "Total Sensible Heat Emission Rate (megawatts)." However, the Fire Emission Production Simulator (FEPS) can be used to provide estimates of these three variables. There is a website (<http://www.fs.fed.us/pnw/fera/feps/index.shtml>) to download both the software and the User's Guide. Consult the FEPS manual to learn how to operate that software. Also, Appendix B includes step-by-step guidance on running FEPS.

The largest improvement in this version (2.2.1) of the VSMOKE and VSMOKE-GIS interface is the way the Fire Emission Production Simulator (FEPS) results are retrieved. The process to import the FEPS results is significantly easier than earlier versions of the software.

**Before VSMOKE is run for the first time, you must open FEPS and save an Event. For all subsequent runs, go directly to VSMOKE and VSMOKE-GIS to begin the smoke dispersion analysis (you will access FEPS from within VSMOKE and VSMOKE-GIS).**

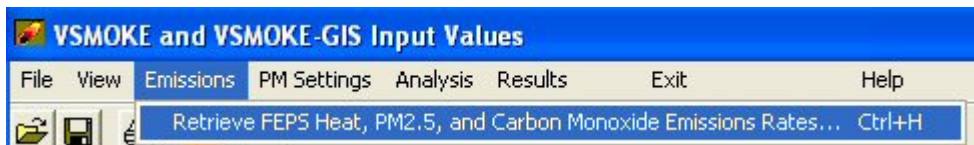
1. Open FEPS
2. Select "System Default"
3. Select "Create" and save as an Event (use any name)
4. Go to "Action" on the menu bar and click on "Reports/Charts".
5. Close FEPS

## Using the FEPS Results

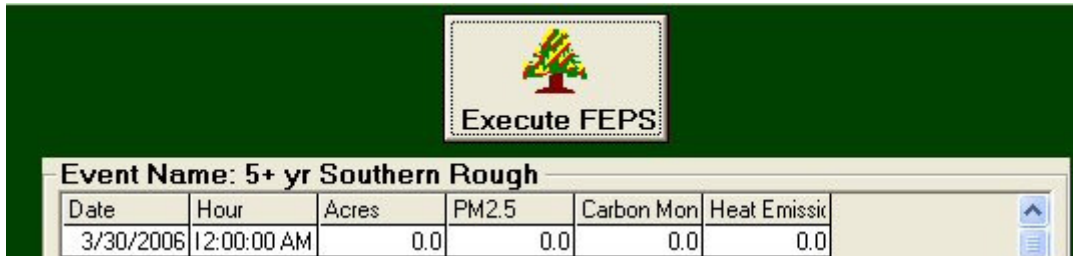
The following highlights the important steps that need to be followed to use the Fire Emission Production Simulator (FEPS) results in the VSMOKE and VSMOKE-GIS models.


- A. Execute the FEPS software by either launching the program from the

Windows® "Start" menu or the FEPS icon () on your desktop. A third option is to select the "Retrieve FEPS Heat, PM2.5, and Carbon Monoxide Emissions Rates ..." under the "Emissions" dropdown menu.



One thing you may have noticed below the "Execute FEPS" button is a table with the numbers from your last FEPS run. You do not need to execute FEPS if the "Event Name:" listed at the top of the table matches the FEPS event you want to include in your VSMOKE and VSMOKE-GIS simulation. If this is the case then proceed to step C. below. Otherwise, select the "Execute FEPS" button to launch the software.

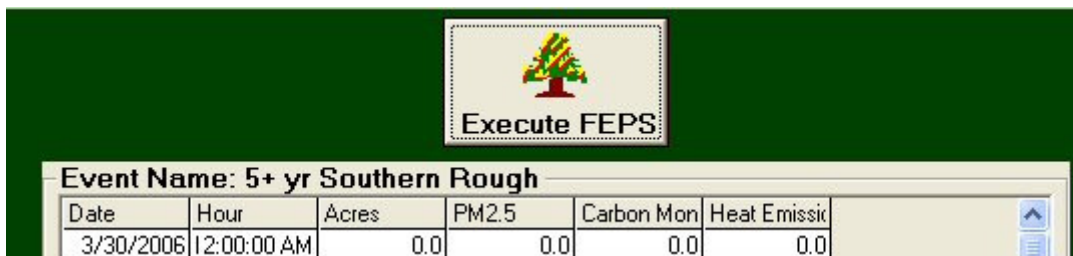


Once you have completed filling out the FEPS forms then select the "View Reports and Charts" button (  ) found on the right side of the top row of buttons. Now you can exit the FEPS software.

Next, on the "VSMOKE and VSMOKE-GIS Input Values" form select "Retrieve FEPS Heat, PM2.5, and Carbon Monoxide Emissions Rates..." under the "Emissions" dropdown menu.



The "Event Name:" below the FEPS button and at the top of the table should match your last FEPS run. If the "Event Name:" is wrong then proceed to step "A." above.



- B. Look at the tabular results and select the hour, which you want to use in the simulation, by clicking on the row of data. The results will be written to boxes at the bottom of the screen.

3/30/2006	11:00:00 PM	409.0	69.7	892.9	0.0
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Select a row of data from above and the results will be copied to the fields below.

**Results to be used by VSMOKE and VSMOKE-GIS**

Year	Month	Day	Hour	Acres
2006	03	30	15	409.0
Total Source Emission Rate of Particulate Matter (gm / sec)	Total Source Emission Rate of Carbon Monoxide (gm / sec)		Total Sensible Heat Emission Rate (megawatts)	
1108.3	13568.9		459934.5	

Use Answers      Don't Use Answers

Finally, select the  button to transfer the results to the "VSMOKE and VSMOKE-GIS Input Values" form.




# How to Run VSMOKE and VSMOKE-GIS


## Information specific to VSMOKE-GIS

### ArcView

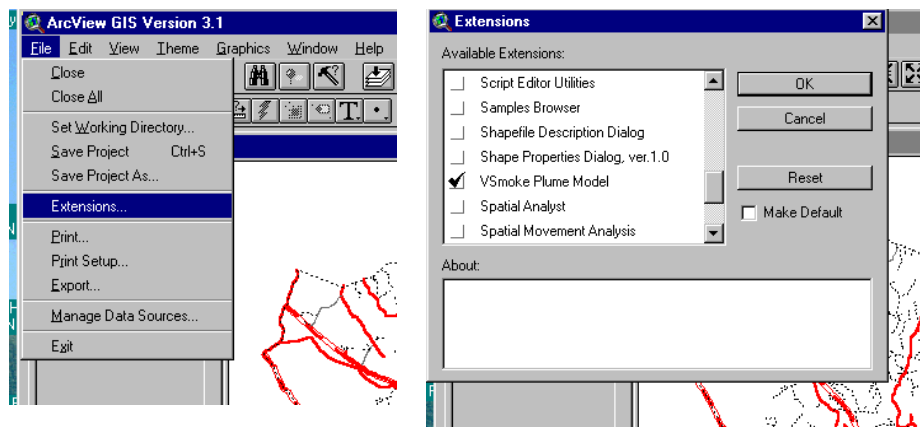
ArcView users will need to complete one or more of the following steps.

- A. Copy the smoke.avx file from c:\vsmkgs to the directory containing the ArcView extensions, which is C:\fsapps\esri\AV\_GIS30\ARCVIEW\EXT32\ for USDA Forest Service computers. This step needs to be completed the first time you load the extension into ArcView, and this will allow you to perform a smoke analysis with any ArcView project.

- B. Start ArcView and select the “Add Theme” button  and navigate to a shape file or coverage that has a **metric projection**. **Make sure the maps you are loading as themes all have the same map projection.** The plume calculations in VSMOKE-GIS assume the View map units are meters. One file with a metric projection is found in the c:\vsmkgs folder and it is called “national\_forests.shp.” This file shows all of the National Forests in the lower 48 United States and is in a metric projection called Albers. If the National Forest shapefile is used then any other data that is added to the ArcView project would also need to have an Albers projection.

After you have loaded all the files into legend of the View then select the “Add Theme” button  in ArcView and navigate into the c:\vsmkgs folder and then click the “Cancel” button. This step ensures the coordinates are written to the proper directory. Occasionally, the model results will not display in the proper location on the screen because the coordinates were not written to the c:\vsmkgs directory.

- C. Load the ArcView extension called “VSMOKE Plume Model”




## ArcMap

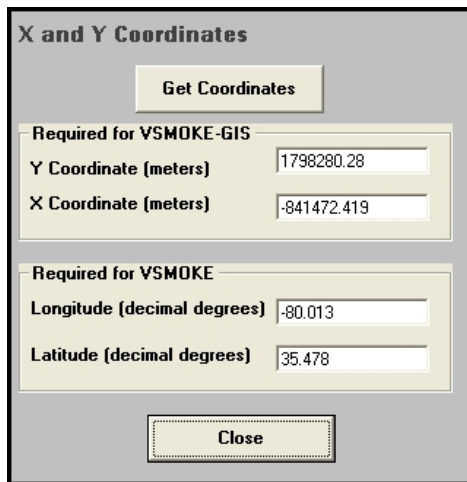
ArcMap users begin by navigating to the c:\vsmkgs folder and double clicking on the "VSMOKE.mxd" file. This opens the ArcMap project. Next, add the national\_forest.shp file (if it is not present) as the first spatial data to the project. This will establish the project in a metric project that is necessary for the VSMOKE-GIS program. Next, you can add any other spatial files (such as roads and other smoke sensitive targets) to the project even if the projection is different than the national\_forest.shp file.

## **Steps to Conduct a VSMOKE or VSMOKE-GIS Analysis**


### Step 1: Choose the location of the burn

GIS users will select a location for the burn by moving the arrow with the mouse and

clicking on the match button  then click on a location on the screen where the analysis is to occur. Next, you will see the data input screen for the "VSMOKE and VSMOKE-GIS Input Values" form. The screen on top will display the metric coordinates (X and Y) acquired when you clicked on the screen and these are used in the VSMOKE-GIS program. The ArcMap software will also supply the latitude and longitude (in decimal degrees) used by the VSMOKE program, but you will need to enter the values into the form if you are using ArcView.




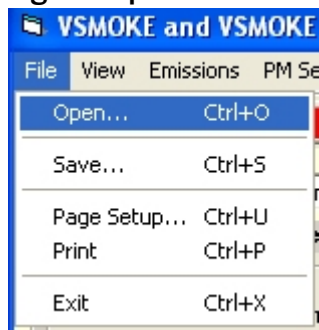
X and Y Coordinates	
Get Coordinates	
Required for VSMOKE-GIS	
Y Coordinate (meters)	1798280.28
X Coordinate (meters)	-841472.419
Required for VSMOKE	
Longitude (decimal degrees)	-80.013
Latitude (decimal degrees)	35.478
Close	

You can retrieve the last coordinates calculated by ArcMap or ArcView by selecting the "Get Coordinates" button at the top of the form. This input form can be viewed again after closing by selecting the "XY Coordinates..." in the "View" dropdown menu, or by clicking on the "XY" button . Select the "Close" button at the bottom of this form when you are finished.

Those not using GIS will need to have latitude and longitude for the location of the burn, and enter this into the "X and Y Coordinates" box.

## Step 2: Fill out the VSMOKE and VSMOKE-GIS Input Forms

Fill out the "VSMOKE and VSMOKE-GIS Input Values" form. **Do not use a comma (",")** in the "Title." One option you may use frequently is to fill out the form by retrieving the input values from a previous analysis by selecting "Open..." under the "File" dropdown menu, or clicking the Open button .



There are four "boxes" that need to be completed on the Input Form.

### Emissions and Heat Release Rates Inputs (Grey box):

The first set of input values are the Emissions and Heat Release Rate Inputs. Use FEPS Version 1.1.0 to get the **Total Sensible Heat Emission Rate (megawatts)** and the **Total Source Emission Rate (gm/sec) for PM2.5 and CO** values. (These are the hardest values to provide reasonable estimates for and the FEPS program does a good job of estimating these values for the user.) Click on "Emissions" in the menu bar. Retrieve the FEPS results by selecting the "Retrieve FEPS Heat, and PM2.5 Emissions Rates" under the "Emissions" dropdown menu. This takes you to the results of the last FEPS run you performed. If this is the run you want to use, then simply select the hour that you want to model, confirm that you want to use those data and press "Use Answers". The tool automatically fills the appropriate numbers into the top box. If you need to do a new FEPS run you can Press the "Execute FEPS" button and it will take you to the FEPS program. Go back to the preceding Using the FEPS Results instructions. Appendix B includes additional step-by-step guidance on running FEPS.

VSMOKE uses information such as the **surface temperature and atmospheric pressure** to convert carbon monoxide emissions generated to a concentration in the atmosphere. When available, you should use the actual atmospheric pressure rather than the pressure at sea level. There is a table in the Help files that can be used to approximate atmospheric pressure at varying elevations. This table is under Emissions and Heat Release Rates/Atmospheric pressure in the Help files.

Estimating the **background concentration of carbon monoxide** in rural areas will be difficult and it would be worthwhile to contact the appropriate State or Local air pollution control agency and discuss reasonable values. According to Bernard et al.

(2004), outdoor carbon monoxide levels may range between 2 parts per million (ppm) to 4 ppm near heavily traveled roads.

Next enter the **background concentration of PM<sub>2.5</sub>** in micrograms per cubic meter. VSMOKE needs a background concentration to accurately estimate the cumulative impact of the plume. If you don't know a reasonable background concentration then this data can be obtained from several sources. *The Visibility Information Exchange Web Site (Views)* website provides PM<sub>2.5</sub> estimates from mainly rural sites near wildernesses, wildlife refuges, and national parks designated as Class 1 by the Clean Air Act Amendments of 1977. You could contact your local state air quality regulatory agency to discuss reasonable value. Or you can check the following websites:

- The *AirData* website can provide historical data for the 24-hour maximum and annual average fine particulate matter (PM<sub>2.5</sub>) concentrations.
- The *AirNow* website provides data on recent (past two hours) fine particulate matter concentrations measured in the atmosphere on the day of the fire.

If you use the current results from the *AirNow* website and they are reported as AQI values, then it is recommended the following values (units are micrograms per cubic meter) be used:

**Green (good): 19**

**Yellow (moderate): 63**

**Orange (unhealthy for sensitive groups): 113**

**Red (unhealthy): 245**

**Purple (very unhealthy): 439**

### **Meteorology (Green box):**

Enter the **transport wind speed** (the average of all wind speeds within the mixing layer, including the surface wind speed). Get this from the Weather Forecast. The transport wind speed will affect horizontal dispersion of the plume.

Enter the **mixing height**. The mixing height can be thought of as the height above the ground which smoke can not rise above.

**Notes on mixing height:** you need to make sure you are using the appropriate mixing height. The input into VSMOKE-GIS is the mixing height in feet **above ground level**. Some NWS offices give mixing height above sea level, so make sure to know how your forecaster reports this. If they only report height above sea level you can correct this by subtract the elevation at which you are burning from the forecast mixing height above sea level to get the mixing height above ground level.

**Relative Humidity** is used by VSMOKE to calculate Low Visibility Risk Occurrence Index (LVORI). Valid numbers range between 0 and 100 percent. Please note however, that if the relative humidity is above 70 percent the VSMOKE visibility predictions are not valid. Forecasted relative humidity can be found at the National Fire Weather Page.

*The next two boxes contain information that is used only in VSMOKE or VSMOKE-GIS. For example, the VSMOKE model calculates stability class for you, based on the inputs you provide in the "Calculate Stability Class" box (aqua). For VSMOKE-GIS you actually enter the atmospheric stability class directly (in the bottom tan box). For this reason, there is the potential that the VSMOKE and VSMOKE-GIS results may not match.*

### **Calculate Stability Class with VSMOKE (Aqua box):**

**Time zone:** make sure you input the correct time zone. Determining the proper time zone may be difficult since the value represents the decimal hours behind the time in Greenwich, England (UTC). Valid numbers for the continental United States are: Eastern daylight time = 4.0, Eastern Standard Time = 5.0, Central Daylight Time = 5.0, Central Standard Time = 6.0, Mountain Daylight Time = 6.0, Mountain Standard Time = 7.0, Pacific Daylight Time = 7.0 and Pacific Standard Time = 8.0.

**Year, Month, Day and Hour:** The stability class is also influenced by the time of year the fire is occurring; just enter the year, month, day and hour values you entered in previous steps of the analysis.

**Surface Wind Speed:** This is the wind speed 20 feet above the ground.

**Opaque Cloud Cover:** The amount of "Opaque Cloud Cover" [ICOVER] is a value between 0 and 10, where 1 means 10 percent and 10 means 100 percent.

**Cloud Cover Ceiling Height (feet):** The "Cloud Cover Ceiling Height (feet)" [CEIL] is the distance above the ground to the bottom of the clouds and is generally reported by the National Weather Service at the Ceiling Height.

### **Inputs Used Only in VSMOKE-GIS (Orange box):**

**Check box:** this value is only used by VSMOKE-GIS. Generally VSMOKE-GIS is used to model burning conducted during daylight hours.


**Wind Direction:** This variable is used only by VSMOKE-GIS. The model evaluates wind direction in a 360 degree radius. Valid numbers are to the nearest degree and are greater than 0 and less than or equal to 360, which is due north. Remember, as in a wind rose, this is the direction the wind is coming from, not the direction it is blowing.

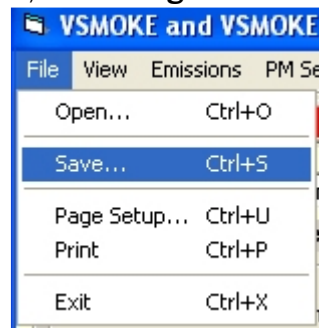
**Stability Class:** the help files provide the user with helpful information for estimating stability class under Meteorology/Stability Class section. There is also a section in the help files which assists the user in estimating stability class in the field under Estimating Stability Class/Field. \*\*\*Remember this value is used only by VSMOKE-GIS, so what you manually enter here may differ from what is calculated by VSMOKE using the stability class inputs.

### **Step 3: Check the Coordinates**

Once you have completed the input values, you will probably want to retrieve the XY coordinates that the GIS software calculated at the beginning of the analysis. Otherwise, this could result in the plume being plotted in the wrong place in the GIS software. There will be other times when the coordinates from a previously saved file are correct and you will not need to retrieve the coordinates calculated at the beginning of the analysis.

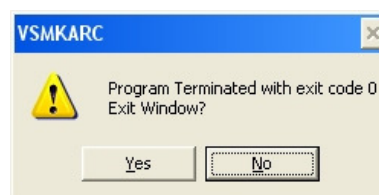
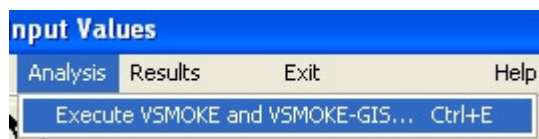
### **Step 4: Save the Results**

Once the changes are made to the forms then save the results by selecting "Save..." under the "File" dropdown menu, or clicking the Save button .



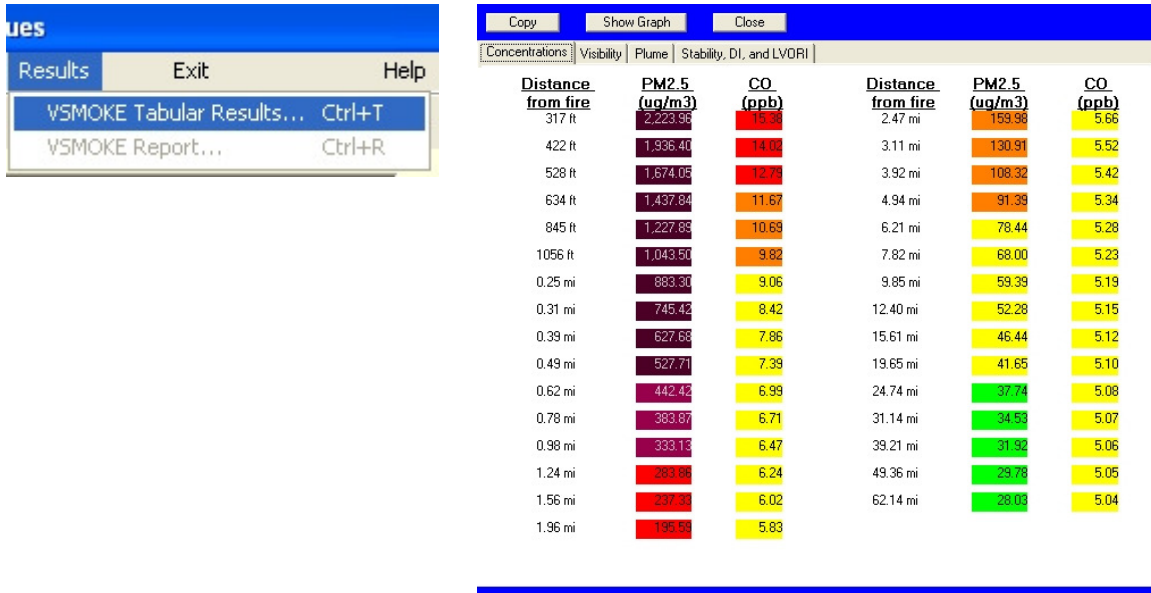
### **Step 5: Execute the Models**

Run both models by clicking on the "Execute VSMOKE and VSMOKE-GIS" under the "Analysis" dropdown menu. Make sure the last screen says the "END OF RUN FLAG = OK", and answer "Yes" to the box that says: Program Terminated with exit code 0 Exit Window?



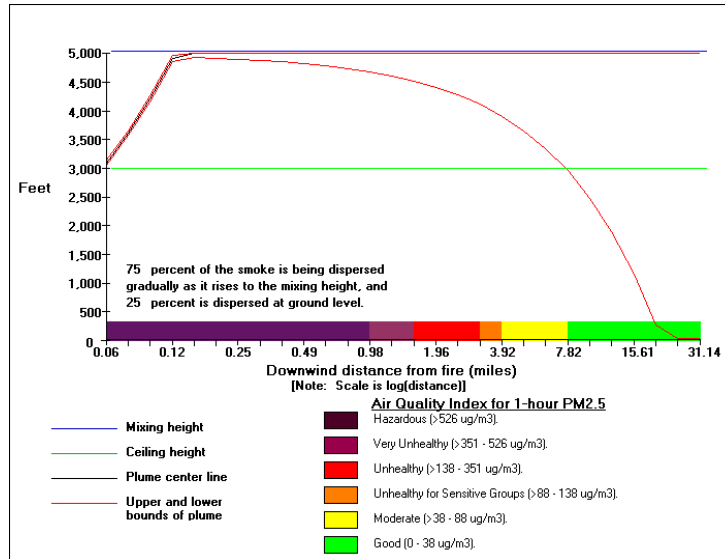
## Step 6: View the Results and Prepare the Smoke Monitoring Report

Next, you can review the tabular and graphic results from the VSMOKE model by selecting "VSMOKE Tabular" option in the "Results" dropdown menu.



The results are divided into five summaries. Four of the summaries are located by selecting one of the following tabs: "Concentrations", "Visibility", "Plume", or "Stability, DI, and LVORI." The values in the "Concentrations" tab are color coded according to the Air Quality Index (AQI) for the 1-hour fine particulate matter concentration, and the AQI for carbon monoxide. The "Copy" button allows you to copy the contents of any of the results from the four tabs and then you can paste the graphic into your word processing or graphics software program.


The fifth summary can be viewed by selecting the "Show Graph" button. The graph presents information from the "Concentration" and "Plume" tabs for about 30 miles downwind of the fire being analyzed. The information on the graph is as if you are viewing the plume (during the hour of the simulation) as it was passing in front of you. Along the X-axis of the graph is the concentration of particulate matter, which is color-coded according to the 1-hour fine particulate AQI. The graphic also shows the shape of the smoke plume rise with the approximate locations of the plume center and the upper and lower bounds of the plume. The graphic also provides a description on the assumptions regarding the plume rise of the smoke, and a line showing the height above the ground of the ceiling height of the clouds, and the mixing height. One thing to note about the VSMOKE results (since it is a Gaussian model) is the smoke plume will never rise above the mixing height. The contents of the graph can also be copied and then pasted into your word processing or graphics software program.



Once the tabular results are viewed then a report containing the inputs used for models and the VSMOKE results can be viewed by selecting "VSMOKE Report..." from the "Results" dropdown menu. The "Copy" option under the "Edit" dropdown menu allows you to copy the text and then you can paste it into your word processing software document. This allows you to add additional information to the text and you can choose the graphics you want to include in the smoke management report.

You can also print a copy of the report (no graphics are included) by selecting the "Print report" under the "File" dropdown menu. Please note the printed report may not look as good as copying the text and pasting it into your word processing software.

Finally, to view the results in the GIS software, close the "VSMOKE and VSMOKE-GIS Input Values" Form by clicking on the "Exit" option on the top right side the form. This will return you to the GIS software. Display the results in ArcView or ArcMap by

selecting the plume tool . **Be sure to store the shape file results for ArcView in the directory called "c:\vsmkgs".**

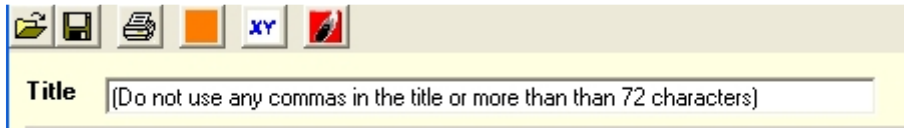
ArcMap will assign colors to the different concentrations selected in the "Particulate Matter Downwind Intervals" form using the 1-hour AQI for fine particulate matter. The ArcView results will display the results using a gray scale color palette. If you used the default PM2.5 concentrations then change the colors in ArcView as follows: 39 = yellow, 89 = orange, 139 = red, 352 = purple, and 527 = maroon.



## Detailed Description of Input Variables

### Title [KTITLE]

The title of the run can be up to 72 characters in length. **Do not place any commas in the title.** The title assists the user to keep track of different analysis and is written to the report title.

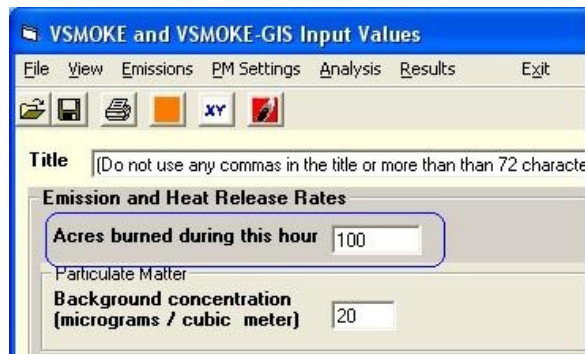


The screenshot shows a software window with a toolbar containing icons for file operations and a 'Title' input field. The input field contains the text: "(Do not use any commas in the title or more than than 72 characters)".

### Acres burned during this hour [ACRES]

Enter the total number of acres in an active fire phase or smoldering phase the hour of simulation. Do not enter the total number of acres to be burned if the analysis is during the active fire phase – the total number of acres needs to be spread over the hours of the active fire phase. A zero or negative values can be entered if you want to perform an analysis from a point source.

The size of the fire will influence the downwind concentrations. If everything else is held constant then a model analysis with a larger number of acres will have less downwind concentrations of particulate matter and carbon monoxide than a smaller sized area. This is because the smoke is being released over a larger area.



The screenshot shows the 'VSMOKE and VSMOKE-GIS Input Values' dialog box. It has a menu bar with 'File', 'View', 'Emissions', 'PM Settings', 'Analysis', 'Results', and 'Exit'. Below the menu bar is a toolbar with icons for file operations and a 'Title' input field. The 'Title' input field contains the text: "(Do not use any commas in the title or more than than 72 characters)". Below the 'Title' input field is a section titled 'Emission and Heat Release Rates'. This section contains two input fields: 'Acres burned during this hour' with a value of '100' and 'Background concentration (micrograms / cubic meter)' with a value of '20'.

### Background concentration of PM2.5 (micrograms / cubic meter) [BKGPM]

Contact the appropriate State or Local air pollution control agencies to obtain five years of data from any fine particulate monitors located within 30 miles of the area of interest (such as a Ranger District or county). Sometimes it may be necessary to select monitors greater than 30 miles away, or you can use suitable portable samplers to begin gathering background fine particulate data. For each month calculate the minimum, maximum, average, and standard deviation for each

monitoring location. The background concentration is one value you should change with several modeling scenarios. For example, you may want to perform a modeling analysis using the maximum value for the month, the average for the month, and adding the standard deviation to the average to see how much the background concentrations could influence the downwind concentrations at the smoke sensitive targets.

The screenshot shows a web form titled "Emission and Heat Release Rates". It has a section for "Particulate Matter" with a "Background concentration (micrograms / cubic meter)" input field containing the value "20". Above this, there is a field for "Acres burned during this hour" with the value "100". Below the particulate matter section, there is a partially visible section for "Carbon Monoxide".

Three useful websites to locate fine particulate matter monitoring data are:

1. The AirData can provide historical data for the 24-hour maximum and annual average fine particulate matter (PM2.5) concentrations. <http://www.epa.gov/air/data/geosel.html>
2. The Visibility Information Exchange Web Site (Views) website provides PM2.5 estimates from mainly rural sites near wildernesses, wildlife refuges, and national parks designated as Class 1 according to the Clean Air Act Amendments of 1977. <http://vista.cira.colostate.edu/views/>
3. The AirNow website provides data on recent (past two hours) fine particulate matter concentrations measured in the atmosphere on the day of the fire. <http://cfpub.epa.gov/airnow/index.cfm?action=airnow.showmap&pollutant=PM2.5>

If you use the current results from the AirNow website then it is recommended the following values (units are micrograms per cubic meter) be used for the AQI values:

- Green (good): 19
- Yellow (moderate): 63
- Orange (unhealthy for sensitive groups): 113
- Red (unhealthy): 245
- Purple (very unhealthy): 439

### Particulate Matter Emission Rate (gm/sec) [EMTQPM]

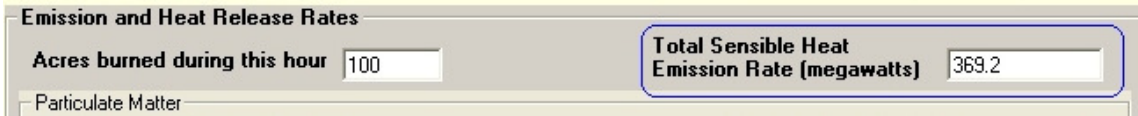
The value entered for the total source emission rate of particulate matter must be non-negative and represent the same particle size as the background concentration of particulate matter. For example if the background concentration of particulate matter represents particles 2.5 micrometers or smaller (PM2.5), then total source emission rate of particulate matter must also represent fine particles. Using the Fire Emission Production Simulator (FEPS) model provides reasonable estimates of the PM2.5 release rate.

The screenshot shows a web form for "Particulate Matter". It has a "Background concentration (micrograms / cubic meter)" input field with the value "20". To the right, there is a "Total Source Emission Rate (gm / sec)" input field with the value "302.39". Below this, there is a partially visible section for "Carbon Monoxide".

Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 5 – Smoke Source Characteristics

### **Total Sensible Heat Emission Rate (megawatts) [EMTQH]**

The value entered for the total source heat emission rate must be non-negative. Using the Fire Emission Production Simulator (FEPS) model provides reasonable estimates for the heat emission rate.



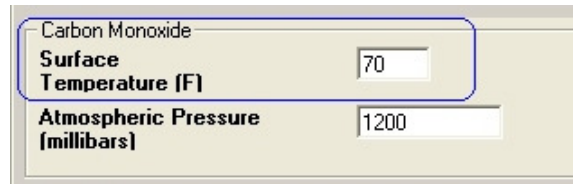
Emission and Heat Release Rates	
Acres burned during this hour	100
Total Sensible Heat Emission Rate (megawatts)	369.2
Particulate Matter	

For modeling purposes, it may be reasonable to enter a value of zero when the active fire phase has ceased and you are performing an analysis when the burn unit is smoldering.

Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 5 – Smoke Source Characteristics

### **Surface Temperature (Fahrenheit) [TTA]**

The surface temperature does not influence the smoke dispersion, but instead is used to convert carbon monoxide emissions to concentrations (parts per million) in the atmosphere. Typically, higher surface temperatures will result in greater downwind carbon monoxide concentrations.



Carbon Monoxide	
Surface Temperature (F)	70
Atmospheric Pressure (millibars)	1200

### **Background Concentration of Carbon Monoxide (parts per million) [BKGCOA]**

Estimating the background concentration of carbon monoxide in rural areas will be difficult and it would be worthwhile to contact the appropriate State or Local air pollution control agency and discuss reasonable values. According to Bernard (2004), outdoor carbon monoxide levels may range between 2 parts per million (ppm) to 4 ppm near heavily traveled roads.

Carbon Monoxide	
Surface Temperature (F)	70
Background Concentration (parts per million)	5

### Carbon Monoxide Emission Rate (gm / sec) [EMTQCO]

The value entered for the total source emission rate of carbon monoxide must be non-negative. Generally speaking, carbon monoxide is a lower health threat to the public than PM2.5, except when organic soils are smoldering. Smoldering organic soils can release very high concentrations of carbon monoxide. Using the Fire Emission Production Simulator (FEPS) model provides reasonable estimates of the carbon monoxide release rate.

Carbon Monoxide	
Surface Temperature (F)	70
Background Concentration (parts per million)	5
Atmospheric Pressure (millibars)	1200
Total Source Emission Rate (gm / sec)	2015.97

Further reading: Smoke Management Guide for Prescribed and Wildland Fire Chapter 5 – Smoke Source Characteristics

### Atmospheric Pressure (millibars) [PPA]

The atmospheric pressure does not influence the smoke dispersion, but instead is used to convert carbon monoxide emissions to concentrations in the atmosphere. As the atmospheric pressure decreases (as occurs with increasing elevation) then the predicted downwind concentration of carbon monoxide will increase.

Carbon Monoxide	
Surface Temperature (F)	70
Background Concentration (parts per million)	5
Atmospheric Pressure (millibars)	1200
Total Source Emission Rate (gm / sec)	2015.97

Use the actual station pressure rather than sea level pressure when available. The following table can be used to approximate atmosphere pressure based upon the elevation of the area with a fire.

Elevation (feet)	Atmospheric Pressure (millibars)
0	1013
328	1000
500	994
656	988
1000	976
1312	964
1500	956
2000	939
2500	923
3000	906
3500	888
4000	871
4500	858
5000	842
5500	825
6000	811
6500	794
7000	781
7500	767
8000	750

Source: [http://www.uigi.com/Atmos\\_pressure.html](http://www.uigi.com/Atmos_pressure.html)

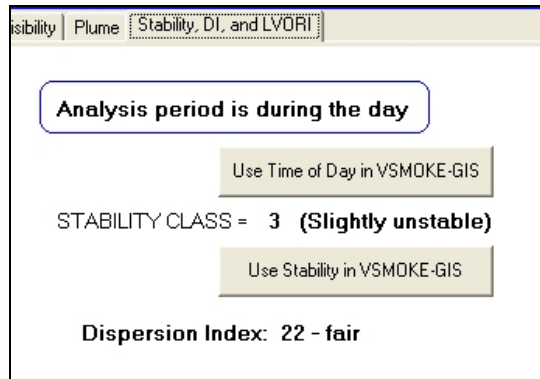
**Check if time period is before sunset (daylight) [LTOFDY]**

Only the VSMOKE-GIS program uses this value. A check in this box means the fire is after sunrise and before sunset. If there is a check mark for this variable then the value will be set to 'T'. Otherwise, the value will be set to 'F' and this means the time period for the analysis is after sunset. A different set of coefficients for the equations is used for stability at night than the stability calculations for the daylight. **Use the night option (i.e. no check mark) if the time period is one hour before the sun actually sets or one hour after the sun actually rises.**

Inputs used only in VSMOKE-GIS

Check if time period is before sunset (daylight)

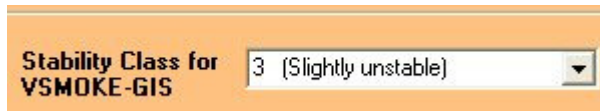
The VSMOKE model uses the location of the burn, time period, and date to calculate this value. The VSMOKE results can be seen in the "Stability, DI, and LVORI" tab by selecting the "VSMOKE Tabular Results" in the "Results" dropdown menu.



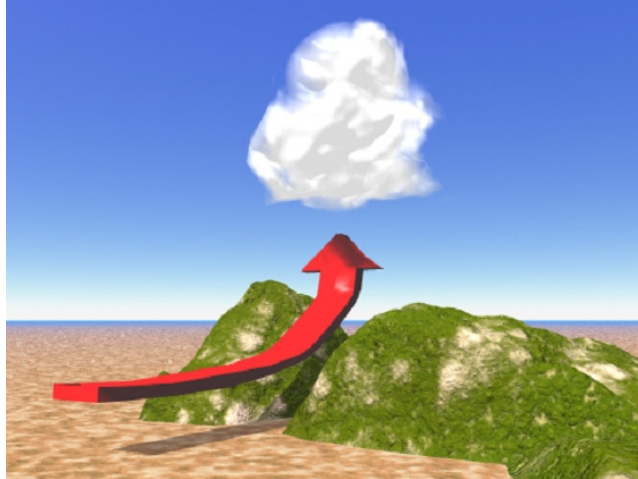
### Stability Class [ISTAB]

The VSMOKE-GIS program allows you to select the stability class to be used in the analysis, while VSMOKE calculates the stability class. Stability class can also be estimated in the field on the day of the fire. The valid number range is between 1 and 7 according to Turner (1964) where:

- 1 = Extremely unstable (typically a high hazard for wildfires)
- 2 = Moderately unstable
- 3 = Slightly unstable
- 4 = Near neutral
- 5 = Slightly stable
- 6 = Moderately stable
- 7 = Extremely stable



Atmospheric stability is concerned with the vertical motions of air and particles in the atmosphere. The vertical motion is a critical factor in determining how quickly and effectively pollutants from a fire will be mixed and dispersed in the atmosphere. Typically, during the day the air near the earth's surface is warmer than the air found higher in the atmosphere. The warmer air will rise and the cooler air higher in the atmosphere will sink and replace the warmer air near the ground. This situation is considered an unstable atmosphere and is a desirable condition for the mixing and dispersion of smoke. An unstable atmosphere will result in a circulation of the atmosphere where large volumes of air can disperse the particulate matter and other pollutants associated with fires.



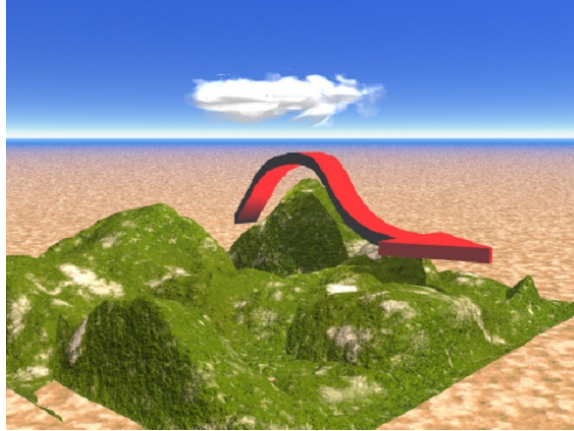
Source: Craig Sanders, National Weather Service, Duluth, Minnesota.

Some visual indicators of unstable atmospheric condition to use in the field are:

1. Good vertical growth of clouds.
2. Cumulus clouds.
3. Gusty winds.
4. Upward and downward movements of the wind.
5. Good visibility
6. Dust devils (vortices)



Stable atmospheric conditions occur when warmer air is above cooler air in the atmosphere. This situation occurs frequently at night and is also referred to as an inversion. There is very little vertical mixing of the atmosphere and consequently pollutants released from the fire remain closer to the ground and the concentrations of pollutants in the plume tend to be higher than in an unstable atmosphere. Inversions can occur at nighttime (nocturnal), but also inversions can occur from a stationary high-pressure system (subsistence), marine influence from winds blowing from the sea to the land, and where warm and cold fronts are near one another.



Source: Craig Sanders, National Weather Service, Duluth, Minnesota.

Some visual indicators of stable atmospheric condition to use in the field are:

1. Clouds in layers - No vertical motion.
2. Stratus-type clouds.
3. Smoke column drifts apart after limited rise.
4. Poor visibility in lower atmosphere due to pollution.
5. Fog formation.
6. Light and steady winds.



Finally, in a neutral stability the atmosphere neither enhances nor inhibits the dispersion of pollutants. Typically, the smoke will remain at the same level once the smoke temperature matches the surrounding air temperature. A neutral atmosphere is the best stability class that can occur at nighttime and is the worst that can occur during the daytime.



Source: Craig Sanders, National Weather Service, Duluth, Minnesota.



Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 7 – Smoke Management Meteorology

### **Transport windspeed (miles per hour) [U]**

The transport windspeed is the average of all windspeeds within the mixing layer, including the surface windspeed. Greater dispersal of smoke occurs when the windspeeds are higher (see figure below), but if the winds are too high then they will reduce the maximum height to which the smoke plume will rise and can cause the surface concentrations of pollutants to increase. Transport windspeeds of less than 4 meters per second are indicators of stagnant air conditions and there may be a lack of smoke dispersal. Smoke that rises to the mixing height and then disperses in all direction is an indicator of little to no transport winds, whereas smoke that bends as it is rising indicates that transport winds are having an effect on dispersing the smoke. Transport windspeed values should be increased and decreased from the forecasted values to see what effect the smoke will have on smoke sensitive targets.



Meteorology

Transport windspeed (miles per hour)

Values greater than 0.22 miles per hour can be used as input into VSMOKE and VSMOKE-GIS. The transport windspeed values are converted to metric units by multiplying the English units (miles per hour) by 0.447 when the VSMOKE and VSMOKE-GIS input files are saved.

Forecasted transport wind speeds can be found at the National Fire Weather Page (<http://fire.boi.noaa.gov/>).



Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 7 – Smoke Management Meteorology

## Wind Direction (degrees) [WDIR]

This variable is used only by VSMOKE-GIS. Valid numbers are to the nearest degree and are greater than 0 and less than or equal to 360 (due north). Data can be obtained from meteorology equipment near the fire that measures surface winds directions to the nearest degree, or the National Weather Service forecast gives a value in one on 8 classes (each covering 45 degrees). If National Weather Service forecasts are used then enter one of the following values:

Wind Direction (degrees)

<u>Forecasted Winds</u>	<u>Value To Use</u>
N (337.5 - 22.5)	360
E (67.5 - 112.5)	90
S (157.5 - 202.5)	180
W (247.5 - 292.5)	270
NE (22.5 - 67.5)	45
SE (112.5 - 157.5)	135
SW (202.5 - 247.5)	225
NW (292.5 - 337.5)	315

Caution is needed when inputting the wind direction. Lavdas (1997a) has found that the actual hourly wind directions have a low (40 percent) occurrence of matching the category predicted in National Weather Service forecasts, but about 80 percent of the time the measured wind direction will be within one class of the predicted wind direction. Therefore, it is recommended that lines be drawn (with the aid of a protractor) on the VSMOKE-GIS map at a 30-degree angle for observed winds and a 45-degree angle for forecast winds from the edges of the smoke plumes. The two new lines plotted from the edges of the plume represent the area where the smoke plume is likely to travel and all smoke sensitive targets (such as roads, nursing homes, schools, and etc.) need to be considered if they fall within the new boundaries. If light and variable wind conditions exist then draw concentric circles about the fire at each of the particulate matter concentrations.

Two websites to location information on wind direction are:

1. Forecasted: National Fire Weather Page: <http://fire.boi.noaa.gov/>
2. Historical: Ventilation Climate Information System: <http://www.fs.fed.us/pnw/airfire/vcis/>

Further reading: Smoke Management Guide for Prescribed and Wildland Fire Chapter 7 – Smoke Management Meteorology.

## Mixing Height (feet) [AMIX]

The mixing height can be thought of as the height above the ground where the smoke will no longer rise above. It is also at and below where vigorous mixing of

the atmosphere does occur (see figure below). The mixing height is reported with most fire weather forecasts. This value can strongly influence the downwind concentration, so it is recommended to have one modeling run with the forecasted mixing height at least one other run with the mixing height at least 500 feet less than the forecasted mixing height. During the nighttime and early morning hours the mixing height can decrease significantly (perhaps between 700 and 2000 feet) when compared to values found during the day. If the stability class is stable then the mixing height should be set to no less than 330 feet.

A screenshot of a software interface with a green background. It features a label "Mixing Height (feet)" in black text, followed by a white input box containing the number "1500".

Valid mixing height values for VSMOKE and VSMOKE-GIS are between 3.2 and 32,808 feet. Also, the values used in the model should represent the height above ground level (AGL). The mixing height values are converted to metric units by multiplying the English units (feet) by 0.3048 when the VSMOKE and VSMOKE-GIS input files are saved.

Two websites to locate information on mixing heights are:

1. Forecasted: National Fire Weather Page: <http://fire.boi.noaa.gov/>
2. Historical: Ventilation Climate Information System: <http://www.fs.fed.us/pnw/airfire/vcis/>



Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 7 – Smoke Management Meteorology

### **Relative Humidity [IRHA]**


This value is used by VSMOKE to calculate Low Visibility Risk Occurrence Index (LVORI). Valid numbers range between 0 and 100 percent. Please note that if the relative humidity is above 70 percent then the VSMOKE visibility predictions are not valid.

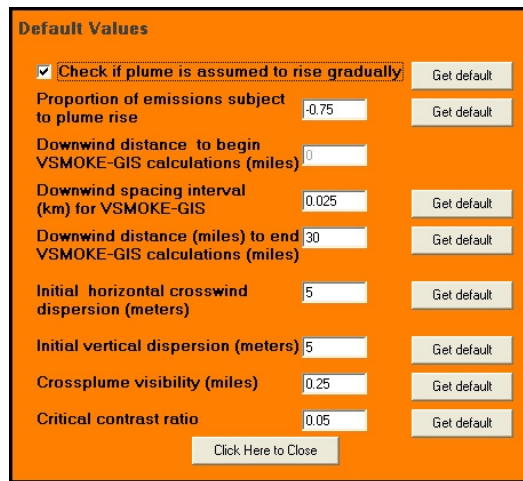
Relative Humidity [%] 40

Forecasted relative humidity can be found at the National Fire Weather Page (<http://fire.boi.noaa.gov/>)

Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 7 – Smoke Management Meteorology

## How to Get to the Default Values

There are nine additional variables that can be changed that are not found on the "VSMOKE and VSMOKE-GIS Input Values" form. These are located on the "Default Values" form, which can be located either selecting the "Defaults..." under the "View" dropdown menu or by selecting the orange button . Typically, you will not change these values, except for a specific modeling analysis. Please note that every time the software is started the values are set to the default values. If you change the numbers in the form then you can retrieve the default value by selecting the "Get default" button next to the variable of interest.



Variable	Value	Action
<input checked="" type="checkbox"/> Check if plume is assumed to rise gradually		Get default
Proportion of emissions subject to plume rise	-0.75	Get default
Downwind distance to begin VSMOKE-GIS calculations (miles)	0	
Downwind spacing interval (km) for VSMOKE-GIS	0.025	Get default
Downwind distance (miles) to end VSMOKE-GIS calculations (miles)	30	Get default
Initial horizontal crosswind dispersion (meters)	5	Get default
Initial vertical dispersion (meters)	5	Get default
Crossplume visibility (miles)	0.25	Get default
Critical contrast ratio	0.05	Get default

Click Here to Close

## Is the Plume Rise Gradual? [LGRISE]

Check this box if the plume is assumed to rise gradually to its final height as it travels downwind from the prescribed burning or wildfire site. This variable should remain checked, which means the value will be 'T'. The final rise of the plume is attained immediately if the box does not have a check (that is, LGRISE is 'F').

### **Percentage of Smoke Gradually Rising [EMTQR]**

Valid numbers are between -1.0 and 1.0. The value previously recommended by Southern Forestry Smoke Management Guidebook (1976) was +0.6, but Lavdas (1996) is now recommending a value for EMTQR of -0.75 (see figure below). A value of 1.0 indicates all of the emissions will rise to the height predicted by the plume rise equations for a stack (Briggs 1975) and undergo model dispersion processes initially from that height only. If the value is zero it denotes no plume rise and dispersion is initially from ground level only. A positive fraction indicates the plume is initially split between full plume height and ground level. A negative fraction denotes that the rising proportion of smoke (as expressed by the absolute value of EMTQR) is initially uniformly distributed in the vertical from ground level to the Briggs (1975) height. A negative value also means this uniform vertical distribution is then subjected to model dispersion processes as it moves downwind, and the remaining smoke is dispersed from ground level. For example, if the value is -1.0 then all of the smoke is initially uniformly distributed in the vertical. If the value is -0.5 then half of the smoke is initially uniformly distributed in the vertical and the other half is distributed from ground level.



Plume rise value of +1.0



Plume rise value of +0.5



Plume rise value of -0.75

**Downwind Distance to Begin VSMOKE-GIS Calculations (miles)  
[XBGN]**

This value will always be zero and can not be changed. A zero value means calculations will always begins at the coordinates of DUTMFE and DUTMFN.

**Downwind Spacing Interval (kilometers) for VSMOKE-GIS  
[XNTVL]**

Any positive number is valid, but it is recommended a value of 0.025 kilometers be used. The value for XNTVL is the distance from the last DUTMFE and DUTMFN values where the next set of calculations will be performed. Setting a value too low may result in excessive calculations, or awkward results. **Never use a value of less than or equal to zero.** Also, setting the value too low (less than 0.025) will cause a large increase in the number of predictions from the VSMOKE-GIS calculation and this may cause an error in ArcView or ArcMap when you try to display the results.

**Downwind Distance to End VSMOKE-GIS Calculations (miles)  
[XEND]**

The value can not be greater than 62 miles. VSMOKE-GIS is a Gaussian dispersion model that assumes a steady state for the winds and many atmospheric modelers are cautious for predictions made beyond 30 miles. Furthermore, it is commonly believed that the model results will be unreliable beyond 30 miles because the wind direction, or other atmospheric conditions, is very likely to be different. The value is converted to metric units by multiplying the English units (miles) by 1.60934 when the VSMOKE-GIS input files are saved.

### **Initial Crosswind Dispersions (meters)**

Both the VSMOKE and VSMOKE-GIS models use the horizontal [OYINTA] and vertical [OZINTA] initial dispersion coefficients. This is an area where further research is needed, but the best estimate is that both values should be set at 5 meters. Note that the values entered does influence the calculation of the particulate matter and carbon monoxide concentrations, which use the Pasquill-Gifford-Turner system developed for smooth or gently rolling terrain.

### **Crossplume Visibility (miles) [VISCRT]**

Visibility is defined as the distance a person can see an object (for example, the vehicle in front of them or a scenic view) with a given clarity (as defined by the contrast ratio). The default value is 0.25 miles. However, other acceptable values for roadway safety include 0.125, 0.5, and 1.0 miles (Lavdas 1996). A higher value may be warranted depending on the speed of the traffic, type of vehicle stopping, and how steep is the road grade. Values as great as 90 miles in the eastern United States and 140 miles for the western United States may be used as an input to VSMOKE to protect visibility in Class I areas. The Views website can be consulted to determine the current visibility estimates for many Class 1 areas in the United States.

The following table lists the California Department of Transportation guidelines on minimum stopping distances when smoke is on a highway. The daytime values were calculated by multiplying the normal stopping distance by 1.75; whereas, the nighttime values were calculated by multiplying the normal stopping distance by 3.0.

<u>Speed limit (miles per hour)</u>	<u>Minimum Stopping Distance During the Day (miles)</u>	<u>Minimum Stopping Distance During the Night (miles)</u>
25	0.02	0.04
35	0.04	0.07
45	0.05	0.11
55	0.08	0.15
65	0.10	0.20

### **Crossplume Contrast Ratio [CCOCRT]**

The contrast ratio defines how clearly an object can be seen at a given distance (Lavdas 1996) and the input value has a greater influence on the VSMOKE model results than the crossplume visibility value. The default value has been set a 0.05.

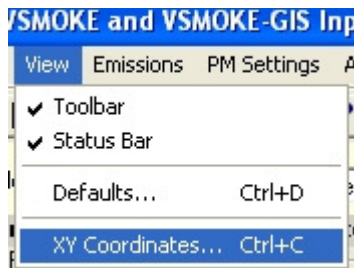
A value of 0.02 has been used for determining airport runway visual range. However, a greater value such as 0.05 may be needed for driving situation that involve glare and some cases it may need to be 0.25 (Lavdas 1996). The plume

contrast ratio of 0.05 can not be exceeded when a new source of pollution (such as a manufacturing plant) could impact visibility in Class 1 area within 31 miles. Therefore, it appears a value of 0.05 may be reasonable to protect visibility at a Class 1 area from smoke from a prescribed fire if the Class 1 area is within 31 miles of the fire.

## How to Get the Coordinate Values

You can retrieve the last coordinates calculated by ArcMap or ArcView by selecting the "Get Coordinates" button at the top of the "X and Y Coordinates" form. This input form can be viewed again after it has been closed by selecting the "XY

Coordinates..." in the View dropdown menu, or by clicking on the "XY" button . Select the "Close" button to close the form.



### X Coordinate (meters) [DUTMFE]

This is the X coordinate, in meters, for the location of the fire and is calculated when you click on the screen in ArcMap or ArcView. Any numeric value is acceptable.

### Y Coordinate (meters) [DUTMFN]

This is the Y coordinate, in meters, for the location of the fire and is calculated when you click on the screen in ArcMap or ArcView. Any numeric value is acceptable.

### Longitude [ALONG]

The longitude is calculated if you are using the ArcGIS software. ArcView users will need to obtain estimates from a map and the estimates should be made to three decimal places. The value is used by VSMOKE to calculate the stability class. Valid



numbers are between -240.0 and +240.0. Locations in the United States will be entered as a negative value.

VSMOKE does have an error in the coding and reverses the actual longitude location on where it occurs on the earth. For example, locations in the United States are inputted as a positive value into VSMOKE. The conversion of the longitude will be taken care of when you save the file. This means negative values inputted on the "X and Y Coordinate" form will be made a positive longitude, and positive values will be made negative.

### Latitude [ALAT]

The latitude is calculated if you are using the ArcGIS software. ArcView users will need to obtain estimates from a map and the estimates should be made to three decimal places. The value is used by VSMOKE to calculate the stability class. Valid numbers are between -90.0 and +90.0. Locations in the United States will be entered as a positive value.

### Particulate Matter Downwind Intervals

The particulate matter settings are used only by VSMOKE-GIS. Under the "PM Settings" dropdown there are two choices to calculate the distance downwind a particulate matter concentration may occur. The first choice is to select the "Use default PM2.5 Concentration Below" button at the top of the form. Selecting this option will use five fine particulate matter where the range in values match the Air Quality Index (AQI) for codes yellow (39 - 88  $\mu\text{m}/\text{m}^3$ ), orange, red, purple, and maroon.

Isopleth Number	PM ( $\mu\text{g}/\text{m}^3$ )	Tolerance
1	39	0.1
2	89	0.1
3	139	0.1
4	352	0.1
5	527	0.1

The second choice allows you to change the desired particulate matter concentration to the ones you want to see in the GIS software display. Listed below are the steps to complete if you want to enter the particulate matter concentrations:

1. **Number of isopleths [NISO]:** First, enter the number of particulate matter concentrations you want to make predictions for using VSMOKE-GIS. Valid numbers are between 1 and 10. The "Number of isopleths for VSMOKE-GIS" on the "VSMOKE and VSMOKE-GIS Input Values" Form will be updated with the value finally entered on the form.
2. **PM (ug/m3)[CHIISO(I)]:** The numbers entered needs to be larger than the value entered for the "Background concentration of particulate matter" entered on the "VSMOKE and VSMOKE-GIS Input Values" form. Arrange the numbers so the lowest concentration is first, then the second highest concentration, and continue the pattern until the highest concentration is listed last. Select the row under the PM (ug/m3) column and enter the value. VSMOKE-GIS will estimate the maximum downwind distance that a specific concentration is likely to occur. Please note the model does not tell the amount of time the specific concentration will occur at the location.
3. **Tolerance Level [CHITOL(I)]:** Check the box next to the words "Select Tolerance Level" to change the value. Enter any value greater than zero. Entering a low number will result in a better estimate of the plume distance downwind, but entering too low of a number can increase the computation time significantly. Entering too large of a value can cause loss of accuracy and possibly an irregularly shaped outline. Experience has shown that a value of 0.05 and 0.1 works well.

## **Field Method to Estimate Stability Class**

Meteorologists have specific instruments that estimate vertical motions of the atmosphere, but they are not present at many observing sites. Typically, field personnel conducting prescribed fires will not have estimates of stability class according to Turner (1964), therefore the tables below were taken from the Southern Forestry Smoke Management Guidebook (SFFLP 1976), as modified by Lavdas (1986), and it should assist in estimating an appropriate stability class while in the field. Complete the following steps to use the table:

1. Use the first table below for daytime estimates and second table for night estimates. **Night applies from one hour before sunset to one hour after sunrise.**
2. Locate the subcolumn heading for cloud cover. Use a stability class of 4 if 100 percent of the cloud cover is low. Also, read the publication on how to estimate cloud-ceiling height (Lavdas 1997b).
3. If for day situation, find the appropriate sub-subcolumn for 6-foot vertical standard shadow length.
4. Locate the row with the proper surface windspeed.
5. Follow the appropriate row and column and read the stability class category.

### Estimates of stability class during the day.

Surface windspeed (mph)	Clear or 50% or less cloud cover with low and mid clouds or any high clouds			More than 50% low and mid clouds			More than 50% low clouds		
	6-foot vertical standard shadow length (in feet)								
	less than 3.5	3.5 to 8.5	greater than 8.5	less than 3.5	3.5 to 8.5	greater than 8.5	less than 3.5	3.5 to 8.5	greater than 8.5
less than 4	1	1 or 2	2	1 or 2	2	3	2	3	3
4 to 7	1 or 2	2	3	2	3	4	3	4	4
8 to 10	2	2 or 3	3	2 or 3	3	4	3	4	4
11 to 14	3	3 or 4	4	3 or 4	4	4	4	4	4
more than 14	3	4	4	4	4	4	4	4	4

### Estimates for stability class during the night.

Surface windspeed (mph)	50% or more cloud cover with low and mid clouds or high overcast	Clear or less than 50% cloud cover with low and middle clouds
less than 4	6	7
4 to 7	5	6
8 to 10	4	5
11 to 14	4	4
more than 14	4	4

### VSMOKE Method to Estimate Stability Class

The VSMOKE model does calculate the stability class. The model uses inputs that affect the heating of the earth's surface. These include the location on the earth (longitude and latitude) and if the earth is being cooled by the surface winds [WSSFC], and the amount and height of the cloud cover. The amount of "Opaque Cloud Cover" [ICOVER] is a value between 0 and 10, where 1 means 10 percent and 10 means 100 percent. The "Cloud Cover Ceiling Height (feet)" [CEIL] is the distance above the ground to the bottom of the clouds.

The stability class is also influenced by the time of year the fire is occurring. These variables include the Time zone [TIMZON], Year [IYEAR], Month [MO], Day [IDAY] and the Hour of simulation [HRSTRT].

**Calculate Stability Class with VSMOKE**

Time Zone	<input type="text" value="5"/>	Year (ex. 2004)	<input type="text" value="2007"/>	Month	<input type="text" value="11"/>	Day	<input type="text" value="24"/>	Hour of simulation (enter 14.5 for 2:30 pm)	<input type="text" value="17"/>
Surface Wind Speed (miles per hour)	<input type="text" value="9"/>	Opaque Cloud Cover (values between 0 and 10)	<input type="text" value="2"/>	Cloud Cover Ceiling Height (feet)	<input type="text" value="3000"/>				

Determining the proper time zone may be difficult since the value represents the decimal hours behind the time in Greenwich, England (UTC). Valid numbers for the continental United States are: Eastern daylight time = 4.0, Eastern Standard Time = 5.0, Central Daylight Time = 5.0, Central Standard Time = 6.0, Mountain Daylight Time = 6.0, Mountain Standard Time = 7.0, Pacific Daylight Time = 7.0 and Pacific Standard Time = 8.0.

Two helpful websites to determine the proper value for the time zone are:

1. Daylight Saving Time
2. Current Time Zone

Further reading: Smoke Management Guide for Prescribed and Wildland Fire  
Chapter 7 – Smoke Management Meteorology

## Exercise 1

You have used a simple screening method to evaluate if the smoke from a prescribed fire will have an impact on two communities (Buffalo and Union in the figure below) and an intersection of two US Highways (black lines in the figure below). The wind direction tomorrow is predicted to be from the southwest (225 degrees). The area for the prescribed fire was plotted on a map and lines were drawn at 30-degree angles (yellow lines in the figure below) from the outer edge of the burn unit as though the winds were blowing from the southwest. This initial analysis (Figure 1) using the simple screening method has you concerned that the smoke from the prescribed fire will impact the smoke sensitive targets (i.e. the two communities and the two US Highways). Therefore, you have decided to use the VSMOKE and VSMOKE-GIS models to estimate if the fine particulate matter concentrations could be code red or worse at the two communities, and if a 0.25-mile visibility with a contrast ratio of 0.05 can be maintained on both US Highways. These smoke sensitive targets are about five miles from the burn unit.

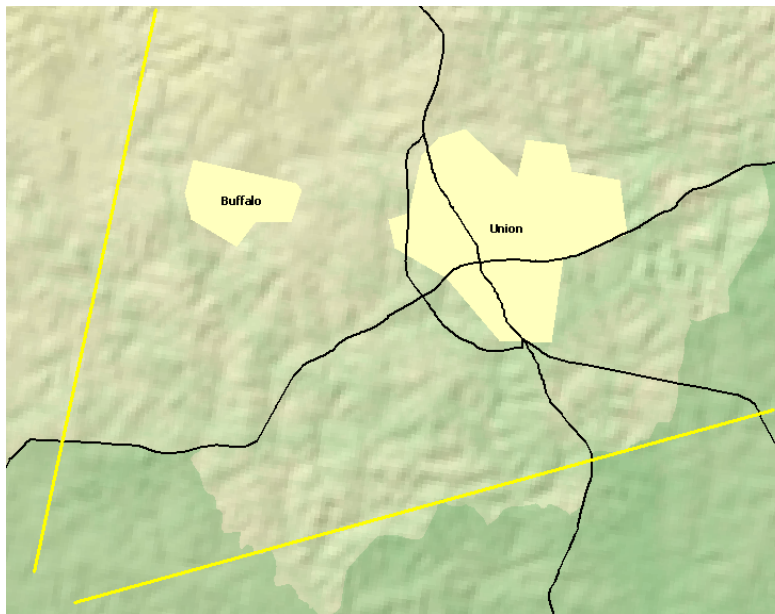


Figure 1. Simple screening analysis.

You would like to conduct the prescribed fire tomorrow (March 20, 2005) and 300 acres will be burned in a southern pine plantation. The fire will begin at 10:00 AM and 50 acres will be in active fire phase each hour until 4:00 PM and then the smoldering phase will continue into the next day. The Fire Emission Production Simulator (FEPS) model was used to provide emission rates for fine particulate matter and carbon monoxide, and the amount of heat released (Figure 2) for March 20 and 21, 2005. Portable samplers were set up two days prior to the burn to measure the background fine particulate matter and the values were constant at 5 micrograms per cubic meter. The meteorological forecast for tomorrow predicts the transport windspeed will be 12 miles per hour and the mixing height will be 5000 feet. The surface windspeed, temperature, and relative humidity were recorded

today near the burn area and the forecast tomorrow predicts similar values. The completed “VSMOKE and VSMOKE-GIS Input Value” form for the daytime analysis is shown in Figure 2, while the nighttime analysis is shown in Figure 3. The time periods were chosen to represent the maximum emission release rate during active fire phase during the day, and 5:00 AM was chosen on March 21 because your experience tells you this is the time when the smoke is most likely to contribute to severe fog formation.

The screenshot shows the 'VSMOKE and VSMOKE-GIS Input Values' software window. The title bar indicates the simulation is for 'Example 1d: Normal burn during daytime'. The interface is divided into several sections:

- Title:** Example 1d: Normal burn during daytime. Number of isopleths for VSMOKE-GIS: 5.
- Emission and Heat Release Rates:**
  - Acres burned during this hour: 50. Total Sensible Heat Emission Rate (megawatts): 359789.1.
  - Particulate Matter:
    - Background concentration (micrograms / cubic meter): 5. Total Source Emission Rate (gm / sec): 554.
  - Carbon Monoxide:
    - Surface Temperature (F): 70. Background Concentration (parts per million): 4.
    - Atmospheric Pressure (millibars): 1200. Total Source Emission Rate (gm / sec): 6857.
- Meteorology:**
  - Transport windspeed (miles per hour): 12. Mixing Height (feet): 5000. Relative Humidity (%): 40.
- Calculate Stability Class with VSMOKE:**
  - Time Zone: 5. Year (ex. 2004): 2005. Month: 3. Day: 20. Hour of simulation (enter 14.5 for 2:30 pm): 15.
  - Surface Wind Speed (miles per hour): 9. Opaque Cloud Cover (values between 0 and 10): 2. Cloud Cover Ceiling Height (feet): 3000.
- Inputs used only in VSMOKE-GIS:**
  - Check if time period is before sunset (daylight). Stability Class for VSMOKE-GIS: 3 (Slightly unstable).
  - Wind Direction (degrees): 225.

The status bar at the bottom shows the date as 11/24/2007 and the time as 5:36 PM.

Figure 2. Completed form to simulate the smoke dispersion during the maximum fine particulate matter emission rate at 3:00 PM on March 20, 2005.

The screenshot shows the 'VSMOKE and VSMOKE-GIS Input Values' software window. The title bar indicates the simulation is for 'Example 1n: Normal burn during nighttime'. The interface is divided into several sections:

- Title:** Example 1n: Normal burn during nighttime. Number of isopleths for VSMOKE-GIS: 5.
- Emission and Heat Release Rates:**
  - Acres burned during this hour: 250. Total Sensible Heat Emission Rate (megawatts): 0.
  - Particulate Matter:
    - Background concentration (micrograms / cubic meter): 5. Total Source Emission Rate (gm / sec): 54.
  - Carbon Monoxide:
    - Surface Temperature (F): 40. Background Concentration (parts per million): 4.
    - Atmospheric Pressure (millibars): 969. Total Source Emission Rate (gm / sec): 690.
- Meteorology:**
  - Transport windspeed (miles per hour): 12. Mixing Height (feet): 2000. Relative Humidity (%): 95.
- Calculate Stability Class with VSMOKE:**
  - Time Zone: 5. Year (ex. 2004): 2005. Month: 3. Day: 21. Hour of simulation (enter 14.5 for 2:30 pm): 5.
  - Surface Wind Speed (miles per hour): 8. Opaque Cloud Cover (values between 0 and 10): 8. Cloud Cover Ceiling Height (feet): 3000.
- Inputs used only in VSMOKE-GIS:**
  - Check if time period is before sunset (daylight). Stability Class for VSMOKE-GIS: 4 (Near neutral).
  - Wind Direction (degrees): 225.

The status bar at the bottom shows the date as 11/24/2007 and the time as 5:40 PM.

Figure 3. Completed form to simulate the smoke dispersion at 5:00 AM on March 21, 2005.

The VSMOKE results indicate that during the daytime the visibility (choose the “Visibility” tab from the “VSMOKE Tabular Results ...” under the “Results” pulldown menu) at about 5 miles (4.94 mi) is estimated to be 52.17 miles. During the day the ground-level concentrations of particulate matter are predicted to have an AQI value of code yellow at about 3.7 miles. Particulate matter concentrations are predicted to be unhealthy (code red) for the general population at about 1.2 miles (measurement from VSMOKE-GIS map) and for carbon monoxide at less than 0.49 miles (VSMOKE table) (Figure 4).

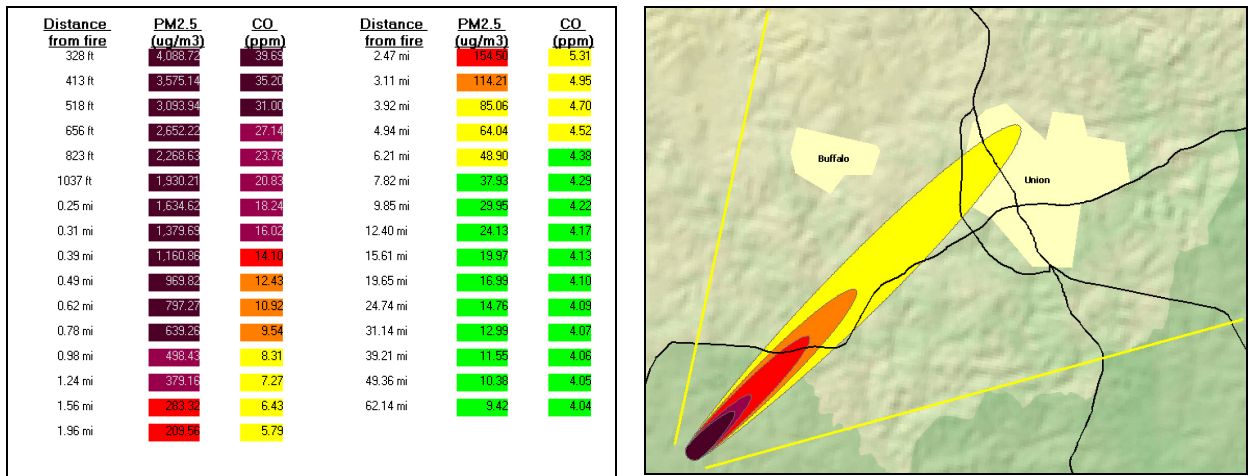
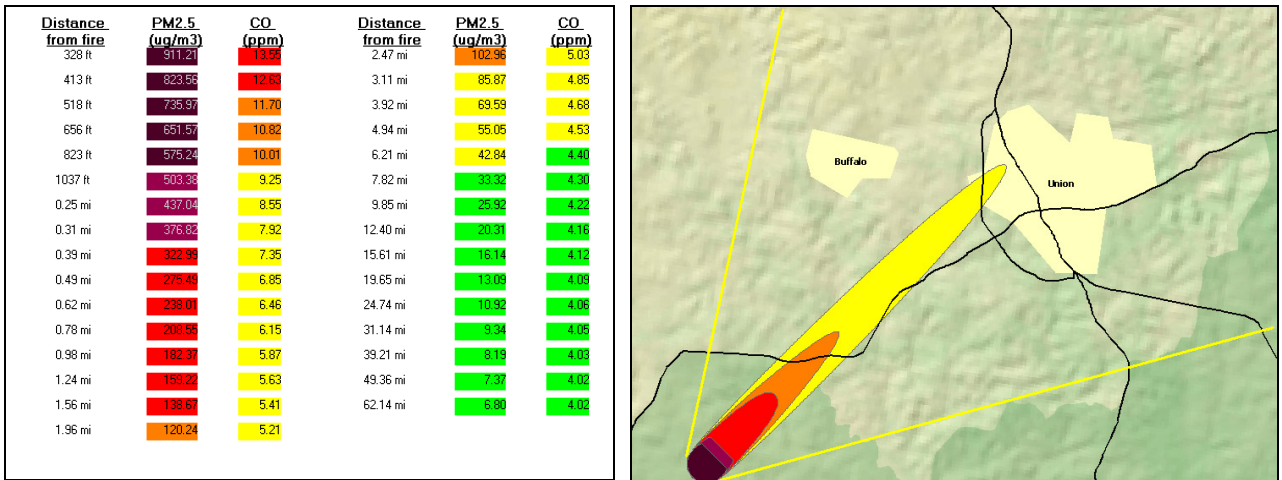


Figure 4. Daytime results from VSMOKE showing the predicted downwind concentrations at ground level of fine particulate matter and carbon monoxide, and VSMOKE-GIS results for fine particulate matter. All of the values are color coded according to the Air Quality Index (AQI) for fine particulate matter or carbon monoxide .

The VSMOKE results indicate that during the nighttime the ground-level concentrations of particulate matter are predicted to have an AQI value of code yellow at about 3 miles. Particulate matter concentrations are predicted to be unhealthy (code red) for the general population at about 0.3 miles (measurement from VSMOKE-GIS map) and for carbon monoxide at less than 528 feet from the burn (Figure 5). The visibility distances predicted by VSMOKE are not reliable since the relative humidity is greater than 70 percent. The Dispersion Index is 17 and combining this value with the relative humidity of 95 predicts the Low Visibility Risk Occurrence (LVORI). The LVORI is 5 which is about 3 times above the base line conditions of 1 highway accident in every 1000 that can be attributed to smoke for wildfires or prescribed fires.



**Figure 5. Nighttime results from VSMOKE showing the predicted downwind concentrations at ground level of fine particulate matter and carbon monoxide, and VSMOKE-GIS results for fine particulate matter. All of the values are color coded according to the Air Quality Index (AQI) for fine particulate matter or carbon monoxide .**

**Questions:**

- 1. Would you conduct this prescribed fire tomorrow if the meteorological conditions were the same as you modeled?**
- 2. The nighttime winds are predicted to be 8 miles per hour at 5:00 AM. How do you think the smoke plume will behave with winds at this speed? Would you take any steps to monitor the smoke during the nighttime?**
- 3. Would you choose a different particulate matter concentration threshold if you knew the smoke could impact a school or rest home? What threshold would you choose and what does this mean according to the AQI values?**
- 4. What would you do if the predicted daytime mixing height were decreased to 3000 feet? What if it is was predicted to be 6000 feet?**



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VSMOKE website: <http://webcam.srs.fs.fed.us/vsmoke/>

## Appendix A - Conversion factors

Variable	Unit of Measure	Conversions
Wind	miles per hour (mph)	m/s x 2.236936 = mph
		knots x 1.150779 = mph
	meters per second (m/s)	mph x 0.44704 = m/s
		knots x 0.51444 = m/s
	knots	mph x 0.8689762 = knots
		m/s x 1.943844 = knots
Temperature	degrees Fahrenheit (F)	$(9/5 \times C) + 32 = F$
	degrees Clesius (C)	$5/9 \times (F - 32) = C$
Pressure	millibars (mb)	atmosphere * 1013.25 = mb
		millimeter of Mercury * 1.33324 = mb
Distance	miles (mi)	km * 0.6213712 = mi
	kilometer (km)	mi * 1.609344 = km

## Appendix B

### Using FEPS Results as Inputs to Smoke Dispersion Models: Identifying the Relative Importance of Parameters within the Tool

**Abstract.** *The Fire Emission Production Simulator (FEPS) is a useful tool for estimating certain air emissions and heat release rates from prescribed burns. These results are often used as the inputs into smoke dispersion models, which then predict the potential air quality impacts from a prescribed burn on smoke sensitive targets, such as surrounding communities. If the smoke dispersion model predicts unhealthy fine particulate matter concentrations in surrounding areas for a particular fire event or time period, the prescribed burn may be postponed until a day with a more favorable forecast or when less fuels are consumed. Since the FEPS results are a critical component of the smoke dispersion model, they need to be as accurate as possible. However, the FEPS outputs are only as accurate as the user inputs. Due to the high number of input parameters that the tool uses, resource managers in the field often rely on default parameters rather than entering specific meteorological or fire event data. If the most relevant variables affecting air emissions and heat release rates from the proposed burn are identified, then the user could focus on accurately entering these values, resulting in more precise estimations of emissions and heat from the fire event.*

#### **Introduction**

Smoke from prescribed fires is not only a nuisance, but may also pose a health or safety hazard to neighboring communities. Before conducting a prescribed burning event, resource managers may conduct a smoke dispersion modeling analysis to ensure that surrounding communities are not negatively impacted by air pollution from the fire. Unwanted smoke may not only decrease visibility on nearby roadways, but may also elevate levels of fine particulate matter which pose a serious health threat to sensitive populations.

In order to accurately predict air pollutant levels from a fire event, resource managers need reasonable estimates of the amount of pollution and heat that will be released from the fire. Such estimates can be obtained by using the Fire Emission Production Simulator (FEPS), a computer program that produces hourly emissions and heat release data based upon either user inputs or default values for the fire event (e.g., acreage, consumption, fire behavior), along with meteorological conditions expected during the time of the burn (e.g., wind speeds, temperature, humidity, stability class). Because of the relative complexity of the data requirements, resource managers may not be inputting the most relevant meteorological or fire event parameters into FEPS. Instead, they could either be relying on the default values provided within FEPS, or entering inaccurate values into the tool. By not entering data specific to the prescribed burn event, resource managers may not be obtaining the accurate results required to forecast impacts on surrounding communities.

The objective of this paper is to evaluate each of the parameters used in the FEPS tool to determine the relative importance of each on the calculated emission and heat release results from the burn event. If those parameters that most influence emissions and heat results can be identified, then resource managers in the field will be able to focus their attention on accurately inputting these values. The ensuing results would then be a more precise estimation of actual values, which when fed into a smoke dispersion model would provide a better forecast of potential air quality impacts from the prescribed burn event on neighboring areas.

This paper is structured into five segments. The FEPS tool is first described, with each of the user inputs defined. Next, an explanation of how each individual parameter was isolated to identify the relative importance of each in emissions and heat release results is set forth. A discussion of the results of the analysis is then presented. How these results affect smoke dispersion modeling is then explained. Finally, a recommended course of action for resource managers in the field is offered.

## What is FEPS?

FEPS, the Fire Emission Production Simulator, is a computer software program that was developed by the USDA Forest Service Fire and Environmental Research Applications Team to manage data concerning consumption, emissions, and heat release characteristics from prescribed and wildland fires. A fire event, such as a prescribed burn, is described in the software through user inputs and/or default values for consumption and hourly weather variables. Hourly emissions and heat release rates are then generated by the FEPS tool.

FEPS is organized into five tabs, as shown in Figure 1. The five tabs where users may enter event-specific information are called “Event Information”, “Fuel Loading”, “Fuel Moisture”, “Consumption”, and “Hourly Input Data”.

The screenshot shows the 'FEPS - Broadcast Forest 1' application window. The title bar includes standard Windows window controls. Below the title bar is a menu bar with 'File', 'Actions', and 'Help'. A toolbar contains icons for file operations. The main area is titled 'User Inputs' and features five tabs: 'Event Information', 'Fuel Loading', 'Fuel Moisture', 'Consumption', and 'Hourly Input Data'. The 'Event Information' tab is active and contains two sections: 'Event Information (required)' and 'Descriptive Information (optional)'. The 'Event Information' section includes fields for 'Event Name' (Broadcast Forest 1), 'Start Date' (3/12/2004), 'End Date' (3/15/2004), 'Fire Shape' (Linear progression), 'Event Type' (Emission Inventory), and 'Fire Type' (Broadcast Natural Fuel). The 'Descriptive Information' section includes fields for 'Permit or Fire #', 'Description', 'Comment', and location coordinates (Longitude: -90, Latitude: 40). At the bottom right of the dialog are 'Save' and 'Cancel' buttons. A status bar at the bottom of the window displays: 'Broadcast Forest 1 | User Event | Broadcast Natural Fuel | Nov 25 2008 | Event: Valid | Tab: Valid'.

**Figure 1:** Screen Shot of FEPS.

**Event Information Tab.** The information contained in this tab describes the fire event, including the following data:

- Event Name,
- Start and End Date,
- Fire Shape (Freely Spreading Oval or Linear Progression),
- Event Type (Emissions Inventory, Real Time Prediction, Burn/Fire Plan, Typical Event, or Other), and
- Fire Type (Wildland Fire – Severe, Wildland Fire – Low Severity, Broadcast Natural Fuel, Broadcast Slash, Piled Slash, or Other).

**Fuel Loading, Fuel Moisture, and Consumption Tabs.** The amount of fuel consumed during the fire event can be calculated within FEPS using information that is entered into the “Fuel Loading” and “Fuel Moisture” tabs. Alternatively, consumption values may be imported directly into FEPS from a software program such as Consume 3.0, or may be manually entered for above ground (A/G) and

duff consumption, in tons/acre. Since resource managers are encouraged to use Consume 3.0 to calculate consumption values that are entered into the “Consumption” tab, the user inputs contained in the “Fuel Loading” and “Fuel Moisture” tabs were not fully examined for this work. However, a cursory assessment of their impacts on results is addressed in the Results section of this document.

**Hourly Input Data Tab.** Both the meteorological conditions expected during the burn event as well as the behavior of the fire (e.g., the hourly cumulative acreage consumed and the percentage of total area being consumed for each fuel profile) are entered into FEPS at this location. The hourly meteorology inputs include transport wind speeds, the wind at flame height (surface wind speed) and the Pasquill stability class. In addition to these hourly inputs, the daily temperature and humidity extremes should be entered; these values are interpolated within FEPS to provide temperature and humidity profiles for each hour of the fire event.

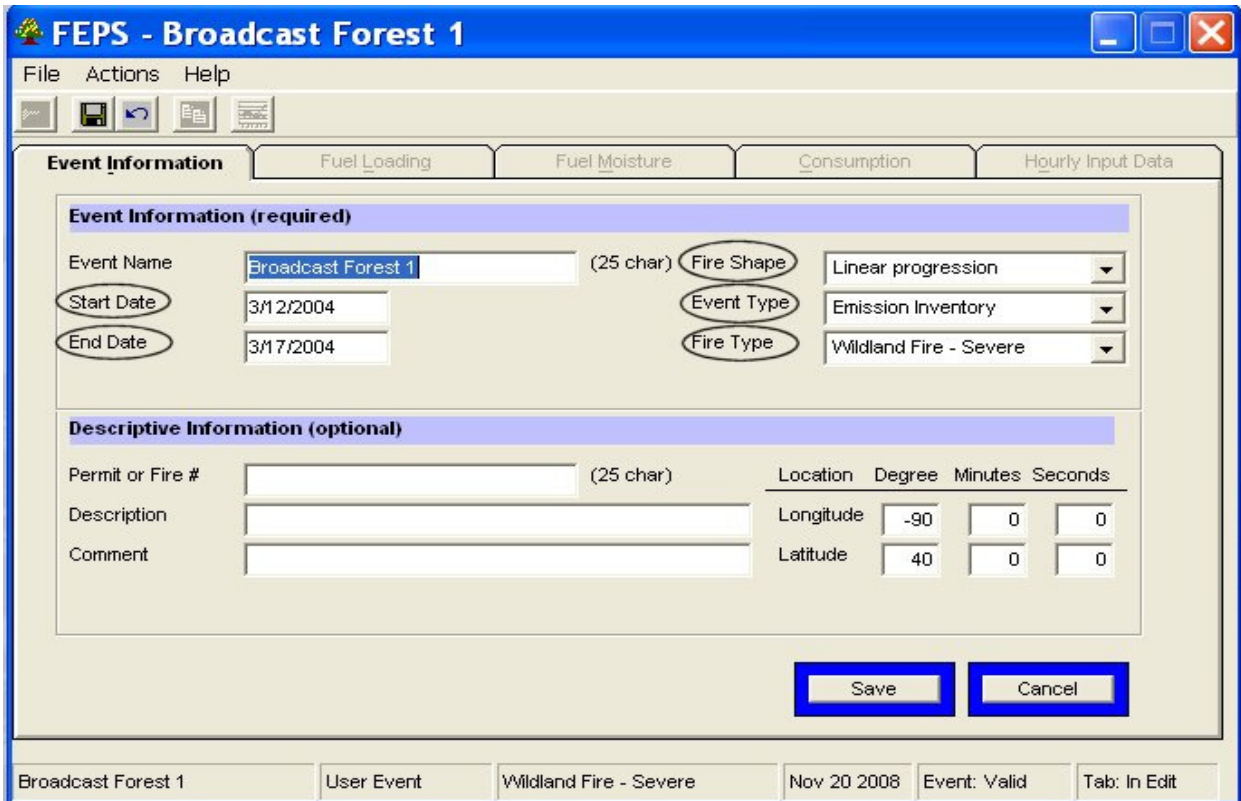
After entering the required information into FEPS, reports detailing hourly emissions and heat release rates can be viewed, printed, or exported as a spreadsheet or in comma delimited format. Most importantly for resource managers, FEPS results can be imported into a smoke dispersion model such as VSMOKE or CalSmoke to be used to estimate smoke impacts on surrounding communities. For a more detailed discussion of the FEPS software tool, see the recent Joint Fire Science Program Fire Science Brief that is included in Appendix A of this report.

### ***Methodology***

In order to evaluate parameters for their individual effect on hourly emissions and heat release rates, a baseline FEPS event was created from the system default event, “Broadcast Forest Underburn”. Each user-required input within FEPS was then independently modified to determine its individual influence on hourly results. How each user input was modified is discussed below.

### **Event Information Tab**

Each of the event information parameters listed above were modified to look at its individual effect on FEPS results. Figure 2 shows the location of each of the inputs that were modified under the Event Information Tab. The Start and End Dates were changed to look at events lasting two, four, five and ten days. The Fire Shape, Event Type, and Fire Type parameters were each modified to look at the individual contribution by each selection listed in the respective pull down menu.



**Figure 2: Screen Shot of the Event Information Tab in FEPS.** The inputs that were individually modified for the work detailed in this paper are circled.

### Fuel Loading and Fuel Moisture

Since most users either import or manually enter consumption values into FEPS, only two parameters contained within these two tabs were examined for their impact on results, even after importing consumption values into the software.

In the “Fuel Loading” tab, various fuel profiles were selected; then, after importing specific consumption values in the “Consumption” tab, results were examined for discrepancies. Manually entering or importing consumption values should negate the fuel profile set in this tab; however, the fuel profile was not overwritten and the user-defined parameter did influence results.

Within the “Fuel Moisture” tab, fuel moisture profiles were selected from the drop-down menu. After importing consumption values from Consume 3.0 in the “Consumption” tab, emissions and heat release results were reviewed to determine the affect of the fuel moisture profile value. Although the Consume 3.0 software takes into account fuel moisture in calculating consumption values, the user-defined fuel moisture profile also had an effect on results.

Both of these issues with the values entered into the “Fuel Loading” and “Fuel Moisture” tabs are discussed further in the Results section of this report.

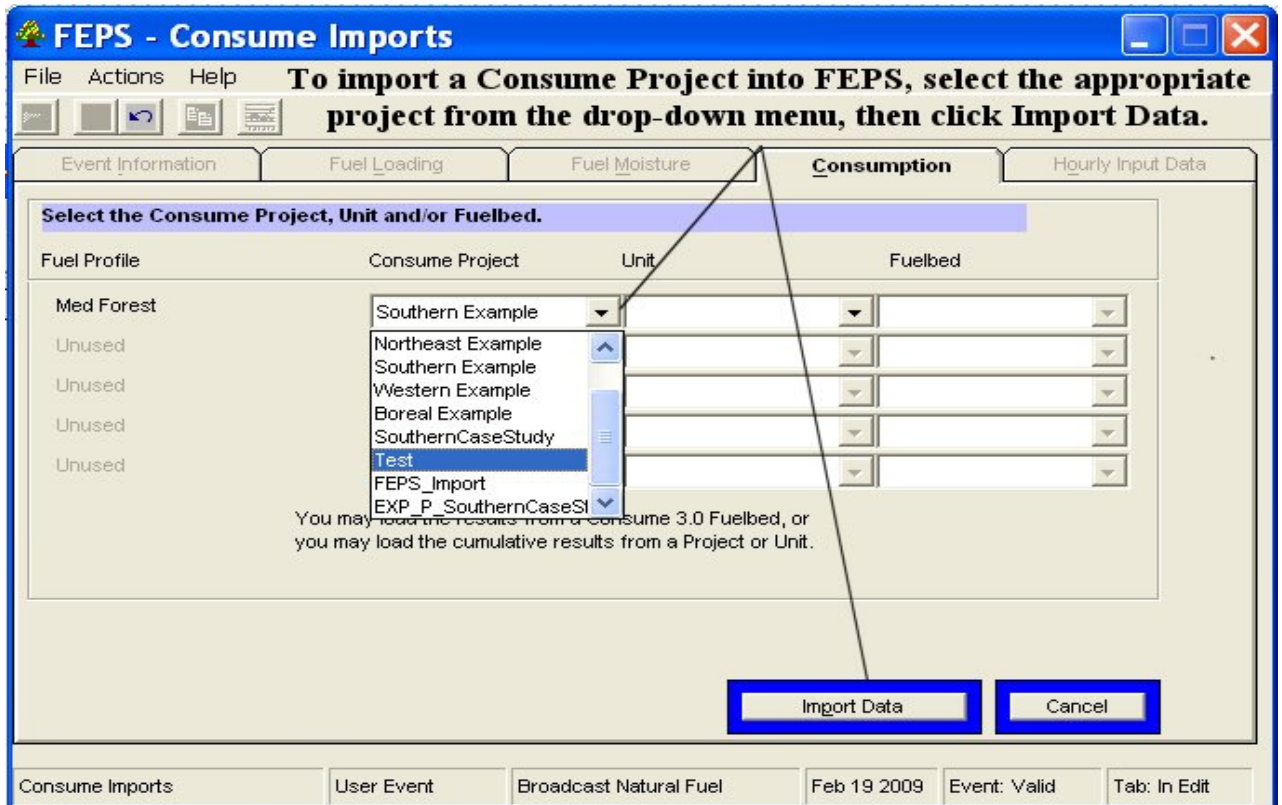
### Consumption

As noted previously, the consumption for a fire event can be obtained in three different ways. Consumption can be calculated within FEPS by inputting various variables in the “Fuel Loading” and “Fuel Moisture” tabs. If the user is confident of their own calculations of the amount of fuel to be consumed, the values for both above ground (A/G) and duff can be entered directly into the software.



Finally, consumption can also be imported into the FEPS tool from software such as Consume by the following steps.

- After completing a project in Consume, save it normally.
- In the “Consumption” tab in FEPS, click on Actions→Import Consumption→Import from Consume 3.0.
- The master project list file from Consume should be selected.
- As shown in Figure 3 below, use the drop down menu to select the appropriate project, and then click Import Data.
- Back in the “Consumption” tab, click on the *Calculate and Save* button.

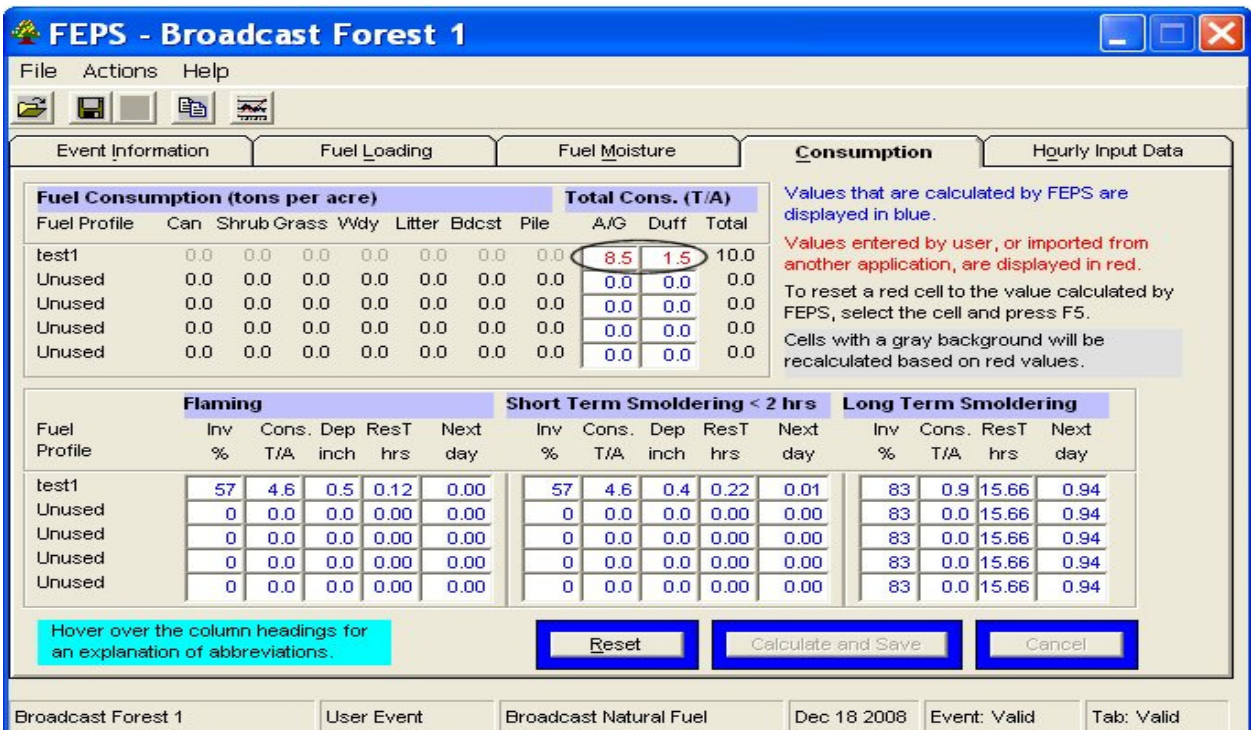


**Figure 3: Importing a Consume Project into FEPS.**

For this work, it was assumed that users either imported or directly entered consumption values. Total consumption values of 10, 7, 4 and 2.5 tons/acre were used. These consumption values were split between above ground and duff fuels as shown in Table 1. Although FEPS will accept any value for duff consumption, for this work only realistic values were chosen. These values were directly entered into FEPS in the location shown in Figure 4.

**Table 1: Consumption Values.** There were eight different consumption values which were evaluated for this work.

<b>Total Consumption (tons/acre)</b>	<b>Above Ground (A/G) Consumption (tons/acre)</b>	<b>Duff Consumption (tons/acre)</b>
10	10	0
	7.5	2.5
7	7	0
	6	1
4	4	0
	3.4	0.6
2.5	2.5	0
	2.1	0.4



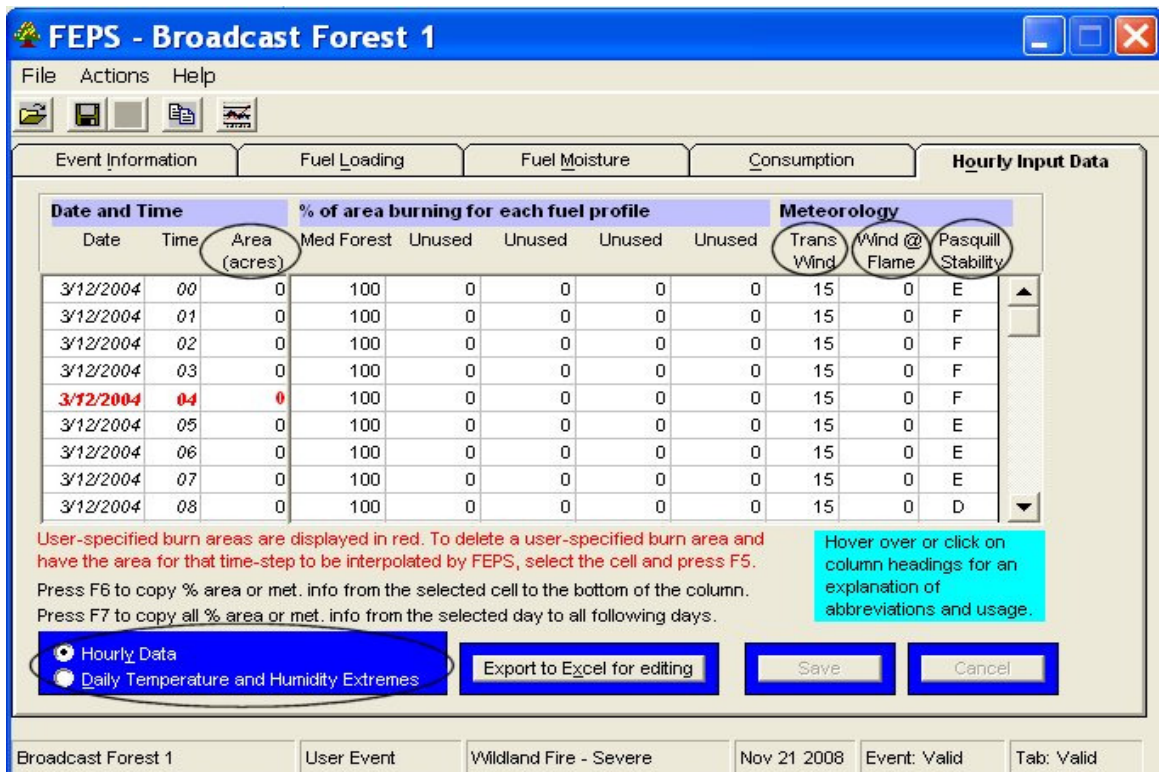
**Figure 4: Screen Shot of the Consumption Tab within FEPS.** Varying consumption values of both above ground (A/G) and duff fuels were examined for this work.

### Hourly Input Data

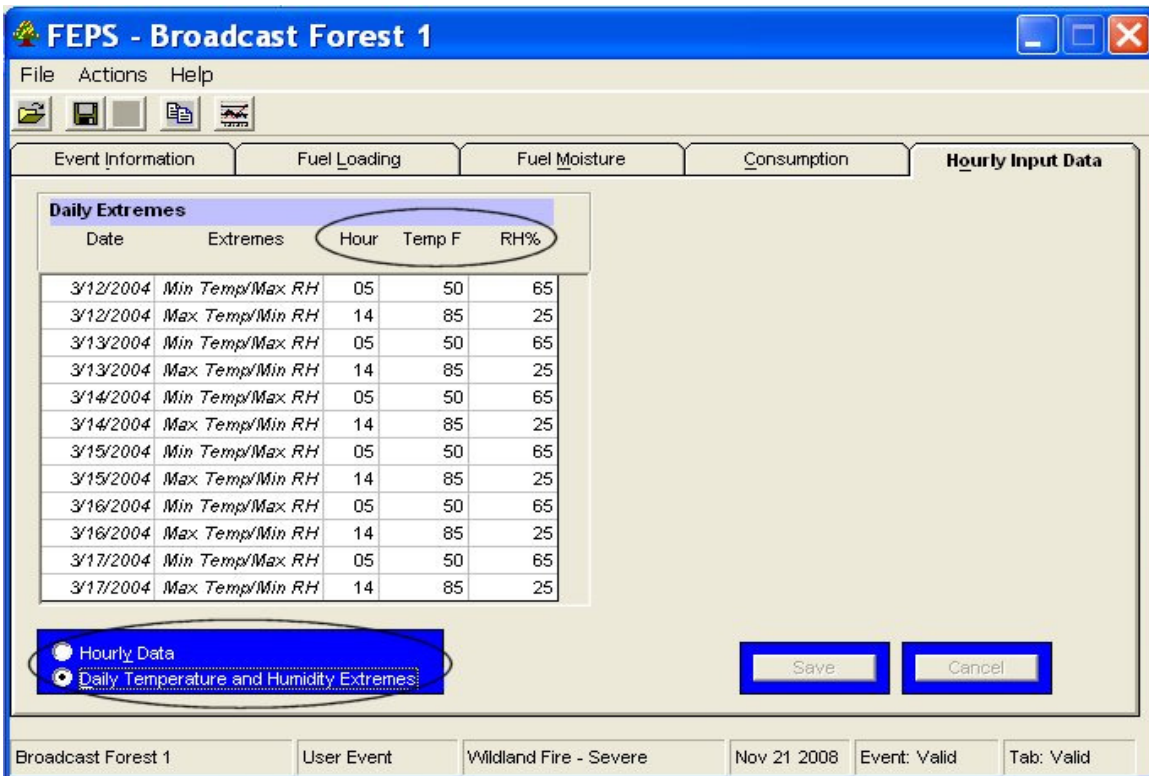
Hourly meteorology and fire behavior information can be entered into FEPS within the Hourly Input Data tab. Figures 5a and 5b show the two views that are available within this tab. For this work, several different parameters were examined for their individual influence on emissions and heat release rates, including hourly acreage consumed (fire spread), transport and surface wind speeds, stability class, humidity and temperature.

For the cumulative hourly acres consumed by the fire event, three events were modeled, each with a cumulative total of 1000 acres consumed over an event period of five days. First, the burn was expanded to encompass 1000 acres during two separate time periods over a period of two days (500 acres over a period of six hours on Day 1, and another 500 acres over a period of eight hours on Day 2). Next, the burn was modeled as expanding from 0 to 1000 acres over just six hours on Day 1. Finally, the fire was expanded from 0 to 1000 acres over 14 hours on Day 1.

For hourly meteorology data, the baseline fire event was modified by isolating the individual parameters in the following manner. The transport wind speed for the event was modeled at 8, 15, 22 and 30 miles per hour. The results from changing the wind speed at flame height, also known as surface wind speed, were examined for values between 1 and 20 miles per hour. The effect of Pasquill Stability Class was tested using the values most unstable (“A”), neutral (“D”) and very stable (“F”). The daily temperature extremes were adjusted to be between 40°F and 95°F. The daily humidity extremes were set to be between 25% and 90%.



**Figure 5a: Hourly Input Data, Hourly Data View.** The parameters that were examined are circled.



**Figure 5b: Hourly Input Data, Daily Temperature and Humidity Extremes View.** The modified parameters are circled.

## Results

All together, more than one hundred different scenarios were evaluated within the FEPS software in order to determine which parameters most influence emissions and heat release rates. The FEPS results from each of the runs outlined above were evaluated to see which parameters play the largest role in emissions and heat release rates. For each parameter that was changed, three model outputs were examined: hourly and total heat released ( $10^6$  Btu); flaming, short-term and long-term smoldering consumption (tons); and hourly and total fine particulate matter emissions (pounds).

Table 2 identifies the parameters in each tab within FEPS, and includes whether changing that parameter changes the emission and heat release rates from the fire event. Note that although certain parameters were found to not influence the air emissions results, they do have an effect on other calculations that were not examined for this report.

**Table 2: The Importance of Various Parameters on FEPS Emissions and Heat Results**

<b>FEPS Tab</b>	<b>Parameter</b>	<b>Effect on Results?</b>
Event Information	<b>Start and End Date</b>	<b>Yes</b>
	Fire Shape	No
	Event Type	No
	Fire Type	No
Fuel Loading	<b>Fuel Profile</b>	<b>Yes<sup>1</sup></b>
Fuel Moisture	<b>Fuel Moisture Profile</b>	<b>Yes<sup>1</sup></b>
Consumption	<b>Above Ground and Duff Fuels</b>	<b>Yes</b>
Hourly Input Data	<b>Area (acres) Cumulative Consumption</b>	<b>Yes</b>
	Transport Wind Speed	No
	<b>Wind at Flame Height (Surface Wind Speed)</b>	<b>Yes</b>
	Pasquill Stability Category	No
	Daily Temperature Extremes	No
	<b>Daily Humidity Extremes</b>	<b>Yes</b>

<sup>1</sup>These two parameters were only examined for their influence if consumption values were imported or manually entered into the software.

A discussion of each of the parameters that influence emissions and heat release rates is presented below. The parameters are organized by where they are located within the FEPS software.

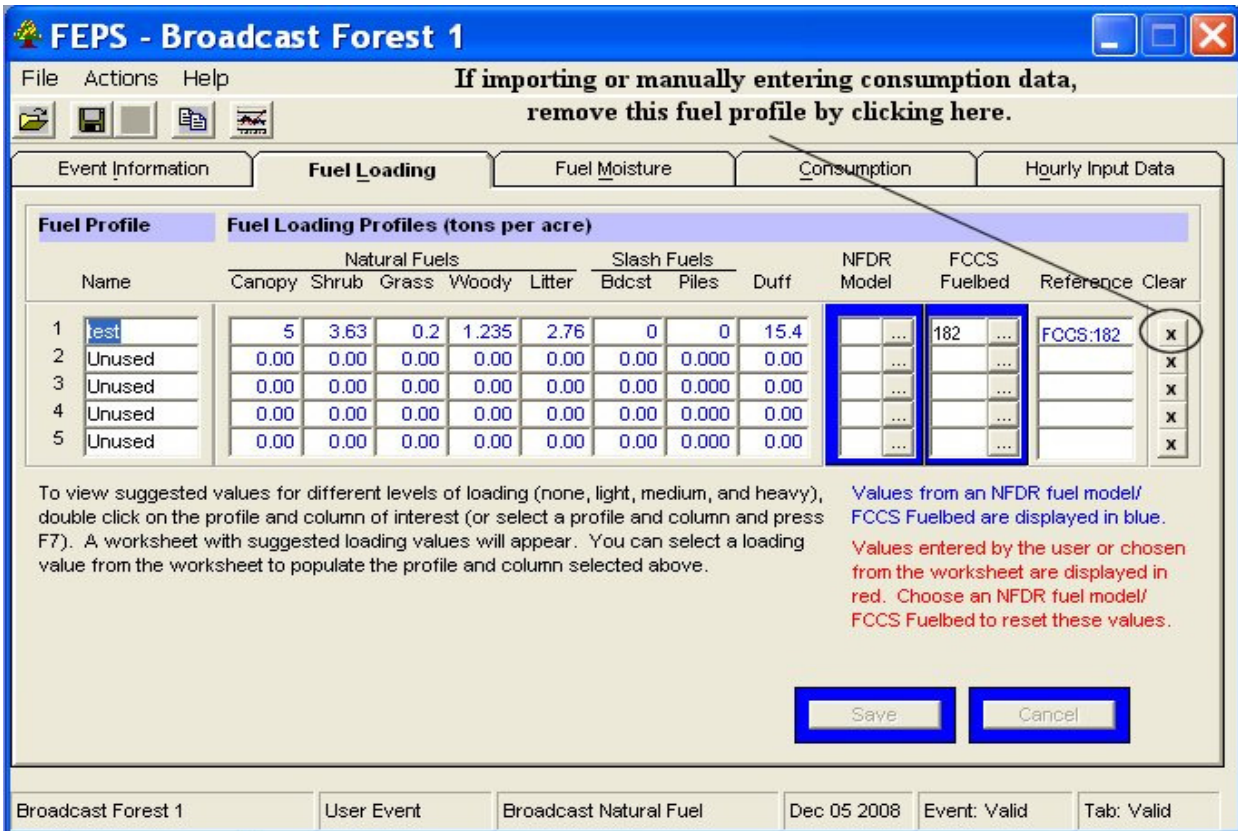
### **Event Information Tab**

**Start and End Date.** It was found that the length of time specified for the burn event was often insufficient to ensure that the long-term smoldering phase was completed before FEPS stopped calculating results. Thus, any emissions and/or heat being generated during this phase may not be captured in the FEPS results. However, when this issue was further examined, it was discovered that the emissions associated with the last portion of long-term smoldering are not significant relative to the rest of the burn event. The emissions contribution during the last few hours of a burn event did not exceed 0.5% of the total emissions. In addition, there was no increase in the amount of heat released from the event, as heat is only released during the flaming consumption phase of the fire. Therefore, although the length of the fire event does influence total emissions, the amount is small enough that it is unlikely to affect the outcome of subsequent smoke dispersion modeling.

### **Fuel Loading and Fuel Moisture**

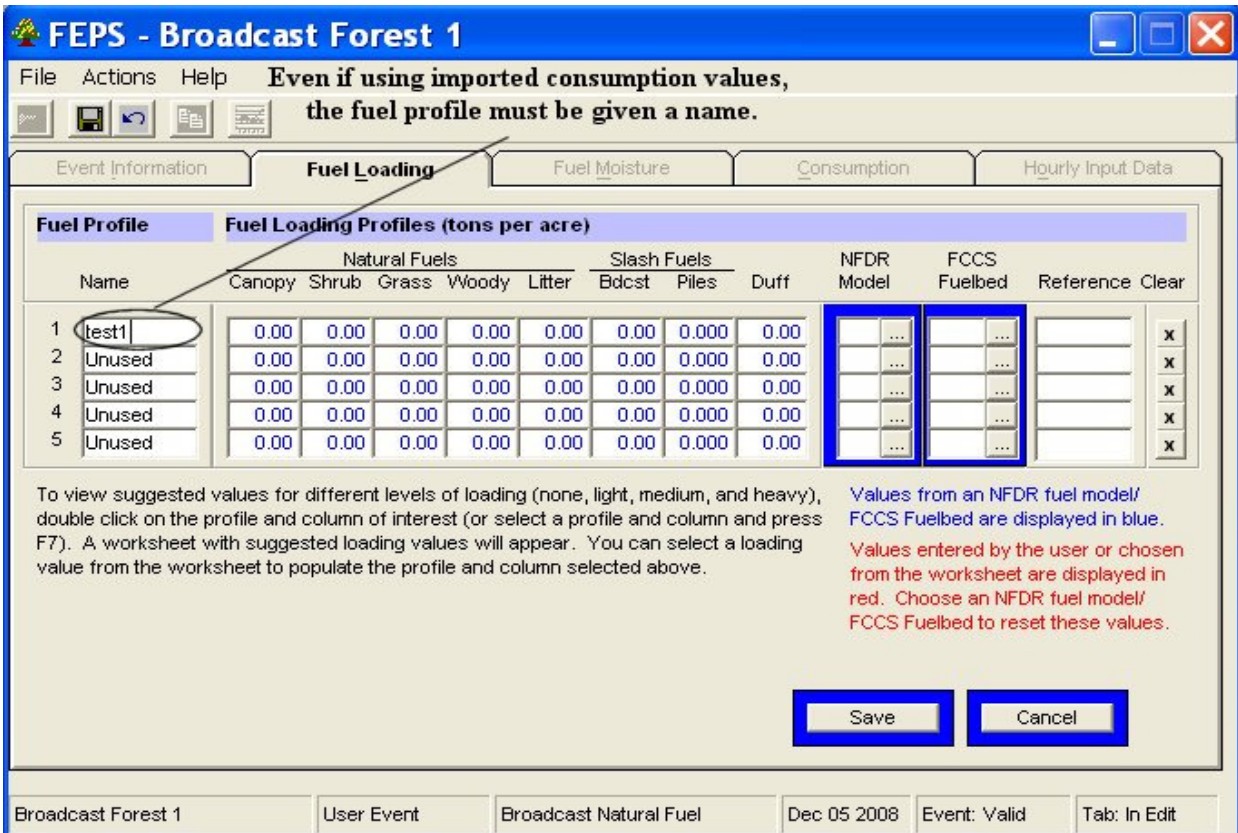
As discussed, it was originally believed that importing or manually entering consumption values in the “Consumption” tab overwrote any values contained in either the “Fuel Loading” or “Fuel Moisture” tabs. However, upon reviewing the findings this was found to be an incorrect assumption. Therefore, the inputs for these two tabs were examined to determine which ones continued to affect emissions and heat release rates, even after importing or directly entering consumption values. In addition, ways to work around this issue were explored.

Within the “Fuel Loading” tab, it was discovered that if all of the fuel profile values were set to zero before importing or manually entering consumption rates, results would not be erroneously affected. Values can be set to zero by first clearing the fuel profile line, as shown in Figure 6a.



**Figure 6a: Fuel Loading Screen Shot.** The fuel profile values can be set to zero by first clicking the X button, as shown.

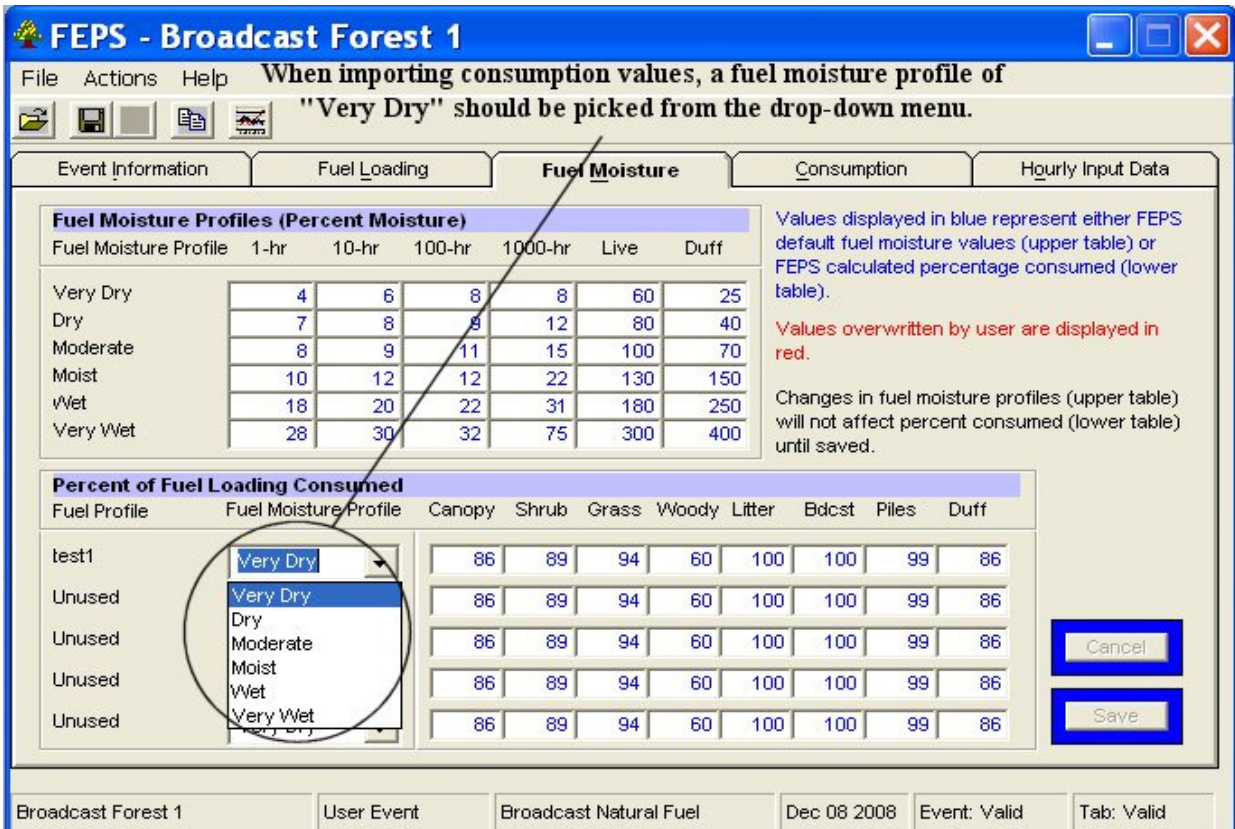
After clearing the fuel profile, the fuel profile name will be automatically set to "Unused". However, another name must be given to the profile, as shown in Figure 6b.



**Figure 6b: Fuel Loading Screen Shot.** After clearing the fuel loading values from the fuel profile, a name other than “Unused” must be given to the profile.

Regarding the “Fuel Moisture” tab, the FEPS software accounts for the fuel moisture profile set in this tab even if consumption values are either imported or manually entered into the software. Consume 3.0 already uses fuel moisture values to calculate the amount of fuel consumed during the event; taking into account fuel moisture again may cause erroneous results. Therefore, in order to ensure that the user obtains the best estimate of emissions and heat release rates, the fuel moisture profile within the “Fuel Moisture” tab should be set to “Very Dry” from the drop down menu shown in Figure 6c. This will basically negate any double-counting of the impact of fuel moisture on results that would otherwise occur.

After making a blank fuel profile in the “Fuel Loading” tab and setting the fuel moisture profile to Very Dry in the “Fuel Moisture” tab, the user should not encounter any issues with importing consumption values.



**Figure 6c: Fuel Moisture Screen Shot.** In order to ensure that fuel moisture values are not accounted for twice within FEPS, if importing consumption values the user should set the fuel moisture profile to "Very Dry".

### Consumption Tab

Whether consumption is calculated within FEPS, manually entered into the software, or imported from a software program such as Consume 3.0, these values are the most critical component for accurate results. Although users may enter infinite combinations of above ground and duff fuels depending on their proposed burn events, in reality duff consumption is generally much lower than the above-ground consumption rates. If a user enters unrealistic values for duff consumption, such as a rate that is equal to or greater than the rate of above ground consumption, emissions and heat release rate results may be unreliable. Therefore, resource managers should ensure that the values they are entering for both above-ground fuel and duff consumption are accurate. If total consumption is known but the split between above-ground and duff is uncertain, consumption should be entered as all above-ground in order to estimate worst-case emissions and heat release rates.

### Hourly Data Input Tab

**Area (Acres) of Cumulative Consumption during Fire Event.** Three events were examined, each taking place over a period of five days and each consuming 1000 total acres. The only difference between the events was how fast the fire expanded to include all 1000 acres. The description of each of the three events is shown in Table 3a, and their corresponding results are shown in Table 3b.



**Table 3a: Event Descriptions for Cumulative Consumption**

Event	Cumulative Consumption Description
Event 1	Expand from 0 to 500 acres over six hours on Day 1 of the event, then expand from 500 to 1000 acres over eight hours on Day 2
Event 2	Expand from 0 to 1000 acres over six hours on Day 1 of the event
Event 3	Expand from 0 to 1000 acres over fourteen hours on Day 1 of the event

**Table 3b: The Impact of Cumulative Consumption on Maximum Hourly and Total Particulate Matter Emissions and Heat Release Amounts**

Event	Highest Hourly PM Emissions (pounds/hour)	Total PM Emissions (pounds)	Highest Hourly Heat Release (10 <sup>6</sup> Btu/hr)	Total Heat Released (10 <sup>6</sup> Btu)
Event 1	285	4,208	3,000	22,369
Event 2	565	4,397	6,080	31,120
Event 3	263	3,625	3,000	20,802

As shown, changing the rate of consumption not only results in different maximum hourly emissions and heat release rates, but also affects the totals for the entire fire event. This is an interesting result, and indicates that resource managers need to pay special attention to the fire expansion behavior when planning prescribed fire activities.

Wind at Flame Height (Surface Wind Speed). Surface wind speeds of 1 to 20 miles per hour were used to examine the effect of surface wind speed on the maximum hourly and total emissions and heat released from the event. As expected, it was found that as surface wind speed increases, hourly and total emissions also increase. Table 4 shows the difference in maximum hourly and event total emissions and heat released for surface wind speeds of 1, 5, 10, 15 and 20 miles per hour.

**Table 4: The Impact of Surface Wind Speed on Maximum Hourly and Total Particulate Matter Emissions and Heat Release Amount**

Wind at Flame Height (Surface Wind Speed) (mph)	Highest Hourly PM Emissions (pounds/hour)	Total PM Emissions (pounds)	Highest Hourly Heat Release (10 <sup>6</sup> Btu/hr)	Total Heat Released (10 <sup>6</sup> Btu)
1	418	8,715	2,970	28,089
5	531	9,695	3,530	32,906
10	615	10,431	3,950	36,565
15	680	10,995	4,280	39,368
20	735	11,472	4,550	41,737

As shown, surface wind speed can have a significant impact on the emissions and heat release rates from a prescribed fire. Interestingly, when the results were fully examined, it was discovered that surface winds only impact hourly emissions and heat release rates during the times when the fire is expanding (e.g., during the flaming and short term smoldering phases of the fire).

Daily Humidity Extremes. The influence of humidity on FEPS results was evaluated by modifying daily humidity values of the baseline fire event. FEPS asks for daily temperature and humidity extremes (e.g., highs and lows), and then interpolates those values to hourly numbers. However, for ease of comparison, the daily high and low values were set at the same percentage, which resulted in the same humidity value during each hour of the day. The values were set from 25% to 90%

relative humidity. Table 5 summarizes the results of hourly and total emissions and heat release rates from the fire event after adjusting the relative humidity.

**Table 5: The Impact of Humidity on Maximum Hourly and Total Particulate Matter Emissions and Heat Release Amount**

Relative Humidity Throughout the Day (%)	Highest Hourly PM Emissions (pounds/hour)	Total PM Emissions (pounds)	Highest Hourly Heat Release (10 <sup>6</sup> Btu/hr)	Total Heat Released (10 <sup>6</sup> Btu)
25	656	11,219	4,160	40,525
35	613	10,780	3,940	38,300
45	569	10,340	3,720	36,117
55	525	9,900	3,500	33,933
65	481	9,461	3,280	31,749
75	437	9,021	3,060	29,566
85	393	8,581	2,850	27,423

During a prescribed burn event, lower relative humidity results in higher emissions and heat release rates, while higher humidity values result in lower emissions and heat release rates. It is important to remember that hourly humidity percentages are interpolated from the user inputs of daily extremes. Therefore, emissions and heat releases will vary through the course of the burn event.

**FEPS Results as Inputs to Smoke Dispersion Models**

Table 6 shows that several parameters within the FEPS software influence emissions and heat release rates that are then used as inputs to smoke dispersion models. Dispersion models typically pinpoint the worst-case hourly impacts from smoke and fine particulate matter pollution on surrounding communities. Those parameters that have an impact on hourly emissions and heat release rates are therefore deemed to be most important.

**Table 6: Summary of Each Parameter's Influence on FEPS Results.** Also included is whether the parameter would have an impact on the worst-case hourly results from smoke dispersion modeling.

Parameter	Effect on Emissions and Heat Release Rate from Burn Event	Impact on Worst-Case Hour in Model?
Start and End Date (length of fire event)	Total emissions predicted by FEPS will be reduced if the specified length of time of the burn event is not sufficient to capture emissions from long term smoldering.	No
Fuel Loading Profile	Even if manually entering or importing consumption data, there needs to be a blank fuel loading profile created and named.	Yes
Fuel Moisture Profile	Even if manually entering or importing consumption data, the fuel moisture profile needs to be set to "very dry" to avoid increasing the impact of fuel moisture on consumption.	Yes
Consumption	When manually entering or importing data, the user needs to ensure that the split between above-ground fuel and duff consumption is accurate. If the split cannot be estimated, all consumption should be entered as above-ground to reflect the worst-case situation.	Yes

<b>Parameter</b>	<b>Effect on Emissions and Heat Release Rate from Burn Event</b>	<b>Impact on Worst-Case Hour in Model?</b>
Area (Acres) Cumulative Consumption	Maximum hourly and total emissions and heat release rates are influenced by the fire expansion behavior.	Yes
Wind at Flame Height (Surface Wind Speed)	As wind increases, emissions and heat release rates increase. Wind speed is only important during the hours when the fire is expanding.	Yes
Humidity	As humidity increases, emissions and heat release rates decrease.	Yes

**Recommendations**

Based on the results set forth above, it is recommended that resource managers who are using FEPS results as inputs to smoke dispersion modeling pay careful attention to the parameters listed in Table 6.

- Fire expansion behavior (cumulative number of acres burning each hour) was found to have an especially important influence on hourly results.
- Surface wind speed during the hours when the fire is expanding has a significant impact on hourly values.
- Humidity also played a role in varying hourly results, so the user should attempt to create reasonable minimum and maximum humidity inputs for the area of the burn.
- When the split between above-ground fuel and duff consumption is unknown, the user should assume all consumption occurs in above-ground fuels to reflect a worst-case situation.
- Finally, when relying on imported or manually entered consumption data, the user should create a blank fuel profile, name it and use a moisture level of “very dry” in order to avoid erroneous results.

As resource managers, the health of the forests is paramount, and prescribed fire plays a vital role in that endeavor. Using FEPS and smoke dispersion modeling to predict the impact that prescribed fire activities have on surrounding communities can minimize or even eliminate any negative health and safety effects from these events.

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