Watershed Analysis for Fuel Management Operations

William J. Elliot
U.S.D.A. Forest Service, Rocky Mountain Research Station, Moscow, ID.
February 2005.
Draft chapter for a General Technical Report on the *Environmental Consequences Toolkit* for *Applied Wildland Fire Research in Support of Project Level Hazardous Fuels Planning*.

http://www.fs.fed.us/fire/tech_transfer/synthesis/synthesis_index.htm
http://forest.moscowfsl.wsu.edu/fuels/tools.html

Watershed Analysis for Fuel Management Operations

This chapter discusses the main components for completing a watershed analysis to support fuel management activities. The main tool is the Water Erosion Prediction Project Fuel Management Tool (WEPP FuME). Other tools will be discussed that provide more detailed analysis.

Introduction

One of the main products of many forests is surface water. The main pollutant in most forest streams is sediment. Upland management disturbances including fuel management activities and forest roads can cause erosion, leading to increased stream sedimentation and reduced water quality. Forest managers need to evaluate the impact of most forest activities on stream sedimentation, including fuel management.

A special computer interface has been developed to assist with analyzing soil erosion rates associated with fuel management activities. This interface estimates background erosion rates, and predicts erosion associated with mechanical thinning, prescribed fire, and the road network. The interface uses the Water Erosion Prediction Project (WEPP) model to predict sediment yields from hillslopes and road segments to the stream network. The WEPP model is a physically-based soil erosion model developed over the past 15 years to predict soil erosion and sediment yields for agriculture, rangeland, and forest conditions (Laflen et al., 1997). The simple interface has a large database of climates, vegetation files, and forest soil properties to support this and other interfaces, including Disturbed WEPP for forests, and WEPP:Road for road segment analyses (Elliot, 2004). The soil databases for roads and disturbed forested hillslopes are based on rainfall simulation and natural rainfall studies carried out over the past 20 years (Elliot and Hall, 1997).

For this application, the WEPP hillslope interface is used to model a single strip of hillslope (Figure 1). It is assumed that the sediment generated from this hillslope from a number of disturbances will be routed through the watershed. In the year of the disturbance, there is likely to be considerable deposition of sediment from the disturbed hillslope in the stream network. This sediment is gradually routed through the watershed in subsequent wet years. If the years are dry, there is unlikely to be any sediment routed. As the disturbed hillslope recovers, erosion from that hillslope will gradually decline. This application assumes that road erosion occurs every year, with the magnitude dependent only the level of traffic and the weather during the year.

Description of the Tool

The WEPP FuME interface carries out erosion prediction runs for seven forest conditions:

1. Undisturbed mature forest
2. Wildfire
3. Prescribed fire
4. Thinning
5. No traffic roads
6. Low traffic roads
7. High traffic roads

The climate, soil texture, topography, road density, wildfire return interval, prescribed fire cycle and thinning cycle are specified by the user.

Mechanics

From the simple online input screen (Figure 2), the input data are formatted for the WEPP model for each of the seven runs. The WEPP model is then run on the server for each condition. The results of the runs are converted into common units of tons sediment delivered per square mile per year and presented in a table with an accompanying summary narrative (Figures 3 and 4).

Base Assumptions

The WEPP FuME interface makes a number of simplifying assumptions for the seven runs (Table 1). Five additional runs (described later) are also carried out to aid the user in developing alternative management scenarios. If users wish to consider others levels of disturbance than those presented in Table 1 or the additional runs for disturbed forests, these runs can be carried out with the Disturbed WEPP interface (http://forest.moscowfsl.wsu.edu/fswepp/).

For the road analysis, roads may deliver sediment to a stream crossing, or may have runoff and sediment diverted across the specified buffer before entering a stream. For "No Treatment," it is assumed that some roads will have no traffic, while others have low traffic, so the predicted sediment yield range is from no traffic with a buffer to low traffic with no buffer. For the treatment scenario, it is assumed that some of the roads will be low traffic and others will have high traffic with gravel. Therefore sediment yields will range from the lowest value from low or high traffic with a buffer to the highest value from low traffic or high traffic with no buffer. The true road impact will be somewhere between these two values. Users who wish to make a more detailed analysis of road sediment generation should use either the WEPP:Road or WEPP:Road Batch interface (http://forest.moscowfsl.wsu.edu/fswepp/).

Scope of WEPP FuME

The WEPP FuME interface can be used anywhere within the U.S. using the existing climate database. It is intended to provide an overview of the sources of sediment on a given fuel management site. Users who want more detailed analysis will have to use more complex interfaces available online (http://forest.moscowfsl.wsu.edu/fswepp/) or standalone windows (USDA, 2004) or GIS interfaces (Renschler, 2004).

Sediment predictions from WEPP FuME are for surface erosion only. In some watersheds, landslides may be a significant source of sediment, and in others, stream channels may be sources of sediment. Users will need to obtain estimates for these potential sources of sediment from local specialists.

Data Input Needs

The WEPP FuME input screen (Figure 2) has several input fields for climate, soil, road density and length of simulation, hillslope and buffer lengths, hillslope steepness, wildfire return interval and frequencies of proposed treatments.

Selecting a Climate

In order to select a climate for a given site, the user should click the Custom Climate button on the input screen. This takes the user to the first screen of the Rocky Mountain Research Station Climate Generator (Rock Clime; Elliot, 2004). On this screen, they can delete unwanted climates from past analyses, or select a state for their study. Once a state is selected, a list of weather stations for that state is presented. The user should select the weather station nearest the site of interest. If the weather station has temperatures and precipitation values similar to the site, it can be selected by clicking ADD TO PERSONAL CLIMATES. On many sites, this will not be the case because the weather station is in the valley, and the site is higher, cooler, and wetter. In this case, the user should click MODIFY CLIMATE. On the Modify Climate screen, the user can enter local monthly precipitation, number of wet days, and temperature values if they are known, or enter the latitude and longitude of the site (in degrees and decimal degrees) and click the PRISM button on the upper right of the screen to enter into the PRISM precipitation and elevation database (Scheele et al. 2001). This database contains monthly precipitation values and average elevations for a grid of approximately 2.5 miles, covering the entire U.S. The user can navigate to adjacent cells on the PRISM Precipitation page until the desired cell is selected. Ridges and valleys are apparent on this page, and can often aid the user in ensuring that the desired elevation and climate are selected. Once the desired grid is selected, the user clicks Use PRISM Values and returns to the Modify Climate screen. On this screen, the user can further alter the climate variables if desired. On the bottom of the screen is a box to select “Adjust temperature for elevation by lapse rate.” This should be selected unless the user knows that temperature inversions are common in the area of interest. The user should then enter the new climate name, click Use these values and Return to input screen to make the climate available for WEPP FuME.

Soil

The soil texture field contains four USDA soil textures. Once a texture is selected, the appropriate erodibility values for that texture are used for all the soil components of the twelve runs. If a user wants to see the properties for a given texture, he should go to the WEPP:Road or Disturbed WEPP interfaces (http://forest.moscowfsl.wsu.edu/fswepp/), select the texture and road or vegetation treatment, and click the Texture button on WEPP:Road or the [Describe] button on Disturbed WEPP to get a list of the assumed soil properties.

Road Density

The road density is the average miles of road per square mile of forest. Typical values range from 2 to 6 or more miles of road per square mile of forest. In some cases, roads may be on ridge tops. Such roads, greater than about 300 feet from any ephemeral channels, are unlikely to contribute sediment to the stream system, and can be ignored in the analysis.

Topography

In the topography fields, the user is asked to input values for a typical horizontal slope length and steepness. Slope lengths and steepnesses can be obtained from field surveys or contour maps. Users may also have access to GIS topographic analysis tools to aid in estimating these values, providing average values, or determining a range of topographic values to consider.

The buffer length is included in the overall slope length. For example, a 400-ft long slope with a 50-ft buffer would have 350 ft of hillslope thinned and prescribed burned with a 50-ft undisturbed buffer. The entire 400 ft would be burned with a wildfire or be covered with undisturbed forest. The road analysis assumes either delivery to a seasonal or perennial stream, or delivery across the specified buffer length. Users may wish to evaluate several different buffer widths to determine the optimal width for their conditions. They may also wish to evaluate several different slope lengths or steepnesses to evaluate a range of conditions and determine which sites are likely to generate more sediment. In some of the wetter climates, the buffers may not reduce sediment delivery because they become sources of sediment as well.

The hillslope gradients represent the top of the hill, the overall average steepness, and the gradient of the toe of the hill. The top of the hill is near zero if the area of interest starts at the crest of the hill. It is likely the same as the average hillslope gradient if the treated area starts midslope. The bottom slope may be flatter or steeper than the average, depending on local topography.

Disturbance Return Periods

The wildfire return interval should be entered in the wildfire input box. The interval will likely range from 20 years with low elevation, dry forests, to 200 years with high elevation moist forests, to 300 years with very wet forests on the west slopes of the Cascades or the Coastal ranges (McDonald et al. 2000). Prescribed fire return periods can vary from 2 to 40 years, or more, and thinning periods from 10 to 80 years.

Once all of the input fields have been specified, the user should click Run WEPP FuME.

Information Output

Once the twelve WEPP runs are complete, and the data are adjusted to common units, the input and output tables (Figure 3), and narrative (Figure 4 and WEPP FuME Example) are presented on the output page. Details of all twelve runs are presented after the narrative. The user may wish to print this page, save it, or copy all or part of it for pasting into a spreadsheet or word processor.

On the output table, the results from each of the four hillslope erosion runs are presented as average annual erosion rates, converted to tons/mi^2. The erosion rates for each of these hillside disturbances are divided by the frequency of the disturbances to get an average annual sediment yield expected from a watershed. The three road runs are summarized on a low access range (for no traffic and low traffic) and a high access range (for low traffic and high traffic with gravel). Road erosion is assumed to occur every year.

The narrative that follows (Figure 4 and WEPP FuME Example) can serve as a basis for the report of the analysis. Users will likely want to incorporate information from some of the additional runs, carry out runs for other hillslopes or different buffer widths and modify the narrative to reflect what is learned from those runs within a final report. Users may wish to add a value for sediment from landslides or from stream channel erosion to background or treatment values.

Additional Information

Details of inputs and outputs from the initial seven runs, plus the additional five runs are summarized at the end of the output page. The user can use these as guidelines to get additional information for any of the runs by clicking on the run description in the condition column. Information includes surface runoff and probabilities associated with different amounts of erosion or sediment yield. Clicking on the Sediment Yield column heading will give a summary of the WEPP FuME interface calculations and give diagrams describing each of the runs. The output information can also serve as a guide for the variables that would have been entered into the Disturbed WEPP or WEPP:Road online interfaces so the user can use these interfaces to do a similar run, or to explore the sensitivity of the predicted sediment yields to the input variables.

In addition to the initial seven runs, five additional runs are carried out to address other potential erosion scenarios if needed. The five runs are:

1. A lower impact thinning operation, as might occur with cable or similar low impact operation.
2. A higher severity prescribed fire as might occur in a dry fall burn, with no buffer.
3. A lower severity prescribed fire as might occur with a wetter spring burn and with a buffer.
4. A moderate severity wildfire that may be more likely to occur with fuel management activities in place.
5. A low severity wildfire that may be more likely to occur with fuel management activities in place.

These additional runs can be used to present additional options or outcomes, with the existing discussion serving as a guide for incorporating the results into an environmental analysis document. For example, the user may wish to present as an alternative to severe wildfire once every 80 years, a lower intensity wildfire once every 80 years plus impacts from the proposed fuel management activities. Another example might be to use the low impact thinning as an indication of the erosion associated with a cable thinning operation to compare to the erosion predicted from the assumed tractor logging operation in the main output to see if the extra costs associated with the cable operation are justified by reducing sediment generation.

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Table 1. Main assumptions for WEPP FuME runs

Run	Main Assumptions
Undisturbed forest	"20-yr forest" soil Ground Cover 100 percent, including buffer All buffer slopes assumed to be half the hillslope steepness
Thinned forest	"5-yr forest" soil Ground cover 85% on treated hillslope, 100% on buffer
Prescribed fire	"Low Intensity Fire" soil Ground cover 85% on treated hillslope, 100% on buffer
Wildfire	"High Intensity Fire" soil Ground cover 30%, no buffer
No traffic road	Gradient = 1/10 of hillside slope, road length = 300 ft, width is 13 ft Treatment is insloped vegetated ditch, vegetated surface, no traffic Fillslope length is 30 feet, and steepness is twice the hillslope steepness Buffer length and steepness as specified
Low traffic road	Gradient = 1/10 of hillside slope, road length = 300 ft, width is 13 ft Treatment is insloped vegetated ditch, native surface, low traffic Fillslope length is 30 feet, and steepness is twice the hillslope steepness Buffer length and steepness as specified
High traffic road	Gradient = 1/10 of hillside slope, road length = 300 ft, width is 13 ft Treatment is rutted, gravel surface, high traffic Fillslope length is 30 feet, and steepness is twice the hillslope steepness Buffer length and steepness as specified

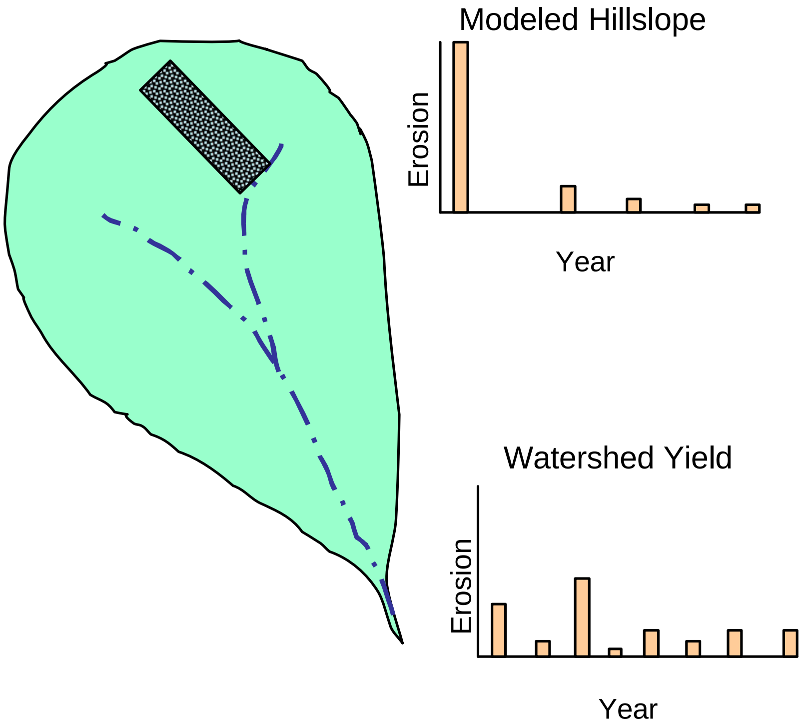


Figure 1. Diagram of a WEPP FuME hillslope within a watershed, and relationship of timing and magnitude of sediment generation from the hillslope and the watershed

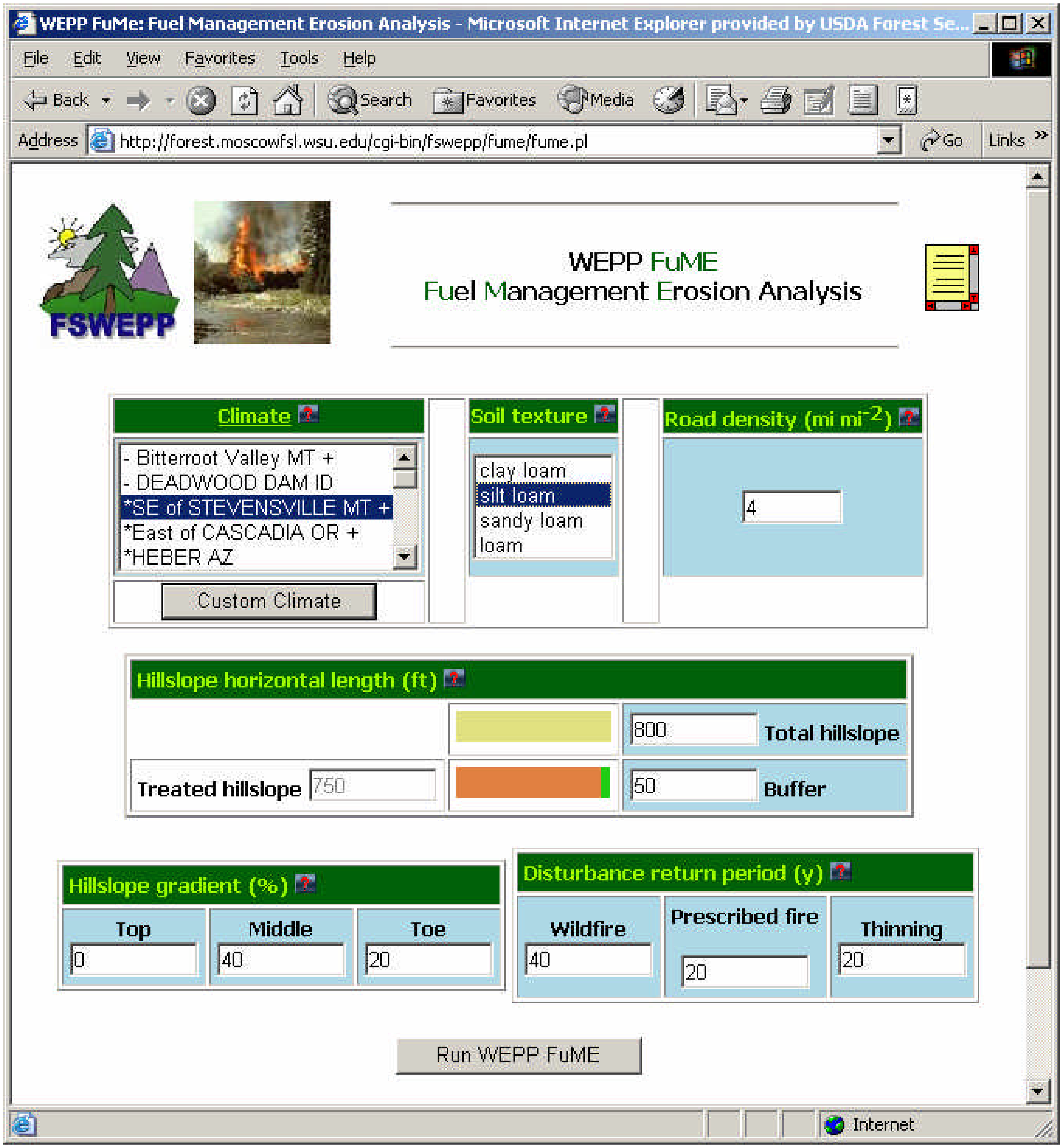
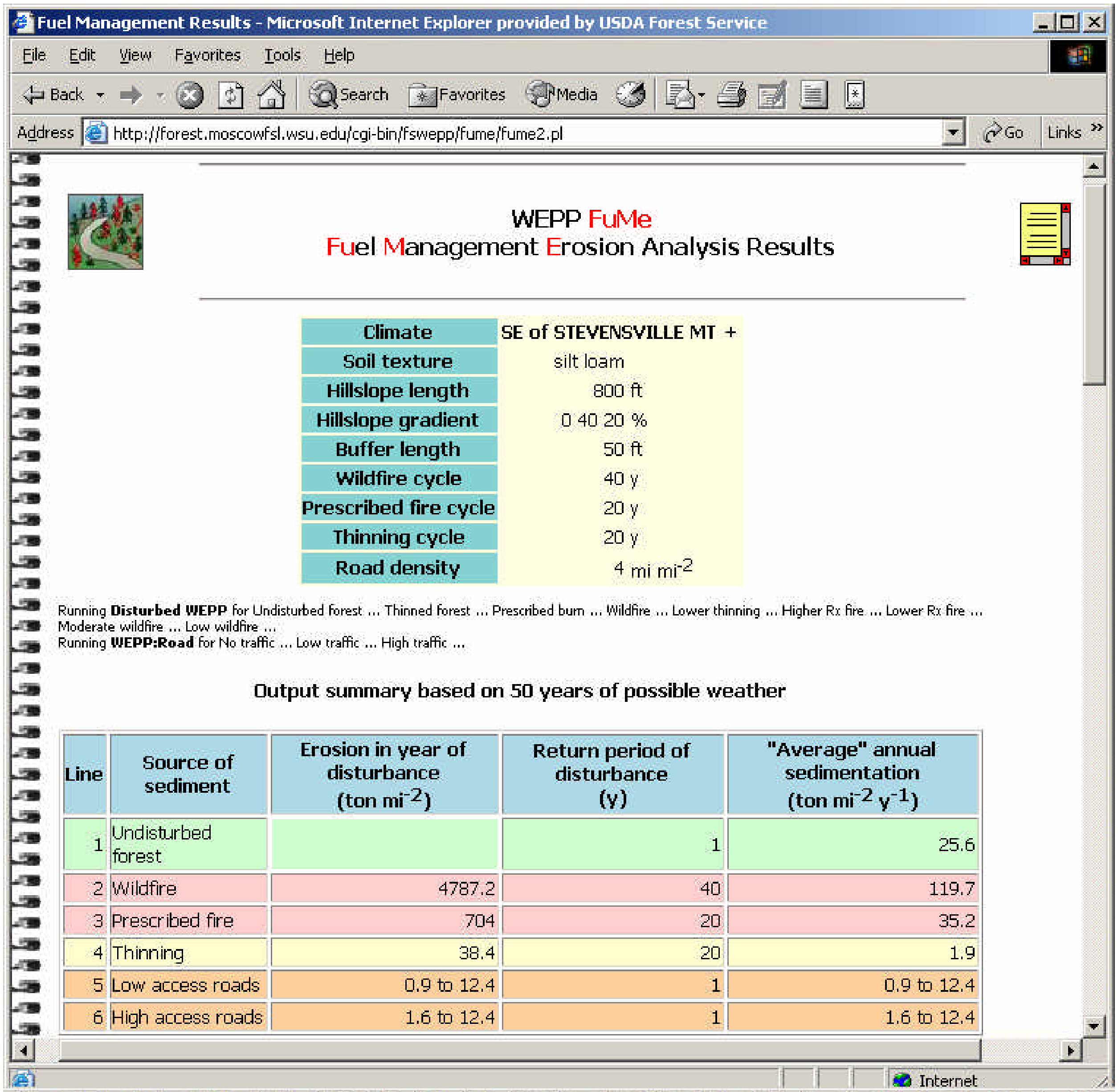


Figure 2. Main WEPP FuME input screen



WEPP FuMe
Fuel Management Erosion Analysis Results

Climate	**SE of STEVENSVILLE MT +**
Soil texture	silt loam
Hillslope length	800 ft
Hillslope gradient	0 40 20 %
Buffer length	50 ft
Wildfire cycle	40 y
Prescribed fire cycle	20 y
Thinning cycle	20 y
Road density	4 mi mi^{-2}

Running **Disturbed WEPP** for Undisturbed forest ... Thinned forest ... Prescribed burn ... Wildfire ... Lower thinning ... Higher Rx fire ... Lower Rx fire ... Moderate wildfire ... Low wildfire ...
Running **WEPP:Road** for No traffic ... Low traffic ... High traffic ...

Output summary based on 50 years of possible weather

Line	Source of sediment	Erosion in year of disturbance (ton mi^{-2})	Return period of disturbance (y)	"Average" annual sedimentation (ton mi^{-2} y^{-1})
1	Undisturbed forest		1	25.6
2	Wildfire	4787.2	40	119.7
3	Prescribed fire	704	20	35.2
4	Thinning	38.4	20	1.9
5	Low access roads	0.9 to 12.4	1	0.9 to 12.4
6	High access roads	1.6 to 12.4	1	1.6 to 12.4

Figure 3. WEPP FuME output table

Summary of Analysis

Background sedimentation.

Wildfire + Undisturbed Forests
With and without roads

Thinning effects.

With and without roads
Impacts on wildfire occurrence or severity

Prescribed fire effects.

Without roads
Impacts on wildfire occurrence or severity

Combined thinning and prescribed fire effects.

With and without roads
Impacts on wildfire occurrence or severity

Road Impacts

Effects of road design and management
Benefits of road removal

Multiple Hillslopes

Details of Inputs and Outputs for all 12 Runs

Figure 4. Contents of WEPP FuME discussion paragraphs to aid in interpreting the WEPP FuME output table (Figure 3)

WEPP FuME Example

For this example, the climate was based on that of the Sheafman watershed, southwest of Stevensville, Mt. The nearest weather station was Stevensville, MT, and monthly precipitation values were selected for the latitude (46.33 ° N) and longitude (114.28° W) of the site from the PRISM database. The topography was assumed to be a hillslope with a length of 800 ft, starting flat at the top, a middle steepness of 40 percent, and a toe steepness of 20 percent. The other assumptions can be noted on the input tables in Figures 2 and 3.

The predicted sediment yield values for this average topography are shown on the output table in Figure 3. The narrative that follows uses the information from the run in Figure 3 to present the following discussion.

Summary of Analysis

The output summary table presents the predicted sediment yield rates from seven runs with the WEPP model. The outputs from those runs were converted to common units of ton mi^{-2} y^{-1}. From these runs, several key watershed sedimentation values can be estimated.

Background sedimentation. The background sedimentation rate -- the rate that will occur with no action -- can be estimated either with or without roads. In the absence of roads, the background sedimentation rate is erosion from undisturbed forest plus erosion from wildfire. This value is the sum of lines 1 and 2, or 25.6 + 119.7 = 145.3 ton mi^{-2} y^{-1}. If the existing low access road network is included in the background sediment rate, then the background rate will be the sum of lines 1, 2, and 5, or 145.3 + (0.9 to 12.4) = 146.2 to 157.7 ton mi^{-2} y^{-1}, depending on what percent of the road network crosses live water during major runoff events.

Thinning effects. From the summary table, line 4, thinning will generate 38.4 tons of sediment the year following thinning, and when averaged over the thinning period of once in 20 years, will average about 1.9 ton mi^{-2} y^{-1}. This is an increase of about 1 percent above background without roads.

In order to carry out the thinning operation, however, traffic on the roads will have to be increased to the high access level to support the traffic associated with an ongoing thinning operation in the watershed. The total sediment yield from the watershed will then be the background value plus that from thinning and from high access roads for a total of 145.3 + 1.9 + (1.6 to 12.4) = 148.8 to 159.6 ton mi^{-2} y^{-1}. This is an increase of 2 to 10 percent above the background rate, if roads are not considered in the background, or 2 to 1 percent if the road network is considered in the background rate.

Further comparisons can be made by assuming that thinning will eliminate wildfire from the watershed, thus reducing the wildfire sedimentation value, or that thinning will lead to a less severe wildfire, and the moderate or low severity fire sedimentation rate from the table below can be substituted for the wildfire erosion rate in line 2.

Prescribed fire effects. From the summary table, line 3, prescribed fire will generate 704 ton mi^{-2} the year of the prescribed fire, or when averaged over the prescribed fire return period of 20 y, it will generate 35.2 ton mi^{-2} y^{-1}. This is an increase of 24 percent above background. As there will be no need for heavy traffic to carry out the prescribed burn, there is no increase in sedimentation from the road network. For a watershed with an active prescribed fire program, the total erosion will then be the background rate plus the low access road rate and the average erosion from prescribed fire, or 145.3 + 35.2 + (0.9 to 12.4) = 181.4 to 192.9 tons $mi^{-2}\ y^{-1}$, or an increase of 25 to 33 percent above background, if roads are not included in the background value.

If the prescribed fire eliminates the risk of wildfire, the background erosion rate will need to be set to 25.6 (line 1 of the outputs summary) for the analysis. Alternatively, the impact of the prescribed fire program may be to reduce the intensity of the wildfire, in which case, the sedimentation associated with a moderate or low severity fire from the following table can be substituted for the wildfire prediction for the analysis.

Combined thinning and prescribed fire effects. The combined effects of thinning and prescribed fire can be determined by summing up the background rate, the thinning rate, the prescribed fire rate, and the high access road rate. In this case, this leads to a total predicted erosion rate of 145.3 + 1.9 + 35.2 + (1.6 to 12.4) = 184 to 194.8 ton $mi^{-2}\ y^{-1}$, an increase of 27 to 34 percent above the background erosion rate without roads.

If this intensive fuel management scenario can reduce the severity of wildfire in the watershed, then the moderate severity fire sedimentation value of 1664 ton mi^{-2} can be substituted for the wildfire erosion rate once every 40 years to give an average value of 41.6 ton $mi^{-2}\ y^{-1}$. Using this value to determine the total impact of fuel management gives 41.6 + 1.9 + 35.2 + (1.6 to 12.4) = 80.3 to 91.1 ton $mi^{-2}\ y^{-1}$, a decrease of 45 to 42 percent compared to background including roads.

Road Impacts. The range of values given for road sedimentation represent the amount of sediment delivered across the buffer, and the amount delivered to a stream crossing. Roads with buffers greater than 50 ft will generate less sediment. The summary table shows that roads generate significant amounts of sediment within a watershed, even when traffic is low. Road management strategies -- including minimizing rutting, minimizing stream crossings, and maximizing the use of buffers between the road and the stream -- are well established to minimize sedimentation. The WEPP:Road interface can be used to evaluate the impacts of some of these improved practices. Another alternative to reduce sedimentation from the road network is to reduce the road density within the watershed by removing roads that are no longer needed with modern timber operations. Watershed managers may wish to offset the increase in sediment associated with fuel management with a decrease in sediment from improved road management or a reduction in road density.

Multiple Hillslopes. This analysis was for a single hillslope. Users are advised to run this simulation for a number of different hillslopes within the watershed, and to report a range of sedimentation rates in the output table before completing the analysis. Results from each hillslope can be copied and pasted into a word processor or spreadsheet to serve as a log for a series of runs.

To complete this analysis, the user would most likely evaluate different buffer lengths, consider some other hillside lengths and gradients, and consider alternative management strategies or reduced wildfire erosion with information from the additional runs in the final section with details of inputs and outputs.

Discussion

In this example the wildfire erosion rate (4800 ton mi^{-2} y^{-1}) can be compared to erosion rates presented by Spigel on hillslope erosion rates after the 2000 Bitterroot wildfires averaging about 7400 t mi^{-2} y^{-1}, and by Elliot and Robichaud (2004) on small watersheds on the Gallitan National Forest where they observed the equivalent of an average of 2900 ton mi^{-2} y^{-1} in the year following the 2001 wildfire. Measured rates vary considerably depending on the weather the year immediately following the fire, but the predicted wildfire values are similar to the observed value. In studies of sediment delivery following low severity prescribed fire in Idaho and Montana, Covert et al. (under review) reported erosion rates of zero t/sq mile/yr when relatively dry years of 1993, 1994, and 1995 immediately followed the prescribed fire. After the sites had begun to recover, in the wet year of 1996, they reported observed sediment yields up to the equivalent of 22 ton mi^{-2} for that year.