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A probabilistic approach to modeling postfire erosion after the 2009 Australian bushfires

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Abstract: Major concerns after bushfires and wildfires include increased flooding, erosion and debris flows due to loss of the protective forest floor layer, loss of water storage, and creation of water repellent soil conditions. To assist postfire assessment teams in their efforts to evaluate fire effects and make postfire treatment decisions, a web-based Erosion Risk Management Tool (ERMiT) has been developed. ERMiT uses the Water Erosion Prediction Project (WEPP) model to predict postfire hillslope erosion and to evaluate the potential effectiveness of some common hillslope erosion mitigation practices. The model uses a probabilistic approach that incorporates variability in climate, soil properties, and burn severity for forests, rangeland, and chaparral hillslopes. For user specified climate, burn severity, and soil conditions, ERMiT produces a distribution of erosion rates with a likelihood of their occurrence for each of five years after the fire. ERMiT also provides single-event erosion rate distributions for hillslopes that have been treated with seed, straw mulch, and erosion barriers. ERMiT's outputs help managers establish the probability associated with a given level of sediment yield for a given location, and this information can be used along with information about the value of resources at risk and acceptable loss thresholds to make postfire erosion treatment decisions. The objectives of this paper are to describe: 1) the conceptual framework and components of the ERMiT model; and 2) an application of ERMiT from 2009 Victoria, Australia bushfires.

Keywords*: sediment yield, wildfire, WEPP, ERMiT, Victoria Bushfires*

1. INTRODUCTION

High severity fires affect the physical properties of soil (DeBano et al., 1998) and alter watershed responses to rainfall causing increased runoff and erosion (Robichaud, 2000). Following a fire, land managers often have to decide which mitigation actions, if any, are needed to protect life, property, and the environment downstream of burned areas. The decision depends on: 1) the probability that damaging amounts of runoff and erosion will occur; 2) lost resource value given the event; and 3) the cost and effectiveness of potential mitigation. The probability of the occurrence of damaging runoff and erosion and the effectiveness of mitigation treatments are not well established. Consequently, managers often must use professional judgment to make these decisions. The Erosion Risk Management Tool (ERMiT) technology can aid land managers in determining the risks of the postfire hazards and the potential benefits of treatments.

The ERMiT model was developed to address the need for a postfire erosion prediction tool that incorporates spatial and temporal variability of fire effects, provides probabilities of occurrence of postfire erosion rates, and includes erosion mitigation treatment effectiveness information (Robichaud et al., 2006, 2007a and b). ERMiT is a web-based application that predicts event sediment delivery in probabilistic terms on burned and recovering forest, range, and chaparral lands. The objectives of this paper are to describe: 1) the conceptual framework and components of the ERMiT model; and 2) an application of ERMiT from 2009 Victoria, Australia bushfires.

2. COMPONENTS OF ERMiT

The ERMiT user interface consists of a single web-page of user-chosen model inputs (Figure 1). The user can describe the modeled hillslope through a selection of pre-set or customized climate, four levels of soil texture, the amount of exposed rock, three levels of vegetation type, the hillslope gradient for three slope positions, hillslope length, and three levels of soil burn severity.

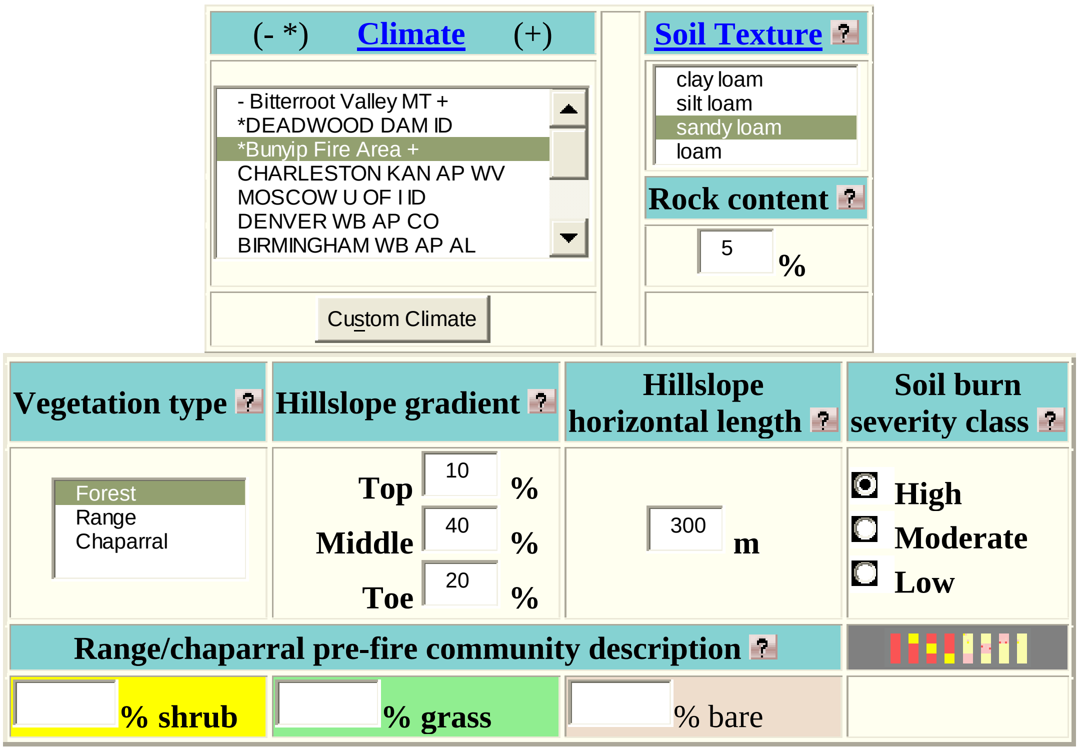

Figure 1. ERMiT input screen for typical hillslope on the 2009 Bunyip Fire, Victoria, Australia.

ERMiT uses the Water Erosion Prediction Project (WEPP) model to calculate the runoff and erosion outputs. WEPP simulates both interrill and rill erosion processes and incorporates the processes of evapo-transpiration, infiltration, runoff, soil detachment, sediment transport, and sediment deposition to predict runoff and erosion at the hillslope scale (Flanagan and Neary, 1995).

Through the ERMiT interface, stochastic weather files generated by CLImate GENerator (CLIGEN) are selected for use in WEPP. Users also may create custom climate parameter files by using the integrated Rock:Clime web interface (Elliot 2004; Scheele et al., 2001). Although the CLIGEN stations are based in the United States, climates for areas in other countries can be developed. The user would first select a climate station in the U.S that has similar attributes to the modeled climate (e.g., Australian climate). Next the user would modify the monthly minimum and maximum temperatures, precipitation, and/or number of wet days to fit the modeled climate.

3. VARIABILITY OF ERMiT INPUT PARAMETERS

Weather variability as well as the spatial and temporal variability of the soil effects of burn severity and other soil properties is incorporated into ERMiT. The general process used to incorporate weather and spatial variability is to: 1) determine a range of parameter values (CLIGEN and field measurements), 2) select representative values from the range, and 3) assign 'occurrence probabilities' for each selected value. The computational constraints of the model require that the sum of occurrence probabilities for each source of variability add to 100%. Thus, all possible parameter values are represented in the model by the four to five selected values.

3.1 Precipitation

A 100-year weather file is created using CLIGEN, and this is used to produce a 100-year runoff record for the specific site conditions (soil texture, ground cover, and burn severity). The maximum runoff event from each year is ranked and the years with the 5th, 10th, 20th, 50th, and 75th largest runoff events are selected for further analysis. The rain events associated with these selected runoff events are assigned occurrence probabilities of 7.5, 7.5, 20, 27.5, and 37.5%, respectively.

3.2 Burn Severity

Fire's effects are not homogeneous across the landscape. Soil burn severity is a description of the impact of a fire on the soil, duff and litter, and it describes the degree of impact to the ground cover, soil water repellency, infiltration, and tendency for erosion (DeBano et al., 1998; Robichaud, 2000; Pierson et al., 2001). The variability in soil burn severity creates landscapes with varying degrees of low, moderate, or high soil burn severity (DeBano et al., 1998).

Rainfall simulation experiments have shown that only high and low soil burn severity classes can be distinguished on the basis of runoff and erosion (Robichaud, 1996; Pierson et al., 2001). Hence, in ERMiT, each of the three user-designated soil burn severity classes (high, moderate, or low) is modeled with a set of four spatial arrangements of high and low burn severity elements. For each specific arrangement of each of these combinations within each burn severity class, ERMiT applies a probability of occurrence of between 10 and 30%.

3.3 Soil Properties

The variable effects of postfire ground cover, soil water repellency, and soil erodibility are modeled by variability in four parameters: interrill erodibility (K_i); rill erodibility (K_r); effective hydraulic conductivity (K_e); and critical shear stress (τ_c). The ranges of K_i, K_r, K_e, and τ_c values used in ERMiT were derived from field measurements taken at postfire research sites across the western United States (Robichaud, 2000; Pierson et al., 2001; Moffet et al., 2007; Robichaud et al., in preparation). These parameters are grouped according to soil texture (clay loam, silt loam, sandy loam, and loam) and high or low burn severity categories. To capture within-class variability of K_i, K_r, K_e, and τ_c, which may vary by two or more orders of magnitude, values within each soil texture-burn severity range were assigned probabilities of occurrence using cumulative distribution functions (CDFs).

4. COMBINING THE SOURCES OF VARIATION

To combine burn severity variability with soil parameter variability, the two soil parameter sets—one for high burn severity and one for low burn severity—were combined with each of the burn severity spatial arrangements, and arranged in order of erodibility from most erodible to the least erodible.

To account for the climate variability, the 20 groups of burn severity-soil parameter sets are used in the 6-10 WEPP-modeled years that include the percentile runoff values and the preceding years' climates described above. WEPP then produces erosion predictions for those climate and soil/burn severity combinations.

5. TREATMENT EFFECTIVENESS AND MODEL OUTPUT

Using field data as a basis, estimates of the erosion reduction and/or sediment trapping efficiency of seeding, straw mulching, and contour-felled log/straw wattle erosion barrier treatments have been incorporated into ERMiT. Treatment effects are modeled by increasing the occurrence probabilities of the less erosive soil parameter sets and reducing the occurrence probabilities of the more erosive soil parameter sets.

Erosion Risk Management Tool

Bunyip Fire Area + Modified by Rock:Clime on February 18, 2009 from SANTA MONICA PIER CA 47953 0 T MAX 23.70 23.90 21.50 17.80 14.50 12.00 11.40 12.70 14.60 17.10 19.50 21.40 deg C T MIN 10.60 10.30 9.00 6.90 5.40 3.80 2.80 3.40 4.80 6.50 7.90 9.20 deg C MEANP 85.09 72.39 88.90 107.70 103.89 133.35 136.91 137.67 155.45 145.80 126.75 116.08 mm # WET 9.30 7.30 10.94 11.47 14.59 17.50 18.60 18.08 17.50 15.50 13.85 11.42
sandy loam soil texture, **5%** rock fragment
10% top, 40% average, 20% toe hillslope gradient
300 m hillslope horizontal length
high soil burn severity on **forest**

Figure 2. A portion of the ERMiT output for the 2009 Bunyip Fire, Victoria, Australia showing the user-designated inputs.

ERMiT output summarizes user inputs (Figure 2) and the precipitation and runoff for the 100-year WEPP run and describes the five rain events associated with selected runoff events that were used to create the reduced climate file. A graphical output shows the single-rain event, postfire, hillslope sediment delivery exceedance probabilities plotted against the predicted event sediment delivery for each of the first five postfire years.

In addition to the sediment delivery exceedance probability curves, a table of the predicted sediment yields from untreated and treated areas for the first five postfire years is produced. In this table the user can select an exceedance probability and the corresponding event sediment delivery predictions are adjusted.

6. ERMiT CASE STUDY: 2009 AUSTRALIAN BUSHFIRES

In early 2009, bushfires burned approximately 4500 km^2 in Victoria, Australia. The area burned affected many of the catchments that supply water to the Melbourne metropolitan area. Land managers were concerned about the amount of sediment that may be delivered to the water supply system as well as the risk of flooding in these areas. U.S and Australian Burned Area Emergency Response (BAER) assessment teams used the ERMiT model and field surveys to gauge the risk of post-fire erosion in several of these burned areas. Custom climates were developed using the climate of Santa Monica, California but modified for the local monthly precipitation and temperature values in the region obtained from the Australian Bureau of Meteorology. Two modeling approaches to the erosion problem will be discussed.

The first approach, used on the Churchill-Jeeralang Complex Fire, was to evaluate the 50% and 80% exceedance probabilities for the areas in each soil burn severity class (Table 1). The concern for this fire was potential flooding down stream of the burned area, and so the higher exceedance probabilities were used as an indicator of a likely scenario. From this analysis it appears that the predicted median sediment yield from a high soil burn severity, 60% gradient hillslope was 26 Mg ha^{-1}, but the 80% exceedance sediment yields was 12 Mg ha^{-1}. The predicted sediment yields decrease with decreasing hillslope gradient, as well as with lower levels of soil burn severity (Table 1).

Table 1. ERMiT calculated sediment delivery rates for the 2009 Churchill-Jeeralang Complex Fire, Victoria, Australia for the 50% and 80% exceedance probabilities.

Soil burn severity class	Slope range (%)	Area affected (ha)	Sediment delivery (Mg/ha)	
			50% probability	80% probability
High	0 to 20	1,125	n/a	0
	21 to 40	1,485	11	5
	41 to 60	670	15	6
	60 +	80	26	13
Moderate	0 to 20	3,725	3.5	1
	21 to 40	3,850	7	3
	41 to 60	2,310	9.5	2.5
	60 +	520	18	5
Low/unburned	0 to 20	3,910	0.5	0
	21 to 40	2,560	n/a	0
	41 to 60	1,030	6	0
	60 +	360	n/a	0

The other approach, used on the Bunyip Fire, was to model the 50% and 20% exceedance probabilities. In this fire, the main concern was sediment delivery to a water supply reservoir. From this analysis the 50% probability of occurrence for the Ryson Creek 1 catchment was about 21 Mg ha^{-1} (Figure 3), while the 20% probability of occurrence sediment yield for this same catchment was 39 Mg ha^{-1} (Figure 4). This approach was useful in understanding the higher risk events, given the burned conditions. In this analysis the managers also evaluated the effects of applying 1 Mg ha^{-1} of mulch to the burned hillslopes. In each of the probability levels, the reduction in potential sediment yield was significant with the mulch application. At the 50% exceedance level, the sediment yield was reduced by about two-thirds in the Ryson Creek 1 catchment, while at the lower exceedance prediction the reduction in sediment yield by the mulching was about 40%.

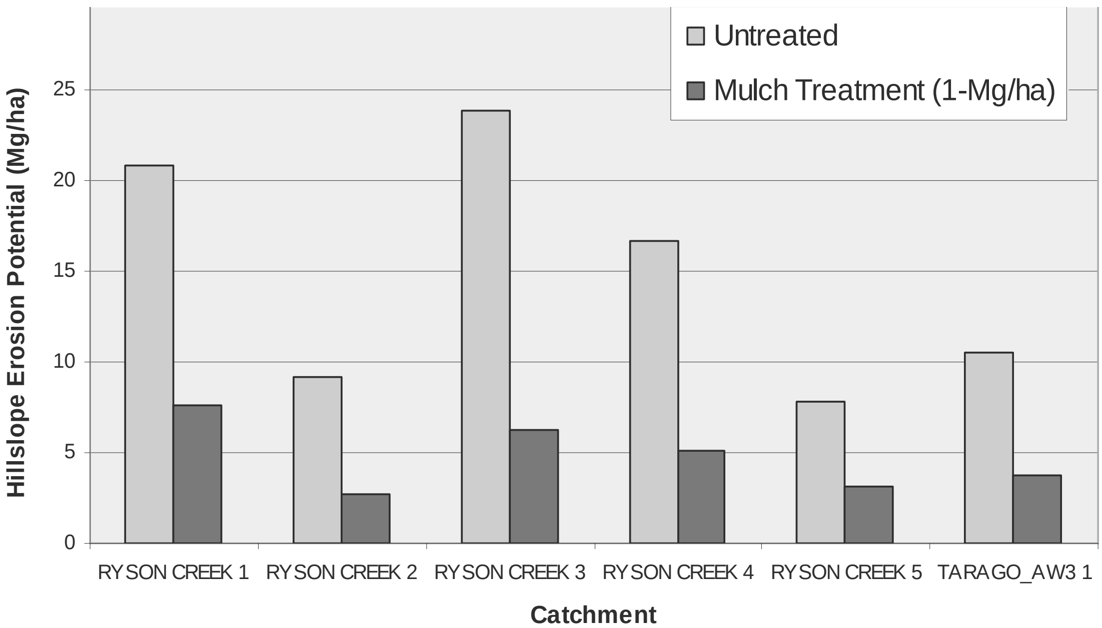

Figure 3. Predicted erosion rates for the 50% exceedance probability as modeled by the BAER assessment team for several catchments affected by the 2009 Bunyip Fire, Victoria, Australia.

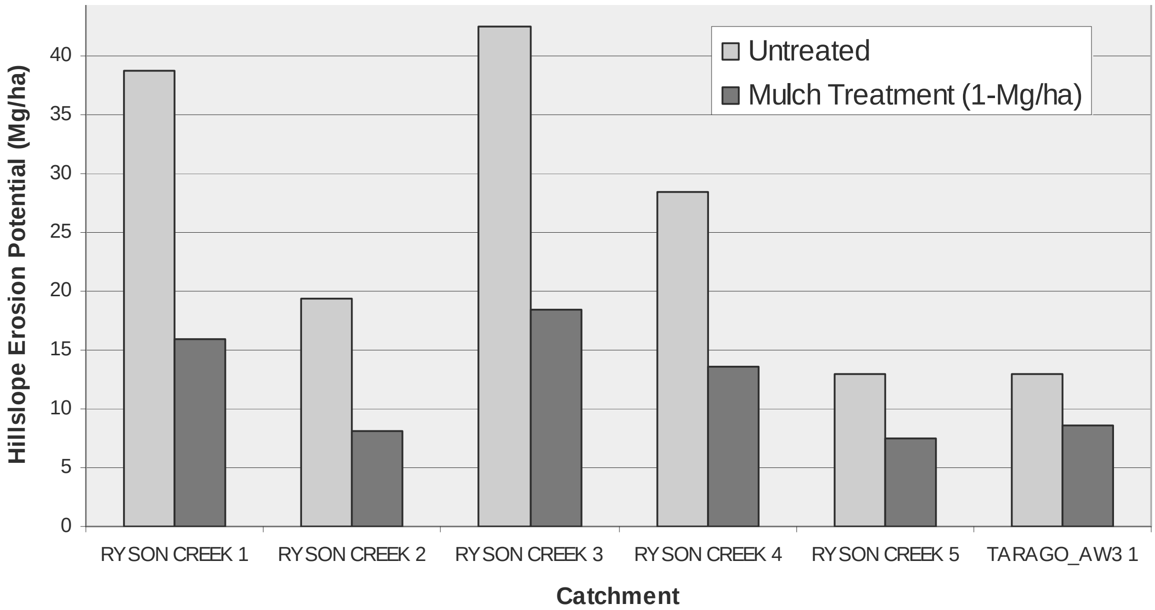

Figure 4. Predicted erosion rates for the 20% exceedance probability as modeled by the BAER assessment team for several catchments affected by the 2009 Bunyip Fire, Victoria, Australia.

7. CONCLUSIONS

ERMiT is a WEPP-based dynamic process-based model that can be readily updated as additional data, user feedback, and validation results become available. Unlike most erosion prediction models, ERMiT provides a distribution of runoff-event based erosion rates with the likelihood of their occurrence. After the 2009 Bushfires, BAER assessment teams and land managers used ERMiT to estimate the probabilities of erosion-producing runoff events occurring, the expected event sediment deliveries, and predicted rates of recovery for the burned area. In addition, comparative measures of treatment effectiveness with predicted sediment yields were analyzed. The ERMiT model provided land managers the information needed to better understand the risks of sediment delivery and compare treatment options. By tailoring the modeled exceedance probabilities the model can provide specific information for assessing the risk of potential erosion.

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