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ABSTRACT

The decision of whether or not to apply post-fire hillslope erosion mitigation treatments, and if so, where these treatments are most needed, is a multi-step process. Land managers must assess the risk of damaging runoff and sediment delivery events occurring on the unrecovered burned hillslope. We developed the Erosion Risk Management Tool (ERMiT) to address this need. ERMiT is a web-based application that uses the Water Erosion Prediction Project (WEPP) technology to estimate sediment delivery, in probabilistic terms, on burned and recovering forest, range, and chaparral lands with and without the application of mitigation treatments. User inputs are processed by ERMiT to combine rain event variability with spatial and temporal variability of soil burn severity and soil properties, which are then used as WEPP input parameter values. Based on 20 to 40 individual WEPP runs, ERMiT produces a distribution of single sediment delivery rates with a probability of occurrence for each of five postfire years. In addition, sediment delivery rate distributions are generated for postfire hillslopes that have been treated with seeding, straw mulch, and erosion barriers such as contour-felled logs or straw wattles. Using postfire sediment data from 21 small instrumented watersheds (< 14 ha), we compared each storm's measured sediment delivery to the ERMiT-predicted delivery. Observed delivery rates were within the predicted range of values 77 percent of the time, with 14 percent of the observed values being greater than the estimated range, and 9 percent being less than the predicted range. Most of the under predictions were associated with studies in the Colorado Front Range. The ERMiT tool tended to over predict sediment delivery in the Northern Rockies and in California. Only 3 percent of the observed delivery events were associated with snow melt processes, whereas 36 percent of the predicted values were influenced by snow melt. Based on these results, we are considering improvements such as incorporating erodibility values for more forest soil types, adjusting the weather characteristics in the climate generator, and reducing the occurrence of snow melt erosion response. Postfire assessment teams are actively using the ERMiT model for making hillslope mitigation treatment decisions based on the probability of damaging sediment delivery occurring after a wildfire.

KEYWORDS. ERMiT, Wildfire, Erosion, WEPP, Postfire, Validation.

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INTRODUCTION

Soil erosion is a major concern for forest watershed managers. Erosion events are associated with forest disturbances including forest management, roads, and wildfires. To address post wildfire erosion prediction, Robichaud et al. (2007) developed the Erosion Risk Management Tool (ERMiT). The ERMiT tool predicts the probability of a given amount of sediment delivery by event from a forest hillslope every year for the first five years following wildfire. ERMiT considers the variability in weather, fire severity, and spatial variability when making a sediment delivery prediction.

Following wildfire, forest watershed managers evaluate the values at risk associated with the wildfire, and may consider mitigation measures to reduce sediment delivery and other potential undesirable effects of the fire. The most common erosion reduction mitigation measures are seeding, log erosion barriers sometimes known as contour-felled logs (“logs” in this paper) and mulching with straw or other organic material (Robichaud et al., 2000). Predictive tools were needed to estimate the effectiveness of these mitigation treatments and justify the considerable costs involved. To address this need, the effects of these three mitigation measures were incorporated into the ERMiT tool. The ERMiT tool assigns a probability to each event based on three factorial probabilities: return period of predicted runoff, soil burn severity class (high or low), and soil spatial variability characteristics (Robichaud et al., 2007). The return period of the predicted runoff is calculated from the ranking of the runoff from an initial 100-year hydrologic simulation that assumes the entire hillslope has just experienced the highest severity fire. From this run, the days with the 20-, 10-, 5-, and 1.5-year runoff events are selected. The stochastic weather file is then truncated to include only those years selected, and the years immediately before those years for all subsequent runs. 61 plot years of data associated with post fire soil erosion have been collected, and were available to validate the 2007 release of the ERMiT tool (Robichaud et al., 2008a and b).

The objectives of this paper are to: compare observed sediment delivery from small watersheds to estimates generated by the ERMiT tool, determine if the soil erodibility properties in the 2007 ERMiT release need to be altered; and identify strengths, weaknesses, and possible improvements to the ERMiT tool.

METHODS

Field Data Collection

Field data were collected from nine paired watershed studies (two sites with three watersheds each following the Hayman Fire) in the western U.S. (Robichaud et al., 2008b) for periods ranging from three to eight years after burning. There were ten control watersheds, five watersheds treated with logs, two treated with straw mulch, two treated with hydromulch, and one treated with hydromulch applied in contoured strips.

The study design used paired watersheds with one control and one or two treatments at each site. Field data collection is described in depth in Robichaud et al., 2008 a and b. It was assumed that the matched paired watersheds behaved similarly before treatment. At each site, the two watersheds were equipped with a sediment trap and control section at the outlet of each watershed. The watersheds were located in close proximity to each other to minimize differences in weather, soils, prefire vegetation, land use, topography (elevation, aspect, and slope), and burn severity. All sites were located in areas of high burn severity as determined by post-fire assessment teams, but one site, (the Roberts Fire) was found to be low to moderate severity following plot installation. All plots were protected from other disturbances, such as salvage logging or grazing, for the duration of the study (4 to 8 years). Trained crews used standard techniques to install the logs on each of those treated watersheds within weeks of wildfire containment. Straw mulch and hydromulch treatments were applied by helicopters. A weather station was installed at each site to measure climate and soil conditions. Tipping bucket rain gauges measured rainfall near the outlet and in the uplands of each watershed. Return periods were estimated using a rainfall-frequency atlas (Bonnin et al., 2004).

Because the ERMiT tool is a single storm probability model, only the largest runoff event from each watershed for each year was selected for the validation data set. In many cases, there were no runoff events in a given year, so the value for validation for that year was zero.

<u>Inputs to ERMiT</u>

The ERMiT tool version 2009.02.23 (Robichaud et al., 2006) was used to predict event-based sediment yields for each location. This version of ERMiT used WEPP Version 2000.100 for predicting runoff and sediment yield. Model inputs were selected to closely match the site characteristics (Tables 1 and 2). From the ERMiT database of 2600 U.S. weather stations (Scheele et al., 2001) we chose the station nearest to each site. We then adjusted the monthly precipitation values for the station using the 4-km database from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 1994). This was done with the online software that complements ERMiT (Scheele et al., 2001). The number of wet days was increased by half the amount of the monthly precipitation to account for the wetter climates (Bayley et al., 2010) and the maximum and minimum temperatures were adjusted to account for differences in elevation between the nearest weather station and the site (Scheele et al., 2001). The soil textural class and surface soil rock content were obtained from site observations and the Natural Resource Conservation Service soil series descriptions (NRCS, 2009). Topographic information was obtained from site observations, contour maps, and for some sites from a 10-m DEM (Table 2).

Table 1. Characteristics of field sites providing observed data.

Fire Name	Location	Latitude, Longitude (Degrees)	Elev. (m)	Year burned	Years observed	Post-fire treatment(s)	Ref.Year(s) Robichaud et al.
North 25	Central Washington	47.99, -120.34	1565	1998	1999-2002	Logs	2008b
Mixing	Southern California	33.68, -116.73	1615	1999	2000-2004	Logs	2008b
Valley	Western Montana	45.91, -114.02	1725	2000	2001-2006	Logs	2008b
Fridley	Southern Montana	45.51, -110.78	1940	2001	2002-2005	Logs	2008b
Hayman	Central Colorado	39.18, -105.36 39.22, -105.34	2440 2430	2002	2002-2010	Logs, straw mulch and hydromulch	2008b; in press
Cannon	Central California	38.45, -119.47	2325	2002	2002-2006	Logs	2008b
Roberts	Northern Montana	48.53, -114.19	1565	2003	2004-2008	Straw Mulch	in press
Cedar	Southern California	32.88, -116.76	755	2003	2004-2009	Hydromulch Hydromulch Strips	in press

Verification of erosion models in the past focused on average values from all storms, or average annual values. Data may have come from natural rainfall, or from rainfall simulation. ERMiT was not designed to predict annual values nor average values, but rather the probability associated with the delivery of a given amount of sediment. In many cases, the observed amount of sediment delivered has been zero (Robichaud et al., 2008b; Elliot and Glaza, 2009).

In order to verify the ERMiT predictions, we made the following comparisons:

- Compare the observed 10-min and 30-min storm intensities vs. NOAA (Bonnin et al., 2004) values for the site, and the storm intensities from ERMiT associated with the runoff events selected during the initial 100-y ERMiT run.
- For each year, for the probability of the largest observed event (1÷ Return Period), compare the observed delivered sediment to the predicted delivery from the main ERMiT output table for that probability.
- For the return period of the observed storm, determine the ERMiT storm nearest that intensity. On the detailed ERMiT output table, record the maximum, median, and minimum erosion values for that storm in the appropriate year since recovery to compare to the observed sediment delivery.

When the largest observed event for the year was due to snow melt only, we assumed a 2-year ERMiT event (50% exceedance probability) for comparison.

Table 2. Input data for the ERMiT model runs

Fire Name	Nearest CLIGEN Station	Prism Annual Precipitation (mm)	Soil Texture	Rock Content (Percent)	Slope Length (m)	Slope Steepness Top, Mid, Toe (Percent)
North 25	Wenatchee, WA	742	Sandy Loam	20	222	50, 39, 30
Mixing	Beaumont, CA	589	Sandy Loam	20	87	24, 24, 19
Valley	Stevensville, MT	522	Loam	30	127	46, 39, 30
Fridley	Livingston, MT	798	Silt Loam	20	263	40, 37, 30
Hayman Logs	Cheesman, CO	478	Sandy Loam	20	139	33, 27, 30
Mulch		476		20	300	8, 18, 17
Cannon	Bridgeport, CA	644	Silt Loam	20	247	44, 44, 38
Roberts	Kalispell, MT	987	Loam	20	300	15, 42, 52
Cedar	El Capitan Dam, CA	467	Sandy Loam	20	240	11, 17, 17

The nature of both the observed data and the predicted values do not lend themselves to traditional statistics parametric analytical methods. The data sets have many values of zero, with the occasional large event. Even though sites are generally experiencing declining erosion in the years following a wildfire, a large runoff event can result in a large amount of sediment delivery in any year. Thus, we decided to use descriptive statistics only for our evaluation. The first statistic was to compare the probability of sediment delivery to the prediction of delivery for the same storm event. We then compared the observed amount of sediment delivered to the range of sediment delivered for the ERMiT storm nearest the observed storm. From this, we could determine the fraction of observed sediment delivery values that were within the range of sediment delivery predicted by ERMiT for that year's storm event.

RESULTS

There were nine sites (Table 1), some with two plots (control and treated), and some with three plots (control and two treatments). The largest runoff event for each year resulted in a total of 39 events for comparison, two of which had some snowmelt contribution. We had a total of 122 plot years of data where we compared the largest sediment delivery event from each year to a predicted value and range from the ERMiT tool.

Figure 1 shows a comparison of the 10-minute intensities generated by ERMiT to intensities observed on the sites for storms greater than a 2-yr return period. We also found that the observed 10-minute and 30 minute intensities were similar to the NOAA atlas values (Bonnin et al., 2004). One of the assumptions was that the best indicator of sediment yield was the ten-minute peak rainfall intensity. Our results indicate a reasonable relationship between these two variables (Figure 2).

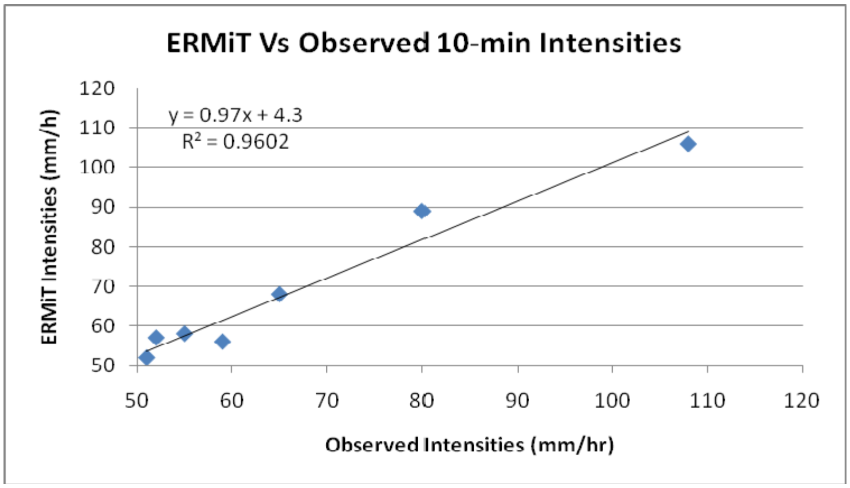

Figure 1. Predicted versus observed storm intensities for those sites where ERMiT predicted a storm associated with a given runoff event. Only storms associated with a return period of 2 years or greater are compared.

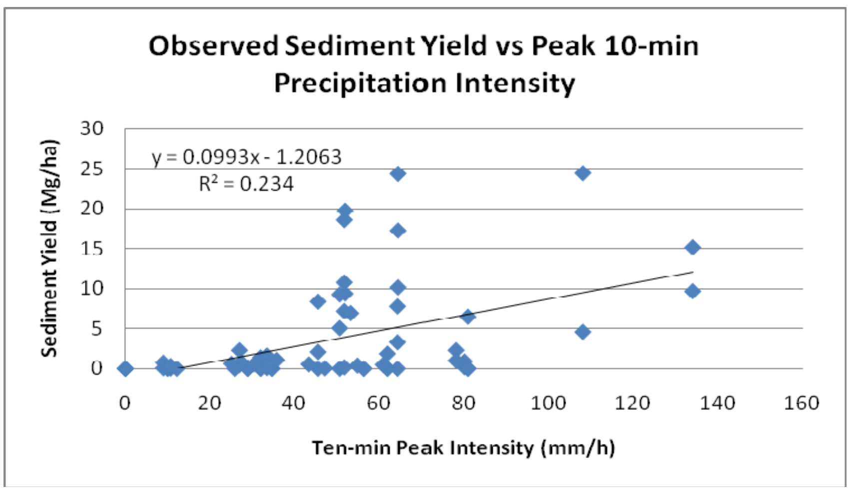

Figure 2. Observed sediment yield versus ten-minute peak rainfall intensity.

Table 3 shows the overall observed and predicted storm characteristics and sediment delivery values. Table 4 compares predicted sediment delivery to observed values averaged over the duration of observations at each site.

DISCUSSION

The range of intensities generated by the ERMiT tool appears to be similar to the range of observed values (Figure 1). One of the challenges in this validation is that large events are rare, so the ability to evaluate this component of ERMiT is limited.

The large number of sediment delivery values less than 0.01 Mg/ha in both the observed (65 events) and predicted values (76 events) cause a significant skew in analysis (Table 3). The results are not normally distributed, but rather are influenced by a small number of very large events, both in the observed the predicted data. Table 3 shows that the variability in sediment delivery following wildfire is large, which is one of the post fire characteristics that the ERMiT tool was specifically developed to address.

Table 3. Observed storm amounts and intensities, observed and predicted means and ranges of sediment delivery, and summary of relationships between observed and predicted sediment yields.

Value	Observed	Predicted
Mean Daily precipitation amount (mm)	26.4	
Peak 10-min storm intensity (mm h^{-1})	35.98	
Peak 30-min storm intensity (mm h^{-1})	24.42	
Daily runoff (mm)	1.51	
Mean sediment delivery (Mg ha^{-1})	2.02	2.88
Median of predicted sediment delivery (Mg ha^{-1})		4.47
Range of sediment delivery (Mg ha^{-1})	0 – 24.5	0 – 47.8
Number of years with sediment delivery < 0.01 Mg ha^{-1}	65	76
Number of times out of 122 observations that observed delivery was greater than the range of values predicted by ERMiT	17	
Number of times observed delivery was less than the range of values predicted by ERMiT	11	

Table 4. Observed and predicted sediment deliveries by site, and the number of predicted events (out of 5) that were associated with snow melt.

Fire Name	Number of observed events in how many years (events in years)	Mean observed 10-min peak intensity (mm h^{-1})	Mean observed runoff (mm)	Mean observed sediment delivery (Mg ha^{-1})	Mean predicted sediment delivery (Mg ha^{-1})	Number of predicted snow melt events
North 25	2 in 4	12.0	0.40	0.045	1.573	4
Mixing	6 in 6	31.8	0.72	0.205	3.094	0
Valley	3 in 6 and 1 snow melt	18.8	1.10	0.180	1.072	4
Fridley	4 in 7 including 1 rain + snow	16.0	1.12	0.051	1.996	2
Hayman *						
Logs	6 in 8	44.3	1.58	4.141	1.967	0
Mulch	8 in 8	53.8	1.16	5.557	0.405	0
Cannon	3 in 5	57.7	0.28	2.516	8.655	4
Roberts	0 in 4	38.0	0.0	0.000	9.578	2
Cedar	6 in 6	35.8	3.92	0.860	3.123	0
Overall Mean	4.3 in 6	35.98	1.51	2.02	2.88	1.8

* The observed weather and the events selected for the log sites were not the same as the mulched sites.

Following the Roberts Fire, a 20-yr event (observed maximum 10-min. intensity was 56 mm h^{-1}) produced no observed runoff or erosion from either the control or the treated plot, whereas the ERMiT tool predicted more than 47 Mg ha^{-1} from the control plot and 15 Mg ha^{-1} from the treated plot. This was the only site that had experienced a low/moderate rather than a high severity fire. It may be that ERMiT is over predicting for low/moderate severity fires, but further field studies following low/moderate severity fires would be needed before making such a conclusion. It is also possible that the soil water content is unusually low in the year following a wildfire, and that unusually dry soil reduced the runoff to zero. The ERMiT tool was developed to evaluate individual storms after considering the weather in the preceding year or years, and thus will not likely have such dry soil conditions. Four years following the Cannon Fire, a 100-year storm occurred, the most intense storm in the data set. We observed a maximum ten-minute intensity of 134 mm h^{-1}. The ERMiT tool was not intended to address such extreme events, so we used the minimum recommended exceedance value, 5 percent, for the estimate. This resulted in ERMiT predictions in excess of 35 Mg ha^{-1} compared to observed values of 10 and 15 Mg ha^{-1} for the control and treated sites, respectively.

The ERMiT tool has been programmed to have a slower recovery in monsoonal climates, but the recovery in some climates may take longer than initially assumed. The Hayman site was the only monsoonal site in the database, so it is difficult to determine whether other sites with a monsoonal climate would also experience such a prolonged recovery period.

In general, the ERMiT tool predicted sediment delivery rates greater than the observed rates (Tables 3, and 4). The Hayman site was an exception to this, and the five largest observed sediment delivery values on Figure 2 are all from the Hayman plots. We hypothesize that the reason for the under predictions on the Hayman site are related to the nature of the storms on the Hayman site, which is typical of the Colorado Front Range. This area is reputed to experience high intensity storms, and the observed data show unexpectedly high erosion rates from relatively moderate storms. It is also possible that the Pikes Peak Batholith granitic soils that are prevalent in this area are more erodible than the ERMiT soil, or that the recovery rate is slower than is assumed in ERMiT.

Considering the overall results presented in Tables 3 and 4, if the range of values predicted by ERMiT are used rather than a single values, we observed that 77 percent of the time, the observed prediction was within the predicted range (Table 3). The observed values were greater than the ERMiT predictions 14 percent of the time, most of these at the Hayman site (Table 4), and were less than the ERMiT predictions 9 percent of the time. Table 3 shows that the median of the ERMiT predictions was greater than the mean, typical of a skewed distribution dominated by a few very large events.

The ERMiT tool selects events based on runoff, and not precipitation. Because of this, a significant number of runoff events in the ERMiT output were associated with snowmelt, whereas only 2 of the observed runoff events resulted from snow melt, in year 2 on the Valley site in Montana. All the other events that generated sediment were associated with high intensity rainfall events.

The observed sediment delivery values were measured at the outlet weir, whereas the ERMiT tool predicts sediment delivery from an eroding hillslope. In the small research watersheds much of the sediment would be routed through at least a short length of channel between the hillslope and the sediment basin. The channel effects may have contributed to increased sediment from the large runoff events on the Hayman site (Table 4) compared to all the other sites except the Cedar site. The channel may have been an area of deposition on the other sites, contributing to the over prediction on those sites.

SUMMARY AND CONCLUSIONS

Sediment delivery rates following wild fire predicted by the Erosion Risk Management Tool (ERMiT) were compared to observed erosion rates. The ERMiT tool predicted rates that were similar to observed rates, including the likelihood of no delivery. On seven sites, the predictions tended to be greater than observed rates, whereas on the two sites in Colorado, the predicted rates were less than the observed rates. The reason for under prediction may have been due to either weather or soil properties that were not adequately described or channel processes not modeled in ERMiT. The ERMiT tool predicted more erosion from winter events (16 events predicted compared to 2 observed), but the intensities of individual storms were similar to observed storm intensities. The assumption that the ten-minute peak intensity was a good indicator of sediment delivery was supported by the observed data.

Suggested areas for further research to improve post fire soil erosion modeling are: 1) increasing the number of soils in the ERMiT database, in particular, adding a soil to better describe the Pike's Peak

Batholith, 2) improving the modeling of highly erosive climates, like the Colorado front range and 3) investigating the ability to better consider exceptionally dry soils when modeling runoff and erosion in the years immediately following wildfire.

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