

Tools to aid post-wildfire assessment and erosion-mitigation treatment decisions

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Abstract. A considerable investment in post-fire research over the past decade has improved our understanding of wildfire effects on soil, hydrology, erosion and erosion-mitigation treatment effectiveness. Using this new knowledge, we have developed several tools to assist land managers with post-wildfire assessment and treatment decisions, such as prediction models, research syntheses, equipment and methods for field measurements, reference catalogues and databases of past-practice, and spreadsheets for calculating resource valuation and cost–benefit analysis. These tools provide relevant science to post-fire assessment teams and land managers in formats that often can be directly entered into assessment and treatment decision-making protocols. Providing public access to these tools through the internet not only has increased their dissemination, but also has allowed them to be updated and improved as new knowledge and technology become available. The use of these science-based tools has facilitated a broader application of current knowledge to post-fire management in the United States and in other fire-prone areas around the world.

Additional keywords: burn severity, erosion modeling, remote sensing, resource valuation.

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Introduction

Wildfires continue to be a major land-management concern throughout the world. The number and severity of wildfires has increased during the past several decades and the rise is likely to continue, especially in the western United States, Australia, and Mediterranean regions where drought and other effects of climate change are exacerbating wildfire conditions (Margaris *et al.* 1996; Flannigan *et al.* 2000; Williams *et al.* 2001; Westerling *et al.* 2006; Miller *et al.* 2009). At the same time, the number of people living in the wildland–urban interface continues to grow, putting human life and safety, infrastructure, homes, buildings, and natural areas that support livelihoods (grazing, timber, etc.) at risk from wildfire and secondary fire effects such as increased runoff, flooding, erosion, and debris flows (Moody and Martin 2009a). Mitigating these fire effects has resulted in increased use of post-fire treatments (Robichaud 2005; Robichaud *et al.* 2010).

For the past decade, our engineering research team (under Dr Robichaud) at the Rocky Mountain Research Station has focussed on understanding the effects of wildfire on hydrology and erosion, modelling and predicting those effects, and evaluating the capacity of post-fire treatments to reduce damage to values-at-risk (VAR) from increased flooding and erosion. Our research efforts, generally funded by US federal dollars, reflect the questions and needs of land managers working in public land agencies on post-fire stabilisation and rehabilitation. A general requirement for receiving public research funds is to identify

and accommodate a valid public interest. In addition, government-funded research usually requires grantees to produce appropriate technology-transfer products and activities to facilitate moving new science findings into practice. The Joint Fire Science Program, a consistent and generous supporter of our research, has solicited and funded projects for the development and dissemination of tools that can directly affect the ability of land managers to put science into practice. Supporting these endeavours reflects the Joint Fire Science Program mission to ‘focus on science delivery when research is completed...to ensure that managers are aware of, understand, and can use the information to make sound decisions and implement projects’ (www.firescience.gov, accessed 27 June 2012). Thus, it is not surprising that as scientists in a federal land-management agency whose research is supported in large part by competitive public funding, our research team has developed and disseminated many tools to improve the quality, timeliness, and effectiveness of post-fire assessment and erosion-mitigation treatment selection. This paper provides an overview of those tools, their use, and potential improvements that are under consideration.

The term ‘tool’ is applied broadly as any information, device, or method that puts research findings into a functional format for use by land managers in making decisions or implementing projects. Tools include predictive models, spreadsheets, maps, images, photo guides, field methods and equipment, decision trees, glossaries, databases and catalogues of past practice, and

syntheses. Some tools require a user guide on how to interpret and apply the output to management tasks or significant training for users to become proficient. However, research can affect management practices more successfully when accurate, user-friendly tools are available – especially when tools target complex and time-consuming management tasks. For example, in 1995 a user interface was released for the Water Erosion Prediction Project (WEPP) soil-erosion model, a complex model adapted for agriculture, rangeland, and forest land (Flanagan and Livingston 1995). In the following 3 years, ~200 forest specialists were trained to use the WEPP model; yet only three or four of those trained specialists subsequently applied the model because of difficulties in assembling the input data, operating the interface, and interpreting the output (Elliot 2004). To facilitate a greater number of forest users to access the erosion- and sedimentation-prediction capabilities of the WEPP, a suite of simplified user interfaces was developed for a range of climatic and forest disturbances, including roads, fires, and timber harvest. These interfaces, accessed and run on the internet, limit needed user inputs to a few essential variables with other input variables automatically retrieved from internal databases. Outputs are generally designed to match the specific information and formats needed by forest managers for their work. The Forest Service WEPP (FSWEPP) internet interfaces were introduced in 2000, and within 1 year more than 600 users had used the WEPP model through the interfaces (Elliot 2004). Additional interfaces have been added to the FSWEPP suite and annual use has continued to expand with 29 100 mean annual model runs since 2006.

The impetus for developing or modifying a tool for use in the post-fire environment often starts with the managers and specialists who work in the field. They may request assistance applying research findings in their work, such as when a post-fire assessment team member asks for advice selecting and using an erosion-prediction model or discusses treatment options for a current post-fire situation. Such inquiries clarify management needs and may result in how-to manuals, field guides, etc. Other tools are developed as deliverables within funded research projects where technology transfer is required by the funding agency. Often these technology-transfer products are workshops and training activities designed to transfer new knowledge from researchers to the land-management community; however, new tools, such as online databases and user manuals, may also be developed. Research funding has supported projects for specific tool development; our research team has used such funding to develop new FSWEPP interfaces and syntheses of current knowledge. Many tools are at least partially developed before anyone asks for them because of a perceived potential for the tool. This rationale motivated our development of a protocol for using a mini-disk infiltrometer (MDI) to assess post-fire soil water repellency and the use of high-resolution remotely sensed imagery to map burn severity and monitor invasive weeds.

No matter what the impetus, tool development rarely follows a linear path from inception to completion. It generally includes creation (designing, writing, programming, etc.), validation, refinement, user training, field evaluations, and further cycles of refinement and testing as new information and user responses become available. Many of these steps or activities occur simultaneously, moving the entire process towards completion.

Occasionally, tool development will spur new research by exposing knowledge gaps and field contingencies that have not been adequately studied.

This discussion of tools designed to assist land managers with work in the post-wildfire environment is divided into two sections – post-fire assessment tools and post-fire treatment decision-making tools. As new knowledge and technologies become available, the function of existing tools may be improved by expanding the scope of applicability, simplifying the interface or output, improving accuracy, etc. Current efforts to improve these tools are also discussed.

Post-fire assessment tools

Post-fire effects on the environment (also referred to as secondary fire effects) are incorporated into the concept of burn severity and are generally assessed and classified as low, moderate, or high burn severity (Jain *et al.* 2004; Lentile *et al.* 2006). In post-fire assessments, it has proven useful to divide burn severity into ‘vegetation burn severity’ and ‘soil burn severity’. Vegetation burn severity classifies the effects of a fire on vegetative ecosystem properties and depends on the fire intensity (amount of energy or heat released per unit time or area during the consumption of organic matter, Keeley 2009) and the fire-resistant properties of the ecosystem (Morgan *et al.* 2001; Lentile *et al.* 2006). In contrast, soil burn severity classifies the effects of fire on the ground surface and near-surface soil and is based on fire-induced changes in physical, chemical, and biological soil properties. Recently, there has been an intentional effort to use the term ‘soil burn severity’ to differentiate post-fire soil properties from fire effects on vegetation (such as tree mortality) or general fire effects on long-term ecosystem health (Parsons *et al.* 2010).

Fire-effects research continues to refine our understanding of the factors that affect post-fire watershed response to hydrological events. Some factors, such as rainfall characteristics, topography, soil type, and pre-fire land use, are inherent to the area and not directly tied to the fire. In particular, rainfall intensity has been positively associated with large post-fire runoff and erosion responses (Spigel and Robichaud 2007; Moody and Martin 2009a). The other characteristics that directly affect watershed response, such as remaining ground cover, soil erodibility, infiltration rate, and time since the fire, are attributed directly to the fire that occurred (DeBano *et al.* 1998, 2005; Neary *et al.* 2005a; Cerdà and Robichaud 2009; Moody and Martin 2009b). With the exception of time since fire, the fire-related factors are incorporated into the classification of soil burn severity, and as soil burn severity increases, the potential watershed response increases. However, the potential watershed response is moderated by the time since fire (recovery time) and tends to decrease as time since fire increases (Neary *et al.* 2005a).

A map of soil burn severity enables post-fire assessment teams to identify potential areas of concern and prioritise initial field reconnaissance (Parsons *et al.* 2010). In the past, these maps were drawn by hand from aerial and ground-based observations, but post-fire assessment teams found this increasingly challenging as fires became larger and burned areas more inaccessible. Currently, a combination of geospatial tools and

field measurements are used to produce a map that depicts the general distribution of soil burn severity as accurately and quickly as possible (Clark and Bobbe 2006; Parsons *et al.* 2010). With a field-validated soil burn severity map, post-fire assessment teams can more readily evaluate potential wildfire effects including increased runoff, flooding, erosion and sedimentation, vulnerability to invasive weeds, and potential recovery time (Neary *et al.* 2005a; Calkin *et al.* 2007; Robichaud *et al.* 2008).

Mapping burn severity

Remote sensing

Post-fire soil burn severity mapping does not require the use of remote sensing or geographic information systems (GIS); however, both technologies are commonly used on large wildfires to improve the speed, precision, and accuracy of post-fire mapping efforts. Since 2002, the US Department of Agriculture, Forest Service, Remote Sensing Applications Center and the US Geological Survey, Center for Earth Resources Observation and Science have used pre- and post-fire Landsat (US remote-sensing satellite program) satellite images of the burned area to derive a preliminary classification of landscape change. The differences between the pre- and post-fire image data form a continuous raster GIS layer that is classified into four burn severity classes – unburned, low, moderate, and high. This product is referred to as the Burned Area Reflectance Classification (BARC) map (Clark and Bobbe 2006) and is usually the starting point for the soil burn severity map on most fires (Orlemann *et al.* 2002).

The BARC is not considered a soil burn severity map until it has been field verified and, if necessary, adjusted to reflect the actual post-fire soil conditions (Parsons *et al.* 2010). In many cases, the BARC threshold values that divide the burn severity classes do not provide a satisfactory fit to the observed post-fire soil and ground conditions. Satellite sensors measure reflectance from the uppermost layer and, as a result, often reveal the vegetative (canopy) conditions more directly than soil or ground conditions. By making systematic adjustments to the break points between the severity classes, the BARC map may be brought into closer alignment with field observations (Parsons *et al.* 2010). Other situations may require adjustments in localised areas. Clouds, snow, smoke from surrounding fires, or large water bodies create inconsistencies in satellite imagery data. Land-use changes and management activities that occur between the pre- and post-fire satellite images can also create localised errors in the BARC soil burn severity classifications (Parsons *et al.* 2010). Whether systematic or localised, field observations of soil burn severity are integrated into the BARC map to generate a soil burn severity map of the fire.

At this time, new and archived Landsat imagery is readily available, but the federal funding for this program is not guaranteed making the future of the Landsat program somewhat uncertain. In addition, Landsat images have a 'moderate' ground resolution of ~30 m, which is coarser than the scale of post-wildfire effects on soil and vegetation (Hudak *et al.* 2007), and because of a satellite-system malfunction, not all land areas are equally well imaged on each satellite pass, resulting in image data gaps. For these reasons, other remote sensing products are

being evaluated for their application to assessing soil burn severity. Although higher-resolution imagery is available, images tend to be more expensive and difficult to obtain and processing times may be weeks or months (Robichaud *et al.* 2007a). For example, QuickBird (DigitalGlobe, Longmont, CO, USA) satellite images have 0.6–2.4 m pixel resolution, which is similar to the scale of variability found in post-fire soil characteristics of interest. Hyperspectral images, which have 1–5 m spatial resolution and high spectral resolution, can be obtained by flying a sensor-equipped aircraft over the site, and these images have been successfully correlated with soil burn severity (van Wagendonk *et al.* 2004; Kokaly *et al.* 2007; Lewis *et al.* 2007; Robichaud *et al.* 2007a). When compared with BARC maps, the maps generated from these higher-resolution sensors are more precise and may better reflect the variability in post-fire ground conditions, but the high cost, both in time and money, effectively precludes their immediate use in post-fire management (Kokaly *et al.* 2007; Robichaud *et al.* 2007a).

Field guide for mapping post-fire soil burn severity

A recently developed field guide provides a decision-making protocol to assist with soil burn severity mapping (Parsons *et al.* 2010). This field guide is designed for use by post-fire assessment teams to improve consistency of soil burn severity mapping by identifying key indicators of soil conditions that define the soil burn severity classes. Included in the field guide are guidelines for identifying soil burn severity classes, a photo series illustrating representative post-fire soil and ground conditions, and field data sheets to assist in data collection. Observations can be compared with those in the tables and photos to determine the soil burn severity classification at each field location. The *Field guide for mapping post-fire soil burn severity* can be used to field-validate the soil burn severity classes defined through remote sensing (for example, BARC) or as a reference for hand mapping when remotely sensed data are inadequate or not available. The guide also provides a description of mapping concepts and step-by-step instructions for mapping soil burn severity.

The field guide directs the user to make five observations (ground cover; ash colour and depth; soil structure; roots; and soil water repellency) at 10 data-collection locations for each field site (Fig. 1). Some observations require an approximate measurement (ground cover) while others require a comparison to unburned conditions (change in fine roots). Where possible, observations are categorised by selecting from a list the best descriptor that corresponds to soil burn severity classifications. For example, the three categories of ground cover observations are greater than 50%, 20–50%, and less than 20%, which correspond to low, moderate, or high soil burn severity (Fig. 1). The five observed factors do not have to reflect the same level of soil burn severity – 'the presence of two or more factors of high soil burn severity dominating an area may justify a classification of high soil burn severity for that polygon' (Parsons *et al.* 2010).

Mini-disk infiltrometer (MDI)

Soil water repellency is one of the five factors used to assess post-fire soil burn severity, and it is a required component of the

Soil Burn Severity Assessment Field Data Form			Fire Name:				Observers:		
Date:		Site ID:	GPS Coordinates:				BARC Classification:		
Observation Point	Ground cover (1)	Surface Color and Ash Depth (2)	Soil Structure (3)	Roots (4)	Soil Water Repellency (5)		Observed Soil Burn Severity Class (6)	Photo #	Other Comments
<i>EXAMPLE</i>	<i>20 to 50%</i>	<i>white, 1 mm</i>	<i>no change</i>	<i>intact</i>	<i>l</i>	<i>3 mL surf</i>	<i>Mod</i>	<i>23</i>	<i>homogenous</i>
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
Average/Majority for Site (7)									
Site Characteristics:		Aspect (deg):		Slope %:					
Slope Length (ft or m):		Slope Position:		Lower	Middle	Upper	Ridge	Other	
Soil Texture Class: clay loam, silt loam, loam		Dominant Pre-Fire Vegetation Type		Pre-Fire Vegetation Density		Vegetation Comments:		Other Notes:	
Surface Rock %:		Chaparral		Low					
Soil Comments:		Forest		High					
		Sagebrush/grassland		Other					
		Other							

Fig. 1. Post-fire assessment field data sheet from the *Field guide for mapping post-fire soil burn severity* (Parson *et al.* 2010, appendix B).

current Burned Area Emergency Response (BAER) assessment report (USDA Forest Service 2004). The Water Drop Penetration Time test has been the common field test for soil water repellency (DeBano 1981). Because soil water repellency has a large effect on soil infiltration characteristics, the degree and extent of post-fire soil water repellency is often used to estimate the reduced infiltration rate used for modelling post-fire hydrological processes (Pierson *et al.* 2001; Robichaud 2000). Recently, a MDI has been adapted for use as a field test of post-fire soil water repellency and infiltration (Robichaud *et al.* 2008) (Fig. 2). The MDI field test provides a relative infiltration rate that not only reflects existing soil water repellency, but also reflects soil sealing and other factors that may affect post-fire infiltration rates. The *Field guide for mapping post-fire soil burn severity* is designed to accommodate either the Water Drop Penetration Time or the MDI field tests for soil water repellency assessment (Parsons *et al.* 2010). The MDI test protocol and sampling method described in *New Procedure for Sampling Infiltration to Assess Post-fire Soil Water Repellency* (Robichaud *et al.* 2008) was specifically developed to provide a rapid, practical evaluation of burned soil infiltration characteristics for post-fire assessment. It includes instructions for using a MDI, field data sheets, detailed sampling scheme with pre-determined sample size and confidence levels, and a formatted data analysis spreadsheet tool for use in post-fire assessment.

The ease of using the MDI in the field has prompted ongoing efforts to correlate post-fire infiltration rates, as measured by rainfall simulation, to MDI measurements. Efforts to determine these correlations have been hindered by the large temporal and spatial variability of soil water repellency and post-fire infiltration rates as well as the relatively small number of post-fire



Fig. 2. Using the mini-disk infiltrometer in the field (from Robichaud *et al.* 2008).

rainfall simulation studies that include MDI tests for soil water repellency. Since infiltration is an important input for predictive hydrological and erosion models, it would be useful to derive an estimate of the infiltration rate from a field-measurement protocol such as the MDI.

Post-fire treatment decision tools

Soil burn severity is combined with climate (particularly rainfall regimes), topography, soil type, and pre-fire vegetation to predict the potential hydrological and erosion response of burned watersheds. These predictions, in combination with identified VAR, are evaluated to determine if and where post-fire treatments are justified (Robichaud 2005; Foltz *et al.* 2009; Robichaud *et al.* 2010). Several tools have been developed for these tasks. Hydrological and erosion models have been adapted for burned landscapes, and an economic valuation tool has been developed to calculate the economic justification for using post-fire treatments to reduce potential damage and loss to VAR.

Hydrological and erosion modelling

Hydrological and erosion response predictions are generally made using a combination of models and techniques. Post-fire treatment decisions, particularly decisions concerning road and channel treatments, rely on viable estimates of potential post-fire runoff and peak flows and to a lesser degree on erosion estimates, while hillslope treatment decisions are mostly based on potential erosion estimates. Estimates of rainfall and runoff are needed to predict erosion and are part of most erosion prediction models, yet they are not always included in the output. Consequently, post-fire assessment teams frequently use two or more models to obtain the estimates they need.

Estimating peak flows

In the US, post-fire assessment teams select from a variety of available models to estimate pre- and post-fire peak flows based on design storms. Ideally, the user would select the most effective and accurate model for the available information and site conditions. However, in practice the selected models and methods are often the ones most familiar to the user (Foltz *et al.* 2009). An estimation of peak flows and runoff are most often accomplished using a model based on either the US Geological Survey Regression Equations (Thomas *et al.* 1997) or one of several models that incorporate Curve Number (CN) methods (Ponce and Hawkins 1996). In StreamStat (<http://water.usgs.gov/osw/streamstats>, accessed 27 June 2012), the US Geological Survey regression method is adapted to a burned area by including the fraction of the area burned at high and moderate severity as an input and as a part of the 'modifier' calculation for estimating post-fire runoff. CN models used for post-fire assessment include WILDCAT4 (Hawkins and Greenberg 1990), HYDRO (Cerrelli 2005), and WinTR-55 (Natural Resources Conservation Service 2005). These models require a user-selected CN based on cover type, treatment (the model includes a soil burn severity option), hydrological conditions, and hydrological soil group. Although the CN is the single most-important parameter in this method, its selection for post-fire conditions is not straightforward or consistent (Foltz *et al.* 2009). We have developed a new web-based peak flow calculation model based on CN methods that allows the user to directly input a CN value or accept an estimated CN value based on the output from the Erosion Risk Management Tool (ERMiT), an erosion prediction model (Elliot *et al.* 2010) described below. The peak flow calculator is currently available at: <http://forest.moscowfsl.wsu.edu/fswepp/ermit/peakflow> (accessed 27 June 2012).

Several of the peak flow models discussed above are also available within our website at: <http://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/> (accessed 27 June 2012).

Estimating erosion

Estimation of potential post-fire erosion is often accomplished using the FSWEPP interfaces (Elliot 2004; Robichaud *et al.* 2007b) – adaptations of WEPP (Flanagan and Livingston 1995) for forest and rangeland environments. The climate file that drives WEPP is stochastically generated from historical weather station data and modified by the Rock Clime interface for mountainous regions (Elliot 2004). WEPP and the full suite of FSWEPP interfaces can be accessed online at: <http://forest.moscowfsl.wsu.edu/fswepp> (accessed 27 June 2012).

There are several FSWEPP interfaces that calculate potential post-fire erosion rates, such as Disturbed WEPP (Elliot 2004), ERMiT (Robichaud *et al.* 2006, 2007b), and GeoWEPP (Renschler 2008) (Fig. 3). Disturbed WEPP allow users to describe numerous disturbed forest and rangeland erosion conditions including low and high soil burn severity conditions. The interface output provides mean annual runoff depth, erosion rates, sediment yields, and the probability of a given amount of erosion occurring the year following a disturbance. ERMiT was developed specifically for post-fire assessments. Using a simplified interface for inputs (Fig. 4), ERMiT predicts the probability associated with a given hillslope sediment yield (untreated, Fig. 5, and treated with seeding, dry agricultural straw mulching, or erosion barriers) from a single storm in each of 5 years following wildfire (Robichaud *et al.* 2006, 2007b). In addition, ERMiT Batch is available as a downloadable spreadsheet that is designed to make running multiple ERMiT scenarios much more efficient; input data can be entered manually or imported via a GIS toolbox (<http://forest.moscowfsl.wsu.edu/fswepp/batch/bERMiT.html>, accessed 12 July 2012). GeoWEPP develops a drainage network for the region selected, and then defines the channel network and hillslope polygons for a watershed that is selected by defining the watershed outlet for pre- and post-fire conditions (Renschler 2008). GeoWEPP utilises two modes – flowpath and watershed. Flowpath mode predicts runoff and erosion for every pixel within the selected watershed. Watershed mode predicts runoff and peak flow values as well as sediment delivery from each hillslope polygon and stream channel segment identified.

Future refinement of the FSWEPP interfaces will enable the model to accept inputs from GIS sources and produce reliable estimates of post-fire runoff, peak flow, and erosion with user-friendly output formats that are integrated with GIS and other post-fire assessment tools. In addition, post-fire models for wind erosion and dry ravel (gravity-driven) erosion are currently being developed.

Syntheses of post-fire erosion research

Prediction models are very useful in post-fire decision making; however, models generally provide an annual average or, more recently, a range of expected outcomes that may require professional judgment to apply to the specific conditions of an

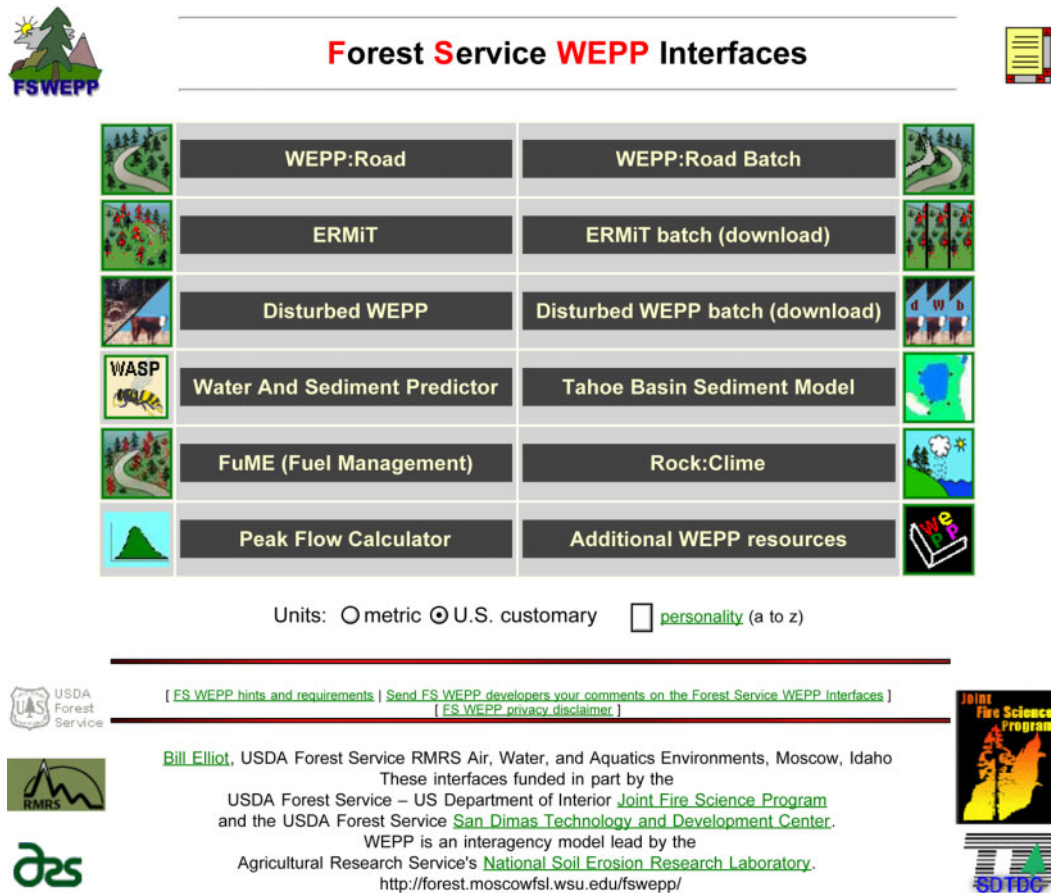


Fig. 3. The opening web page for user selection of available Forest Service Water Erosion Prediction Project interfaces [screen capture] (<http://forest.moscowfs.wsu.edu/fswepp/>, accessed 27 June 2012).

individual fire. By comparing model predictions to reported erosion rates, post-fire assessment teams can validate model predictions. Recent research syntheses that include measured post-fire erosion rates include ‘*Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States*’ (Moody and Martin 2009a), *Fire effects on soils and restoration strategies* (Cerdà and Robichaud 2009), and *Wildland fire in ecosystems: effects of fire on soil and water* (Neary et al. 2005b). Syntheses may also provide insight as to the storm intensities and sediment yields that have had damaging consequences in the past.

Post-fire treatment decisions

Using the post-fire soil burn severity map and predictive models to determine the likelihood of damaging floods and erosion occurring, post-fire assessment teams can then recommend land treatments, road improvements, channel treatments, and warning systems that will mitigate these and other threats. In the US, post-fire assessment teams that request funding for treatments must show that the threats of increased runoff, erosion, flooding, sedimentation, or vulnerability to invasive weeds will likely cause loss or damage to life, property or resources. With the important exception of public safety, they must also show that the cost of recommended treatments is justified based on the

value of the threatened resource, the probability that the treatment will be successful, and the cost of the treatment itself.

Assessing post-fire VAR with a new calculation tool

Recently, a spreadsheet calculation tool (Calkin et al. 2007) was developed to aid in assessing post-fire VAR in connection with treatment decisions. Cost-benefit analysis is fairly straightforward when the cost of repair or replacement of the VAR can be determined; however, it becomes much more complicated for non-market VAR (such as sensitive wildlife species, undeveloped recreation, cultural artefacts). The time and economic expertise needed for valuation of non-market resources are rarely, if ever, available to post-fire assessment teams. In this valuation tool, a non-market VAR is assessed in terms of its implied minimum value (IMV = treatment cost/change in likelihood of loss or damage due to treatment). Once the IMV is determined, the assessment team and the funding agency must determine if the IMV justifies the use of public funds to mitigate potential damage or loss of that resource (Calkin et al. 2007) (Fig. 6).

Post-fire treatment calculations for both market and non-market VAR require an estimate of the probability of damage or loss occurring and the probability of treatment success as inputs (Fig. 6). Although we know that some treatments are more

Erosion Risk Management Tool

FSWEPP

(-) Climate (+)

- Bitterroot Valley MT +
- DEADWOOD DAM ID
- Cheesman 1 +
- KAHRAMANMARAS Turke
- CHARLESTON KAN AP WV
- MOSCOW U OF I ID

Custom Climate

Soil Texture ?

- clay loam
- silt loam
- sandy loam
- loam

Rock content ?

20 %

Vegetation type ?	Hillslope gradient ?	Hillslope horizontal length ?	Soil burn severity class ?
Forest Range Chaparral	Top 10 % Middle 40 % Toe 20 %	250 m	<input checked="" type="radio"/> High <input type="radio"/> Moderate <input type="radio"/> Low
Range/chaparral pre-fire community description ?			
<input type="checkbox"/> % shrub	<input type="checkbox"/> % grass	<input type="checkbox"/> % bare	

Run ERMIT

Citation:
Robichaud, Peter R.; Elliot, William J.; Pierson, Frederick B.; Hall, David E.; Moffet, Corey A. 2006. **Erosion Risk Management Tool (ERMIT) Ver. 2006.01.18.** [Online at <http://forest.moscowfsl.wsu.edu/fswepp/>.] Moscow, ID: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

2051 ERMIT runs in 2006. Personality ""

Fig. 4. The Erosion Risk Management Tool input screen with sample user selections shown [screen capture].

effective than others (Table 1), the process for estimating the probability of treatment success (in other words, the reduction in risk due to treatment) is not an exact science. The tabular output from ERMIT can be used to estimate the probability of hillslope treatment success for seeding, erosion barriers, and dry agricultural straw mulch (Calkin *et al.* 2007), but it currently is limited to those treatments. The likelihood of treatment success is generally a professional judgment based on past experience, treatment effectiveness research, and treatment catalogues (see Napper 2006). The valuation process developed by Calkin *et al.* (2007) is supported by the spreadsheet-based 'VAR Calculation Tool' that can be downloaded from our website (<http://forest.moscowfsl.wsu.edu/BAERTOOLS>, accessed 27 June 2012) (Fig. 6).

Post-fire treatment information

Once it is decided that treatments are needed, choosing the best treatments for a particular site requires access to treatment effectiveness and performance information. Realistic assessments of post-fire treatment effectiveness are essential if post-fire assessment teams are to choose treatments that balance protection of public safety and VAR with justifiable, cost-effective expenditures of public funds. Managers also need to know how and why treatments work so they can determine the best treatment(s) for a specific location and decide how to adapt treatments to improve their effectiveness. For example, the formulation and application rate of mulches can be modified to enhance performance characteristics such as longevity, adherence to soil, and interlocking of mulch strands. The

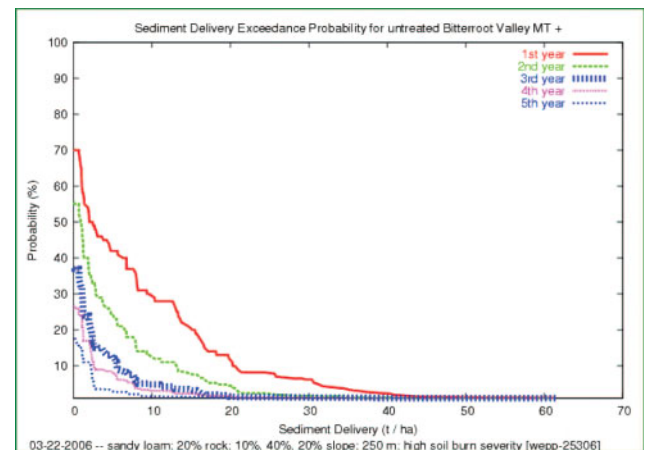


Fig. 5. An Erosion Risk Management Tool output graph showing exceedance probability versus event sediment delivery for 5 years after the fire from a modelled, untreated hillslope [screen capture].

importance of such characteristics is dependent on specific site characteristics such as steepness, exposure to high winds, and general rate of vegetative recovery.

Post-fire treatment syntheses and treatment catalogues provide current information on various treatments in formats that are easily used by post-fire assessment teams. Recently published treatment syntheses include the *Burned area emergency response treatments catalog* (Napper 2006), *A synthesis of postfire road treatments for BAER teams* (Foltz *et al.* 2009), *Post-fire treatment effectiveness for hillslope stabilization* (Robichaud *et al.* 2010), which are available at the BAERTOOLS website (<http://forest.moscowfsl.wsu.edu/BAERTOOLS>, accessed 27 June 2012), and *Post-wildfire seeding in forests of the western United States: An evidence-based review* (Peppin *et al.* 2010).

Research on post-fire treatments continues to evolve. Not only are new treatment materials and methods being developed and refined, but treatment research is expanding to include long-term effects of treatments on soil and post-fire recovery, wind erosion mitigation, and headwater channel treatments.

International issues

The post-wildfire management issues that drive much of our work are not unique to the United States. The post-fire assessment tools developed for the US have been used by managers and researchers in many countries, including Argentina, Australia, Canada, Greece, Italy, Israel, Lebanon, Mexico, Portugal, Spain, and Turkey. Research publications on fire effects, post-fire modelling, and treatment effectiveness have an international readership. However in some countries, the process has gone beyond the sharing of information; concerted efforts have been made to evaluate and adapt portions of the US post-fire assessment and treatment recommendation protocol for use within their land management agencies.

After a devastating bushfire in 2009, Australia requested US assistance with the post-fire assessment and treatment decisions and three US BAER 12-member teams were deployed in response. These BAER teams worked closely with their Australian counterparts over a 2-month period. Subsequently, the State

Fire Name	Santiago Fire		
Location	Orange County, CA	Live Oak Canyon	
Date	11/18/2007		
EACH MAP ZONE REPRESENTS A SYSTEM OF LINKED TREATMENTS AND ASSOCIATED VALUES AT RISK			
MAP ZONE D - VALUES AT RISK (VAR)			
Map link #	Life and Safety	Description	
	Debris Flow and flood threat	Throughout canyon floor adjacent to streams	
PLEASE NOTE: IF PUBLIC SAFETY IS A FACTOR, B/C RATIO SHOULD NOT BE RELEVANT AND SHOULD STRICTLY BE AN ACCOUNTING EXERCISE			
Map link #	Non-Market: Cultural Values	Description	
Map link #	Non-Market: Ecological	Description	
Map link #	Market Values: Direct	Description	Total
	4 Structures	Assumed to be residential	\$ 2,321,092
	1 water tank	estimated - no data available	\$ 100,000
			\$ -
Map link #	Market Values: Loss-of-Use	Description	
			\$ -
			\$ -
			\$ -
Probability of experiencing the loss with no treatment (enter as decimal)			0.500
Source of loss probability with no treatment:			Select Source...
Market Resource Value			\$ 2,421,092
TREATMENT DESCRIPTION			
Map link #	Proposed treatment	Total	
	Hydromulching upper watershed - 41 acres	\$ 143,680	
		\$ -	
		\$ -	
Probability of experiencing loss if treatment occurs (enter as decimal)			0.375
Source of loss probability with treatment:			Select Source...
Total Treatment Cost			\$ 143,680
VAR CALCULATION RESULTS			
REDUCTION IN PROBABILITY OF LOSS			0.125
EXPECTED BENEFIT OF TREATMENT			\$ 302,637
Expected Benefit/Cost ratio of treatment for market resources only (economically justified if > 1.0)			2.1
IMPLIED MINIMUM VALUE OF PROTECTING NON-MARKET RESOURCE VALUES			JUSTIFIED
Comments			

[Non-Market Values Literature](#) [View Literature](#)

Fig. 6. A worksheet (Map Zone D) from the values-at-risk calculation tool sample for the 2007 Santiago Fire [screen capture] (<http://forest.moscowsl.wsu.edu/BAERTOOLS/VAR/>, accessed 27 June 2012).

of Victoria (Department of Sustainability and Environment) established Bushfire Rapid Risk Assessment Teams (Bushfire RRAT) that would use methods, tools, and rehabilitation techniques that had been learned by their work with the US BAER teams (Department of Sustainability, Victoria 2009). The Bushfire RRAT perform a rapid risk assessment and produce a written report of post-fire conditions and recommend risk-mitigation strategies within 7 days. In addition, they assist fire and land managers transition from suppression to recovery. However, unlike the short-term US BAER response, the

Bushfire RRAT's report is designed to contribute to the development of longer-term rehabilitation and recovery plans.

In Greece, the Reforestation and Mountainous Hydrology Division of the Greek Forest Service developed guidelines for post-fire conservation practices (Myronidis and Arabatzis 2009). The guidelines focussed on post-fire stabilisation measures that would decrease the post-fire erosion potential, maintain the soil on the hillslopes, and trap the sediments in smaller tributary channels to avoid delivery downstream. US BAER technical advisors were requested to assist Greek land managers

Table 1. Summary table of post-fire hillslope treatment effectiveness and performance characteristics

Overall effectiveness ratings for post-fire hillslope stabilisation treatment effectiveness for three rainfall regimes (high intensity, low intensity, and high total amount). Treatment effectiveness codes: 1 = more effective; 2 = somewhat effective; 3 = not effective. Treatments rated as more likely (more) or less likely (less) to exhibit performance characteristics that affect treatment effectiveness, post-fire recovery, or the environment. Other phrases are used to describe the performance characteristics of treatments that are dependent on circumstances or are not effectively rated as more or less likely (from Robichaud *et al.* 2010, appendix A)

		Straw mulches	Wood mulches	Hydro-mulches	Soil binders (polyacrylamide)	Contour-felled logs (log erosion barriers)	Straw wattles
Overall effective- ness (rating: 1, 2, or 3)	High-intensity rainfall (>2-year return interval)	1	1	3	3	3	3
	Low-intensity rainfall	1	1	1	2	1	1
	High rainfall amount (>50 mm in 6 h)	1	1	2	3	2	2
Performance characteristics that affect effectiveness	Resistant to wind displacement	Less ^A	More ^A	More	More	More	More
	Remains functional for more than 1 year	More	More	Less	Less	More	More
	Provides ground cover	More	More	More	Less	Less	Less
	Increases infiltration	More	More	Not known	Depends on conditions	Less	Less
	Increases soil moisture retention	More	More	More	Less	Less	Less
	Shortens flow paths	More	More	Less	Less	More	More
	Traps sediment	More	More	Less	Less	More	More
Slows development of concentrated flow	More	More	More	More	Less	Less	
Other considerations	Contains noxious weed seeds	Possible	Less	Less	Less	Less	Possible
	Delays revegetation	Depends on mulch thickness	Depends on mulch thickness	Less	Less	Less	Less
	Harmful to the environment	Less	Less	Depends on components	Depends on type and concentration	Less	Less

^AIn wind tunnel tests, agricultural straw resisted movement in wind speeds of 15 miles h⁻¹ (6.5 m s⁻¹), and wood straw resisted movement in wind speeds of 40 miles h⁻¹ (18 m s⁻¹) (Copeland *et al.* 2009).

after the wildfires in 2009, this technical assistant visit resulted in improvements to their assessment process, which is modelled on the US BAER program.

The British Columbia, Canada, Southern Interior Forest Region used components of the US BAER program to develop a systematic approach for post-wildfire risk assessment of severe surface erosion, landslide, gully processes, and flood events (Jordan *et al.* 2006). During the program development, numerous interactions occurred among the lead author and several Canadian specialists, including on-site visits. These interactions led to a joint US–Canadian research project evaluating the effectiveness of wood shreds, generated from burnt trees, and used as a mulch to reduce erosion on burned hillslopes (P. R. Robichaud, P. Jordan, S. A. Lewis, L. E. Ashmun, S. A. Covert, R. E. Brown, unpubl. data).

Conclusion

The tools that have been developed for post-fire assessment and erosion-mitigation treatment decisions have been the focus of much of our research team's work in the past decade. Increased knowledge of post-fire effects and improvements in the processes and tools available for post-fire assessment has allowed

for more targeted and cost effective management. Efforts to make post-fire assessment tools and information accessible via the internet have allowed for quick access from remote locations. In addition, websites can be quickly updated – an advantage over published materials – and linked to relevant models, databases, etc. Consequently, the post-fire management tools developed in the United States, particularly those tools that are web-based and publicly accessible, are being used by land managers in fire-prone areas around the world.

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