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Post-Disaster Geotechnics

What happens after the smoke clears?

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What Happens After the Smoke Clears? Post-Wildfire Assessment and Stabilization Strategies

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Fire is a natural phenomenon in many ecosystems, but land use and climate change have altered many natural fire regimes. In the western U.S., a century of fire suppression has resulted in forests with large fuel loads—thick stands of trees and large amounts of forest floor material—that are primed to burn by increasingly hot dry summer weather. The result has been a significant increase in the number, size and severity of wildfires in the past two decades. High severity fires are of particular concern not only because of the vegetation consumed and the large amounts of smoke and ash that are produced, but also because of a fire's effects on surface soil that can significantly alter watershed response to rainfall. After consumption and charring of vegetation, increased erosion and flooding are the most visible and striking physical consequences of fire.

When high severity wildfires are followed by major rainfall events, runoff and erosion often increase by orders of magnitude over pre-fire rates. Mud and debris flows, landslides and general flooding can clog and undermine culverts, cover roads and re-route water into developed areas where flooding causes damages to the built environment. Channels become choked with sediment, ash and debris; overflow their banks; pile up debris at bridges and carry sediment and ash into reservoirs, threatening municipal water supplies. In the western U.S., this is a special concern where 40 percent of all drinking water is generated in forested watersheds. Eroded hillslope material may be carried downslope into streams, adding to the sediment from washed-out forest roads, and damage large portions of aquatic habitat (Figure 1).

Figure 1. A debris flow blocks the highway following intense rainfall near the 2011 Wallow Fire in eastern Arizona.

After the smoke clears and the fire suppression crews are mopping up, the Burned Area Emergency Response (BAER) team begins its work.

In the past several decades, the number of people living in the wildland-urban interface continues to grow, increasing the risk to public safety, infrastructure, property and natural resources from the direct and secondary effects of wildfires. When there are significant resources at risk for loss and damage, "letting nature take its course" is rarely accepted public policy for fire suppression or post-fire stabilization. Therefore, considerable efforts are implemented for both fire suppression and post-fire stabilization.

Post-Fire Response

After the smoke clears and the fire suppression crews are mopping up, the Burned Area Emergency Response (BAER) team begins its work. The BAER program, a joint effort among four public land agencies within the Department of Interior and the Department of Agriculture-Forest Service, was developed about 25 years ago to enhance and codify the federal response to post-fire situations. In the U.S., a BAER team is assembled whenever a fire may pose a threat to life; safety; built structures such as roads, buildings and irrigation ditches; managed resources such as timber; cover for grazing and cultural sites; and/or environmental resources such as water quality, spawning habitat and biodiversity. These teams may include soil scientists, hydrologists, foresters, ecologists, engineers, archeologists and other specialists, depending on the location of the fire and lives and resources at risk.

Once assembled, their tasks are to 1) assess the fire-induced changes in the burned area; 2) estimate the risk for loss or damage posed by the post-fire conditions to identified resources such as public water supplies, culverts and road systems; 3) recommend cost-effective treatments to reduce the risk where both possible and economically justified; and 4) implement selected treatments. BAER teams work under strict time constraints to accomplish these tasks as protection of public safety and burned area stabilization need to be put into place as rapidly as possible. To assess post-fire conditions, predict potential erosion and flooding, and make treatment recommendations within two to three weeks of fire suppression, the methods and tools used by BAER teams must efficiently provide reasonable estimates and accurate information for decision-making.

Wildfires are unconcerned with jurisdictional boundaries and often burn through lands with multiple public and private ownerships. The tools and protocols developed for the BAER program could be useful to geotechnical and civil engineers who are called in to evaluate and mitigate threats from burned land that may impact areas for which they have responsibility. Engineers working for state departments of transportation, public utilities and city and county governments, as well as private consultants, likely will be increasingly involved in shaping their employer's or client's response to the risks posed by post-fire threats. The Air, Water and Aquatic Environments Program at the U.S. Forest Service, Rocky Mountain Research Station has developed several tools specifically for federal BAER teams, and has made these tools free and accessible to the public through the BAERTOOLS website.

Post-Fire Assessment

Numerous studies on fire effects have provided a strong consensus of the general factors that impact 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 are not directly tied to the fire. In particular, rainfall intensity has been positively associated with large post-fire runoff and erosion responses. The other characteristics that directly affect watershed response, such as remaining ground cover, soil erodibility, infiltration rate and time since the fire, are directly tied to the fire that occurred.

With the exception of time since the fire, the fire-related factors are incorporated into the classification of soil burn severity that is generally designated in discrete categories of unburned, low, moderate and high. As soil burn severity increases, the potential watershed response increases. In addition, soil burn severity is an important input into several hydrologic and erosion prediction models. Consequently, one of the first tasks a BAER team faces is to develop the soil burn severity map for the wildfire area.

A combination of remote sensing products, 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 (Figure 2). Since 2002, the U.S. Forest Service, Remote Sensing Applications Center (RSAC) and the USGS Center for Earth Resources Observation and Science (EROS) use pre- and post-fire Landsat satellite images of the burned area to derive the Burned Area Reflectance Classification (BARC)—a preliminary classification of landscape change. 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.

The *Field Guide for Mapping Post-Fire Soil Burn Severity* was designed for use by post-fire assessment teams to improve consistency of soil burn severity mapping. The guidelines for identifying soil burn severity classes and a photo series illustrating representative post-fire soil and ground conditions are used to validate and adjust the BARC. The user is directed to make five observations—ground cover, ash color and depth, soil structure, roots and soil water repellency—over 10 locations per site. A mini-disk infiltrometer (MDI) has been adapted for use as a field test of post-fire soil water repellency and infiltration and has been incorporated into the *Field Guide* protocol. Observations are averaged for each of the five observed factors to classify the soil burn severity which can then be confirmed by comparisons with the photos.

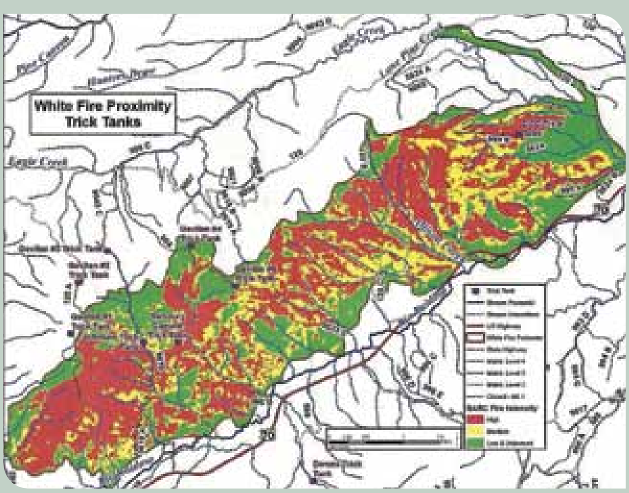

Figure 2. Burn Severity Map for the 2011 White Fire in New Mexico.

Post-Fire Prediction Tools

Hydrologic 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.

Potential post-fire erosion estimates are often made using the U.S. Forest Service's FS WEPP forest and rangeland environments. The climate file that drives WEPP is generated from historical weather station data and modified by the Rock Clime interface for mountainous regions that adapts the climate to the specific area of fire. The full suite of FS WEPP interfaces include (Figure 3):

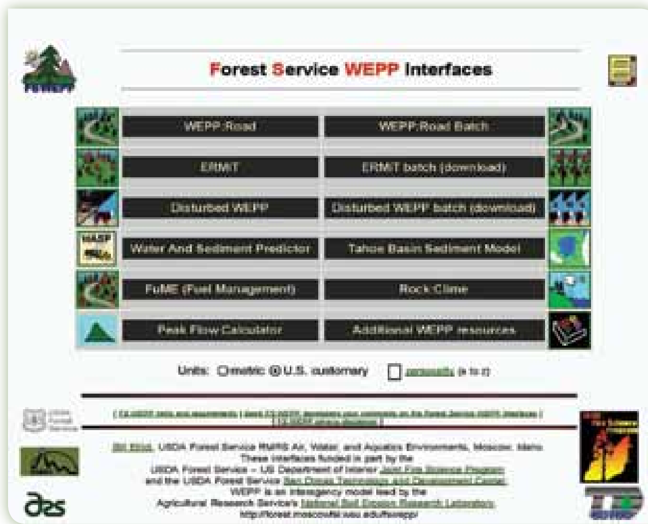

Figure 3. The FS WEPP interface access page.

- WEPP:ROAD - predicts erosion from insloped or outsloped forest roads given several user defined road erosion conditions, including fire;
- ERMiT, Erosion Risk Management Tool - specifically designed for post-fire assessments to predict the probability associated with a given hillslope sediment yield, such as untreated and treated with seeding, dry straw mulching or erosion barriers, from a single storm in each of five years following wildfire; and
- DISTURBED WEPP - allows users to describe numerous disturbed forest and rangeland erosion conditions, including low and high soil burn severity, and provides mean annual runoff depth, erosion rates, sediment yields and the probability of a given amount of erosion occurring the year following a disturbance.

These prediction models have "batch" capabilities that allow multiple roads or hillslopes to be modeled simultaneously. Future interface refinements 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 integrate with GIS and other post-fire assessment tools. In addition, post-fire models for wind erosion and dry ravel erosion driven by steep slopes and gravity are currently being developed. FS PEAK FLOW has been added to the suite of FS WEPP models. It is a peak flow calculation model based on curve number (CN) methods that allows the user to directly input a CN value or accept an estimated CN value based on the output from the ERMiT model. In addition to these tools, other runoff and peak flow calculators that have been used by post-fire assessment teams are also available from the U.S. Forest Service.

Post-Fire Treatments

Post-fire treatments are often used to stabilize hillslopes and reduce damage to infrastructure and resources. Treatments are divided into three basic categories based on where they are applied—hillslope, road and channel.

Hillslope treatments. These treatments are intended to reduce surface runoff and keep hillslope soil in place to prevent sedi-

A combination of remote sensing products, 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.

Figure 4. A composite photo of aerial straw mulching after the 2002 Hayman Fire in the Colorado Front Range.

ment deposition in unwanted areas. There are three basic types of post-fire hillslope treatments that have been used—broadcast seeding, mulching and erosion barriers. Of these, mulching offers the most effective erosion reduction and hillslope stabilization. Currently, the most frequently used post-fire mulching is done with aerial application of agricultural straw with wheat, barley, and rice straw. Despite being more expensive than straw, hydromulches, particularly aerially applied hydromulch, and wood mulches, including on-site derived wood shreds and manufactured wood strands, are being used as an alternative where specific performance characteristics are needed (Figure 4).

Road treatments. These treatments include a variety of techniques aimed at increasing the water handling capabilities of roads and road structures, such as culverts, low-water crossings and bridges, to prevent failures that would damage the road and add to downstream sedimentation. The functionality of the road drainage system is generally not affected by fire, but runoff from burned watershed can overwhelm the system. Typical road treatments include armoring of the running surface, drainage ditches, cut and fill slopes and ends of culverts (Figure 5), as well as installation of flow directors such as water bars, rolling dips and jersey barriers. Other common treatments include constructing water passage structures such as overflow dips, up-sizing culverts or installing trash racks to catch debris upstream of a culvert.

Channel treatments. Channel treatments modify sediment and water movement in ephemeral or low-order channels to reduce sediment inputs into larger streams and prevent flooding and debris torrents. Most channel treatments involve some mechanism to slow water flow, reduce down-cutting and allow sediment to settle. Check dams and channel-grade stabilizing structures made of straw bales, logs and/or rocks are anchored in the channel. Stream-bank armoring and channel clearing are also sometimes used to stabilize channels.

What's the Best Response?

Not all treatments are equally effective in reducing runoff and erosion and stabilizing the post-fire landscape. 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 resources at risk with justifiable, cost-effective expenditures of public funds. Managers also need to know how and why treatments work so they can determine the best treatments for a specific location and decide how to adapt treatments to improve their effectiveness. Post-fire management tools developed for federal public land agencies in the U.S., particularly those tools that are web-based and publicly accessible, are being used by land managers and researchers in fire-prone areas around the world. These same tools can be useful to engineers charged with responding to aftermath of a wildfire.

Figure 5. A new, larger culvert and inlet armoring installed after the 2003 Piru Fire in southern California.

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