27 Nuts and bolts of BAER soil and watershed assessments

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Introduction

Soils and watersheds are two of many resources affected by fire that are evaluated on-site by the Department of the Interior's Burned Area Emergency Rehabilitation (BAER) Team. Fire effects on these resources and potential post-fire conditions and processes may result in adverse community and ecological consequences. The primary purpose for evaluating soils and watersheds is to determine if the fire created emergency watershed conditions. If emergency watershed conditions are found, then the magnitude and scope of the emergency is mapped and described, values at risk are identified, and treatment prescriptions are developed to protect the values at risk. Emergency watershed conditions include both hydrologic and soil factors, typically potential for flash floods and debris flows, and deterioration of soil condition, particularly loss of soil structure that can lead to a decline in soil productivity. On occasion loss of vegetative cover may also contribute to wind erosion. Values at risk include human life, property and critical natural and cultural resources. This paper. based on a poster presented at the conference, highlights the objectives and parameters of the BAER soil and watershed assessment. An accompanying poster highlighted application of treatments.

Common BAER Soil and Watershed Issues

- Threats to human life, property, (e.g. roads, bridges, fences, buildings, recreational facilities, waste and contaminant sites), and resources to be protected (archeological sites, rare, threatened, and endangered species habitat) from fire-related flooding and debris flows.
- Threats to human life, wildlife, and property from falling rock and wind-blown dust (e.g., highway safety conditions).
- Degradation of site productivity for vegetative recovery through loss of ash, soil, and nutrients.
- Threats to water quality, fish, and aquatic resources from nutrient loading and sedimentation.
- Hydrogeologic corrections resulting in large-scale erosion and long-term channel adjustment.

BAER Soil and Watershed Objectives

- Assess fire effects to, determine post-fire condition of, and map burn severity of soils.
- Assess overall changes to soil productivity, hydrologic function, and watershed response to precipitation events in each burned watershed to determine where and what kind of soil and watershed emergencies exist.
- Identify the most critical soil and watershed issues, map their locations, and develop treatment alternatives to mitigate impacts and risks—particularly those that

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pose substantial threats to human life, property, and critical natural and cultural resources—downstream of, as well as within, the burned area.
- Model potential flooding and sediment loss in highly burned watersheds, especially if there are threatened life or property values at risk or resources to be protected.
- Produce a watershed risk/vulnerability map showing source areas of excessive watershed response, flow paths, and potential impact areas.
- Produce a watershed treatment map showing the location of each treatment to be implemented.
- Assist other BAER resource specialists with treatment recommendations to mitigate potential excessive watershed response impacts on other resources (e.g. archeological sites; rare, threatened, and endangered species habitat).

Indicators of Watershed Emergency

Aerial reconnaissance is conducted to identify the spatial distribution and extent of fire severity (canopy condition), burn severity (surface indicators—e.g., color of ash), and values at risk. Field reconnaissance is conducted to evaluate surface and subsurface indicators of burn severity, soil condition, watershed condition, and values at risk. Field evaluations include, but are not limited to:

- Edaphic fire effects (soil productivity);
- Vegetation fire effects: fire intensity and burn intensity;
- Areal extent and strength of hydrophobic soil conditions;
- Mapping burn severity;
- Channel stability or lack thereof;
- Accumulated material within ordinary high water;
- Extent and location of floatable large woody debris;
- Evaluation of mass movement potential;
- Threats to infrastructure from storm flow and debris;
- Current channel and culvert capabilities; and
- Flow routing related to protecting values at risk and critical resources.

"Burn severity" is not the same concept as "fire intensity" and "fire severity" as recognized by fire behavior specialists (see "Some Key Concepts," below). "Fire intensity" relates to behavior of the fire, and "fire severity" to fire effects on vegetation, while "burn severity" relates specifically to effects of the fire on soil conditions and hydrologic function (e.g., amount of surface litter, erodibility, infiltration rate, run-off response). Although burn severity is not primarily a reflection of effects of fire to vegetation, vegetative conditions and pre-fire vegetation density are among indicators used to assess burn severity.

Site indicators used to evaluate and map burn severity include size of residual fuels (fire intensity), ash depth and color (burn intensity), soil texture, and structure and soil hydrophobicity. These criteria indicate fire residence time, depth of litter layer consumed, radiant heat throughout the litter layer, ease of detachability of the surface soil, and soil permeability. Using these indicators, burned areas are mapped as a mosaic of three relative burn severity categories. These include high, moderate, and low/unburned. Because this is a relative scale, it is important that the soil and watershed specialists doing the mapping make time early in the assessment to review the field parameters and calibrate themselves to one another, especially if they have not worked together on previous fires.

In some cases there may be complete consumption of vegetation by fire, with little effect on soil and watershed function. In general, the denser the pre-fire vegetation, the longer the residence time and the more severe the effects of the fire on soil–hydrologic function. For example, deep ash after a fire usually indicates a deeper litter layer prior to the fire, which generally supports longer residence times.

Increased residence times promote the formation of water-repellant layers at or near the soil surface, and loss of soil structural stability. The results are increased run-off and soil particle detachment by water and increased transport off-site (erosion). The presence of white ash indicates a hotter fire and more complete consumption of organic matter. Powdery ash without identifiable remnants of twigs and leaf litter also indicates more complete consumption.

Generally, there is a close correlation between soil properties and the amount of heat experienced by the soil as well as the residence time of the heat in contact with the soil. The burn severity map then becomes a basis to predict the hydrologic response of soil to the fire, and the rate of natural revegetation of the site following the fire.

Mapping is usually done on 7.5-minute U.S. Geological Survey (USGS) quadrangles (1:24,000). It is important to note that burned-area map units are usually mapped at no less than 40 acres in size (about the size of a quarter) and may include areas of other burn severity, but which are too small to segregate. Small areas of different burn severity can therefore be present in each map unit.

Edaphic fire effects are evaluated for several parameters that affect soil conditions. These parameters are hydrophobicity, changes in vegetative ground cover, soil structure, and susceptibility to water erosion. Hydrophobicity is evaluated by observing the depth, thickness, and continuity of a water-repellent horizon in surface soils where it exists, and duration of a water drop beading on this surface. Changes in vegetative ground cover as affected by the fire are noted and compared with pre-fire conditions. Loss of soil structure is usually indicated by a change to a powdery soil. Presence or absence of fibrous roots, fungal mycelium, and seeds in the soil are also noted. Soils susceptible to wind erosion are examined in the field to determine if there is an increased risk of erosion. Soil survey maps and air photos are used to assist in making predictions of areas with the greatest risks of wind or water erosion.

Hydrophobic soils form when soils are heated by fire. This occurs due to volatilization of organic matter in and on the surface soil that have high amounts of lignin and other waxy compounds. After the fire passes, the gasses cool to a waxy coating on soil particles. The effect is similar to putting wax on a car to cause water to bead up and run off. If the hydrophobic layer is thick, or the degree of water repellency is strong, it can seriously inhibit infiltration of rainfall, increase run-off, and detach surface soil particles, all of which increases flooding, erosion, and sedimentation. Some soils can be significantly hydrophobic, even without fire. Vegetation type, amount of organic matter, and soil texture are the primary factors that determine whether or not soils will become hydrophobic.

Watershed response. On-the-ground field observations and aerial reconnaissance are conducted to determine the potential for high run-off response. Channel morphology related to transport and deposition processes are noted, along with channel crossings and stream outlets. Observations include condition of riparian vegetation along seeps, springs, and perennial streams and the potential for vegetation loss and conversion. Burn severity and changes in soil infiltration are considered for run-off potential. Other watershed observations include slope, existing and potential ground cover density (e.g., unburned vegetation, rock fragments, needle cast), and sediment available for transport both on the hillsides and in the channels, to assess watershed response. A literature search of local and regional documented studies is conducted and local scientists and resource specialists are consulted about past watershed responses to wildfires. All of the above criteria are used to identify areas of excessive watershed response that can lead to emergency watershed conditions and threats to life and other resources.

Products

Reports and documents. The soil and watershed assessment is one of many resource elements of the BAER plan. Each resource assessment states its objectives and issues relevant to the specific incident, describes and documents background resource information, field methodology, and findings (including maps, tables, and photos), prescribes treatments to be implemented (including cost analysis and compliance with National Environmental Policy Act and National Historic Preservation Act), and makes other monitoring and management recommendations to the site managers.

Maps. Maps are the key tool used in the gathering, organization, and display of critical information collected by BAER resource specialists. Maps require a scale appropriate for necessary detail, as well as use in a geographic information system (GIS). Typically, we map on standard USGS quadrangles at 1:24,000 scale. Maps produced during the BAER soil and watershed assessment include: observation and data maps (burn severity by watershed, areas of water-repellent soils and potential flood-source areas); analysis/derived maps (watershed risk assessment; pre- and post-fire soil movement / debris flow-source areas); emergency area maps (critical resource areas, flood-prone area); and watershed treatment area maps.

Treatments. Mitigating or warning the public of potential adverse fire effects to soil productivity and excessive watershed response is the goal of the soil and watershed assessment. Watershed stabilization treatments may be applied to hillslopes and channels. It is important to understand that BAER cannot design treatments to protect against all scales of floods and other mass movement events. Treatments applied to burned watersheds are most effective in mitigating two- to ten-year storm events. Storms smaller in magnitude than a two-year event usually do not affect a burned watershed sufficiently to necessitate treatment. Storms generally greater than a ten-year event may create a run-off response in excess of one or two orders of magnitude. Watershed stabilization treatments are often ineffective under such conditions. Other BAER soil and watershed recommendations include installing remote weather stations and hazard warning signs at critical sites, and monitoring storms and changes in resource condition.

Some Key Concepts

Burn intensity accounts for fire effects on understory (ground) vegetation and soils (burn severity). Measured in BTU/minute/ft, burn intensity depends upon moisture content of duff and large fuels (lying on the ground). It accounts for the amount of conductive and radiant heat that goes down into the soil. The amount of duff consumed and depth and color of char and ash are visible indicators. Burn intensity is difficult to measure and is qualitatively defined on a relative post-fire burn severity scale: low (or partial consumption) = black ashes; moderate = gray or mixed ashes; high = white or red ashes. Finally, burn intensity is in part defined by its effect on ecosystems, e.g. a function of plant responses to fire.

Burn severity is a relative measure of the degree of change in a watershed that relates to the severity of the effects of the fire on soil and watershed conditions. It is delineated on topographic maps covering the area of the fire as a mosaic of polygons labeled high, moderate, and low burn severity.

Emergency watershed condition refers to the existence of watershed conditions in which processes can accelerate in response to fire effects on the watershed leading to excessive watershed/hydrologic response.

Excessive watershed/hydrologic response occurs when watershed functions, such as run-off and sediment yield, will approach the upper limit of the natural range of variability of the stream channel, and may exceed our ability to protect the values at risk from accelerated water yield (floods), release of stored sediments (mud and debris flows), and degraded water quality (suspended sediment and chemical enrichment from ash).

Fire intensity accounts for fire effects on overstory vegetation (fire severity). Measured by the rate of heat release (from combustion) per unit time per unit length of fire front (BTU/sec/ft), fire intensity depends upon (a) rate of spread, (b) heat of combustion, and (c) total amount of fuel consumed (flame length, violence, temperature, destructive energy of the fire). It accounts for convective heat rising into the atmosphere (outward heat flow). Flame length and size of residual fuels are visible indicators. Fire intensity is defined on a relative scale: low = up to 0.25-inch diameter fuels consumed; moderate = greater than 0.25-inch, but less than 0.75-inch fuels consumed; high = fuels 0.75-inch diameter and larger consumed.

Common Watershed Treatments

Hillslope treatments

- Aerial / hand seed
- Contour rake
- Contour tree fall
- Directional tree fall
- Log erosion barriers
- Hydromulch
- Straw mulch
- Straw wattles

Channel treatments

- Armor stream crossings
- Clean out catchment basins
- Clean out culverts
- Construct sediment traps in tributary channels
- Install stream grade control structures
- Protect wellheads, power poles, and archeological sites from flooding and debris
- Remove floatable debris from channels and floodplains

Life and safety measures

- Install flood-hazard safety signs along roads, trails, campgrounds, and picnic areas
- Install RAWS

Monitoring specifications

- Assess structures at flood risk
- Monitor water quality
- Monitor storm flows and sediment transport

Fire severity is a relative measure of the degree of change in overstory vegetation caused by fire intensity; usually referred to in terms of low, moderate, or high fire severity.

Hydrophobicity is the water repellency of soils affected by fire. Waxes released from volatilized organic matter move downward into the soil and condense around individual soil particles to form a water-repellent layer which restricts water movement. Soil penetration may be a few millimeters to several centimeters below the surface and the impervious barrier may be a few centimeters thick. Site conditions favorable for hydrophobic development include: high fire severity, long fire residence time, deep leaf-litter layer consumed by the fire, high burn severity, and coarse-grained soils (permeable for liquefied waxes). The depth and thickness of the barrier is determined by a water-drop penetration time test. The longer the duration or greater the depth, the greater the potential watershed response; this relates to storm intensity and duration.

Values at risk are those which are vulnerable to impact from excessive watershed response due to loss of control of water on-site, in-stream or downstream (fire- or burn-caused hydrologic or geologic events). These values include on-site and in-stream site productivity, and on-site and downstream threats to human life, property, and natural and cultural resources.

The ***water-drop penetration time test*** is a relative measure of hydrophobicity by timing the duration of a water drop beading on and penetrating exposed soil after gently scraping ash away from the surface, and at successive depths in the soil. The U.S. Forest Service classification standard is: less than 10 seconds = weak hydrophobicity; 10-40 seconds = moderate hydrophobicity; longer than 40 seconds = strong hydrophobicity.