**Peter R. Robichaud**
**Jan L. Beyers**
**Daniel G. Neary**

# Chapter 10: Watershed Rehabilitation

Recent large, high severity fires in the United States, coupled with subsequent major hydrological events, have generated renewed interest in the linkage between fire and onsite and downstream effects (fig. 10.1). Fire is a natural and important disturbance mechanism in many ecosystems. However, the intentional human suppression of fires in the Western United States, beginning in the early 1900s, altered natural fire regimes in many areas (Agee 1993). Fire suppression can allow fuel loading and forest floor material to increase, resulting in fires of greater intensity and extent than might have occurred otherwise (Norris 1990).

**Figure 10.1**—Flood flow on the Apache-Sitgreaves National Forest, Arizona, after the Rodeo-Chediski Fire of 2002. (Photo by Dave Maurer).

High severity fires are of particular concern because the potential affects on soil productivity, watershed response, and downstream sedimentation often pose threats to human life and property. During severe fire seasons, the USDA Forest Service and other Federal and State land management agencies spend millions of dollars on postfire emergency watershed rehabilitation measures intended to minimize flood runoff, onsite erosion, and offsite sedimentation and hydrologic damage. Increased erosion and flooding are certainly the most visible and dramatic impacts of fire apart from the consumption of vegetation.

## Burned Area Emergency Rehabilitation (BAER)

The first formal reports on emergency watershed rehabilitation after wildfires were prepared in the 1960s and early 1970s, although postfire seeding with grasses and other herbaceous species was conducted in many areas in the 1930s, 1940s, and 1950s (Christ 1934, Gleason 1947). Contour furrowing and trenching were used when flood control was a major concern ( Noble 1965, DeByle 1970b). The Forest Service and other agencies had no formal emergency rehabilitation program. Funds for fire suppression disturbance were covered by fire suppression authorization. Watershed rehabilitation funding was obtained from emergency flood control programs or, more commonly, restoration accounts. Prior to 1974, the fiscal year had ended June 30 of each year, allowing year-end project funds to be shifted to early season fires. After July 1, fires were covered by shifts in the new fiscal year funding. The shift to an October 1 to September 30 fiscal year made it difficult to provide timely postfire emergency treatments or create appropriated watershed restoration accounts.

In response to a Congressional inquiry on fiscal accountability, in 1974 a formal authority for $2 million in postfire rehabilitation activities was provided in the Interior and Related Agencies appropriation. Called Burned Area Emergency Rehabilitation (BAER), this authorization was similar to the fire fighting funds in that it allowed the Forest Service to use any available funds to cover the costs of watershed treatments when an emergency need was determined and authorized. Typically, Congress reimbursed accounts used in subsequent annual appropriations. Later, annual appropriations provided similar authorities for the Bureau of Land Management and then other Interior agencies. The occurrence of many large fires in California and southern Oregon in 1987 caused expenditures for BAER treatments to exceed the annual BAER authorization of $2 million. Congressional committees were consulted and the funding cap was removed. The BAER program evolved, and policies were refined based on determining what constituted a legitimate emergency warranting rehabilitation treatments.

The BAER-related policies were initially incorporated into the Forest Service Manual (FSM 2523) and the Burned Area Emergency Rehabilitation (BAER) Handbook (FSH 2509.13) in 1976. These policies required an immediate assessment of site conditions following wildfire and, where necessary, implementation of emergency rehabilitation measures. These directives delineated the objectives of the BAER program as:

1. Minimizing the threat to life and property onsite and offsite.
2. Reducing the loss of soil and onsite productivity.
3. Reducing the loss of control of water.
4. Reducing deterioration of water quality.

As postfire rehabilitation treatment increased, debates arose over the effectiveness of grass seeding and its negative impacts on natural regeneration. Seeding was the most widely used individual treatment, and it was often applied in conjunction with other hillslope treatments, such as contour-felled logs and channel treatments.

In the mid 1990s, a major effort was undertaken to revise and update the BAER handbook. A steering committee, consisting of regional BAER coordinators and other specialists, organized and developed the handbook used today. The issue of using native species for emergency revegetation emerged as a major topic, and the increased use of contour-felled logs (fig. 10.2) and mulches caused rehabilitation expenditures to escalate. During the busy 1996 fire season, for example, the Forest Service spent $11 million on BAER projects. In 2000, 2001, and 2002 the average annual BAER spending rose to more than $50 million.

Improvements in the BAER program in the late 1990s included increased BAER training and funding review. Increased training needs were identified for BAER team leaders, project implementation, and on-the-ground treatment installation. Courses were developed for the first two training needs but not the last. Current funding requests are scrutinized by regional and national BAER coordinators to verify that funded projects are minimal, necessary, reasonable, practicable, cost effective, and a significant improvement over natural recovery.

In the late 1990s, a program was initiated to integrate national BAER policies across different Federal agencies (Forest Service, Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs) as each agency had different authorities provided in the Annual Appropriations Acts.

**Figure 10.2**—Installing contour-felled logs for erosion control after a wildfire. (Photo by Peter Robichaud).

The U.S. Department of Agriculture and Department of the Interior approved a joint policy for a consistent approach to postfire rehabilitation in 1998. The new policy broadened the scope and application of BAER analysis and treatment. Major changes included:

1. Monitoring to determine if additional treatment is needed and evaluating to improve treatment effectiveness.
2. Repairing facilities for safety reasons.
3. Stabilizing biotic communities.
4. Preventing unacceptable degradation of critical known cultural sites and natural resources.

## BAER Program Analysis

Early BAER efforts were principally aimed at controlling runoff and consequently erosion. Research by Bailey and Copeland (1961), Christ (1934), Copeland (1961, 1968), Ferrell (1959), Heede (1960, 1970), and Noble (1965) demonstrated that various watershed management techniques could be used on forest, woodland, shrub, and grassland watersheds to control both storm runoff and erosion (fig. 10.3). Many of these techniques were developed from other disciplines (such as agriculture and construction) and refined or augmented to form the set of BAER treatments in use today (table 10.1).

In spite of the improvements in the BAER process and the wealth of practical experience obtained over the past several decades, the effectiveness of many emergency rehabilitation methods have not been systematically tested or validated. Measuring erosion and runoff is expensive, complex, and labor intensive (fig. 10.4). Few researchers or management specialists have the resources or the energy to do it. BAER team leaders and decisionmakers often do not have information available to evaluate the short- and long-term benefits (and costs) of various treatment options.

**Figure 10.3**—Straw bale check dams placed in channel by the Denver Water Board after the Hayman Fire, 2002, near Deckers, CO. (Photo by Peter Robichaud).

In 1998, a joint study by the USDA Forest Service Rocky Mountain Research Station and the Pacific Southwest Research Station evaluated the use and effectiveness of postfire emergency rehabilitation methods (Robichaud and others 2000).

The objectives of the study were to:

1. Evaluate the effectiveness of rehabilitation treatments at reducing postwildfire erosion, runoff, or other effects.
2. Assess the effectiveness of rehabilitation treatments in mitigating the downstream effects of increased sedimentation and peakflows.
3. Investigate the impacts of rehabilitation treatments on natural processes of ecosystem recovery, both in the short and long term.
4. Compare hillslope and channel treatments to one another and to a no-treatment option.
5. Collect available information on economic, social, and environmental costs and benefits of various rehabilitation treatment options, including no treatment.
6. Determine how knowledge of treatments gained in one location can be transferred to another location.
7. Identify information gaps needing further research and evaluation.

Robichaud and others (2000) collected and analyzed information on past use of BAER treatments in order to determine attributes and conditions that led to treatment success or failure in achieving BAER goals. Robichaud and others (2000) restricted this study to USDA Forest Service BAER projects in the continental Western United States and began by requesting Burned Area Report (FS-2500-8) forms and monitoring reports from the Regional headquarters and Forest Supervisors' offices. The initial efforts revealed that information collected on the Burned Area Report forms and in the relatively few existing postfire monitoring reports was not sufficient to assess treatment effectiveness, nor did the information capture the knowledge of BAER specialists. Therefore, interview questions were designed to enable ranking of expert opinions on treatment effectiveness, to determine aspects of the treatments that lead to success or failure, and to allow for comments on various BAER-related topics.

Interview forms were developed after consultation with several BAER specialists. The forms were used to record information when BAER team members and regional and national leaders were interviewed. Onsite interviews were conducted because much of the supporting data were located in the Forest Supervisors' and District Rangers' offices and could be

**Table 10.1**—Burned Area Emergency Rehabilitation (BAER) treatments (From Robichaud and others 2000).

| Hillslope | Channel | Road and trail |
|---|---|---|
| Broadcast seeding | Straw bale check dams | Rolling dips |
| Seeding plus fertilizer | Log grade stabilizers | Water bars |
| Mulching | Rock grade stabilizers | Cross drains |
| Contour-felled logs | Channel debris clearing | Culvert overflows |
| Contour trenching | Bank/channel armoring | Culvert upgrades |
| Scarification and ripping | In-channel tree felling | Culvert armoring |
| Temporary fencing | Log dams | Culvert removal |
| Erosion fabric | Debris basins | Trash racks |
| Straw wattles | Straw wattle dams | Storm patrols |
| Slash scattering | Rock gabion dams | Ditch improvements |
| Silt fences | | Armored fords |
| Geotextiles | | Outsloping |
| Sand or soil bags | | Signing |

retrieved during the interviews. Because much of the information was qualitative, attempts were made to ask questions that would allow for grouping and ranking results.

BAER program specialists were asked to identify treatments used on specific fires and what environmental factors affected success and failure. For each treatment, specific questions were asked regarding the factors that caused the treatment to succeed or fail, such as slope classes, soil type, and storm events (rainfall intensity and duration) affecting the treated areas. They were also asked questions regarding implementation of treatments and whether any effectiveness monitoring was completed. For cases where monitoring was conducted (either formal or informal), interviewees were asked to describe the type and quality of the data collected (if applicable) and to give an overall effectiveness rating of “excellent,” “good,” “fair,” or “poor ” for each treatment.

**Figure 10.4**—During a short duration high intensity rain event, this research sediment trap was filled. Using pre- and postsurveys, Hydrologist Bob Brown and Engineer Joe Wagenbrenner measure the sediment collected with the help of a skid-steer loader. Research plots are in high severity burned areas of the 2002 Hayman Fire, Pike-San Isabel National Forest near Deckers, CO. (Photo by J.Yost).

This evaluation covered 470 fires and 321 BAER projects, from 1973 through 1998 in USDA Forest Service Regions 1 through 6. A literature review, interviews with key Regional and Forest BAER specialists, analysis of burned area reports, and review of Forest and District monitoring reports were used in the evaluation. The resulting report, Evaluating the Effectiveness of Postfire Rehabilitation Treatments (Robichaud and others 2000), includes these major sections:

1. Information acquisition and analysis methods.
2. Description of results, which include hydrologic, erosion and risk assessments, monitoring reports, and treatment evaluations.
3. Discussion of BAER assessments and treatment effectiveness.
4. Conclusions drawn from the analysis.
5. Recommendations.

This chapter provides a synopsis of the findings in that report, as well as new information that has been determined since the report was published.

# Postfire Rehabilitation Treatment Decisions

## The BAER Team and BAER Report

As soon as possible (even before a fire is fully contained), a team of specialists is brought together to evaluate the potential effects of the fire and to recommend what postfire rehabilitation, if any, should be used in and around the burned area. Hydrology and soil science are the predominant disciplines represented on nearly all BAER teams. Depending on the location, severity, and size of the fire, wildlife biologists, timber, range, and fire managers, engineers, archeologists, fishery biologists, and contracted specialists may be included on the team.

The Burned Area Report filed by the BAER team describes the hydrologic and soil conditions in the fire area as well as the predicted increase in runoff, erosion, and sedimentation. The basic information includes the watershed location, size, suppression cost, vegetation, soils, geology, and lengths of stream channels, roads, and trails affected by the fire. The watershed descriptions include areas in low, moderate, and high severity burn categories as well as areas with water repellent soils. The runoff, erosion, and sedimentation predictions are then evaluated in combination with both the onsite and downstream values at risk to determine the selection and placement of emergency rehabilitation treatments. The BAER team uses data from previous fires, climate modeling, erosion prediction tools, and professional judgment to make the BAER recommendations.

## Erosion Estimates from BAER Reports

Robichaud and others (2000) found a wide range of potential erosion and watershed sediment yield estimates in the Burned Area Report forms. Some of the high values could be considered unrealistic (fig. 10.5). Erosion potential varied from 1 to 6,913 tons/acre (2 to 15,500 Mg/ha), and sediment yield varied over six orders of magnitude. Erosion potential and sediment yield potential did not correlate well (r = 0.18, n = 117). Different methods were used to calculate these estimates on different fires, making comparisons difficult. Methods included empirical base models such as Universal Soil Loss Equation (USLE), values based on past estimates of known erosion events, and professional judgment. In recent years, considerable effort has been made to improve erosion prediction after wildfire through the development and refinement of new models (Elliot and others 1999, 2000). These models are built on the Water Erosion Prediction Project (WEPP) technology (Flanagan and others 1994), which has been adapted for application after wildfire. The model adaptation includes the addition of standard windows interfaces to simplify use and Web-based dissemination for general accessibility at:

http://forest.moscowfsl.wsu.edu/fswepp/

and

http://fsweb.moscow.rmrs.fs.fed.us/fswepp.

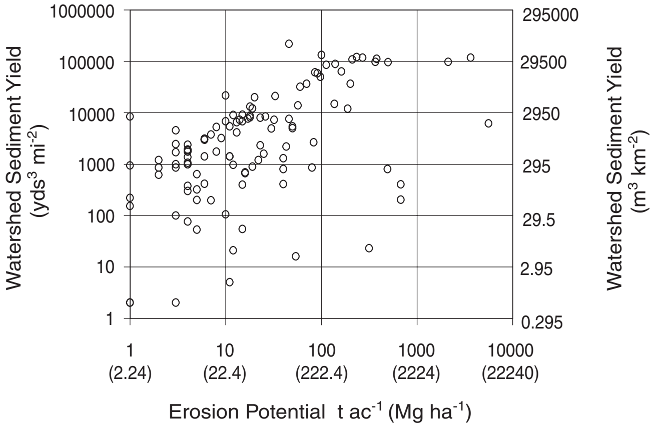

**Figure 10.5**—Estimated hillslope erosion potential and watershed sediment yield potential (log scale) for all fires requesting BAER funding. (From Robichaud and others 2000).

## Hydrologic Response Estimates

Evaluating the potential effects of wildfire on hydrologic responses is an important first step in the BAER process. This involves determining storm magnitude, duration, and return interval for which treatments are to be designed. Robichaud and others (2000) found that the most common design storms were 10-year return events (fig. 10.6, 10.7). Storm durations were

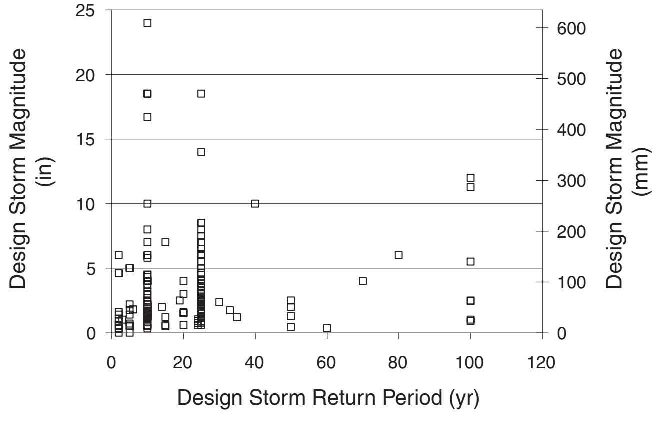

**Figure 10.6**—Design storm duration by return period for all fires requesting BAER funding. (From Robichaud and others 2000).

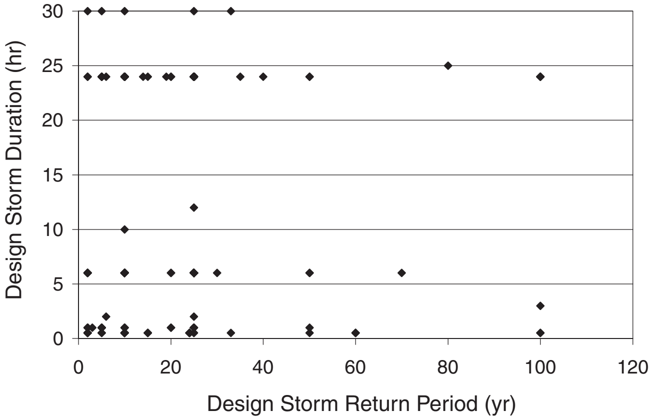

**Figure 10.7**—Design storm magnitude and return period for all fires in the Western United States requesting BAER funding. (From Robichaud and others 2000).

usually less than 24 hours, with the common design storm magnitudes from 1 to 6 inches (25 to 150 mm). Five design storms were greater than 12 inches (305 mm), with design return intervals of 25 years or less. The variation in estimates reflects some climatic differences throughout the Western United States.

The Burned Area Report also contains an estimate of the percentage of burned watersheds that have water repellent soil conditions. Soils in this condition are often reported after wildfires and are expected to occur more commonly on coarse-grained soils, such as those derived from granite (fig. 10.8). However, no statistical difference was found in the geologic parent material and the percent of burned area that was water repellent. Robichaud and Hungerford (2000) also found no differences in the water repellant conditions with various soil types. BAER teams estimate a percentage reduction in infiltration capacity as part of the Burned Area Report. Comparison of reduction in infiltration rate to percentage of area that was water repellent showed no statistically significant relationship (fig. 10.9). However, Robichaud (2000) and Pierson and others (2001a) showed a 10 to 35 percent reduction in infiltration after the first year. Factors other than water repellent soil conditions, such as loss of the protective forest floor layers, obviously affect infiltration capacity.

Estimation methods for expected changes in channel flow due to wildfire were variable but primarily based on predicted change in infiltration rates. Thus, a 20 percent reduction in infiltration resulted in an estimated 20 percent increase in channel flows. Various methods were used to determine channel flow including empirical-based models, past U.S. Geological Survey records from nearby watersheds that had a flood response, and professional judgment. Some reports show a large percent increase in design flows (fig. 10.10).

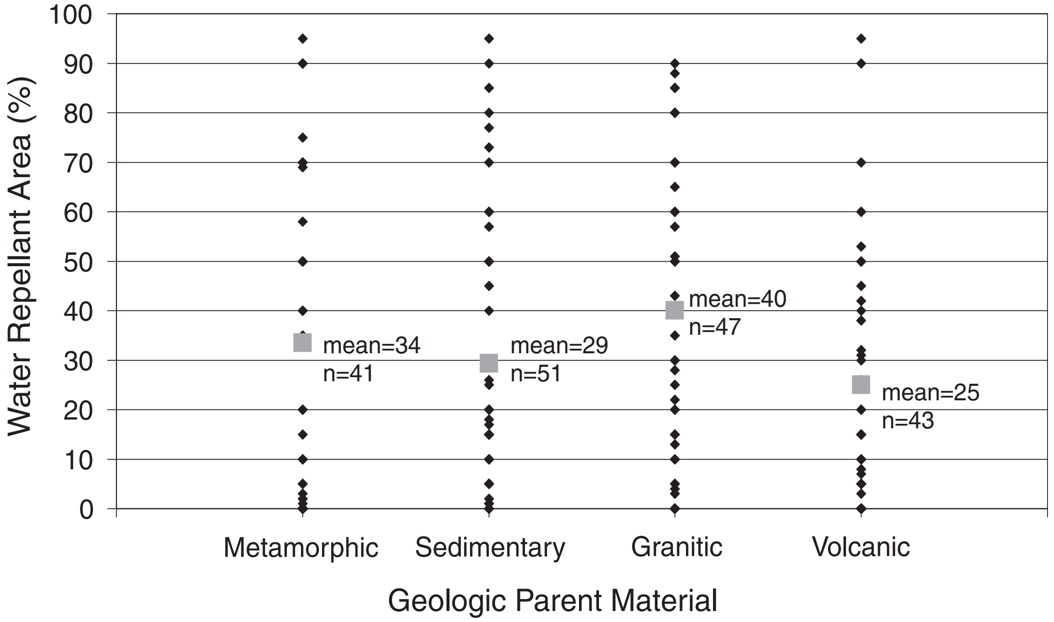

**Figure 10.8**—Fire-induced water repellent soil areas and their geologic parent material for all fires requesting BAER funding. Fire-induced water repellency was not significantly different by parent material (t-test, alpha = 0.05). (From Robichaud and others 2000).

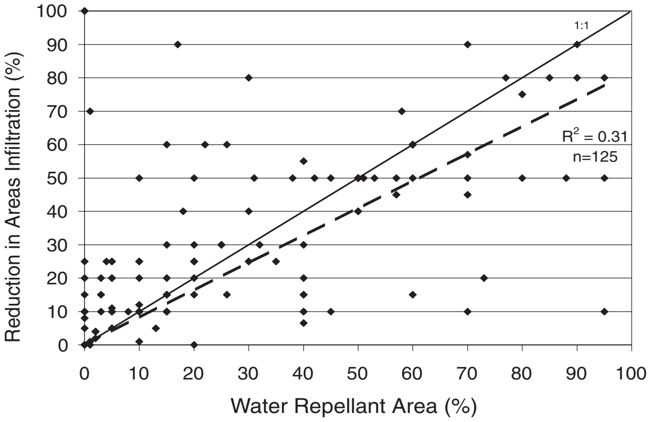

**Figure 10.9**—Fire-induced water repellent soil areas compared to the estimated reduction in infiltration for all fires requesting BAER funding. (From Robichaud and others 2000).

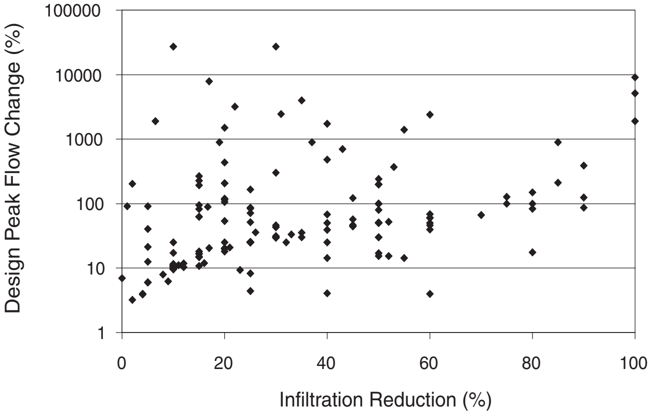

**Figure 10.10**—Estimated design peakflow change (log scale) due to wildfire burned areas relative to the estimated reduction in infiltration for all fires requesting BAER funding. (From Robichaud and others 2000).

## Hillslope Treatments and Results

### Hillslope Treatments

Hillslope treatments are intended to reduce surface runoff and keep postwildfire soil in place on the hillslope and thereby prevent sediment deposition in unwanted areas. These treatments are regarded as a first line of defense against postfire erosion and sediment movement. Hillslope treatments comprise the greatest portion of time, effort, and expense in most BAER projects. Consequently, more information is available on hillslope treatments than on channel or road treatments.

**Broadcast Seeding—** The most common BAER practice is broadcast seeding. Grass seeding after fire for range improvement has been practiced for decades, with the intent to gain useful products from land that will not return to timber production for many years (Christ 1934, McClure 1956). As an emergency treatment, rapid vegetation establishment has been regarded as the most cost-effective method to promote rapid infiltration of water and keep soil on hillslopes (Noble 1965, Rice and others 1965, Miles and others 1989).

Grasses are particularly desirable for this purpose because their extensive, fibrous root systems increase water infiltration and hold soil in place. Fast-growing nonnative species have typically been used. They are inexpensive and readily available in large quantities when an emergency arises (Barro and Conard 1987, Miles and others 1989, Agee 1993). Legumes are often added to seeding mixes for their ability to increase available nitrogen in the soil after the postfire nutrient flush has been exhausted, aiding the growth of seeded grasses and native vegetation (Ratliff and McDonald 1987). Seed mixes were refined for particular areas as germination and establishment success were evaluated. Most mixes contained annual grasses to provide quick cover and perennials to establish longer term protection (Klock and others 1975, Ratliff and McDonald, 1987). However, nonnative species that persist can delay recovery of native flora and alter local plant diversity. Native grass seed can be expensive and hard to acquire in large quantities or in a timely manner compared to cereal grains or pasture grasses. When native seed is used, it should come from a nearby source area to preserve local genetic integrity. When native seed is not available, BAER specialists have recommended using nonreproducing annuals, such as cereal grains or sterile hybrids that provide quick cover and then die out to let native vegetation reoccupy the site.

Application of seed can be done from the air or on the ground. In steep areas and in areas where access is limited, aerial seeding is often the only option. Effective application of seed by fixed-wing aircraft or helicopter requires global positioning system (GPS) navigation, significant pilot skill, and low winds for even cover. Ground seeding, applied from all-terrain vehicles or by hand, assures more even seed application than aerial seeding. Seeding is often combined with other treatments, such as mulching and scarifying, as these additional treatments help anchor the seeds and improve seed germination.

Effectiveness of seeding depends on timeliness of seed application, choice of seed, protection from grazing, and luck in having gentle rains to stimulate seed germination before wind or heavy rains blow or wash soil and seed away. Proper timing of seed application depends on location. In some areas, it is best to seed directly into dry ash, before any rain falls, to take advantage of the fluffy seedbed condition, while in other areas, seed is best applied after the first snow so that it will germinate in the spring. Both conditions also reduce loss to rodents. The potential advantage of seeded grass to inhibit the growth and spread of noxious weeds also depends on timely application and germination.

**Mulch**—Mulch is any organic material spread over the soil surface that functions like the organic forest floor that is often destroyed in high and moderate severity burn areas. Both wet mulch (hydromulch) and dry mulch (wheat straw, jute excelsior, rice straw, and so forth) are available; however, mulches have only recently been used as a postfire rehabilitation treatment. Mulch is applied alone or in combination to reduce raindrop impact and overland flow and, thereby, to enhance infiltration and reduce soil erosion. It is often used in conjunction with grass seeding to provide ground cover in critical areas. It also intercepts precipitation for subsequent infiltration. Mulch protects the soil and improves moisture retention underneath it, benefiting seeded plants in hot areas but not always in cool ones. Use of straw from pasture may introduce exotic grass seed or weeds, so BAER projects are now likely to seek "weed-free" mulch such as rice straw.

Mulches can be applied from the air or from the ground. Aerial dry mulching uses helicopters with attached cargo net slings carrying the straw mulch, which is released over the treatment area (San Dimas Technology Development Center 2003). Hydromulch can be applied from the air using helicopters fitted with hydromulch slurry tanks or buckets, which are released in controlled drops over the treatment areas. Both of these aerial applications are expensive. Ground application of dry mulch is done by hand using all terrain vehicles to carry the straw from a staging area into the treatment area. Ground application of hydromulch is done from spray trucks and is limited to an area 200 feet (61 m) of either side of a road. Given its expense, mulch is usually used in high value areas, such as above or below roads, above streams, or below ridge tops.

Mulching is most effective on gentle slopes and in areas where high winds are not likely to occur. Wind either blows the mulch off site or piles it so deeply that seed germination is inhibited. On steep slopes, rain can wash some of the mulch material downslope. Use of a tackifier or felling small trees across the mulch may increase onsite retention. Hydromulches often have tackifiers that help bind the mulch in the soil. Both hydromulch and dry mulch were used to stabilize soils on the Cerro Grande Fire of 2000 and Rodeo-Chediski and Hayman Fires of 2002. However, use of these treatments escalated the BAER treatment costs to $10 to $20 million per fire.

**Contour Log Structures (Contour Log Basins, Log Erosion Barriers, Log Terraces, Terracettes)**—This treatment involves felling logs on burned-over hillsides and laying them on the ground along the slope contour to provide mechanical barriers to water flow, promote infiltration, and reduce sediment movement. Contour-felled logs reduce water velocity, break up concentrated flows, induce hydraulic roughness to burned watersheds, and store sediment. The potential volume of sediment stored is highly dependent on slope, the layout design, the size and length of the felled trees, and the degree to which the felled trees are adequately staked and placed into ground contact. In some instances contour-felled log barriers have filled with sediment following the first several storm events after installation, while others have taken 1 to 2 years to fill (Robichaud 2000).

This treatment was originally designed to provide the same function as contour trenches and furrows. The primary function of the Contour Log Basins or Contour Log Terraces was to detain and infiltrate runoff from a design storm. To accomplish this, logs ranging generally from 6 to 12 inches (15 to 30 cm) in diameter were felled on the contour and staked in place. The treatment was begun at the top of the slope because each course of contour logs depends on the design spacing and capacity of the upslope courses to be effective. The spacing depends on the capacity of the structure to contain runoff according to the formula:

$$S = RO/12 \text{ x } C$$

Where: S = spacing of log courses down slope measured horizontally in feet.

RO = Storm runoff in inches.
C = Basin capacity in cubic feet/lineal foot of log.

Basins were created behind each log by scraping soil against the log to seal it. Earthen end sills and baffles complete the structure. To contain 1.0 inch (25 mm) of runoff typically requires spacing of less than 20 feet (9.6 m) between courses. Contour placement is vital, and eliminating long, uninterrupted flow paths by "brick coursing" provides additional effectiveness. The treatments detain storm runoff on site, thereby eliminating transport of eroded soils. If the design capacity is exceeded, the structure provides some secondary benefit by reducing slope length, which interrupts concentrated flows and sediment movement. Because of their small size, the effective life of properly installed treatments is only a few years at most. Undesigned and underdesigned treatments with wide spacing and lacking runoff storage capacity can effectively concentrate runoff and cause damage that might conceivably be greater than no treatment. In high rainfall areas of the West Coast, contour log basins may be infeasible. In these cases, contour logs are placed in the same manner as above, but the exception is that they will provide only secondary benefits. It should be kept in mind that these structures are intended to detain runoff. If they immediately fill with sediment, they were likely underdesigned.

Shallow, rocky soils that are uneven are problematic for anchoring, so care must be taken to ensure that logs are adequately secured to the slope. Overly rocky and steep slopes should be avoided because benefits gained from contour-felling treatment can be easily offset by the extra implementation time required and the limited capacity to detain runoff or provide stabilization of small amounts of soil. Gentler slopes and finer textured soils (except clayey soils) lead to better installation and greater runoff control efficiency. In highly erosive soils derived from parent material such as granitics or glacial till, so much sediment can be mobilized that it might overwhelm small contour-felled logs. Availability of adequate numbers of straight trees must be considered when choosing this treatment.

**Straw Wattles**—Straw wattles main purpose is to break up slope length and reduce flow velocities of concentrated flow. Straw wattles are 9 to 10 inches (23 to 25 cm) in diameter and made of nylon mesh tubes filled with straw. They are permeable barriers used to detain surface runoff long enough to reduce flow velocity and provide for sediment storage. With end sills, baffles, and on the proper design spacing, straw wattles can provide runoff detention.

Straw wattles have been used in small, first order, drainages or on side slopes for detaining small amounts of sediment. They should never be placed in main or active drainages. Straw wattles function similarly to contour-felled logs. The sediment holding capacity can be increased by turning 2 feet at each end of the wattle upslope. Straw wattles are a good alternative in burned areas where logs are absent, poorly shaped, or scarce. Straw wattles are relatively inexpensive, but they can be disturbed by grazing animals or decompose or catch fire. Although the wattle netting is photodegradable, there are concerns that it persists long enough to pose hazards for small animals.

**Contour Trenching and Terraces**—Full-scale contour trenches are designed to totally detain the runoff from a design storm on site. The treatment must progress from the top of the slope downward as each trench course is dependent on the next one upslope. Smaller "outside" trenches can be constructed on slopes less than 30 percent. For slopes greater than 30 percent an "inside" trench must be built. This requires building a "full bench" platform for bulldozers to operate on. In subsequent passes, the trench is tipped into the slope, forming a basin. On the final pass, bulldozers back out and push up baffles that segment the trench and allow flows to equalize into other cells. The formula for digging trenches is:

$$S = RO/12 \times C$$

Where: S = spacing of trench courses down slope measured horizontally in feet.

RO = Storm runoff in inches.

C = Basin capacity in cubic feet/lineal foot of trench.

The practical upper limit of capacity is about 3 inches (76 mm) of runoff. Contour trenches require a minimum of 4 feet (1.2 m) of soil above bedrock for adequate construction. They work best in gravelly loams and have been applied in granitic soils and clay soils with less success (Schmidt Personal Communication 2004). Granitic soils do not maintain a structural shape well because of their coarseness and difficulty to get regenerated with cover. Clay soils can become plastic with the addition of water, and in landslide-prone topography, contour trenches can activate localized mass failures. Contour trenching has proven to be effective in a number of localities in the past, but concerns about visual effects and cultural heritage values have limited their use in the past three decades.

More recently, smaller scale contour trenches have been used to break up the slope surface, to slow runoff, to allow infiltration, and to trap sediment. These trenches or terraces are often used in conjunction with other treatments such as seeding. They can be constructed with machinery (deeper trenches) or by hand (generally shallow). Width and depth vary with design storm, spacing, soil type, and slope. When installed with heavy equipment, trenches may result in considerable soil disturbance that can create immediate erosion problems. In addition, erosion problems can occur many years after installation when runoff cuts through the trench embankment. Trenches have high visual impact when used in open areas. Shallow hand trenches tend to disappear with time as they are filled with sediment and covered by vegetation. On the other hand, large trenches installed several decades ago are still visible on the landscape. Because contour trenching and terraces are ground-disturbing activities, cultural clearances are required, and these may significantly slow the installation process.

**Scarification and Ripping**—Scarification and ripping are mechanical soil treatments aimed at improving infiltration rates in water repellent soils. Tractors and ATVs can be used to pull shallow harrows on slopes of 20 percent or less. Hand scarification uses steel rakes (McLeods). These treatments may increase the amount of macropore space in soils by the physical

United States
Department
of Agriculture

Forest Service

**Rocky Mountain
Research Station**

General Technical
Report RMRS-GTR-42-
volume 4

September 2005

# Wildland Fire in Ecosystems

## Effects of Fire on Soil and Water

# Abstract

Neary, Daniel G.; Ryan, Kevin C.; DeBano, Leonard F., eds. 2005. **Wildland fire in ecosystems: effects of fire on soils and water**. Gen. Tech. Rep. RMRS-GTR-42-vol.4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p.

This state-of-knowledge review about the effects of fire on soils and water can assist land and fire managers with information on the physical, chemical, and biological effects of fire needed to successfully conduct ecosystem management, and effectively inform others about the role and impacts of wildland fire. Chapter topics include the soil resource, soil physical properties and fire, soil chemistry effects, soil biology responses, the hydrologic cycle and water resources, water quality, aquatic biology, fire effects on wetland and riparian systems, fire effects models, and watershed rehabilitation.

**Keywords**: ecosystem, fire effects, fire regime, fire severity, soil, water, watersheds, rehabilitation, soil properties, hydrology, hydrologic cycle, soil chemistry, soil biology, fire effects models

The larger bold check-mark boxes indicate the volumes in “The Rainbow Series” currently published. To order, check any box or boxes below, fill in the address form, and send to the mailing address listed below. Or send your order and your address in mailing label form to one of the other listed media.

☐ RMRS-GTR-42-vol. 1. **Wildland fire in ecosystems: effects of fire on fauna**.

☐ RMRS-GTR-42-vol. 2. **Wildland fire in ecosystems: effects of fire on flora**.

☐ RMRS-GTR-42-vol. 3. **Wildland fire in ecosystems: effects of fire on cultural resources and archeology**.

☐ RMRS-GTR-42-vol. 4. **Wildland fire in ecosystems: effects of fire on soil and water**.

☐ RMRS-GTR-42-vol. 5. **Wildland fire in ecosystems: effects of fire on air**.

**Send to**: ____________________
Name

____________________
Address

***Cover photo***—Left photo: Wildfire encroaching on a riparian area, Montana, 2002. (Photo courtesy of the Bureau of Land Management, National Interagency Fire Center, Image Portal); Right photo: BAER team member, Norm Ambos, Tonto National Forest, testing for water repellancy, Coon Creek Fire 2002, Sierra Ancha Experimental Forest, Arizona.