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Evaluating the Effectiveness of Postfire Rehabilitation Treatments

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Abstract

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Spending on postfire emergency watershed rehabilitation has increased during the past decade. A west-wide evaluation of USDA Forest Service burned area emergency rehabilitation (BAER) treatment effectiveness was undertaken as a joint project by USDA Forest Service Research and National Forest System staffs. This evaluation covers 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 study found that spending on rehabilitation has increased to over $48 million during the past decade because the perceived threat of debris flows and floods has increased where fires are closer to the wildland-urban interface. Existing literature on treatment effectiveness is limited, thus making treatment comparisons difficult. The amount of protection provided by any treatment is small. Of the available treatments, contour-felled logs show promise as an effective hillslope treatment because they provide some immediate watershed protection, especially during the first postfire year. Seeding has a low probability of reducing the first season erosion because most of the benefits of the seeded grass occurs after the initial damaging runoff events. To reduce road failures, treatments such as properly spaced rolling dips, water bars, and culvert reliefs can move water past the road prism. Channel treatments such as straw bale check dams should be used sparingly because onsite erosion control is more effective than offsite sediment storage in channels in reducing sedimentation from burned watersheds. From this review, we recommend increased treatment effectiveness monitoring at the hillslope and sub-catchment scale, streamlined postfire data collection needs, increased training on evaluation postfire watershed conditions, and development of an easily accessible knowledge base of BAER techniques.

Keywords: burn severity, erosion control, BAER, burned area emergency rehabilitation, mitigation, seeding, monitoring.

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Introduction

Recent large, high severity fires coupled with subsequent major hydrological events have generated renewed interest in the linkage between fire and onsite and downstream effects. 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 1900's, has 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). High severity fires are of particular concern because they can affect soil productivity, watershed response, and downstream sedimentation, causing threats to human life and property. During severe fire seasons, the USDA Forest Service and other 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.

USDA Forest Service Burn Area Emergency Rehabilitation (BAER) History

The first formal reports on emergency watershed rehabilitation after wildfires were prepared in the 1960's and early 1970's, although postfire seeding with grasses and other herbaceous species was conducted in many areas in the 1930's, 1940's and 1950's (Christ 1934, Gleason 1947). Contour furrowing and trenching were used when flood control was a major concern (DeByle 1970b, Noble 1965). No formal emergency rehabilitation program existed, and funds for watershed rehabilitation were obtained from fire suppression accounts, emergency flood control programs, or appropriated watershed restoration accounts. In response to a Congressional inquiry on fiscal accountability, in 1974 a formal authority for postfire rehabilitation activities was provided in the Interior and Related Agencies appropriation. This BAER authority integrated the evaluation of fire severity, funding request procedures, and treatment options.

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. On several occasions inappropriate requests were made for nonemergency items, and clarifications were issued that defined real emergency situations warranting rehabilitation treatments. Policies were incorporated into the Forest Service Manual (FSM 2523) and the BAER Handbook (FSH 2509.13) that required an immediate assessment of site conditions following wildfire and, where necessary, implementation of emergency rehabilitation measures to: (1) minimize the threat to life and property onsite or offsite; (2) reduce the loss of soil and onsite productivity; (3) reduce the loss of control of water; and (4) reduce deterioration of water quality. A concerted effort was made to train BAER team leaders, and regional and national BAER training programs became more frequent. At the same time, debates arose over the effectiveness of grass seeding and its negative impacts on natural regeneration. Seeding was still the most widely used treatment, though often applied in conjunction with other hillslope treatments, such as contour-felled logs, and channel treatments, including straw bale check dams. National Forest specialists were encouraged to do implementation monitoring of treatment establishment, as well as some form of effectiveness monitoring of treatment performance, using regular watershed appropriation funds.

In the mid 1990's, 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 bulk of 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 caused rehabilitation expenditures to escalate. During the busy 1996 fire season, for example, the Forest Service spent $11 million on BAER projects.

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

Also in the late 1990's, a program was initiated to integrate national BAER policies across different Federal agencies, as each agency interpreted BAER funding differently. The U.S. Department of Agriculture and Department of the Interior approved a joint policy for a consistent approach to BAER 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; and (4) preventing unacceptable degradation of critical known cultural sites and natural resources. These changes affect the Forest Service, the Bureau of Land Management, the National Park Service, the Fish and Wildlife Service, and the Bureau of Indian Affairs.

Problem Statement and Objectives

In spite of the improvements in the BAER process and the wealth of practical experience obtained over the last several decades, the effectiveness of many emergency rehabilitation methods has not been systematically tested or validated. BAER team leaders and decisionmakers often do not have information available to thoroughly evaluate the short- and long-term benefits (and costs) of various treatment options.

In 1998, at the request of and funded by the USDA Forest Service Washington office Watershed and Air staff, a joint study was initiated by the USDA Forest Service Rocky Mountain Research Station and the Pacific Southwest Research Station to evaluate the use and effectiveness of postfire emergency rehabilitation methods. The objectives of the study were to: (1) evaluate the effectiveness of rehabilitation treatments at reducing postfire erosion, runoff, or other effects; (2) assess the effectiveness of rehabilitation treatments in mitigating 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 in terms of relative benefits, and how they compare 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; and (7) identify information gaps needing further research and evaluation.

The study collected and analyzed information on past use of BAER treatments. Specifically, we sought to determine attributes and conditions that led to treatment success or failure, and the effectiveness of treatments in achieving BAER goals. Because much of the information was unpublished and qualitative in nature, resource specialists were interviewed regarding their BAER activity experiences.

This report is divided into six major sections: (1) a review of published literature on fire effects and BAER treatments; (2) information acquisition and analysis methods; (3) description of results, which include hydrologic, erosion and risk assessments, monitoring reports, and treatment evaluations; (4) discussion of BAER assessments and treatment effectiveness; (5) conclusions drawn from the analysis; and (6) recommendations.

Definitions

The literature of emergency watershed rehabilitation contains may terms from hydrological, ecological and fire science disciplines. For clarity the terms used in this manuscript are defined below.

Aerial Seeding: See **Seeding**.

Allelopathy: Inhibition of competing plant growth by exudation of naturally produced, phytotoxic biochemicals.

Annuals (Annual Plants): Plant that completes its growth and life cycle in one growing season.

Ash-bed Effect: Stimulation of plant growth caused by the sudden availability of fire-mineralized plant nutrients contained in ash residues from a fire.

Armored Ford Crossing: Road crossing of a perennial or ephemeral stream at or near the existing cross-section gradient that is generally constructed of large rocks capable of bearing the weight of the vehicles and resisting transport by the stream.

Armoring: Protective covering, such as rocks, vegetation or engineering materials used to protect stream banks, fill or cut slopes, or drainage structure outflows from flowing water.

BAER: Burned Area Emergency Rehabilitation.

Best Management Practices: Preferred activities which minimize impacts on soil, water, and other resources.

Broadcast seeding: See **Seeding**.

Burn Severity: Qualitative and quantitative measure of the effects of fire onsite resources such as soil and vegetation. Fire intensity contributes to severity but does not alone define it.

Chaparral: Shrub-dominated evergreen vegetation type abundant in low- to mid-level elevations in California and the Southwest.

Channel Clearing: Removal of woody debris from channels by heavy equipment or cable yarding.

Channel Loading: Sediment inputs into ephemeral or perennial stream channels.

Check Dam: Small structure in zero or first order channels made of rocks, logs, plant materials, or geotextile fabric designed to stabilize the channel gradient and store a small amount of sediment.

Contour-Felled Logs: System for detaining runoff and sediment on slopes by felling standing timber (snags) along the contour, delimbing and anchoring the logs, and backfilling to create small detention basins. Also known as contour-felling, contour log terraces, log erosion barriers (LEBs). In some regions, contour-felling describes only felling the standing timber in the direction of the contour but not anchoring or backfilling.

Contour Furrowing: See **Contour Trenching**.

Contour Trenching: Construction of trenches on slope contours to detain water and sediment transported by water or gravity downslope generally constructed with light equipment. These are also known as contour terraces or contour furrowing.

Cross Drain: A ditch relief culvert or other structure or shaping of a road surface designed to capture and remove surface water flow.

Culvert Overflow: Specially designed sections of roadway that allow for overflow of relief culverts or cross-drain culverts without compromising the integrity of the road surface.

Culvert Riser: Vertical extension of culvert on the uphill side to create a small pond for detaining sediment.

Culvert Upgrading: Replacing existing culverts with large diameter ones. May also include armoring of inlet and outlet areas.

Debris Avalanche: Mass failure of variably sized slope segments characterized by the rapid downhill movement of soil and underlying geologic parent material.

Debris Basin: Specially engineered and constructed basin for storing large amounts of sediment moving in an ephemeral stream channel.

Debris Clearing: See **Channel Clearing**.

Design Storm: Estimate of rainfall amount and duration over a particular drainage area. Often used in conjunction with the design storm return period, which is the average number of years within which a given hydrological event is equaled or exceeded (i.e., 5-year return period).

Ditch Maintenance: Various maintenance activities to maintain or restore the capacity of ditches to transport water. Activities include sediment and woody debris removal, reshaping, and armoring.

Dry Ravel: Downhill movement of loose soil and rock material under the influence of gravity and freeze-thaw processes.

Ephemeral Stream or Channel: Drainage way which carries surface water flow only after storm events or snow melt.

Energy Dissipater: Rock, concrete, or impervious material structure which absorbs and reduces the impact of falling water.

Erosion: Detachment and transport of mineral soil particles by water, wind, or gravity

Fire Intensity: Rate at which fire is producing thermal energy in the fuel-climate environment in terms of temperature, heat yield per unit mass of fuel, and heat load per unit area.

Fire Severity: See **Burn Severity**.

Forb: Herbaceous plant other than grasses or grass-like plants.

Gabion: A woven galvanized wire basket sometimes lined with geotextiles and filled with rock, stacked or placed to form an erosion resistant structure.

Geotextile (Geowebbing): Fabric, mesh, net, etc. made of woven synthetic or natural materials used to separate soil from engineering material (rocks) and add strength to a structure.

Grade Stabilizer: Structure made of rocks, logs, or plant material installed in ephemeral channels at the grade of the channel to prevent downcutting.

Ground Seeding: See **Seeding**.

Hand Trenching: Contour trenching done manually rather than mechanically.

Hydrophobic Soil: See **Water Repellency**.

In-channel Felling: Felling of snags and trees into stream channel to provide additional woody debris for trapping sediment.

Infiltration: Movement of rainfall into litter and the soil mantle.

Lateral Keying: Construction or insertion of log or rock check dam 1.5 to 3 ft (0.4 to 1.0 m) into stream or ephemeral channel banks.

Log Check Dam: See **Check Dam**.

Log Erosion Barriers (LEBS): see **Contour-Felled Logs**.

Log Terraces: See **Contour-Felled Logs**.

Mass Wasting: Movement of large amounts of soil and geologic material downslope by debris avalanches, soil creep, or rotational slumps.

Mg ha^{-1}: Metric ton per hectare or megagram per hectare, equivalent to 0.45 tons per acre (0.45 t ac^{-1}).

Monitoring: The collection of information to determine effects of resource management or specific treatments, used to identify changing conditions or needs.

Monitoring, Compliance: Monitoring done to assure compliance with Best Management Practices.

Monitoring, Effectiveness: Monitoring done to determine the effectiveness of a treatment in accomplishing the desired effect.

Monitoring, Implementation: Monitoring done to verify installation of treatment was accomplished as specified in installation instruction documents.

Mulch: Shredded woody organic material, grass, or grain stalks applied to the soil surface to protect mineral soil from raindrop impact and overland flow.

Mychorrhizae: Fungi which symbiotically function with plant roots to take up water and nutrients, thereby greatly expanding plant root systems.

Outsloping: Shaping a road surface to deflect water perpendicular to the traveled way rather than parallel to it.

Peakflow: Maximum flow during storm or snow melt runoff for a given channel.

Perennials (Perennial Plants): Plants that continue to grow from one growing season to the next.

Perennial Stream and Channel: Drainage ways in which flow persists throughout the year with no dry periods.

Plant Cover: Percentage of the ground surface area occupied by living plants.

Plant Species Richness: Number of plant species per unit area.

Ravel: See **Dry Ravel**.

Re-bar: Steel reinforcing bar, available in various diameters, used to strengthen concrete or anchor straw bales and wattles.

Regreen: Commercially available sterile wheatgrass hybrid used to stabilize slopes immediately after a fire but not interfere with subsequent native plant recovery.

Relief Culvert: Conduit buried beneath road surface to relieve drainage in longitudinal ditch at the toe of a cut slope.

Return Interval: Probabilistic interval for recurrence (1, 2, 5, 10, 20, 50, 100 years etc.) of stormflow, rainfall amount or rainfall intensity.

Rill: Concentrated water flow path, generally formed on the surface of bare soil.

Riparian Area: Area alongside perennial or ephemeral stream that is influenced by the presence of shallow groundwater.

Ripping: See **Tilling**.

Risk: The chance of failure.

Rock Cage Dam: See **Gabion or Check Dam**.

Rolling Dip: Grade reversal designed into a road to move water off of short slope section rather than down long segment.

Rotational Slump: Slope failure characterized rotation of the soil mass to a lower angle of repose.

Runoff: Movement of water across surface areas of a watershed during rainfall or snowmelt events.

Sediment: Deposition of soil eroded and transported from locations higher in the watershed.

Sedimentation: Deposition of water, wind, or gravity entrained soil and sediment in surface depressions, side slopes, channel bottoms, channel banks, alluvial flats, terraces, fans, lake bottoms, etc.

Sediment Trap Efficiency: Percent of contour-felled log length showing accumulated sediment relative to available length of log. Or percent of sediment accumulated behind logs relative to available storage capacity of the logs. Or percent of sediment stored behind logs relative to sediment that was not trapped and moved to the base of a hillslope.

Sediment Yield (Production): Amount of sediment loss off of unit area over unit time period usually expressed as tons ac^{-1} yr^{-1} or Mg ha^{-1} yr^{-1}.

Seeding: Application of plant seed to slopes by aircraft (Aerial Seeding or Broadcast Seeding), or by ground equipment or manually (Ground Seeding).

Silt Fence: Finely woven fabric material used to detain water and sediments.

Slash Spreading: Dispersal of accumulations of branches and foliage over wider areas.

Slope Creep: Slow, downhill movement of soil material under the influence of gravity.

Soil/Site Productivity: Capability of a soil type or site to produce plant and animal biomass in a given amount of time.

Soil Wettability: See **Water Repellency**.

Storm Duration: Length of time that a precipitation event lasts.

Storm Magnitude: Relative size of precipitation event.

Storm Patrol: Checking and cleaning culvert inlets to prevent blockage during storm runoff.

Straw Bale Check dam: Check dam made of straw or hay bales often stacked to provide additional storage capacity. Designed to store sediment and/or prevent downcutting.

Straw Wattle: Woven mesh netting (1 ft diameter by 6 to 20 ft in length, 0.3 m diameter by 1.8 m to 6.1 m in length) filled with straw or hay and sometimes seed mixes, used to trap sediment and promote infiltration.

Stream Bank Armoring: Reinforcing of streambank with rock, concrete, or other material to reduce bank cutting and erosion.

Streamflow: Movement of water in a drainage channel.

Temporary Fencing: Fencing installed on a grazing allotment or other unit to keep cattle or native ungulates out of burned area.

Terracette: See **Contour-Felled Logs**.

Tilling: Mechanical turning of the soil with a plow or ripping device. Often used to promote soil infiltration by breaking up water repellent soil layers.

Trash Rack: Barrier placed upstream of a culvert to prevent woody debris from becoming jammed into the inlet.

Ungulate: Herbivorous animals with hooves, e.g., cow, elk, deer, horses, etc.

Water Bar: Combination of ditch and berm installed perpendicular or skew to road or trail centerline to facilitate drainage of surface water; sometimes nondriveable and used to close a road.

Water Repellency: Tendency of soil to form a hydrophobic (water resistant) layer during fire that subsequently prevents infiltration and percolation of water into the soil mantle.

Watershed: An area or region bounded peripherally by ridges or divides such that all precipitation falling in the area contributes to its watercourse.

Water Yield: Total runoff from a drainage basin.

Literature Review

Our evaluation of BAER treatment effectiveness began with the published scientific literature. The general effects of fire on Western forested landscapes are well documented (Agee 1993, DeBano and others 1998, Kozlowski and Ahlgren 1974). Conversely, many of the processes addressed by BAER treatments have not been extensively studied, and relatively little information has been published about most emergency rehabilitation treatments with the exception of grass seeding. To put BAER treatment effectiveness into ecosystem context, we summarize the scientific literature on postfire conditions that are relevant to BAER evaluations. Then we examine published studies on specific BAER treatments.

Fire's Impact on Ecosystems

All disturbances produce impacts on ecosystems. The level and direction of impact (negative or positive) depends on ecosystem resistance and resilience, as well as on the severity of the disturbance. The variability in resource damage and response from site to site and ecosystem to ecosystem is highly dependent on burn or fire severity.

Burn severity (fire severity) is a qualitative measure of the effects of fire onsite resources (Hartford and Frandsen 1992, Ryan and Noste 1983). As a physical-chemical process, fire produces a spectrum of effects that depend on interactions of energy release (intensity), duration, fuel loading and combustion, vegetation type, climate, topography, soil, and area burned.

Fire intensity is an integral part of burn severity, and the terms are often incorrectly used synonymously. Intensity refers to the rate at which a fire is producing thermal energy in the fuel-climate environment (DeBano and others 1998). Intensity is measured in terms of temperature and heat yield. Surface temperatures can range from 120 to greater than 2,730 °F (50 to greater than 1,500 °C). Heat yields per unit area can be as little as 59 BTU ft^{-2} (260 kg-cal m^{-2}) in short, dead grass to as high as 3700 BTU ft^{-2} (10,000 kg-cal m^{-2}) in heavy logging slash (Pyne and others 1996). Rate of spread is an index of fire duration and can vary from 1.6 ft $week^{-1}$ (0.5 m $week^{-1}$) in smoldering peat fires to as much as 15 mi hr^{-1} (25 km hr^{-1}) in catastrophic wildfires.

The component of burn severity that results in the most damage to soils and watersheds, and hence ecosystem stability, is duration. Fast moving fires in fine fuels, such as grass, may be intense in terms of energy release per unit area, but do not transfer the same amounts of heat to the forest floor, mineral soil, or soil organisms as do slow moving fires in moderate to heavy fuels. The impacts of slow moving, low or high intensity fires on soils are much more severe and complex. The temperature gradients that develop can be described with a linked-heat transfer model (Campbell and others 1995) and are a function of moisture and fuel loadings.

Some aspects of burn severity can be quantified, but burn severity cannot be expressed as a single quantitative measure that relates to resource impact. Therefore, relative magnitudes of burn or fire severity, expressed in terms of the postfire appearance of litter and soil (Ryan and Noste 1983), are better criteria for placing burn or fire severity into broadly defined, discrete classes, ranging from low to high. A general burn severity classification developed by Hungerford (1996) relates burn severity to the soil resource response (table 1).

Fire Effects on Watersheds—Soils, vegetation, and litter are critical to the functioning of hydrologic processes. Watersheds with good hydrologic conditions and adequate rainfall sustain stream baseflow conditions for much or all of the year and produce little sediment. With good hydrologic condition (greater than 75 percent of the ground covered with vegetation and litter), only about 2 percent or less of rainfall becomes surface runoff, and erosion is low (Bailey and Copeland 1961). When site disturbances, such as severe fire, produce hydrologic conditions that are poor (less than 10 percent of the ground surface covered with plants and litter), surface runoff can increase over 70 percent and erosion can increase by three orders of magnitude.

Within a watershed, sediment and water responses to wildfire are often a function of burn severity and the

Table 1—Burn severity classification based on postfire appearances of litter and soil and soil temperature profiles (Hungerford 1996, DeBano et al. 1998).

	Burn Severity		
Soil and Litter Parameter	**Low**	**Moderate**	**High**
Litter	Scorched, Charred, Consumed	Consumed	Consumed
Duff	Intact, Surface Char	Deep Char, Consumed	Consumed
Woody Debris - Small	Partly Consumed, Charred	Consumed	Consumed
Woody Debris - Logs	Charred	Charred	Consumed, Deeply Charred
Ash Color	Black	Light Colored	Reddish, Orange
Mineral Soil	Not Changed	Not Changed	Altered Structure, Porosity, etc
Soil Temp. at 0.4 in (10 mm)	<120 °F (<50 °C)	210-390 °F (100-200 °C)	>480 °F (>250 °C)
Soil Organism Lethal Temp.	To 0.4 in (10 mm)	To 2 in (50 mm)	To 6 in (160 mm)

occurrence of hydrologic events. For a wide range of burn severities, the impacts on hydrology and sediment loss can be minimal in the absence of precipitation. However, when a precipitation event follows a large, moderate- to high-burn severity fire, impacts can be far reaching. Increased runoff, peakflows, and sediment delivery to streams can affect fish populations and their habitat (Rinne 1996).

Fire can destroy accumulated forest floor material and vegetation, altering infiltration by exposing soils to raindrop impact or creating water repellent conditions (DeBano and others 1998). Loss of soil from hillslopes produces several significant ecosystem impacts. Soil movement into streams, lakes, and riparian zones may degrade water quality and change the geomorphic and hydrologic characteristics of these systems. Soil loss from hillslopes may reduce site productivity.

Total water yields across the Western United States vary considerably depending on precipitation, evapotranspiration (ET), soil, and vegetation. The magnitude of measured increases in water yield the first year after fire can vary greatly within a location or between locations depending on fire severity, climate, precipitation, geology, soils, topography, vegetation type, and proportion of the vegetation burned. Because increases in water yield are primarily due to elimination of plant cover, with subsequent reductions in the transpiration component of ET, flow increases are greater in humid ecosystems with high prefire ET (Anderson and others 1976). Elevated streamflow declines through time as woody and herbaceous vegetation regrow, with this recovery period ranging from a few years to decades.

Increases in annual water yield after wildfires and prescribed fires are highly variable (table 2). Hibbert and others (1982) reported a 12 percent increase in water yield after prescribed fire in an Arizona pinyon-juniper forest. A wildfire in the mostly ponderosa pine Entiat watershed in Washington produced a 42 percent increase in water yield the first postfire year (Helvey 1980). The first-year increase in water yield after a prescribed burn in a Texas grassland was 1,150 percent of the unburned control watershed, but the increase over the control was only 400 percent where a rehabilitation treatment (seeding) was done after the fire (Wright and others 1982). Seeding also shortened the recovery period from 5 to 2 years. In Arizona chaparral burned by wildfire, the first-year water yield increase exceeded 1,400 percent (Hibbert 1971). Where soil wettability becomes a problem, water yield increases can be very high due to greater stormflows.

The effects of fire disturbance on storm peakflows are highly variable and complex. They can produce some of the most profound watershed and riparian impacts that forest managers have to consider. Intense short duration storms that are characterized by high rainfall intensity and low volume have been associated with high stream peakflows and significant erosion events after fires (Neary and others 1999). In the Intermountain West, high intensity, short duration rainfall is relatively common (Farmer and Fletcher 1972). Five minute rainfall rates of 8.4 to 9.2 in hr^{-1} (213 and 235 mm hr^{-1}) have been associated with

Table 2—Effects of prescribed fires and wildfires on water yield based in different vegetation types.

Location	Precipitation		Flow		Flow Added	Recovery Period	Reference
	(*in*)	(*mm*)	(*in*)	(*mm*)	(%)	(*years*)	
Douglas-fir, OR	98	2480					Bosch and Hewlett 1982
Control			74	1890	—	—	
Cut 82%, Burned			88	2230	20	>5	
Douglas-fir, OR	94	2390					Bosch and Hewlett 1982
Control			54	1380	—	—	
Cut 100%, Burned			72	1840	34	>5	
Ponderosa Pine/Douglas-fir, WA	23	580					Helvey 1980
Control (Preburn)			9	220	—	—	
Wildfire (Postburn)			12	315	42	?	
Chaparral, AZ	29	740					Davis 1984
Control			3	75	—	—	
Prescribed Fire			6	155	144	>11	
Chaparral, AZ	23	580					Hibbert and others 1982
Control			3	75	—	—	
Wildfire			5	130	59	?	
Chaparral, AZ	26	655					Hibbert 1971
Control			0	0	—	—	
Wildfire			5	125	>99	>9	
Control			0.7	20	—	—	
Wildfire			11	290	1421	>9	
Pinyon-Juniper, AZ	19	480					Hibbert and others 1982
Control			1	25	—	—	
Prescribed Fire			1.5	40	12	5	
Juniper-Grass, TX	26	660					Wright and others 1982
Control			0.1	2	—	—	
Prescribed Fire			1	25	1150	5	
Rx Fire, Seeded			0.4	10	400	2	
Aspen-Mixed Conifer							Bosch and Hewlett 1982
Control			6	155	—	—	
Wildfire			8	190	22	5	

peakflows from recently burned areas that were increased 556 percent above that for adjacent areas (Croft and Marston 1950). Anderson and others (1976) produced a good review of peakflow response to disturbance (table 3). Wildfires generally increase peakflows. Peakflow increases of 500 to 9,600 percent are common in the Southwest, while those measured in the Cascade region are much lower (Anderson and others 1976). For example, the Tillamook burn in 1933 in Oregon increased the total annual flow of two watersheds by 9 percent and increased the annual peakflow by 45 percent (Anderson and others 1976). A 310 ac (127 ha) wildfire in Arizona increased summer peakflows by 500 to 1,500 percent, but had no effect on winter peakflows. Another wildfire in Arizona produced a peakflow 58 times greater than an unburned watershed during record autumn rainfalls. Peakflow increases following wildfires in Arizona chaparral of up to 45,000 percent have been reported (Glendening and others 1961). Watersheds in the Southwest are prone to these enormous peakflow responses because of climatic, topographic, and soil conditions. These include intense monsoon rainfalls common in that region at the end of the spring fire season; steep terrain; shallow, skeletal soils; and water repellency, which often develops in soils under chaparral vegetation. Recovery times can range from years to many decades. Studies have shown both increases (+35 percent) and decreases (–50 percent) in snowmelt peakflows following fires (Anderson and others 1976).

Burned watersheds generally respond to rainfall faster than unburned watersheds, producing more “flash floods” (Anderson and others 1976). Water repellent soils and cover loss will cause flood peaks to arrive faster, rise to higher levels, and entrain significantly greater amounts of bedload and suspended sediments. Flood warning times are reduced by “flashy” flow, and the high flood levels can be devastating to property and human life. Although these concepts of stormflow timing are well-understood within the context of wildland

Table 3—Effects of harvesting and fire on peakflows in different habitat types (from Anderson and others 1976).

Location	Treatment	Other Information	Peakflow Change
			(%)
Douglas-fir, OR	Clearcut	Fall Storms	+90
	Clearcut	Winter Storms	+28
Douglas-fir, OR	Clearcut, 100% Burn		+30
	Clearcut, 50% Burn		+11
Douglas-fir, OR	Wildfire		+45
Chaparral, CA	Wildfire		+2282
Chaparral, AZ	Wildfire	Summer Flows	+500
	Wildfire	Summer Flows	+1500
	Wildfire	Winter Flows	0
Chaparral, AZ	Wildfire	Fall Flows	+5800
Ponderosa Pine, AZ	Wildfire	Summer Flows	+9605
Mixed Conifer, AZ	Wildfire (Rich 1962)	Low Summer Flow	+1521
	Wildfire (Rich 1962)	Inter. Summer Flow	+526
	Wildfire (Rich 1962)	High Summer Flow	+960
Aspen-Conifer, CO	Clearcut,		100%

hydrology, some studies have confounded results because of the combined changes in volume, peak and timing at different locations in the watershed, and the severity and size of the disturbance in relation to the size of watershed (Brooks and others 1997).

Water Quality—Increases in streamflow after fire can result in substantial to little effect on the physical and chemical quality of streams and lakes, depending on the size and severity of the fire (DeBano and others 1998). Higher streamflows and velocities result in additional transport of solid and dissolved materials that can adversely affect water quality for human use and damage aquatic habitat. The most obvious effects are produced by suspended and bedload sediments, but substantial changes in anion/cation chemistry can occur.

Undisturbed forest, shrub, and range ecosystems usually have tight cycles for major cations and anions, resulting in low concentrations in streams. Disturbances such as cutting, fires, and insect outbreaks interrupt or temporarily terminate uptake by vegetation and may affect mineralization, microbial activity, nitrification, and decomposition. These processes result in the increased concentration of inorganic ions in soil which can be leached to streams via subsurface flow (DeBano and others 1998). Nutrients carried to streams can increase growth of aquatic plants, reduce the potability of water supplies, and produce toxic effects.

Most attention relative to water quality after fire focuses on nitrate nitrogen (NO_3-N) because it is highly mobile. High NO_3-N levels, in conjunction with phosphorus, can cause eutrophication of lakes and streams. Most studies of forest disturbances show increases in NO_3-N, with herbicides causing the largest increases (Neary and Hornbeck 1994, Tiedemann and others 1978).

Surface Erosion—Surface erosion is the movement of individual soil particles by a force and is usually described by three components: (1) detachment, (2) transport, and (3) deposition. Inherent erosion hazards are defined as site properties that influence the ease which individual soil particles are detached (soil erodibility), slope gradient and slope length. Forces than can initiate and sustain the movement of soil particles include raindrop impact (Farmer and Van Haveren 1971), overland flow (Meeuwig 1971), gravity, wind, and animal activity. Protection is provided by vegetation, surface litter, duff, and rocks that reduce the impact of the applied forces and aid in deposition (Megahan 1986, McNabb and Swanson 1990).

Erosion is a natural process occurring on landscapes at different rates and scales, depending on geology, topography, vegetation, and climate. Natural erosion rates increase as annual precipitation increases (table 4). Landscape disturbing activities such as mechanical site preparation, agriculture, and road construction lead to the greatest erosion, which generally exceeds the upper limit of natural geologic erosion (Neary and Hornbeck 1994). Fires and fire management activities (fireline construction, temporary roads, heli-pad construction, and postfire rehabilitation) can also affect erosion.

Table 4—Natural watershed sediment losses in the USA based on published literature.

Location	Watershed Conditions	Sediment Loss		Reference
		($t\ ac^{-1}$)	*($Mg\ ha^{-1}$)*	
USA	Geologic Erosion			Schumm and Harvey 1982
	Natural Rate, Lower Limit	0.3	0.6	
	Natural Rate, Upper Limit	7	15	
Eastern USA	Forests, Lower Baseline	0.05	0.1	Patric 1976
	Forests, Upper Baseline	0.1	0.2	
Western USA	Forests, Lower Baseline	0.0004	0.001	Biswell and Schultz 1965
	Forests, Upper Baseline	2	6	DeByle and Packer 1972

Sediment yields 1 year after prescribed burns and wildfires range from very low, in flat terrain and in the absence of major rainfall events, to extreme, in steep terrain affected by high intensity thunderstorms (table 5). Erosion on burned areas typically declines in subsequent years as the site stabilizes, but the rate varies depending on burn or fire severity and vegetation recovery. Soil erosion after fires can vary from under 0.4 to 2.6 t ac^{-1} yr^{-1} (0.1 to 6 Mg ha^{-1} yr^{-1}) in prescribed burns and from 0.2 to over 49 t ac^{-1} yr^{-1} (0.01 to over 110 Mg ha^{-1} yr^{-1}) in wildfires (Megahan and Molitor 1975, Noble and Lundeen 1971, Robichaud and Brown 1999) (table 5). For example, Radek (1996) observed erosion of 0.1 to 0.8 t ac^{-1} (0.3 to 1.7 Mg ha^{-1}) from several large wildfires that covered areas ranging from 375 to 4,370 ac (200 to 1,770 ha) in the northern Cascades mountains. Three years after these fire, large erosional events occurred from spring rainstorms, not from snowmelt. Most of the sediment produced did not leave the burned area. Sartz (1953) reported an average soil loss of 1.5 in (37 mm) after a wildfire on a north-facing slope in the Oregon Cascades. Raindrop splash and sheet erosion accounted for the measured soil loss. Annual precipitation was 42 in (1070 mm), with a maximum intensity of 3.5 in hr^{-1} (90 mm hr^{-1}). Vegetation covered the site within 1 year after the burn. Robichaud and Brown (1999) reported first-year erosion rates after a wildfire from 0.5 to 1.1 t ac^{-1} (1.1 to 2.5 Mg ha^{-1}) decreasing by an order of magnitude by the second year, and to no sediment by the fourth, in an unmanaged forest stand in eastern Oregon. DeBano and others (1996) found that following a wildfire in ponderosa pine, sediment yields from a low severity fire recovered to normal levels after 3 years, but moderate and severely burned watersheds took 7 and 14 years, respectively. Nearly all fires increase sediment yield, but wildfires in steep terrain produce the greatest amounts (12 to 165 t ac^{-1}, 28 to 370 Mg ha^{-1}) (table 5). Noble and Lundeen (1971) reported an average annual sediment production rate of 2.5 t ac^{-1} (5.7 Mg ha^{-1}) from a 900 ac (365 ha) burn on steep river breaklands in the South Fork of the Salmon River, Idaho. This rate was approximately seven times greater than hillslope sediment yields from similar, unburned lands in the vicinity.

Sediment Yield and Channel Stability—Fire-related sediment yields vary, depending on fire frequency, climate, vegetation, and geomorphic factors such as topography, geology, and soils (Swanson 1981). In some regions, over 60 percent of the total landscape sediment production over the long-term is fire-related. Much of that sediment loss can occur the first year after a wildfire (Agee 1993, DeBano and others 1996, DeBano and others 1998, Rice 1974, Robichaud and Brown 1999, Wohlgemuth and others 1998). Consequently, BAER treatments that have an impact the first year can be important in minimizing damage to both soil and watershed resources.

After fires, suspended sediment concentrations in streamflow can increase due to the addition of ash and silt-to-clay sized soil particles in streamflow. High turbidity reduces municipal water quality and can adversely affect fish and other aquatic organisms. It is often the most easily visible water quality effect of fires (DeBano and others 1998). Less is known about turbidity than sedimentation in general because it is difficult to measure, highly transient, and extremely variable.

A stable stream channel reflects a dynamic equilibrium between incoming and outgoing sediment and streamflow (Rosgen 1996). Increased erosion after fires can alter this equilibrium by transporting additional sediment into channels (aggradation). However, increased peakflows that result from fires can also produce channel erosion (degradation). Sediment transported from burned areas as a result of increased peakflows can adversely affect aquatic habitat, recreation areas, roads, buildings, bridges, and culverts. Deposition of sediments alters habitat and can fill in lakes and reservoirs (Rinne 1996, Reid 1993).

Mass Wasting—Mass wasting includes slope creep, rotational slumps, debris flows and debris avalanches. Slope creep is usually not a major postfire source of

Table 5—Published first-year sediment losses after prescribed fires and wildfires.

Location	Treatment	Sediment Loss		Reference
		(*t ac*$^{-1}$)	(*Mg ha*$^{-1}$)	
Mixed Conifer, WA	Wildfire	130	300	Sartz 1953
Mixed Conifer, WA	Control	0.01	0.03	Helvey 1980
	Wildfire	1	2	
Mixed Conifer, WA	McCay Wildfire	0.8	2	Radek 1996
	Bannon Wildfire	0.6	1	
	Thunder Mtn. Wildfire		0.2	0.5
	Whiteface Wildfire	0.2	0.3	
Ponderosa Pine, CA	Control	<0.0005	<0.001	Biswell and Schultz 1965
	Prescribed Fire	<0.0005	<0.001	
Chaparral, CA	Control	0.02	0.04	Wells 1981
	Wildfire	13	30	
Chaparral, CA	Control	2	6	Krammes 1960
	Wildfire	25	60	
Chaparral, CA	Control, Steep Slope	0.0009	0.002	DeBano and Conrad 1976
	Rx Fire, Steep Slope	3	7	
	Control, Gentle Slope	0	0	
	Rx Fire, Gentle Slope	1	3	
Chaparral, AZ	Control	0	0	Pase and Lindenmuth 1971
	Prescribed Fire	2	4	
Chaparral, AZ	Control	0.04	0.1	Pase and Ingebo 1965
	Wildfire	13	29	
Chaparral, AZ	Control	0.07	0.2	Glendening and others 1961
	Wildfire	91	204	
Ponderosa Pine, AZ	Control	0.001	0.003	Campbell and others 1977
	Wildfire	0.6	1	
Ponderosa Pine, AZ	Wildfire, Low	0.001	0.003	DeBano and others 1996
	Wildfire, Moderate	0.009	0.02	
	Wildfire, Severe	0.7	1.6	
Mixed Conifer, AZ	Control	<0.0004	<0.001	Hendricks and Johnson 1944
	Wildfire, 43% Slope	32	72	
	Wildfire, 66% Slope	90	200	
	Wildfire, 78% Slope	165	370	
Juniper-Grass, TX	Control	0.03	0.06	Wright and others 1982
	Prescribed Fire	7	15	
	Prescribed Fire, Seed	1	3	
Juniper-Grass, TX	Control	0.006	0.01	Wright and others 1976
	Burn, Level Slope	0.01	0.03	
	Burn, 20% Slope	0.8	2	
	Burn, 54% Slope	4	8	
Larch/Douglas-fir, MT	Control	<0.0004	<0.001	Debyle and Packer 1972
	Slash Burned	0.07	0.2	
Ponderosa-pine/Douglas-fir, ID	Wildfire	4	6	Noble and Lundeen 1971
Ponderosa-pine/Douglas-fir, ID	Clearcut and Wildfire	92	120	Megahan and Molitor 1975
Ponderosa-pine/Douglas-fir, OR	Wildfire, 20% Slope	0.5	1.1	Robichaud and Brown 1999
	Wildfire, 30% Slope	1.0	2.2	
	Wildfire, 60% Slope	1.1	2.5	

sediment. Rotational slumps normally do not move any significant distance. Slumps are only major problems when they occur close to stream channels, but they do expose extensive areas of bare soil on slope surfaces. Debris flows and avalanches are the largest, most dramatic, and main form of mass wasting that delivers sediment to streams (Benda and Cundy 1990). They can range from slow moving earth flows to rapid avalanches of soil, rock, and woody debris. Debris avalanches occur when the mass of soil material and soil water exceed the sheer strength needed to maintain the mass in place. Steep slopes, logging, road construction, heavy rainfall, and fires aggravate debris avalanching potential.

Many fire-associated mass failures are correlated with development of water repellency in soils (DeBano and others 1998). Chaparral vegetation in the Southwestern United States is a high hazard zone because of the tendency to develop water repellent soils. Water repellency also occurs commonly elsewhere in the West after wildfires. Sediment delivery to channels by mass failure can be as much as 50 percent of the total postfire sediment yield. Wildfire in chaparral vegetation in coastal southern California increased debris avalanche sediment delivery from 18 to 4,845 $yd^3 mi^{-2} yr^{-1}$ (7 to 1,910 $m^3 km^{-2} yr^{-1}$) (Wells 1981).

Cannon (1999) describes two types of debris flow initiation mechanisms, infiltration soil slip and surface runoff after wildfires in the Southwestern United States. Of these, surface runoff which increases sediment entrainment was the dominate triggering mechanism.

Dry Ravel—Dry ravel is the gravity-induced downslope surface movement of soil grains, aggregates, and rock material, and is a ubiquitous process in semiarid steepland ecosystems (Anderson and others 1959). Triggered by animal activity, earthquakes, wind, and perhaps thermal grain expansion, dry ravel may best be described as a type of dry grain flow (Wells 1981). Fires greatly alter the physical characteristics of hillside slopes, stripping them of their protective cover of vegetation and organic litter and removing barriers that were trapping sediment. Consequently, during and immediately following fires, large quantities of surface material are liberated and move downslope as dry ravel (Krammes 1960, Rice 1974). Dry ravel can equal or exceed rainfall-induced hillslope erosion after fire in chaparral ecosystems (Krammes 1960, Wohlgemuth and others 1998).

Emergency Watershed Rehabilitation Treatment Effectiveness

Early burned area emergency rehabilitation efforts were principally aimed at controlling erosion. Work 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, shrub, and grass watersheds to control both storm runoff and erosion. Many of these techniques have been refined, improved, and augmented from other disciplines (agriculture, construction) to form the set of BAER treatments in use today.

With the exception of grass seeding, relatively little has been published specifically on the effectiveness and ecosystem impacts of most postfire rehabilitation treatments. We discuss the BAER literature by treatment categories: hillslope, channel, and road treatments. BAER treatments will be categorized in this manner throughout this report.

Hillslope Treatments—Hillslope treatments include grass seeding, contour-felled logs, mulch, and other methods intended to reduce surface runoff and keep postfire soil in place on the hillslope. These treatments are regarded as a first line of defense against postfire sediment movement, preventing subsequent deposition in unwanted areas. Consequently, more research has been published on hillslope treatments than on other methods.

Broadcast Seeding—The most common BAER practice is broadcast seeding of grasses, usually from aircraft. 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, keep soil on hillslopes and out of channels and downstream areas (Miles and others 1989, Noble 1965, Rice and others 1965). Grasses are particularly desirable for this purpose because their extensive, fibrous root systems increase water infiltration and hold soil in place. Fast-growing non-native species have typically been used. They are inexpensive and readily available in large quantities when an emergency arises (Agee 1993, Barro and Conard 1987, Miles and others 1989).

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, non-native species that persist can delay recovery of native flora and potentially alter local plant diversity. More recently BAER teams have recommended nonreproducing annuals, such as cereal grains or sterile hybrids, that provide quick cover and then die out to let native vegetation reoccupy the site.

Chaparral: Chaparral is the shrub-dominated vegetation type abundant in the low to middle elevation foothills in California and the Southwestern States (Cooper 1922, Keeley and Keeley 1988). Chaparral stands are often located on steep slopes, burn with generally high intensity, and typically develop water-repellent soils. They become candidates for postfire seeding due to the threat of increased runoff and sediment movement (Ruby 1989).

Concern over impacts of postfire seeding has focused on chaparral ecosystems because a specialized annual flora takes advantage of the light, space, and soil nutrients available after fire (Keeley and others 1981, Sweeney 1956). Some of the dominant shrub species regenerate after fire only from seed (Keeley 1991, Sampson 1944). Most published research on chaparral comes from California (tables 6 and 7).

Brushfields prone to fire and erosion occur at the urban/wildland interface, where growing population centers in lowland valleys have encroached on foothills and steep mountain fronts. The societal impacts of wildfire and subsequent accelerated erosion in California chaparral are enormous, as are the pressures to treat burned hillsides with grass seed to protect life and property (Arndt 1979, Gibbons 1995).

Foresters in southern California began seeding burned-over slopes with native shrubs in the 1920's. After finding that seeded shrubs emerged no earlier than natural regeneration (Department of Forester and Fire Warden 1985), they experimented with introduced herbaceous species such as Mediterranean mustards in the 1930's and 1940's (Gleason 1947). Mustards proved to be unpopular weeds with downslope orchardists and suburbanites, so other species were tested, including native and non-native subshrubs and non-native grasses (Department of Forester and Fire Warden 1985). By the late 1940's annual ryegrass (*Lolium multiflorum*, also called Italian ryegrass), a native of temperate Europe and Asia, had became the primary species used for postfire seeding. Like mustard, it was inexpensive, could be broadcast easily from aircraft, was available in large quantities, and its fibrous root system appeared effective at stabilizing surface soil (Barro and Conard 1987).

The effectiveness of broadcast grass seeding for erosion control on steep chaparral slopes has been questioned (Conrad 1979), but relatively few data on erosion response exist. The first watershed-scale rehabilitation experiment was set up at the San Dimas Experimental Forest after a wildfire in 1960, including annual and perennial grass seeding. The first winter after the fire was one of the driest on record with negligible grass establishment (Corbett and Green 1965). The treatments were reseeded, and the next year seeded grasses did not affect peak streamflow during four recorded storm events. The high-rate annual grass treatment produced 8 percent grass cover by the time of the last large storm event and resulted in a 16 percent reduction in sediment production over the season (Krammes and Hill 1963). Contour planting of barley, which included hand-hoed rows and fertilization, had the greatest impact on sediment production (Rice and others 1965). All seeded treatments had lower cover of native plants than unseeded controls (Corbett and Green 1965).

Data collected by the California Department of Forestry showed that ryegrass establishment was typically poor in interior southern California and more successful in cooler, northern or coastal locations (Blanford and Gunter 1972). An inverse relationship between ryegrass cover and native herbaceous plant cover was observed, and Blanford and Gunter (1972) felt that more data were needed to properly evaluate the competitive effects of seeded ryegrass on native herbs. Range improvement studies found that high seeded grass cover could reduce shrub seedling density (Schulz and others 1955). Blanford and Gunter (1972) did not observe major failure of shrub regeneration, though no quantitative measurements were made. A general negative relationship between ryegrass cover and erosion was observed using erosion pins. Blanford and Gunter (1972), like Krammes and Hill (1963) and Rice and others (1965), concluded that postfire annual grass seeding was an appropriate rehabilitation method because its low cost made occasional seeding failure an acceptable risk.

Cover or biomass of native chaparral vegetation, especially herbaceous species, tended to be lower on plots with high ryegrass cover, both in operationally seeded areas (Keeley and others 1981, Nadkarni and Odion 1986) and on hand-seeded experimental plots (Gautier 1983, Taskey and others 1989). Native plant species richness was lower on plots containing ryegrass (Nadkarni and Odion 1986, Taskey and others 1989). Gautier (1983) and Taskey and others (1989) found lower density of shrub seedlings, especially species killed by fire, on seeded plots, and warned that long-term chaparral species composition could potentially be affected by grass seeding. Taskey and others (1989) also noted bare areas appearing in seeded plots where ryegrass died out after 3 years, resulting in lower cover than on unseeded plots. These studies suggested that ryegrass grows at the expense of native vegetation.

During a year in which total rainfall was exceptionally high compared to average, Gautier (1983) measured less erosion from plots in which ryegrass seeding increased total plant cover. On the other hand, Taskey and others (1989) found no effect of ryegrass on first-year postfire erosion with average rainfall and

Table 6—Published first-year seeded grass species cover and total plant cover in various ecosystems. Erosion reduction effectiveness is given if it was tested in the study.

Location	Vegetation	Seeded species	Slope	Rate				Cover		Erosion[2]	Source
								Seeded	Total		
			(%)	(lb ac^{-1})	(kg ha^{-1})	(s ft^{-2})	(s m^{-2})	- - - - (%) - - - -			
Otay Mts., So. CA	mixed chaparral	annual ryegrass	44	8.0	9.0			35-80	40-85*	31% less	Gautier 1983
		control	44	0	0			—	20-35		
Santa Lucia Mts., CA	chamise chaparral	annual ryegrass	40-55	13.1	17	37	400	37	71.4*	ns	Taskey and others 1989
		control	40-55	0	0	0	0	—	57.7		
Santa Ana Mts., CA	mixed chaparral	Blando brome	nd[3]	7.5	8.4			3	15-25	—	Conard and others 1995
		Zorro fescue	nd	7.5	8.4			2-5	20-25	—	
		annual ryegrass	nd	7.5	8.4			3-5	18-25	—	
		native forb mix	nd	7.5	8.4			3-8	25	—	
		control	nd	0	0	0	0	—	12-30	—	
Santa Monica Mts., CA	mixed chaparral	annual ryegrass	54	8	9			12	30	ns	Beyers and others 1998a; Wohlgemuth and others 1998
		control	54	0	0	0	0	—	35		
Santa Ana Mts., CA	mixed chaparral	annual ryegrass	65	8	9			5	20	ns	same
		control	65	0	0	0	0	—	20		
Santa Lucia Mts., CA	chamise chaparral	annual ryegrass	52	8	9			2	5*	ns	same
		control	52	0	0	0	0	—	3		
Santa Monica Mts., CA	mixed chaparral	annual ryegrass	49	8	9			5	30	ns	same
		control	49	0	0	0	0	—	35		
Santa Ynez Mts., CA	mixed chaparral	annual ryegrass	63	8	9			12	75	ns	same
		control	63	0	0	0	0	—	75		
Siskiyou Mts., OR —early winter	Douglas-fir	annual ryegrass	40-50	24	27			49	50*	ns	Amaranthus 1989
		control	40-50	0	0	0	0	4	9		
Siskiyou Mts., OR —late spring	Douglas-fir	annual ryegrass	40-50	24	27			85.2	87.1*	ns	
		control	40-50	0	0	0	0	8.2	23.6		
near Loman, ID	Douglas-fir	seed mix[5]	nd	8.21	9.2	48	520	1	14	—	Geier-Hayes 1997
		control	nd	0	0	0	0	—	15		
near Loman, ID	ponderosa pine	seed mix[5]	nd	4.39	4.8	27	292	3	10	—	same
		control	nd						—	11	

(con.)

Table 6 (Con.)

Location	Vegetation	Seeded species	Slope	- - - - - - - - - Rate	- - - - - - - - -			Cover		Erosion[2]	Source
								Seeded	Total		
			(%)	(lb ac^{-1})	(kg ha^{-1})	(s ft^{-2})	(s m^{-2})	- - - - (%)	- - - -		
near Loman, ID	subalpine fir	seed mix[5]	nd	5.36	6	31	334	tr	7	—	same
		control	nd						—	9	
near Greenville, CA	mixed conifer	seed mix[6]	gentle					tr	6	—	Roby 1989
		control							7		
Entiat Exp. Forest, WA	ponderosa pine-Douglas-fir	seed mix[7]	nd	5.89	6.6			3.3	10.3	—	Tiedemann and Klock 1973
		seed mix + fert.	nd	5.89	6.6			1.4, 2	7.5, 10.8	—	
		control	nd	0	0	0	0	tr	5.6		
Snow Basin, OR	pine-mixed fir	seed mix[8]	gentle	10	11.2			12	44*	—	Anderson and Brooks 1975
		control	nd	0	0	0	0	—	12		
Santa Lucia Mts., CA	coulter pine-sugar pine	annual ryegrass	25-65	8	8.96	37	400	5-70	10-75	—	Griffin 1982
		unseeded[4]	nd	0	0	0	0	—	5		

[1] Asterisk (*) next to total cover value indicates that seeded plots had significantly greater total cover than unseeded plots. Statistical significance was not tested in all studies.

[2] For studies in which erosion was measured, "ns" means there was no significant difference between seeded and unseeded plots; if erosion was significantly less, amount of reduction is given.

[3] "nd" indicates no data provided for a given category in the publication.

[4] Unseeded plot was in slightly different area, avoided during seeding because of rare plant concerns.

Seed mixes included:

[5] Intermediate wheatgrass, timothy, orchardgrass, and smooth brome.

[6] Orchardgrass, tall fescue, timothy, slender wheatgrass + fertilizer.

[7] Hard fescue, orchardgrass, perennial ryegrass, timothy, yellow sweetclover.

[8] Intermediate wheatgrass, timothy, hard fescue, legumes.

Table 7—Published second-year seeded grass species cover and total plant cover in various ecosystems. Erosion reduction effectiveness is given if it was tested in the study.

Location	Vegetation	Seeded species	Slope	Rate				Cover		Erosion^2	Source
								Seeded	Total		
			(%)	(lb ac^{-1})	(kg ha^{-1})	(s ft^{-2})	(s m^{-2})	(%)	(%)		
San Gabriel Mts., CA	mix chaparral	annual ryegrass Blando brome	nd^3	20	22.4			9.9	10.3	16% less	Rice and others 1965
		control	0	0	—			7.7			
Santa Ana Mts., CA	mix chaparral	Blando brome	nd^3	7.5	8.4			10-15	40-60	—	Conard and others 1995
		Zorro fescue	nd	7.5	8.4			3-8	45-55	—	
		annual ryegrass	nd	7.5	8.4			5-15	45-60	—	
		native forb mix	nd	7.5	8.4			10-20	45-60	—	
		control	nd	0	0			—	35-50	—	
Santa Monica Mts., CA	mix chaparral	annual ryegrass	54	8	9			4	50	ns	Beyers and others 1998a; Wohlgemuth and others 1998
		control	54	0	0			—	48		
Santa Ana Mts., CA	mix chaparral	annual ryegrass	65	8	9			35	80	ns	same
		control	65	0	0			—	78		
Santa Lucia Mts., CA	chamise chaparral	annual ryegrass	52	8	9			20	55*	ns	same
		control	52	0	0			—	45		
Santa Monica Mts.,CA	mix chaparral	annual ryegrass	49	8	9			25	78	ns	same
		control	49	0	0			—	80		
Santa Ynez Mts., CA	mix chaparral	annual ryegrass	63	8	9			15	65	ns	same
		control	63	0	0			—	70		
Siskiyou Mts., OR	Douglas-fir	annual ryegrass	40-50	24	27			0 live (84 mulch)	91*	—	Amaranthus 1989
		control	40-50	0	0			—	46		
Salmon River, CA	mixed conifer	seed mix^5	64	nd				nd	85*	ns	Van de Water 1998
		control	64	0	0			—	20		
Salmon River, CA	mixed conifer	seed mix^5	82	nd				nd	60*	80% less	same
		control	82	0	0			—	40		
near Loman, ID	Douglas-fir	seed mix^6	nd	8.21	9.2	48	520	8	47	—	Geier-Hayes 1997
		control	nd	0	0			—	47		
near Loman, ID	ponderosa pine	seed mix^6	nd	4.3	4.8	31	334	10	31	—	same
		control	nd					—	48		
near Loman, ID	subalpine fir	seed mix^6	nd	5.3	6			2	31	—	same
		control	nd					—	34		

(con.)

Table 7(Con.)

Location	Vegetation	Seeded species	Slope	Rate				Cover		Erosion[2]	Source
								Seeded	Total		
			(%)	*(lb ac^{-1})*	*(kg ha^{-1})*	*(s ft^{-2})*	*(s m^{-2})*	*(%)*			
near Greenville, CA	mixed conifer	Seed mix[7]	gentle	nd				10	24	ns	Roby 1989
		control		—					27		
Entiat Exp. For, WA	ponderosa pine-Douglas-fir	Seed mix[8]	nd	6.5	6.6			nd	20	—	Tiedemann and Klock 1973
		above mix + fert.	nd	6.5	6.6			nd	17-23	—	
		control	nd	0	0			nd	16		
Snow Basin, OR	pine-mixed fir	Seed mix[9]	nd low	10	11.2			30	57	—	Anderson and Brooks 1975
		control	nd	0	0			—	49		
Santa Lucia Mts., CA	coulter pine-sugar pine	annual ryegrass	25-65	8	9	37	400	30-90	75-95	—	Griffin 1982
		unseeded[4]	nd	0	0			—	25		

[1] Asterisk (*) next to total cover value indicates that seeded plots had significantly greater total cover than unseeded plots. Statistical significance was not tested in all studies.

[2] For studies in which erosion was measured, “ns” means there was no significant difference between seeded and unseeded plots; if erosion was significantly less, amount of reduction is given.

[3] “nd” indicates no data provided for a given category in the publication.

[4] Unseeded plot was in slightly different area, avoided during seeding because of rare plant concerns.

Seed mixes included:

[5] Kentucky bluegrass, red clover, cereal grain.

[6] Intermediate wheatgrass, timothy, orchardgrass, and smooth brome.

[7] Orchardgrass, tall fescue, timothy, slender wheatgrass + fertilizer.

[8] Hard fescue, orchardgrass, perennial ryegrass, timothy, yellow sweetclover

[9] Intermediate wheatgrass, timothy, hard fescue, legumes.

no intense storms, despite higher average cover on seeded plots. Higher dry season erosion was measured on seeded plots the following year, which was attributed to pocket gophers attracted to the site by the abundant ryegrass. Similar densities of pocket gopher mounds were found in operationally seeded areas (Taskey and others 1989).

The most extensive study of annual ryegrass effects on erosion and vegetation response was conducted on five sites burned in hot prescribed fires and a wind-driven wildfire in coastal southern California (Beyers and others 1998a, 1998b; Wohlgemuth and others 1998). Data on prefire vegetation and hillslope sediment movement were gathered, and greater replication was used than in most previous studies. Fire severity varied among sites from moderate to very high, and postfire precipitation varied from half of normal to very high. Only plots that showed severity effects great enough to trigger operational seeding were retained in the study. At all five sites, postfire erosion was greatest during the first year after fire and was not significantly affected by ryegrass seeding (Wohlgemuth and others 1998). Seeding increased total plant cover the first year at only one site, by about 1.5 percent, probably accounting for the lack of difference in erosion rates (Beyers and others 1998a). Average ryegrass cover reached 15 to 30 percent on some sites during the second year after fire. Native herbaceous plant cover and species richness were lower on seeded plots when ryegrass cover was high (Beyers and others 1994, 1998b). Unlike some earlier studies, Beyers and others (1998a) did not find significantly lower shrub seedling density on seeded plots. In later postfire years, some sites had significantly less erosion on seeded than on unseeded plots, but this happened only after erosion rates had dropped to prefire levels, which occurred in as little as 2 years on some sites (Wohlgemuth and others 1998). Dry season erosion (ravel) accounted for a high proportion of first-year sediment movement on sites that burned during early or mid summer. Grass seeding does not affect the channel loading that occurs by this process (Beyers and others 1998b, Wohlgemuth and others 1998). These studies concluded that postfire annual ryegrass seeding is unlikely to reduce postfire hillslope sediment movement the first year after fire in southern California chaparral and has minimal impact on total erosion from a burn site.

Grass species other than annual ryegrass have been used for postfire rehabilitation. Blando brome (*Bromus hordaceous* cv "Blando"), promoted for use in drought-prone areas, did not produce cover as well as annual ryegrass (Blanford and Gunter 1972). Conard and others (1995) tested several non-native grasses and a native forb mix; only the native forb mix significantly increased total plant cover, and then only on a north-facing slope. After the 1993 firestorms in southern California, Keeley and others (1995) found complete failure where native perennial needlegrass (*Nasella*) species were used, and relatively low levels of grass cover (1 to 23 percent) produced by non-native annuals such as Zorro fescue (*Vulpia myuros* cv "Zorro") and Blando brome, used to avoid the competitive problems associated with annual ryegrass. The highest seeded cover, 40 percent, occurred on a site seeded with a mix of native species and annual ryegrass. However, natural regeneration of native and naturalized plants provided much more cover than the seeded species. Although no direct erosion measurements were made, Keeley and others (1995) concluded that seeding was ineffective as a sediment control measure in the cases examined because it contributed very little to total plant cover.

No quantitative studies on the impact of grass seeding on postfire erosion in chaparral have been published from northern California or Arizona. Because annual ryegrass and other grasses typically establish cover more successfully in northern California (Barro and Conard 1987, Blanford and Gunter 1972), they would be more likely to reduce erosion there. The impact of grass seeding on native chaparral vegetation in other areas, aside from suppression of shrub seedlings at very high grass densities (Schultz and others 1955), is largely unknown.

Conifer Forest: High intensity fire may be outside the range of natural variability for many conifer plant communities that have been subject to fire suppression for the last century (Agee 1993). The loss of former understory seed banks due to overgrazing and canopy densification may also reduce the likelihood of rapid regeneration of ground cover after fire. Seeding mixes used in conifer stands often include legumes such as white clover (*Trifolium repens*) or yellow sweet clover (*Melilotus officinalis*) to enhance nitrogen status of the soil. Both annual and perennial grasses may be used in mixes with non-native forage species originally tested for range improvement purposes (Christ 1934, Forsling 1931, McClure 1956).

Orr (1970) examined plant cover and erosion for 3 years after fire in the Black Hills of South Dakota in an area operationally seeded with a mixture of grasses and legumes. Most of the sediment production occurred in two summer storms shortly after erosion-measuring apparatus was set up. Sediment production was inversely related to plant cover. Summer storm runoff was 50 percent less on plots with high plant and litter cover than on those with sparse cover. Regression analysis showed that the decrease in runoff and sediment production with increasing ground cover leveled off at 60 percent cover, similar to results presented by Noble (1965). Orr (1970) concluded that seeded species were essential for quickly stabilizing the sites. However, unseeded plots were not included in the study.

Seeded grasses provided greater cover than natural regeneration in a burned area in Oregon (Anderson and Brooks 1975). Litter and mulch also developed more rapidly on the seeded sites. After 4 years, however, all sites had more than 70 percent ground cover. Legume species included in the seeding mix for wildlife forage generally did not survive. Seeded grasses appeared to suppress growth of native shrubs and annual forbs, particularly in the second and third year after fire. Erosion amounted to only 5 t ac^{-1} (5.5 Mg ha^{-1}) during the first 2 years after fire on seeded sites. The unseeded site was not measured but also appeared to experience little erosion (Anderson and Brooks 1975).

In contrast, Dyrness (1976) measured negligible cover produced by seeded species on severely burned plots in Oregon. Total vegetation cover was only 40 percent after 2 years even on lightly burned sites. He suggested that nitrogen fertilization might have improved vegetation growth. Earlier work by Dyrness (1974) found that grass vigor decreased 4 years after seeding along forest roads for erosion control, and refertilization in year 7 reinvigorated perennial grasses in the plots. On disturbed firelines, Klock and others (1975) seeded various grasses and legumes and found that fertilization greatly increased initial cover of most species tested. Fertilization with 45 lb ac^{-1} (50 kg ha^{-1}) drilled urea significantly increased native plant regrowth, but not production of seeded species, on granitic soil in Idaho (Cline and Brooks 1979).

Seeding and fertilizer treatments were compared on separate watersheds in the Washington Cascades after a fire swept through the Entiat Experimental Forest (Tiedemann and Klock 1973). Seeding increased plant cover at the end of the first growing season by about one third, from 5.6 percent on the unseeded watershed to 7. 5 to 10.8 percent on the seeded watersheds. Seeded grasses made up 18 to 32 percent of total cover on seeded sites. Nitrate concentration in streams increased immediately after fertilizer application, but subsequently fertilized and unfertilized watersheds had similar stream nitrogen dynamics (Tiedemann and others 1978). Later that summer, record rainfall events caused massive flooding and debris torrents from treated and untreated watersheds alike (Helvey 1975). In the second year after fire, average total plant cover increased to 16.2 percent on the unseeded watershed and 16.4 to 23 percent on the seeded watersheds. Seeded grasses comprised about 7 percent cover on seeded watersheds (Tiedemann and Klock 1976). On south-facing slopes, the unseeded watershed had as much or more cover than the seeded ones. Although fertilization did not affect plant cover either year, Tiedemann and Klock (1976) felt that it increased seeded grass vigor and height.

From an erosion standpoint during the first winter after fire, the amount of seeded grass present at the time major storms occur is more important than the amount present at the end of the growing season, when it is usually assessed in studies. In southern Oregon, annual ryegrass seeding and fertilization did not significantly increase plant cover or reduce erosion by early December, when that winter's major storms occurred (Amaranthus 1989). The seeded and fertilized plots had significantly less bare ground than the unseeded plots. Erosion was low and not significantly different between treatments, though it trended lower on the seeded plots. Amaranthus (1989) pointed out that timing of rainfall is critical to both grass establishment and erosion, and that different rainfall patterns could have produced different results from the study.

In contrast, grass seeding plus fertilizer did not significantly increase total plant cover during the first 5 years after a northern Sierra Nevada fire (Roby 1989). Seeded grass cover did not exceed 10 percent until 3 years after the fire, when total cover on unseeded plots was greater than 50 percent. There was no difference in erosion between the seeded and unseeded watersheds during the first 2 years after fire. Roby (1989) concluded that grass seeding was ineffective as a ground cover protection measure in that location. Geier-Hayes (1997) also found that total plant cover did not differ between seeded and unseeded plots for 5 years after an Idaho fire. Seeded plots had lower cover of native species. Erosion was not measured.

Several species commonly used for postfire seeding, because of their rapid growth and wide adaptability (Klock and others 1975), have been found to be strongly competitive with conifer seedlings in experimental plots. Orchardgrass (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), and timothy (*Phleum pratense*) reduced growth of ponderosa pine seedlings in tests conducted in California (Baron 1962). Orchardgrass and crested wheatgrass (*Agropyron desertorum*) reduced ponderosa pine growth in Arizona (Elliot and White 1987). Field studies on aerial seeded sites in California found low pine seedling densities on most plots with annual ryegrass cover higher than 40 percent (Conard and others 1991, Griffin 1982).

Amaranthus and others (1993) reported significantly lower survival of planted sugar pine (*Pinus lambertiana*) seedlings in plots heavily seeded with annual ryegrass than in unseeded controls during the first postfire year in southern Oregon. Soil moisture was significantly lower and pine seedlings showed significantly greater water stress in the seeded plots. Ryegrass cover was 49 percent when tree seedlings were planted and 85 percent by mid-summer, while total plant cover was only 24 percent at mid-summer on the control plots. The next summer, a second group of planted pine seedlings had significantly greater survival and lower water stress on seeded plots than on controls. By then, dead ryegrass formed a dense mulch on the seeded plots, but no live grass was found. Native shrub cover was significantly greater on the unseeded plots the second year and soil moisture was lower (Amaranthus and others 1993). Ryegrass thus acted as a detrimental competitor to tree seedlings the first year after fire, but provided a beneficial mulch and reduced competition from woody plants the second year. Conard and others (1991) also suggested that seeded ryegrass could benefit planted conifer seedlings if it suppressed woody competitors and could itself later be controlled. In their study, however, live ryegrass cover was exceptionally high in many plots during the second year after fire (Conard and others 1991).

The studies examined suggest that grass seeding does not assure increased plant cover during the first critical year after fire (table 6). A wide variety of grass species or mixes and application rates were used in the reported studies, making generalization difficult. Over 50 years ago, southern California foresters were urged to caution the public not to expect significant first-year sediment control from postfire seeding (Gleason 1947). Better cover and, consequently, erosion control can be expected in the second (table 7) and subsequent years.

Measuring erosion and runoff is expensive, complex, and labor-intensive, and few researchers have done it. Such research is necessary to determine if seeded grasses control erosion better than natural regeneration. Another goal of postfire grass seeding on timber sites, soil fertility retention, does not appear to have been investigated. Grass establishment can clearly interfere with native plant growth, and grass varieties that will suppress native shrubs but not conifer seedlings have not yet been developed (Ratliff and McDonald 1987). The impacts of recent choices for rehabilitation seeding, including native grasses and cereal grains, on natural and planted regeneration in forest lands have not been studied extensively.

Mulch—Mulch is material spread over the soil surface to protect it from raindrop impact. Straw mulch applied at a rate of 0.9 t ac^{-1} (2 Mg ha^{-1}) significantly reduced sediment yield on burned pine-shrub forest in Spain over an 18-month period with 46 rainfall events (Bautista and others 1996). Sediment production was 0.08 to 1.3 t ac^{-1} (0.18 to 2.92 Mg ha^{-1}) on unmulched plots but only 0.04 to 0.08 t ac^{-1} (0.09 to 0.18 Mg ha^{-1}) on mulched plots. Kay (1983) tested straw mulch laid down at four rates—0.5, 1, 1.5, and 4 t ac^{-1} (1.1, 2.2, 3.4, and 9.0 Mg ha^{-1})—against jute excelsior, and paper for erosion control. Straw was the most cost-effective mulch, superior in protection to hydraulic mulches and comparable to expensive fabrics. Excelsior was less effective but better than paper strip synthetic yarn. The best erosion control came from jute applied over 1.5 t ac^{-1} (3.4 Mg ha^{-1}) straw. Miles and others (1989) studied the use of wheat straw mulch on the 1987 South Fork of the Trinity River fire, Shasta-Trinity National Forest in California. Wheat straw mulch was applied to fill slopes adjacent to perennial streams, firelines, and areas of extreme erosion hazard. Mulch applied at rates of 2 t ac^{-1} (4.5 Mg ha^{-1}), or 1 t ac^{-1} (2.2 Mg ha^{-1}) on larger areas, reduced erosion 6 to 10 yd^3 ac^{-1} (11 to 19 m^3 ha^{-1}). They considered mulching to be highly effective in controlling erosion (table 8). Edwards and others (1995) examined the effects of straw mulching at rates of 0.9,1,8, 2.7, and 3.6 t ac^{-1} (2,4,6, and 8 Mg ha^{-1}) on 5 to 9 percent slopes. Soil loss at 0.9 t ac^{-1} (2 Mg ha^{-1}) mulch was significantly greater (1.4 t ac^{-1}, 3.16 Mg ha^{-1} of soil) than at 1.8 t ac^{-1} (4 Mg ha^{-1}) mulch (0.9 t ac^{-1}, 1.81 Mg ha^{-1} of soil loss). Above 1.8 t ac^{-1} (4 Mg ha^{-1}) mulch there was no further reduction in soil loss.

Table 8—Comparison of slope and channel BAER treatments, South Fork Trinity River fires, Shasta-Trinity National Forest, CA, 1987 (modified from Miles et al. 1989). Costs are shown in 1999 dollars.

Treatment Type	Cost				Efficacy Category	Install Rate	Risk of Failure
	$(\$\ \mathrm{yd}^{-3})$	$(\$\ \mathrm{m}^{-3})$	$(\$\ \mathrm{ac}^{-1})$	$(\$\ \mathrm{ha}^{-1})$			
	- - - - - - - - - - - - - - *$$1999* - - - - - - - - - - - - -						
Slope Treatment Summary							
Aerial Seeding	$23	$23	$79	$196	Moderate[1]	Rapid	Moderate
Mulching	$50	$52	$504	$1245	High[2]	Slow	Low
Contour Felling	$180	$183	$720	$1778	Low[2]	Slow	High
Channel Treatment Summary							
Straw Bale Check Dams	$105	$107	$158	$392	High[2]	High	Low
Log and Rock Check Dams	$33	$33	$1346	$3325	High[2]	Slow	Moderate

[1] Soil loss estimated using Universal Soil Loss Equation (USLE).

[2] Soil loss estimated using on-site measurements.

Contour-Felled Logs—This treatment involves felling logs on burned-over hillsides and laying them on the ground along the slope contour, providing mechanical barriers to water flow, promoting infiltration and reducing sediment movement; the barriers can also trap sediment. The terms "log erosion barriers" or "log terracettes" are often used when the logs are staked in place and filled behind. Logs were contour-felled on 22 ac (9 ha) of the 1979 Bridge Creek Fire, Deschutes National Forest in Oregon (McCammon and Hughes 1980). Trees 6 to 12 in (150-300 mm) d.b.h. were placed and secured on slopes up to 50 percent at intervals of 10 to 20 ft (3 to 6 m). Logs were staked and holes underneath were filled. After the first storm event, about 63 percent of the contour-felled logs were judged effective in trapping sediment. The remainder were either partially effective or did not receive flow. Nearly 60 percent of the storage space behind contour-felled logs was full to capacity, 30 percent was half-full, and 10 percent had insignificant deposition. Common failures were flow under the log and not placing the logs on contour (more than 25° off contour caused trap efficiency to decrease to 20 percent). Over 1,600 yd^3 (1,225 m^3) of material was estimated trapped behind contour-felled logs on the 22 ac, or about 73 $yd^3\ ac^{-1}$ (135 $m^3\ ha^{-1}$). Only 1 yd^3 (0.7 m^3) of sediment was deposited in the intake pond for a municipal water supply below. Miles and others (1989) monitored contour-felling on the 1987 South Fork Trinity River fires, Shasta-Trinity National Forest in California. The treatment was applied to 200 ac (80 ha) within a 50,000 ac (20,240 ha) burned area. Trees <10 in (250 mm) d.b.h. spaced 15 to 20 ft (4.5 to 6 m) apart were felled at rate of 80-100 trees ac^{-1} (200-250 trees ha^{-1}). The contour-felled logs trapped 0 to 0.07 yd^3 (0 to 0.05 m^3) of soil per log, retaining 1.6 to 6.7 $yd^3\ ac^{-1}$ (3 to 13 $m^3\ ha^{-1}$) of soil onsite. Miles and others (1989) considered sediment trapping efficiency low and the cost high for this treatment (table 8). Sediment deposition below treated areas was not measured, however.

Contour Trenching—Contour trenches have been used as a BAER treatment to reduce erosion and permit revegetation of fire-damaged watersheds. Although they do increase infiltration rates, the amounts are dependent on soils and geology (DeByle 1970b). Contour trenches can significantly improve revegetation by trapping more snow, but they don not affect water yield to any appreciable extent (Doty 1970, 1972). This BAER treatment can be effective in altering the hydrologic response from short duration, high intensity storms typical of summer thunderstorms, but does not significantly change the peakflows of low intensity, long duration rainfall events (DeByle 1970a). Doty (1971) noted that contour trenching in the sagebrush (*Artemisia* spp.) portion (upper 15 percent with the harshest sites) of a watershed in central Utah did not significantly change streamflow and stormflow patterns. The report by Doty (1971) did not discuss sediment. Costales and Costales (1984) reported on the use of contour trenching on recently burned steep slopes (40 to 50 percent) with clay loam soils in pine stands of the Philippines. Contour trenching reduced sediment yield by over 80 percent, from 28 to 5 t ac^{-1} (63 to 12 Mg ha^{-1}).

Other Hillslope Treatments—Treatments such as tilling, temporary fencing, installation of erosion control fabric, use of straw wattles, lopping and scattering of slash, and silt fence construction are used to control sediment on the hillslopes. No published quantitative information is available about the efficiency and sediment trapping ability of these treatments after wildfires.

Channel Treatments—Channel treatments are implemented to modify sediment and water movement in ephemeral or small-order channels, to prevent flooding and debris torrents that may affect downstream values at risk. Some in-channel structures slow water flow and allow sediment to settle out; sediment will later be released gradually as the structure decays. Channel clearing is done to remove large objects that could become mobilized in a flood. Much less information has been published on channel treatments than on hillslope methods.

Straw Bale Check Dams—Miles and others (1989) reported on the results of installing 1300 straw bale check dams after the 1987 South Fork Trinity River fires, Shasta-Trinity National Forest, California. Most dams were constructed with five bales. About 13 percent of the straw bale check dams failed due to piping under or between bales or undercutting of the central bale. Each dam stored an average 1.1 yd^3 (0.8 m^3) of sediment. They felt that filter fabric on the upside of each dam and a spillway apron would have increased effectiveness. They considered straw bale check dams easy to install and highly effective when they did not fail (table 8). Collins and Johnston (1995) evaluated the effectiveness of straw bales on sediment retention after the Oakland Hills fire. About 5000 bales were installed in 440 straw bale check dams and 100 hillslope barriers. Three months after installation, 43 to 46 percent of the check dams were functioning. This decreased to 37 to 43 percent by 4.5 months, at which time 9 percent were side cut, 22 percent were undercut, 30 percent had moved, 24 percent were filled, 12 percent were unfilled, and 3 percent were filled but cut. Sediment storage amounted to 55 yd^3 (42 m^3) behind straw bale check dams and another 122 yd^3 (93 m^3) on an alluvial fan. Goldman and others (1986) recommended that the drainage area for straw bale check dams be kept to less than

20 ac (8 ha). Bales usually last less than 3 months, flow should not be greater than 11 cfs (0.3 $m^3 s^{-1}$), and bales should be removed when sediment depth upstream is one-half of bale height. More damage can result from failed barriers than if no barrier were installed (Goldman and others 1986).

Log Check Dams—Logs 12 to 18 in (300 to 450 mm) diameter were used to build 14 log check dams that retained from 1.5 to 93 yd^3 (mean 29 yd^3) (1.1 to 71 m^3, mean 22 m^3) of sediment after the 1987 South Fork Trinity River fires on the Shasta-Trinity National Forest, California (Miles and others 1989). While log check dams have a high effectiveness rating and 15 to 30 year life expectancy (Miles and others 1989), they are costly to install (table 8).

Rock Dams and Rock Cage Dams (Gabions)—Properly designed and installed rock check dams and rock cage (gabion) dams are capable of halting gully development on fire-disturbed watersheds, and reducing sediment yields by 60 percent or more (Heede 1970, 1976). Although these structures are relatively expensive, they can be used in conjunction with vegetation treatments to reduce erosion by 80 percent and suspended sediment concentrations by 95 percent (Heede 1981). While vegetation treatments such as grassed waterways augment rock check dams and are less expensive, their maintenance costs are considerably greater. Check dams constructed in Taiwan watersheds with annual sediment yields of 10 to 30 $yd^3 ac^{-1}$ (19 to 57 $m^3 ha^{-1}$) filled within 2 to 3 years. Sediment yield rates decreased upstream of the check dams, but were offset by increased scouring downstream (Chiun-Ming 1985).

Other Channel Treatments—No published information was found on the effectiveness of straw wattle dams, log grade stabilizers, rock grade stabilizers, in-channel debris basins, in-channel debris clearing, stream bank armoring or other BAER channel treatments.

Road Treatments—BAER road treatments consist of a variety of practices aimed at increasing the water and sediment processing capabilities of roads and road structures, such as culverts and bridges, in order to prevent large cut-and-fill failures and the movement of sediment downstream. The functionality of the road drainage system is not affected by fire, but the burned-over watershed can affect the functionality of that system. Road treatments include outsloping, gravel on the running surface, rocks in ditch, culvert removal, culvert upgrading, overflows, armored stream crossings, rolling dips, and water bars. The treatments are not meant to retain water and sediment, but rather to manage water's erosive force. Trash racks and storm patrols are aimed at preventing culvert blockages due to organic debris, which could result in road failure that would increase downstream flood or sediment damage.

Furniss and others (1998) developed an excellent analysis of factors contributing to the failure of culverted stream crossings. Stream crossings are very important, as 80 to 90 percent of fluvial hillslope erosion in wildlands can be traced to road fill failures and diversions of road-stream crossings (Best and others 1995). Since it is impossible to design and build all stream crossings to withstand extreme stormflows, they recommended increasing crossing capacity and designing to minimize the consequences of culvert exceedence as the best approaches for forest road stream crossings.

Comprehensive discussions of road-related treatments and their effectiveness can be found in Packer and Christensen (1977), Goldman and others (1986) and Burroughs and King (1989). Recently the USDA Forest Service, San Dimas Technology and Development Program has developed a Water/Road Interaction Technologies Series (Copstead 1997), which covers design standards, improvement techniques, and evaluates some surface drainage treatments for reducing sedimentation.

Methods

This study was restricted to USDA Forest Service BAER projects in the Western continental United States (Regions 1 through 6). We began by requesting Burned Area Report (FS-2500-8) forms and monitoring reports from the Regional headquarters and Forest Supervisors' offices. Our 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 it capture the information knowledge of BAER specialists. Therefore, we designed interview questions to enable us to rank treatment effectiveness, determine aspects of the treatments that lead to success or failure, and allow for comments on various BAER related topics.

Burned Area Report Data

The Forest Service Burned Area Report form contains the fire name, watershed location, size, suppression cost, vegetation, soils, geology, and lengths of stream channels, roads, and trails affected by the fire. The watershed description includes areas in low, moderate, and high severity burn categories and areas that have water repellent soils. Erosion hazard rating and estimates of erosion potential and sediment delivery potential are included, based on specified design storms. The probability of success for hillslope, channel, and road treatments are provided. Cost estimates of no action (loss) versus cost of selected alternatives are identified, as well as BAER funds requested and other matching funds. This information was entered directly into the database.

Interview Survey

Interview forms were developed after consultation with several BAER specialists. The forms were used to record information when we interviewed BAER team members, regional and national leaders. Questions were designed to address specific BAER projects (i.e., individual fires), as well as to elicit opinions regarding the interviewees' experience with treatments used on their forests and other fires they had worked on. Prior to conducting interviews, information such as Burned Area Report forms and postfire monitoring reports was requested to familiarize the interviewer with the various fires and treatment used. Onsite interviews were conducted because much of the supporting data were located in the Supervisor's and District's offices and could be retrieved during the interviews. Attempts were made to ask questions that would allow for grouping and ranking results, because much of the information was qualitative. Example interview forms are included in appendix A.

Project Review Interview Form—Questions were designed to identify the fire size, area treated, and treatment. The values at risk (i.e., downstream or onsite) were identified, and questions were asked whether the site was tested by a significant storm event and what damages resulted. We also asked interviewees to list up to three treatments they felt were overused, and up to three that in hindsight should have been used more, on specific BAER projects. Cumulative ratings were determined by totaling the number of times each treatment was mentioned.

No Action Review Interview Form—For fires where no BAER action was recommended, interviewees were asked to identify the rationale used. They were also asked if the site was tested by a significant storm and their opinion about what treatments might have been beneficial in hindsight.

Treatment Actions Interview Form—These questions identified treatments used on specific fires and what environmental factors affected success and failure. Interviewees were also asked questions regarding implementation of treatments and whether any 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. Because many of the answers were qualitative, we synthesized the responses, highlighting the major points made for each treatment. We summarized this information into paragraphs on effectiveness factors, implementation and environmental factors, and other factors when they occurred (appendix B).

Interview forms were developed for individual hillslope treatments such as aerial seeding, ground seeding, fertilizer, mulch, contour felling, straw wattles, lop and scatter, silt fences, contour trenching, ripping, tilling, temporary fencing and erosion control fabric. Channel treatment forms included straw bale check dams, log grade stabilizers, rock grade stabilizers, log dams, in-channel debris basins, in-channel debris clearing, stream bank armoring, rock cage (gabion) dams, and straw wattle dams. Road treatment forms included road regrading (such as out-sloping), rock in ditches, culvert removal, culvert upgrades, overflows, trash racks, armored stream crossing, storm patrol, and rolling dips and water bars. For each treatment, specific question were asked regarding the factors that caused the treatment to succeed or fail, such as slope classes, soil type, and type of areas treated, as well as appropriate implementation method questions for each treatment.

Relative Benefits Interview Form—Interviewees were asked to rank hillslope, channel, and road and trail treatments for the three most effective treatments in each category. Then they were asked for three overall treatments that provide the greatest benefits. To obtain cumulative rankings, we totaled the number of first, second and third place "votes" for each treatment, multiplied by 3 for first, 2 for second, and 1 for third, then added the adjusted totals to yield a cumulative preference rating. Final questions were open-ended to provide an opportunity for program recommendations or other topics not addressed.

Monitoring Reports

Monitoring reports were requested from Region, Forest, and District offices. We included administrative trip reports, data collection efforts, and regional burn area rehabilitation activity reviews in our request. We also examined BAER accomplishment reports, when provided, for initial post-treatment monitoring results.

Analysis Methods

Burned Area Reports and Interview Forms—Burned Area Report data and interview information were entered into the commercial Microsoft Access database management system. Categorical information (such as treatments that were over-used or underused) was left unchanged. Ranked information results were given a 1 to 3 value with the first ranking receiving three points, second ranking receiving two points and the third receiving one point. Several questions had positive or negative effects response options. Qualitative answers were grouped into categories to reduce the data to a manageable amount. Correlation analysis and categorical t-tests were performed on selected information in the data.

BAER spending and treatment costs were transformed into similar units (i.e., hectares or acres) and adjusted for inflation based on consumer price index to 1999 dollars (Federal Reserve Bank 1999). This made meaningful comparisons possible for analyzing spending trends. Treatment costs were obtained from the final Burned Area Report forms and were assigned to the year of the fire.

Monitoring Reports—Because most of the information in monitoring reports was qualitative in nature, excerpts from reports were entered into the database referenced to specific fires. Other excerpts were included in the general comment fields. Quantitative information was tabulated by hand separately from the main database because of its diverse nature.

Results

Overview of Data Collected

Data were collected from 470 Burned Area Reports and 98 interviews. The results represent our best estimate of the types and amounts of BAER treatments used and their attributes for the past 3 decades in the Forest Service. However, we were not able to collect all possible Burned Area Reports. Regions 1 and 3 are nearly complete data sets, whereas Regions 2, 4, 5, and 6 have missing results, especially from the 1970's and 1980's, because materials had been archived and could not easily be accessed. Therefore, all dollar and area totals reported are at best minimum estimates.

While our goal was to collect information on BAER treatment effectiveness, we also acquired a vast database of information on BAER project and no-action fires from the Burned Area Reports. These report data allowed us to tabulate and examine the various pieces of information that make up the BAER evaluation.

Over the past 3 decades, more than $110 million was spent in total on emergency rehabilitation that involved the Forest Service. Of that, about $83 million came from National Forest Systems (NFS) to treat 4.6 million ac (1.9 million ha) of a total of 5.4 million ac (2.2 million ha) from BAER project fires. About 72 percent of the total area treated was National Forest System lands. The remainder was on other Federal agency, State, and private lands.

Of the 470 fires for which Burned Area Reports were prepared, 321 had BAER treatments recommended. The rest (148) were fires for which no emergency was identified and no BAER treatment requested. Seventy two of the fires were less than 1,000 ac (400 ha), 153 fires were between 1,000 to 10,000 ac (400 to 4,050 ha), and 96 were greater than 10,000 ac (4,050 ha).

Expenditures for BAER treatments have increased substantially, especially during the 1990's (fig. 1). There were several large fires that represent a majority of the spending in the 1990's ($48 million), including the Rabbit Creek, Foothills, and Eighth Street fires on the Boise National Forest in Idaho and the Tyee Creek Complex on the Wenatchee National Forest in Washington (table 9). Regions 4, 5, and 6 accounted for 86 percent of the BAER spending from 1973 to 1998 (fig. 2). Total acres burned by year (fig. 3) shows a trend similar to that for spending especially in the 1990's. In terms of cost per acre burned, the big fire years do not always coincide with the greatest amount per acre (hectare) spent on BAER treatments. In 1989 for example, an average of $67 ac^{-1} ($165 ha^{-1}) was spent on 55,000 National Forest System ac (22,300 ha) burned. When 616,000 National Forest System ac (249,00 ha) burned in 1996, only $16 ac^{-1} ($40 ha^{-1}) was spent (fig. 4).

Fire Severity

Part of the Burned Area Report form contains information on percent of the total burned area in low, medium, and high fire "intensity." However, BAER

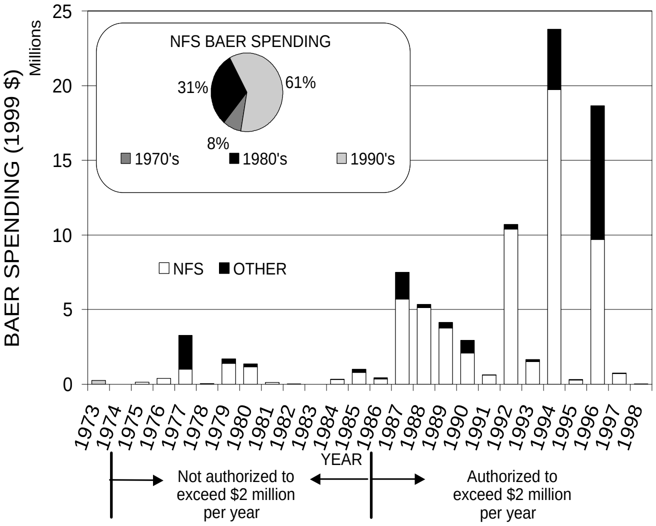


Figure 1—BAER spending by National Forests and other state and private entities that include National Forests by year in 1999 dollars. The insert shows spending by decade as a percent of the total spending. Spending authority changes are shown.

Table 9—The 10 costliest fires for BAER treatment spending. All amounts are in 1999 dollars.

Fire Name	National Forest	Year	NFS (ac)	NFS (ha)	Total (ac)	Total (ha)	NFS ($)	Total ($)
Rabbit Creek	Boise	1994	94880	38425	94880	38425	8,420,000	8,420,000
Foothills	Boise	1993	139955	56680	257600	104330	8,251,500	8,346,000
Tyee Creek Complex	Wenatchee	1994	105600	42770	140195	56780	6,156,100	8,978,000
Lowman Complex	Boise	1989	95000	38475	95000	38475	3,215,500	3,215,500
Stanislaus Complex	Stanislaus	1987	117980	47780	139980	56690	2,109,450	2,609,450
Fork	Mendocino	1997	61930	25080	82993	33610	1,839,100	1,888,000
Buffalo Creek	Pike-San Isabel	1998	11320	4585	11900	4820	1,800,200	2,146,400
Clover Mist	Shoshone	1988	194000	78570	387000	156735	1,393,500	1,393,500
Eighth Street	Boise	1997	3160	1280	15193	66155	1,207,000	8,562,400
Clarks Incident	Plumas	1988	30000	12,150	40000	16,200	1,024,000	1,289,000

teams actually evaluate burn severity, not intensity (DeBano and others 1998), and hereafter we use the term "severity" instead of intensity. The Burned Area Report form burn severity information was used to calculate the total acreage in the Western United States of wildfire-burned lands, by National Forest System Region, in high, moderate, and low burn severity classes over the last three decades. Total reported burn area (National Forest System plus other ownerships) was greatest in Region 5 (1,800,000 ac; 730,000 ha), followed by Regions 6, 4, 2, 3, and 1 (fig. 5). The total burned and treated areas of high severity (National Forest System plus other ownerships) in Region 5 (702,000 ac, 284,000 ha) exceeded that of all other Regions combined (670,000 ac, 271,300 ha) (fig. 6). For Region 5, the high severity areas (39 percent of the total reported wildfire-burned area) exceeded the moderate (29 percent) and low severity categories (33 percent); this is due to the large amount chaparral vegetation in Region 5 which generally burn at high severity conditions. In all the other Regions, the acreage of burned land in the low severity class exceeded the high severity class.

In terms of expenditures for BAER treatments on high fire severity areas, the Regions segregated into two groups (fig. 7). Both Regions 4 and 5 incurred BAER treatment expenses of over $27 million, and Region 6 exceeded $17 million. However, the expenditures for

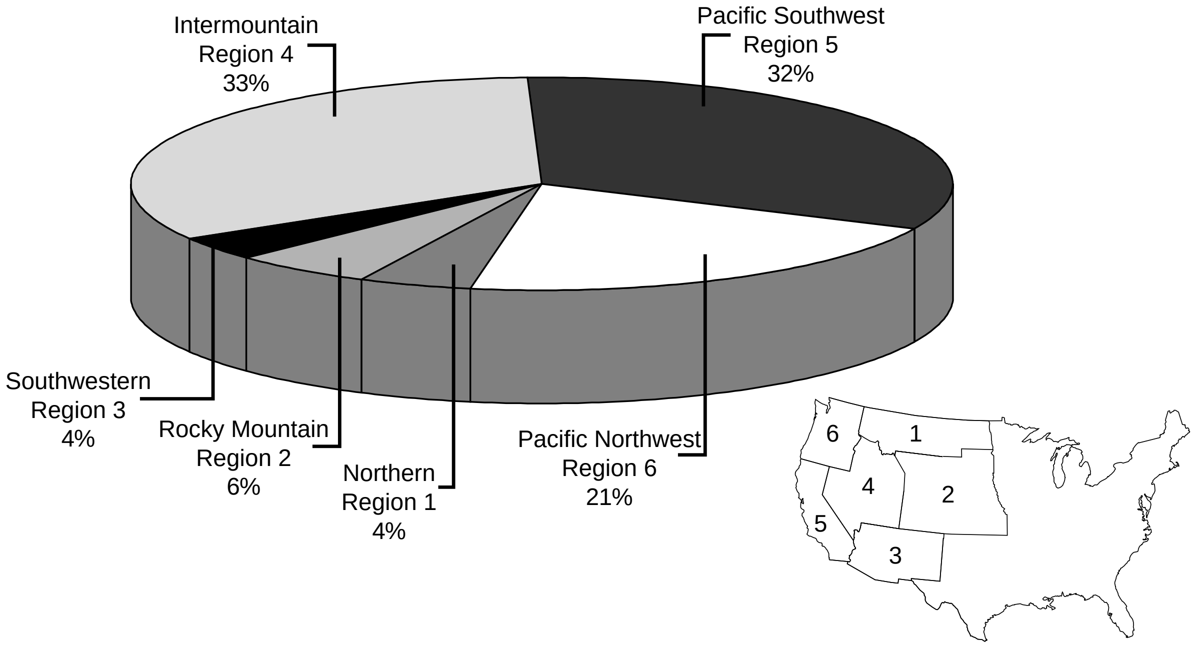


Figure 2—National Forest BAER spending by Region in 1999 dollars, 1973-1998 from Burned Area Reports. The insert shows the Western Forest Service Regions used in this study.

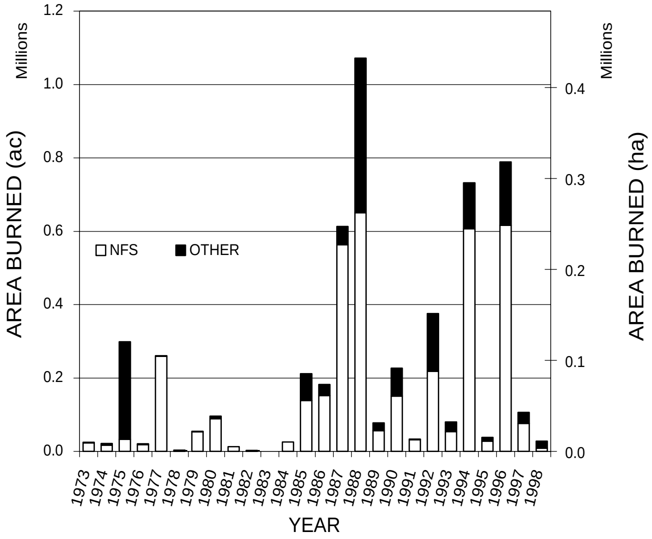


Figure 3—Total area burned in National Forests and other lands that had some portion of National Forest lands by year from the Burned Area Reports.

Regions 1, 2, and 3 did not exceed $5 million. Regions 4, 5, and 6 had 15 of the top 20 most-expensive BAER efforts. Region 4 had four of the top five most costly BAER efforts. The Rabbit Creek, Foothills, and Lowman Fires on the Boise National Forest in Idaho involved National Forest System BAER spending of $8.4, $8.2 and $3.2 million, respectively (table 9). The most expensive BAER project in Region 5 was only $2.1 million (Stanislaus Complex), but the Region had eight of the top 20 most expensive BAER projects.

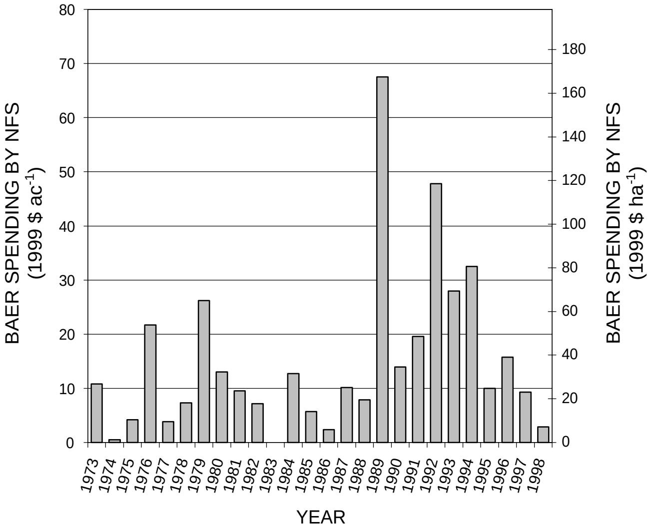


Figure 4—BAER spending by National Forests per unit area burned by year from Burned Area Reports.

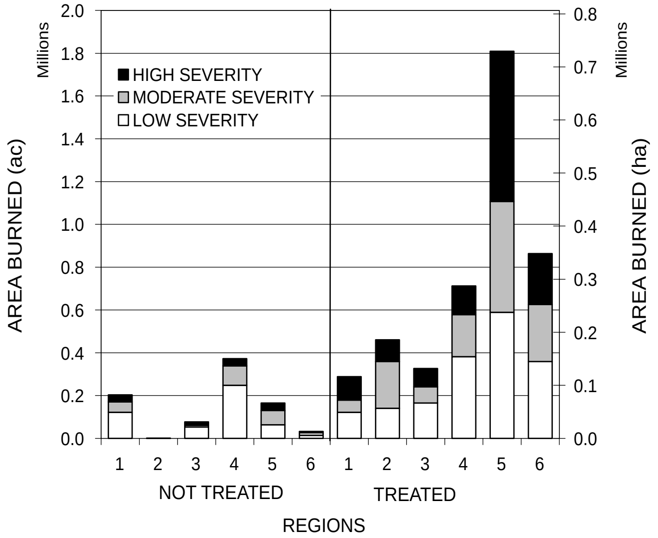


Figure 5—Total areas burned by severity class listed by Region, 1973-1998 from Burned Area Reports. Treated and untreated burned areas by severity are totaled separately.

BAER project costs per unit area treated followed the trend of total treatment costs (fig. 2, 8). Costs per acre (ha) were higher for Regions 4, 6, and 5 than Regions 1, 2, and 3. The most expensive cost per acre, $39 ($96 ha^{-1}), was for Region 4 and the least expensive, $9 ($22 ha^{-1}), was from Region 3. The higher costs per acre in Region 4, 6, and 5 fires reflected investments in BAER projects to protect life and property. This was particularly true for high severity fires in Region 4 (fig. 9).

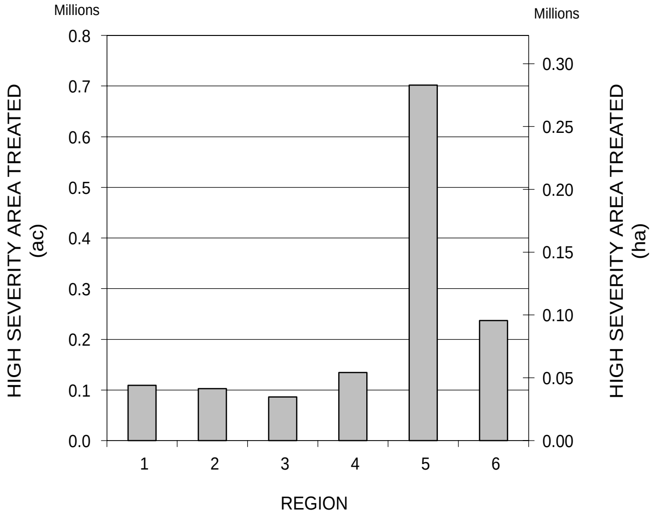


Figure 6—High severity areas burned and treated with BAER funding by region, 1973-1998 from Burned Area Reports.

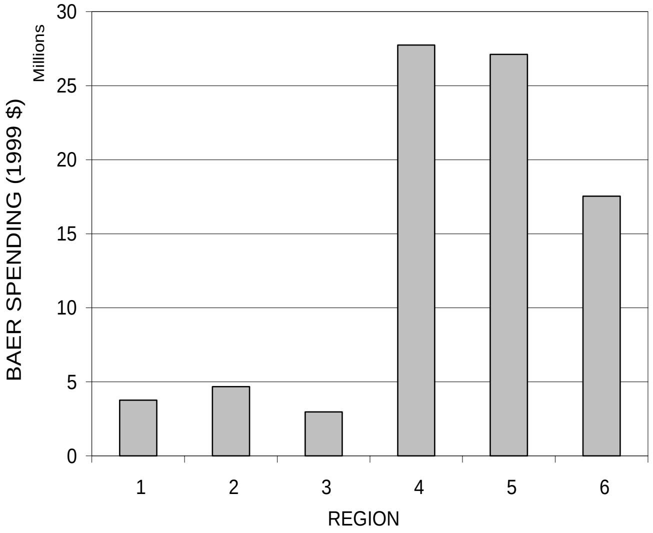


Figure 7—BAER spending by Region for high severity burn areas in 1999 dollars, 1973-1998 from Burned Area Reports.

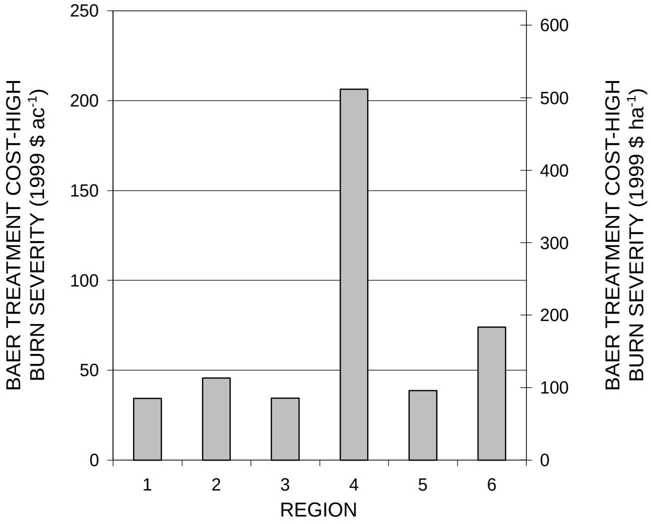


Figure 9—Cost per area for BAER treatment on high severity burned sites in 1999 dollars, 1973-1998 from Burned Area Reports.

Erosion Estimates

The Burned Area Report form asks for an erosion hazard rating for each fire. The rating is divided into low, moderate, and high erosion hazards categories. For the 321 project fires, the ratio of high erosion areas to high burn severity areas was greater than one (fig. 10). More areas were rated high erosion hazard than just those with high burn severity. This was probably due to natural erosion hazards associated with local geology, geomorphology, and precipitation patterns. Regions 2 and 4 both have high ratios due to conditions such as granitic soils and steep slopes, which create naturally high erosion hazards. On the other hand, in all regions the ratio of low erosion hazard areas to low burn severity areas was low, indicating that erosion potential was small.

A wide range of erosion potential estimates and watershed sediment yield (delivered to the channel) potential estimates was found in the Burned Area Report forms, some with very high values that could be considered unrealistic (fig. 11). Erosion potential varied from 1 to 7,000 ton ac^{-1} (2 to 15,500 Mg ha^{-1}), 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

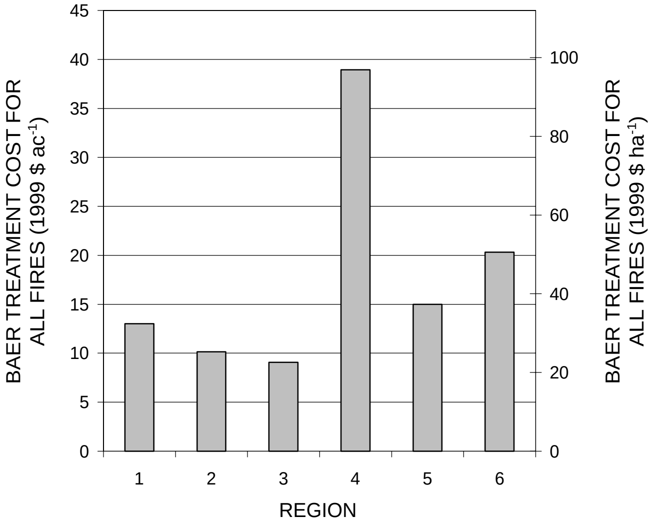


Figure 8—Cost per area for BAER treatment for Forest Service Systems lands by Region in 1999 dollars, 1973-1998 from Burned Area Reports.

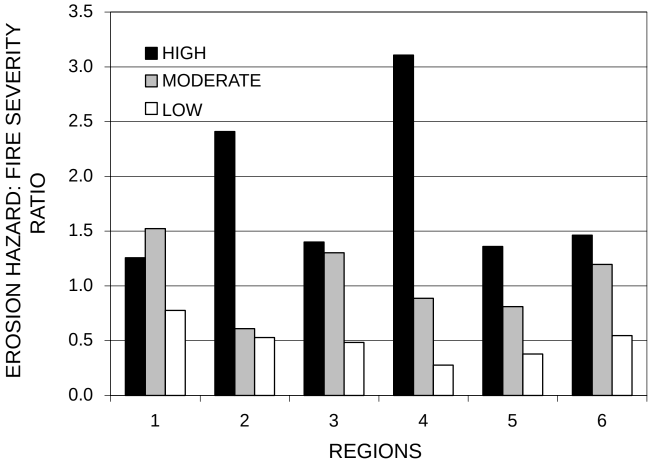


Figure 10—Average ratio of areas described as low, moderate, and high erosion hazard to areas of low, moderate, and high burn severity by Region from Burned Area Reports.

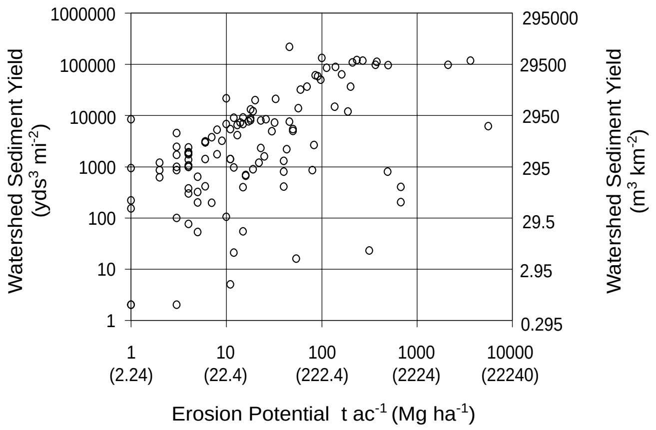


Figure 11—Estimated hillslope erosion potential and watershed sediment yield potential (log scale) for all fires requesting BAER funding.

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 erosional events, and professional judgment.

Hydrologic Estimates

Part of the BAER process evaluates the potential effects of wildfire on hydrologic responses. One facet of this involves determining storm magnitude, duration, and return interval for which treatments are to be designed. On the Burned Area Report forms, the most common design storms were 10-year return events (fig. 12a and b). Storm durations were usually less than 24 hr with the common design storm magnitudes from 1 to 6 in (25 to 150 mm). Five design storms were greater than 12 in (305 mm) with design return intervals of 25 years or less. The variation in estimates reflects some of the climatic differences throughout the Western United States.

The Burned Area Report form also contains an estimate of the percentage of burned watersheds that is water repellent. Water repellent soils are often reported after wildfires, and we expected to find them more common on coarse-grained soils, such as those derived from granite. However, there was no statistical difference among geologic parent materials in the percent of burned area that was water repellent (t-test; fig. 13). Water repellent conditions appeared to be distributed evenly among soil parent materials. BAER teams also 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. 14). Factors other than water repellent soil conditions, such as loss of the protective forest floor layers, obviously affect infiltration capacity.

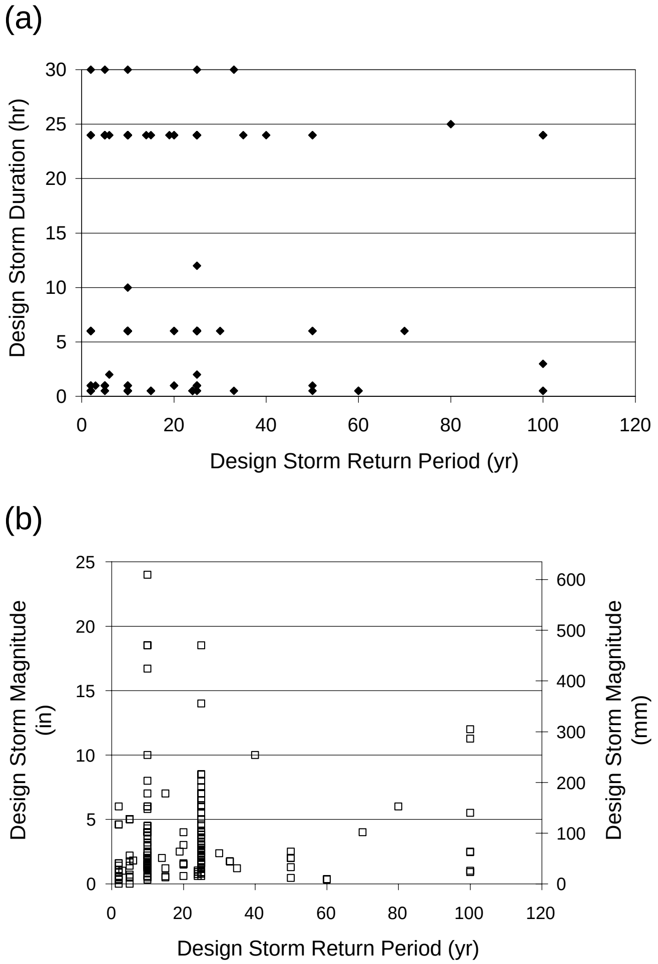


Figure 12—(a) Design storm duration and (b) design storm duration by return period for all fires requesting BAER funding.

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 a estimated 20 percent increase in channel flows. Various methods were used such as empirical-based models, past U.S. Geological Survey records from nearby watersheds that had a flood response, and professional judgment. Some reports show a very large percent increase in design flows (fig. 15).

Risk Analysis

The kinds of resources or human values judged by the BAER evaluation team to be at risk from postfire sedimentation and flooding are listed on the Burned Area Report form. These consisted of life, water quality, threatened and endangered (T & E) species, soil

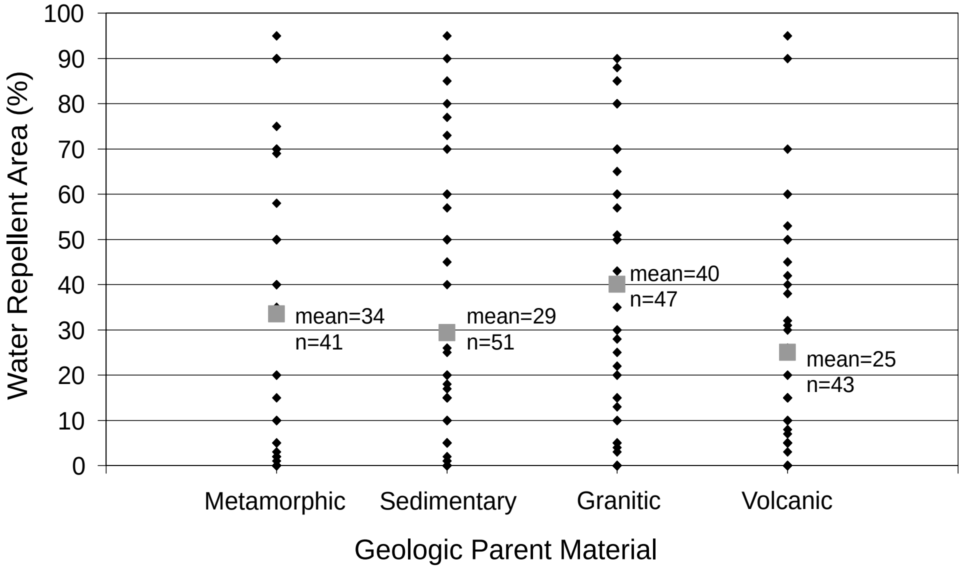


Figure 13—Fire-induced water repellent soil areas and their geologic parent material for all fires requesting BAER funding. Fire-induced water repellency was not significantly different by parent material (t-test, α = 0.05).

productivity, and property. The latter category includes homes, roads, cultural features, water supplies and reservoirs, and agriculture.

Property, water quality, and soil productivity were cited as reasons for conducting BAER projects in about a third of all projects (table 10). Region 5 (California), with its high population, had the highest response (51 percent) for property, while sparsely populated Region 1 had the lowest. In terms of property protection, roads and homes were mentioned most frequently as reasons for treatments in Region 5 (34 and 28 percent of the BAER project responses, respectively) (table 11). In the other regions, homes constituted a reason for implementing BAER treatments in less than 11 percent of the projects. Protection of homes was cited more frequently in the 1990's as a major fire suppression activity objective than it was in previous decades. It is very likely that the same will occur for future BAER projects. Cultural features, water supplies, and agriculture were listed as factors in BAER projects in less than 10 percent of the responses, except for agriculture in Region 2 (20 percent). Considering the

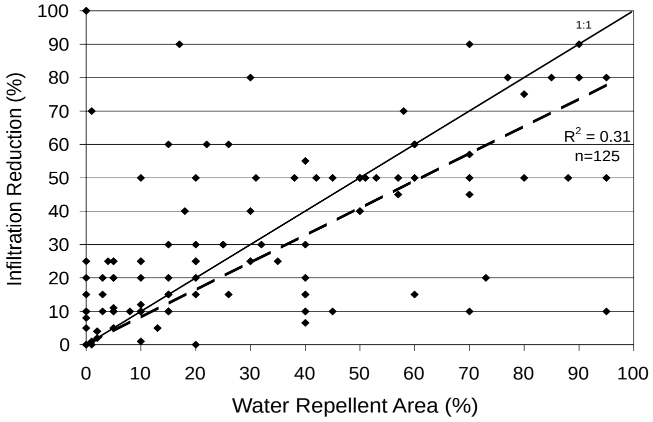


Figure 14—Fire-induced water repellent soil areas compared to the estimated reduction in infiltration for all fires requesting BAER funding. Regression line shows a poor correlation between increased water repellent soil areas and the reduction in infiltration (R^2 = 0.31).

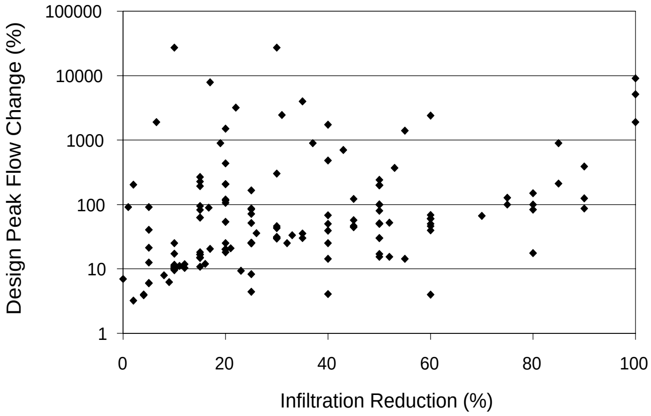


Figure 15—Estimated design peakflow change (log scale) due to burned areas related to the estimated reduction in infiltration for all fires requesting BAER funding.

Table 10—Described values at risk for spending on BAER projects by Region.

Region	Number of Projects	Life	Property	T and E Species	Water Quality	Soil Productivity
		- - - - - - - - - - - - - - - - - - -	*- - - - - -*	*Percent of Projects*	*- - - - - -*	*- - - - - - - - - - - - - - - - - - -*
1	56	2	29	14	14	14
2	20	5	35	0	70	50
3	69	4	29	7	26	58
4	45	18	47	33	60	44
5	201	10	51	8	41	24
6	79	8	33	11	58	52
All Regions	470	9	41	11	41	36

Table 11—Property subcategory breakdown of values at risk for spending on BAER projects by Region.

Region	Number of Projects	Homes	Roads	Cultural Feature	Water Supplies	Agriculture
		- - - - - - - - - - - - - - - - - -	*- - - - - -*	*Percent of Projects*	*- - - - - -*	*- - - - - - - - - - - - - - - - - -*
1	56	11	9	2	4	9
2	20	5	0	5	0	20
3	69	9	20	1	0	4
4	45	11	20	0	7	7
5	201	28	34	3	1	5
6	79	6	24	0	0	9
All Regions	470	17	25	2	2	7

rapidly growing wildland-urban interface fire problem in the West, property protection is likely to keep growing as a reason for implementing BAER treatments.

Protection of life was listed as a reason for conducting BAER projects in Region 4 (18 percent) more often than in the other Regions. Water quality was cited over 50 percent of the time in Regions 2, 4, and 6, but only 14 percent of the time in Region 1. Soil productivity was mentioned as a major purpose for BAER in Regions 2, 3, 4, and 6, with the most concern (58 percent) expressed in the Region 3 (Arizona and New Mexico). Region 1 had a relatively low response for soil productivity. Protection of threatened and endangered (T & E) species values was mentioned most frequently in Region 4 and not even listed as a reason for BAER projects in Region 2.

Probability of Success

The Burned Area Report form contains a section for estimating the probability of success for land, channel, and road treatments 1, 3, and 5 years after implementation. This is required by FSH 2509.13—Burned Area Emergency Rehabilitation Handbook, WO Amendment 2509.13-95-9, effective 1/12/95, Chapter 30—Cost Risk Analysis and Evaluation of Alternatives for Emergency Rehabilitation, Part 31.4 Probability of Success and Potential Resource Value Loss. The handbook states that the BAER team "…should provide an interdisciplinary decision on the estimated probability of each alternative's ability to successfully minimize or eliminate emergency watershed conditions…." Probabilities of success were provided for 321 of the 470 fires for which BAER reports were completed. The data did not contain any particular Region-to-Region trends. The combined treatment probability of success data (averages and ranges) showed a consistently higher predicted probability of success for road treatments than for hillslope and channel treatments (table 12). These estimations are the product of an interdisciplinary team decision and represent the combined experience of the individual BAER team members.

Cost of No Action/Alternatives

Another section of the Burned Area Report form requires estimates of the costs of no action and possible treatment alternatives, as well as determination

Table 12—Probability of treatment success by Regions. Treatments are grouped into three categories: hillslope, channel, and road.

BAER Treatment	Year 1		Year 3		Year 5	
	Mean	Range	Mean	Range	Mean	Range
	Percent					
Hillslope	69	60-80	82	74-87	90	85-94
Channel	74	57-80	83	74-88	89	84-93
Road	86	79-90	89	78-94	94	87-100

of the cost plus estimated loss for the proposed treatments. For the 321 project fires, estimates of the costs of no action and treatment alternatives ranged from $9,000 to $100 million. BAER teams calculated these estimates based on downstream property value at risk, soil productivity value, water quality value, T & E species value, and other resource values estimated to be affected by the fire and possible floods or debris flows. Potential soil productivity losses may be based on: estimated site index changes due to fire and possible loss in harvestable timber during the next regeneration cycle; the cost of top soil if purchased commercially to replace that anticipated to be lost; or estimates by professional judgment. Water quality values are based on the cost of cleaning reservoirs, increased costs of treating drinking water, and estimates of aquatic habitat degradation.

Costs of BAER treatments were compared to estimated losses (without treatment) from the Burned Area Report forms (fig. 16). BAER treatments appear to be very cost effective, generally costing one-tenth as much as the expected losses if no treatment were to be implemented. Expected losses are just estimates; we do not have data on actual losses that may have occurred.

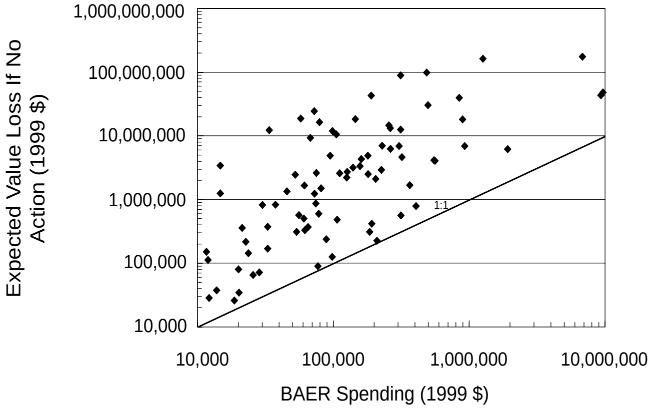


Figure 16—BAER spending compared to projected value loss if no action was taken (log scale). BAER spending did not exceed estimated values.

BAER Team Members

The composition of BAER teams by discipline and Region was determined from the Burned Area Report forms to determine appropriate disciplines to target for additional training (table 13). Just under 43 percent of all the BAER teams included in this data set (470) came from Region 5. The smallest number was from Region 2 (4 percent). Regions 4, 1, 3, and 6 had 10, 12, 15, and 17 percent, respectively.

The predominant disciplines on the BAER teams were hydrology and soil science (table 13). Except for Region 3, the percentages of BAER teams containing hydrologists and soil scientists were fairly consistent (78 to 87 percent) across Regions. Only two-thirds of Region 3 BAER teams had members from these disciplines. The next most common BAER team disciplines, wildlife biology (34 to 71 percent), timber management (30 to 65 percent), and engineering (22 to 56 percent), exhibited a two-fold range between Regions. Region 1 had the lowest representation on its BAER teams for engineering, range management, geology, archeology, fire management, contracting, and research disciplines. Region 4 had the highest representation of wildlife biology, fire management, ecology, fisheries, contracting, and research disciplines.

Monitoring Reports

A wide variety of monitoring reports was collected from the six Regions. Most were internal administrative reports dealing with one fire or several fires in proximity. Several were regional burn area rehabilitation activity reviews, resulting from interdisciplinary team review of multiple fires over several forests to evaluate current policies and techniques.

We obtained 157 documents that contained postfire monitoring information. Of those, 55 (35 percent) contained quantitative data of some kind. The rest (65 percent) contained qualitative evaluations of treatment success, such as trip report narratives or

Table 13—Percentage of BAER teams by Region having personnel from various disciplines.

		Region					
Discipline	Overall	1	2	3	4	5	6
	- - - - - - - -	- - - - - - - -	- - - - - - - -	*Percent*	- - - - - - - -	- - - - - - - -	- - - - - - - -
Hydrology	81.1	81.8	85.0	65.2	84.4	83.2	86.1
Soil Science	78.7	87.3	85.0	65.2	82.2	78.2	82.3
Wildlife Biology	61.9	34.5	65.0	59.4	71.1	66.3	65.8
Timber Management	46.4	49.1	60.0	30.4	44.4	43.1	64.6
Engineering	43.4	21.8	45.0	30.4	37.8	55.9	40.5
Range Management	40.6	18.2	70.0	60.9	68.9	26.2	51.9
Geology	31.5	9.1	20.0	15.9	26.7	41.6	40.5
Archeology	23.4	5.5	20.0	17.4	26.7	28.2	27.8
Fire Management	21.7	16.4	35.0	23.2	37.8	19.3	17.7
Ecology	20.9	23.6	25.0	24.6	51.1	12.4	19.0
Fisheries	18.5	21.8	5.0	5.8	40.0	14.4	29.1
Contracting	7.2	3.6	15.0	4.3	22.2	4.5	8.9
Research	5.1	0.0	5.0	2.9	20.0	3.0	7.6
Total No. of BAER Teams	470	55	20	69	45	202	79

photos. We also received 17 published reports, some of which did not evaluate BAER treatments specifically but included incidental information as part of another study. Most of the published reports were discussed in the Literature Review section.

The type of information contained in the monitoring reports varied widely. Quantitative reports on a single treatment (e.g., seeding) tended to use different measurements (cover, density, biomass, sediment produced), making tabulation and comparison of the results from different projects difficult. Treatments were monitored at varying times after the fires, from 3 months to 12 years. Where "cover" was measured, the category sometimes included only plants, sometimes litter, and sometimes also rock or wood. "Ground cover density" was sometimes used to refer to plant cover only where it was rooted in the ground. In other cases, "ground cover" included the aerial portions of plants. Many reports did not specify what was included in the category "cover." Often reports contained data on plant cover or sediment movement, but not other site variables that could have put the results in a wider context. In particular, vegetation type, watershed size, slope angle, and aspect of monitored sites were frequently missing from data presentations and narrative accounts. Most reports were prepared for internal use, where these variables would be better known to likely readers. However, the lack of descriptive site information made the results of monitoring more difficult to interpret for this analysis.

A wealth of information was recorded in the monitoring reports. To capture the considerable but extremely varied experience represented, qualitative information from the reports was entered into the database in various "comments" fields, along with interview remarks. Comments were aggregated and used to compose effectiveness and implementation factor summaries for each treatment (appendix B).

The quantitative reports covered 46 fires, with some fires covered by multiple reports and some reports covering several fires in one document. Report dates ranged from 1967 to 1998. Most of the data collected concerned ground cover production or erosion reduction by seeded species (32 reports), effectiveness of contour-felled logs (5 reports) or straw bale check dams (3 reports), and water quality parameters such as turbidity (5 reports). Reports sometimes covered more than one treatment. Only a few of the monitoring efforts compared treated areas to untreated areas. The others based effectiveness conclusions on amount of plant cover present, whether structures trapped sediment, and so forth. Many reports simply documented some facet of hillslope or stream recovery after fire, sometimes in areas that did not receive BAER treatments.

Nonquantitative reports documented treatment effectiveness qualitatively or made rough visual estimates of success parameters, such as amount of grass cover or storage effectiveness of log erosion barriers. They covered approximately 85 different fires. Many were trip reports that simply pronounced a treatment successful or not. Most, however, also analyzed reasons for success or failure and made recommendations for improving future projects. Those comments were used extensively to develop treatment effectiveness and implementation factor summaries (appendix B). The bulk of the nonquantitative reports dealt with seeding (54 reports), straw bale check dams (18), contour-felled logs (15), or channel treatments (16). Most reports covered more than one treatment. A number of reports focused on salvage logging "best management practices" evaluation but also mentioned BAER treatments. Reports dated from 1962 through 1998.

Grass seeding (aerial or ground) was usually perceived as "effective" if: (1) it produced at least 30 percent cover by the end of the first growing season; (2) seeded species comprised a significant amount of the total plant cover at the end of the first growing season; or (3) less sediment movement was measured compared to an unseeded plot or watershed. Statistical significance of observed differences between seeded and unseeded sites was seldom tested. In the first year after fire, seeding was considered generally effective in 9 of 16 quantitative monitoring reports (56 percent). Second year effectiveness was similar (10 of 16 reports or 62.5 percent). One 1978 rehabilitation review from Region 3 collected data from 12 fires, ranging from 1 to 12 years after treatment. They found that seeding was generally successful (produced cover) on forested sites but not on chaparral sites (Taylor and others 1979).

The amount of cover produced by seeded grasses during the first and second years after fire varied widely (tables 14 and 15). Many of the monitoring reports contained data on annual ryegrass and cereal grains (rye, barley or oats), the species most in use in recent years. More information was available from California (Region 5) than any other area, most of it from chaparral sites. Annual ryegrass and cereal grains produced considerable cover in some cases. In others, they did not appreciably increase plant cover or reduce erosion, especially the first year after fire.

In the nonquantitative reports, seeding was judged to be "effective" or successful the first year after fire in 22 of 28 cases (79 percent), generally based on the presence or absence of grass, evidence of rilling, or amount of cover compared to unseeded areas. Second-year results were similar, with 11 of 14 cases (79 percent) considered successful. In some cases seeding was considered "effective" in producing cover but probably not necessary, as natural vegetation regrowth was abundant as well (Bitterroot National Forest 1997). In others it was given a mixed rating because the seeded species persisted for many years or appeared to crowd out native vegetation (Isle 1988, Loftin and others 1998). Sometimes seeding was judged effective in one part of a project but not another (Herman 1971, Liewer 1990, Ruby 1995, Story and Kracht 1989). Loftin and others (1998; Region 3) suggested that protection from grazing could be the single most effective method for enhancing cover production by both seeded grasses and recovering native vegetation.

Contour-felled logs were judged to be effective in all 5 documents in which some kind of data were reported. Accumulation of sediment uphill of the barriers (Green 1990), lack of rilling in the treated area, or reduction in sediment collected downhill compared to an untreated plot were considered "effective" outcomes. For example, DeGraff (1982) measured "sediment trap efficiency" (STE) at 0.7 on slopes of less than 35 percent on the Sierra National Forest, meaning that 70 percent of the length of a log, on average, had accumulated sediment. Logs on steeper slopes exhibited an average STE of 0.57. Griffith (1989a) observed 1.5 t ac^{-1} (3.4 Mg ha^{-1}) of sediment behind a silt fence below a watershed treated with contour-felled logs, compared to 10.7 t ac^{-1} (24.2 Mg ha^{-1}) from an untreated watershed, during the first postfire year on the Stanislaus National Forest. Both watersheds were salvage-logged the following year, and sediment output increased to 10 t ac^{-1} (23 Mg ha^{-1}) on the treated and over 34 t ac^{-1} (77 Mg ha^{-1}) on the untreated watershed. Several reports from the first few years after the Foothills Fire (Boise National Forest) stated that no significant amounts of sediment were produced from any of several experimental watersheds treated with contour-felled logs, whether or not they were salvage-logged (e.g., Maloney and Thornton 1995). The reports noted that the area experienced no major thunderstorms until late summer 2 years after the fire.

In nonquantitative reports, contour-felled logs were considered effective in 11 of 13 cases (85 percent) in which they were actually tested by storms. Several reports pointed out that contour-felled logs are designed to reduce water flow energy and promote infiltration, not trap sediment, but they showed some benefit as direct sediment traps and also enhanced establishment of seeded grasses. Different terminology was sometimes used by different Regions in the reports. The term "contour-felled log" was synonymous with "log erosion barrier" in most areas, but in Region 3 contour-felling referred only to felling of material, not anchoring and sealing it. There the terms "log erosion barrier" or "log terracette" were used for anchored logs. The nonanchored logs were not considered a successful treatment.

Mulch was evaluated in two quantitative monitoring reports and found to be very effective. For example, Faust (1998) collected only 0.8 t ac^{-1} (1.8 Mg ha^{-1}) of sediment below a slope mulched and seeded with oats, compared to 5.8 t ac^{-1} (12.9 Mg ha^{-1}) below a slope seeded with oats alone.

Kidd and Rittenhouse (1997) rated mechanically dug contour trenches as the "best" treatment in trapping sediment after the Eighth Street Fire, Boise National Forest, Idaho. However they rated hand-dug contour trenches as the "worst" treatment due to poor construction (shallow depth) and layout (off contour). These trenches often contributed to rilling. Mechanically constructed contour trenches worked better

Table 14—Selected first-year seeded species cover, total plant cover, and soil loss measured in monitoring reports. Location and vegetation type as well as slope are included. Seeded cover percentages include only those species that were seeded. Total cover percentages include all vegetation.

						Cover				
Location	**Vegetation**	**Seeded Species**	**Slope**	**- - - - - Rate**	**- - - - -**	**Seeded**	**Total**	**- - -Soil Loss[1]**	**- - -**	**Source**
			(%)	*(lb ac^{-1})*	*(kg ha^{-1})*	- - - *(%)*	- - -	*(T ac^{-1})*	*(Mg ha^{-1})*	
Cleveland NF, CA	chaparral	annual ryegrass	53	10	11	1	19	6.5	14.6	Blanken- baker and others 1985
Aguanga fire, 1984		annual ryegrass	56	20	22	2	24	12.5	28	
		annual ryegrass	58	40	45	1	18	14.0	31.4	
		unseeded	56	0	0	0	20	6.8	15.2	
Los Padres NF, CA	chaparral	annual ryegrass, lana vetch	nd	7	8	49	63	nd	nd	Esplin & Shackelford 1980
Cachuma fire, 1977	chaparral	missed strips	nd	trace	5	26	nd	nd		
San Bernardino Mts., CA	chaparral	annual ryegrass	nd	8	9	<1	15	60	134	Tyrrel 1981
Panorama fire, 1980	chaparral	annual ryegrass + fert.	nd	16	18	<1	30	88	197	
		Blando brome	nd	12	13	<5	45	72	161	
		Zorro fescue	nd	10	11	<15	55	72	161	
		unseeded	nd	0	0	70	21	47		
Los Padres NF, CA	chaparral	Blando brome	nd	3	3	52	82	nd	nd	Ducummon 1987
Las Pilitis fire, 1985		unseeded	nd	0	0	56	nd	nd		
Tuolumne Canyon, CA Stanislaus complex, 1987	chaparral	Blando brome, Zorro fescue	>50	5	6	16 ± 7	41 ± 9	nd	nd	Janicki 1989
Mendocino NF, CA	chaparral	cereal oats	35	nd	nd	~ 4	24	2.6	5.8	Faust 1998
Forks Fire, 1996		unseeded	35	0	0	0	25	3.7	8.3	
		native mix + oats	38	nd	nd	~ 6	38	2.8	6.3	
		native mix alone	40	nd	nd	nd	40	1.1	2.5	
		seed + mulch	35	nd	nd	nd	95	0.8	1.8	
Tonto NF, AZ Dude fire, 1990	conifer/shrub intense burn	weeping lovegrass + others	nd	nd	nd	1	9	nd	nd	Ambos 1992
	conifer/shrub moderate burn	weeping lovegrass + others	nd	nd	nd	8	33	nd	nd	
Cibola NF, NM Galinas fire, 1976	ponderosa pine/ pinyon-juniper	mix[2]	nd	45 s ft^{-2}	484 s m^{-2}	15	56	nd	nd	Taylor and others 1979
Santa Fe NF, NM Porter fire, 1976	ponderosa pine	orchardgrass, hard fescue, timothy, alfalfa	nd	41 s ft^{-2}	441 s m^{-2}	0.8	9.4	nd	nd	Taylor and others 1979
same, reseeded in July						3	10.4	nd	nd	
Stanislaus NF, CA Stanislaus complex, 1987	pine/oak; mixed conifer	annual ryegrass	10-65	10	11	20 ± 8	29 ± 7	nd	nd	Janicki 1989
	same	unseeded	10-65	0	0	0	19 ± 5	nd	nd	
	mixed conifer (higher elev.)	mix[3]	25-65	7.5	8	5 ± 6	21 ± 5	nd	nd	

(con.)

Table 14—(Con.)

Location	Vegetation	Seeded Species	Slope	Rate		Cover Seeded	Cover Total	Soil Loss[1]		Source
			(%)	*(lb ac^{-1})*	*(kg ha^{-1})*	*- - - (%) - - -*		*(T ac^{-1})*	*(Mg ha^{-1})*	
Stanislaus NF, CA Stanislaus complex, 1987	conifer/metasedimentary soil	annual ryegrass	nd	10	11	nd	nd	3.6	8.1	Griffith 1989b
	same	unseeded	nd	0	0	nd	nd	9.8	21.9	
	conifer/ grantic soil	annual ryegrass “poor catch”	nd	10	11	nd	nd	>8.3	18.6	
	same	annual ryegrass “good catch”	nd	10	11	nd	nd	>2.1	4.7	
	same	annual ryegrass + needle cast	nd	10	11	nd	nd	1.0	2.2	
	same	unseeded	nd	0	0	nd	nd	>8.4	18.8	
NezPerce NF ID Green Cr. Pt. fire, 1988	Douglas-fir	cereal rye	>60	nd	nd	80	92	0.04 in	0.9 mm	Green 1990
NezPerce NF, ID Cotter Bar II fire, 1977	ponderosa pine	cereal rye + yellow sweetclover	59	10	11	5.4	27.6	nd	nd	Cline and Brooks 1979
		cereal rye+clover + drilled urea	59	10 + 45	11 + 50	2.6	27.4	nd	nd	
		drilled urea	59	45	50	(2.5)	48.5	nd	nd	
		untreated	59	0	0	(3.2)	27.6	nd	nd	
	outside of expmt. plots	cereal rye+clover + drilled urea	nd	10 + 45	11 + 50	13.6	62.9	nd	nd	
Stanislaus NF, CA Arch Rock fire, 1990	mixed conifer	cereal barley	nd	73	82	2.8 t ac^{-1}	3.3 t ac^{-1}	nd	nd	Griffith 1991; 1993
		cereal barley	nd	73	82	nd	nd	>1.3	>2.9	
		unseeded	nd	0	0	nd	nd	4.3	9.6	
Eldorado NF, CA	conifer/ granitic soil	cereal barley	52	nd	nd	nd	60.0	5.4 lb trough^{-1}	2.4 kg trough^{-1}	Parsons and McDonald 1993
		unseeded	50	0	0	nd	32.5	9.2 lb trough^{-1}	4.2 kg trough^{-1}	
	conifer/metamorphic soil	cereal barley	38	nd	nd	nd	28.8	0.8 lb trough^{-1}	0.4 kg trough^{-1}	
	unseeded		40	0	0		nd	3.6 lb trough^{-1}	1.6 kg trough^{-1}	
Gila NF, NM	mix conifer	Regreen + others	40	nd	nd	1-2	14	0	0	Souders 1997
HB fire, 1995	ponderosa pine	Regreen + others	40	nd	nd	<1	2	0	0	

[1] Values in table were averaged from individual plots in report in some cases. Statistical significance was not tested in these studies. Some values are minimums because silt fences over-topped or failed during winter. One study just measured sediment loss with erosion pins, and another measured pounds of sediment in troughs with a 25 to 30 ft (7.7 to 9.1 m) contributing area.

[2] Hard fescue, sand dropseed, smooth brome, Russian wildrye, yellow sweetclover, black medic, weeping lovegrass.

[3] Timothy, harding grass, smooth brome, Blando brome.

Table 15—Selected second-year seeded species cover, total plant cover, and soil loss measured in monitoring reports. Location and vegetation type as well as slope are included. Seeded cover percentages include only those species that were seeded. Total cover percentages include all vegetation.

Location	Vegetation	Seeded Species	Slope	- - - - - Rate - - - - -		Cover		- - -Soil Loss[1]- - -		Source
						Seeded	Total			
			(%)	*(lb ac^{-1})*	*(kg ha^{-1})*	- - - *(%)* - - -		*(T ac^{-1})*	*(Mg ha^{-1})*	
Tonto NF, AZ Bob fire, 1975	chaparral	weeping lovegrass, annual ryegrass	nd	39 s ft^{-2}	433 s m^{-2}	0	41	nd	nd	Taylor and others1979
Prescott NF, AZ Mingus Rx fire, 1975	chaparral	unseeded	nd	0	0		38			Taylor and others1979
Los Padres NF, CA Cachuma fire, 1977	chaparral	annual ryegrass	nd	7	8	8	78	nd	nd	Esplin and Shackleford1980
		missed strips	nd	trace	trace	4	78	nd	nd	
Mendocino NF, CA Forks fire, 1996	chaparral	cereal oats	35	nd	nd	nd	nd	0.7	1.6	Faust 1998
		unseeded	35	0	0	nd	nd	0.4	0.9	
Tahoe NF, CA Cotton fire, 1990	brush	cereal barley	20-25	nd	nd	nd	22	8.4	18.8	Janicki 1992
		unseeded	20-25	0	0	nd	28	7.1	15.9	
Stanislaus NF, CA Stanislaus complex, 1987	conifer/meta-sedimentary	annual ryegrass	nd	10	11	nd	nd	>1.9	>4.2	Griffith 1989a
		unseeded	nd	0	0		nd	4.2	9.4	
	conifer/ granitic soil	annual ryegrass “poor catch”	nd	10	11	nd	nd	>10.6	>23.7	
		annual ryegrass “good catch”	nd	10	11	nd	nd	>5.0	>11.2	
		unseeded	nd	0	0		nd	>1.3	>2.9	
Stanislaus NF, CA Arch Rock fire, 1990	conifer	cereal barley	nd	73	82	trace	7.1 T ac^{-1}	nd	nd	Griffith 1991
	conifer – salvage logged	cereal barley	nd	73	82	6.6 T ac^{-1}	13 T ac^{-1}	nd	nd	
Gila NF, NM HB fire, 1995	mixed conifer	Regreen + others	40	nd	nd	5	17	gain		Souders 1997
	ponderosa pine	Regreen + others	40	nd	nd	2-3	7	0.23 in	5.9 mm	

[1] Values in table were averaged from individual plots in report in some cases. Statistical significance was not tested in these studies. Some values are minimums because silt fences over-topped or failed during winter. One study just measured sediment loss with erosion pins, and another measured pounds of sediment in troughs with a 25 to 30 ft (7.6 to 9.1 m) contributing area.

because of their greater depth, better layout on the contour, and improved infiltration from deep ripping.

Straw bale check dams were judged to be effective in 11 of 16 qualitative reports (69 percent), based on accumulation of sediment behind the structures and structural integrity after first year storms. Failures resulted from poor implementation or placement, or from exceptionally large storms that exceeded dam design.

Fites-Kaufman (1993) reported on the failure of straw bale, log, and sandbag check dams after the Cleveland Fire on the Eldorado National Forest, California. Thirty percent of straw bale check dams failed from undercutting and blow outs compared to only 3 percent of log and sand bag check dams. Failures occurred in narrow, steep drainages where only two bales comprised the check dam. Downstream support from rocks or logs reduced the failure rate. No estimates of the sediment trapping efficiency were made.

Niehoff (1995) noted that straw bale check dams had mixed success after the Mary-Mix Fire, Clearwater National Forest, Idaho in 1986. Straw bales placed in low-to-moderately incised first and second order channels were in place and functioning to stabilize stream grade 1 and 9 years postfire. Straw bale check dams placed in deeply incised drainages were completely blown out at the end of the first year.

Kidd and Rittenhouse (1997) reported that 800 straw bale check dams installed in channels after the Eighth Street Fire on the Boise National Forest, Idaho had a 99 percent structural integrity rate. Although these structures were still being monitored, no estimates of sediment trapping efficiency were available. On a scale of "1" to "10", straw bale check dams were rated "9" in terms of their effectiveness. Observations of log and rock check dams installed after the Cleveland Fire on the Eldorado National Forest, California indicated that they were effective in trapping sediment and held up well over time (Parsons 1994). No estimates of sediment storage were made. Other channel treatments of various kinds were also regarded as effective most of the time (13 of 17, or 76 percent of evaluations). These included channel clearing, log sill dams, and similar measures.

Road treatments (outsloping, trashracks at culverts, armored crossings, etc.) were specifically evaluated only in a few narrative reports. Herman (1971) noted that immediately after the Entiat Fire, Wenatchee National Forest, Washington trash racks were in place and still functioning, but had collected only small amounts of debris due to postfire removal of woody material from channels. He believed that long-term maintenance of trash racks was necessary since fire-killed trees would at some point begin contributing large amounts of woody debris into channels.

Boyd and others (1995) reported on the hydrologic functioning of roads and their structures within the Cleveland Fire, Cleveland National Forest, California after a winter storm of 4+ in (100 mm) in 48 hours. An oversized culvert put in place after the fire successfully processed large chunks of wood and rocks. A nearby normal-sized culvert was repeated plugged during the storm, resulting in numerous overflows onto the road. Flanagan and Furniss (1997) described the reduction in flow capacity by partial blockage. During the same storm in which they examined culvert functioning, Boyd and others (1995) observed that some correctly constructed postfire water bars did not have sufficient rocks or slash to dissipate the energy of higher surface runoff. The resulting concentration and channelization of runoff produced additional small gullies and one large, entrenched gully.

Road treatments were generally judged to be effective. Trip reports sometimes mentioned road treatment effectiveness incidental to evaluating other types of treatments.

Treatment Effectiveness Ratings

Interviewees rated the effectiveness of treatments used on specific fires with which they were familiar (table 16). In-channel felling, slash spreading, streambank armoring, trail work, rock gabion dams, culvert inlet/outlet armoring, culvert overflow bypasses, debris basins, culvert risers, outsloping roads, water bars, storm patrol, and armored fords received two or fewer evaluations per treatment and are not tabulated. Treatments were rated across the spectrum from "excellent" to "poor," but just over 76 percent of the effectiveness ratings were either "good" or "excellent."

Hillslope Treatments—Hillslope treatments are implemented to keep soil in place and comprise the greatest effort in most BAER projects. Aerial seeding, the most frequently used BAER treatment, was rated about equally across the spectrum from "excellent" to "poor." The rating for contour-felled logs was "excellent" or "good" in 66 percent of the evaluations. Mulching was rated "excellent" about the same amount (67 percent), and nobody considered it a "poor" treatment. Nearly 82 percent of the evaluations placed ground seeding effectiveness in the "good" category. There was a 100 percent concurrence that silt fences were "excellent" or "good" as a BAER treatment. Evaluations of seeding plus fertilizer covered the spectrum from "excellent" to "poor," although most responses were "fair" or "poor." The remainder of the hillslope treatments, received only three evaluations each, so it is difficult to come up with conclusions beyond the fact that they were generally rated "excellent," "good," or "fair" and none were evaluated as being "poor."

Table 16—BAER treatment effectiveness ratings from individual fires as provided by interviewees. Total responses are listed as percentages in four classes. Only treatments which received three or more evaluations are included.

Hillslope Treatment	Number	Excellent	Good	Fair	Poor
		Percent			
Aerial Seeding	83	24.1	27.7	27.7	20.5
Contour Felling	35	28.6	37.1	14.3	20.0
Mulching	12	66.8	16.6	16.6	0.0
Ground Seeding	11	9.1	81.8	9.1	0.0
Silt Fence	8	37.5	62.5	0.0	0.0
Seeding and Fertilizer	4	25.0	0.0	50.0	25.0
Rock Grade Stabilizers	3	0.0	33.3	67.7	0.0
Contour Trenching	3	67.7	33.3	0.0	0.0
Temporary Fencing	3	0.0	67.7	33.3	0.0
Straw Wattles	3	33.3	33.3	33.3	0.0
Tilling/Ripping	3	33.3	33.3	33.3	0.0
Channel Treatments					
Straw Bale Check Dams	10	30.0	30.0	30.0	10.0
Log Grade Stabilizers	10	30.0	30.0	10.0	30.0
Channel Debris Clearing	7	0.0	71.4	0.0	28.6
Log Dams	5	40.0	60.0	0.0	0.0
Rock Grade Stabilizers	3	0.0	33.3	67.7	0.0
Straw Wattle Dams	3	33.3	67.7	0.0	0.0
Road Treatments					
Culvert Upgrading	6	6.7	66.6	0.0	16.7
Trash Racks	4	50.0	0.0	25.0	25.0

BAER spending on hillslope treatments was compared. From 1973 through 1998, over \$20 million (in 1999 dollars) was spent on contour-felled logs and on aerial seeding (fig. 17). Less than \$1.5 millions was spent on other treatments during the same time period. Clearly these two treatments were the most popular. In the 1970's, there was little spending on contour-felled logs, and in the 1980's over \$4 million was spent. Spending increased dramatically in the 1990's as this treatment gained popularity (fig. 17). Among Regions, Region 4 (mostly Boise National Forest) spent the most (\$18.7 million) on contour-felling treatments, while Region 5 spent the most on aerial seeding (\$8.5 million) (fig. 18). Region 6 spent the most on seeding plus fertilizer and ground seeding.

There were enough evaluations of aerial seeding and contour-felled logs to assess effectiveness by Region for these treatments (table 17). A majority of interviewees from Regions 1, 4, and 6 rated aerial seeding as "excellent" or "good." However, in Regions 3 and 5 the majority rated aerial seeding as "fair" or "poor." For contour-felled logs, a majority of interviewees in Regions 1, 3, 4, and 5 believed that its effectiveness was "excellent" or "good." Region 2 evaluations were evenly split between "good" and "poor." Region 6 evaluations of contour-felled logs were evenly balanced.

Comparison of unit costs for contour-felled logs (fig. 19) and aerial seeding (fig. 20) shows that aerial seeding was considerably less expensive per unit area. Contour-felling had a wide range of costs due to terrain, access, and whether contract or FS labor was used. Region 5 had an average cost of about \$450 ac^{-1} (\$1,100 ha^{-1}) (adjusted to 1999 dollars). Regions 4 and 6 costs averaged \$260 ac^{-1} (\$640 ha^{-1}). Region 1 costs averaged \$165 ac^{-1} (\$410 ha^{-1}), Region 3 costs were \$78 ac^{-1} (\$193 ha^{-1}), Region 2 only used contour-felled logs four times. Some low unit costs for contour-felled logs were probably due to low density or linear feet per area of logs. The high unit costs were often due to difficult terrain and expensive crew costs.

Aerial seeding costs ranged from \$4 to \$115 ac^{-1} (\$10 to 284 ha^{-1}) (adjusted to 1999 dollars). Average cost by Region varied from \$25 ac^{-1} (\$62 ha^{-1}) for Region 3 to \$47 ac^{-1} (\$116 ha^{-1}) for Region 2. Region 5 used aerial seeding for 65 fires, whereas Region 2 used aerial seeding for 16 fires.

Channel Treatments—Effectiveness ratings for straw bale check dams and log grade stabilizers ranged relatively evenly from "excellent" to "poor" (table 16). While most interviewees (71 percent) thought that channel debris clearing effectiveness fell into the "good" category, 29 percent rated it "poor." Log dams and

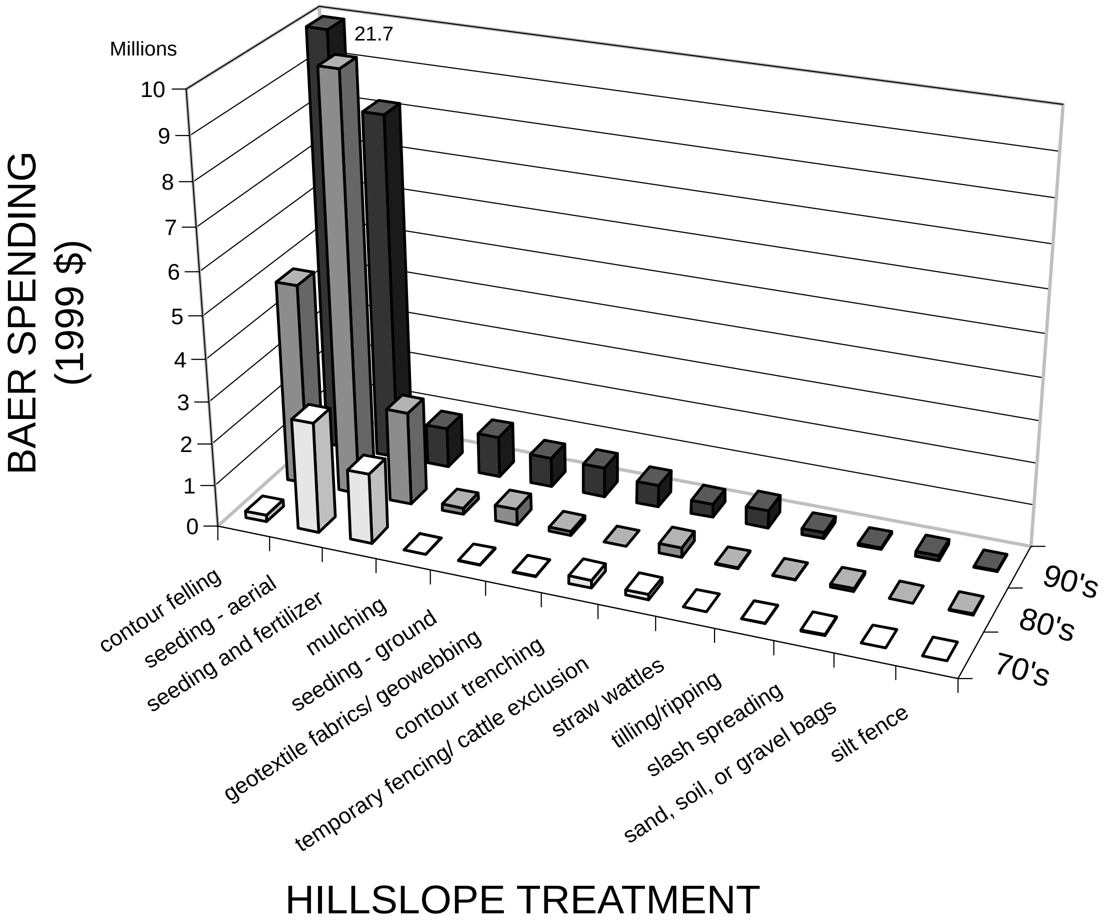


Figure 17—BAER spending on hillslope treatments by decade in 1999 dollars. Treatments are ordered by decreased spending.

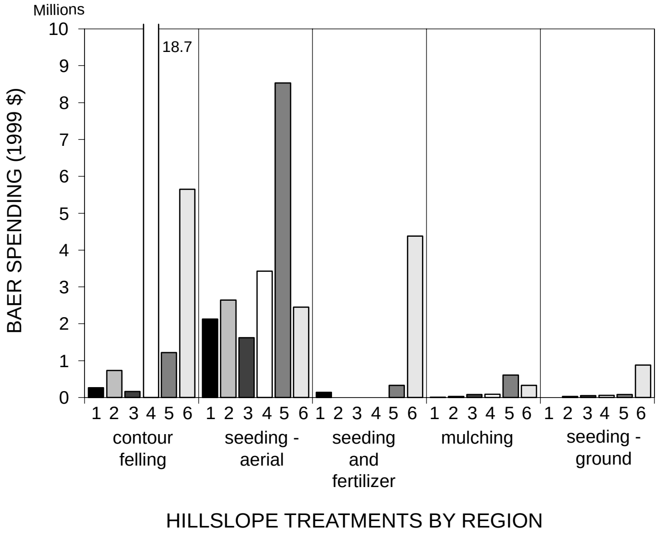


Figure 18—BAER spending on the five most expensive hillslope treatments by Region in 1999 dollars.

straw wattle dams were rated "excellent" or "good" in effectiveness, and better than rock grade stabilizers. No one considered the effectiveness of these BAER treatments to be "poor."

BAER spending on debris basins, straw bale check dams, and channel debris clearing was about three times greater than spending on the other channel treatments (fig. 21). When comparing the change in use over the past three decades, straw bale check dams were extensively used only in the 1990's. BAER spending on debris basins was non-existent in the 1970's, and doubled each decade from the 1980's to the 1990's (debris basins were in use in the 1970's but funding came from sources other than the Forest Service or postfire emergency treatments). These treatments were generally installed in channels to protect downstream urban areas in California. Interestingly, spending on channel debris clearing decreased five-fold during the last 30 years, as the value of instream debris was realized.

Table 17—Effectiveness ratings for aerial seeding and contour-felling effectiveness as provided by interviewees, sorted by Region. Percentages of total replies in each rating class are shown.

BAER Hillslope Treatment	Region	No. of Replies	Excellent	Good	Fair	Poor
			Percent			
Aerial Seeding	1	8	62.5	12.5	12.5	12.5
	2	6	33.3	33.3	0.0	33.3
	3	16	6.3	18.7	37.5	37.5
	4	11	63.6	18.2	0.0	18.2
	5	32	3.0	34.4	43.8	18.8
	6	10	40.0	40.0	20.0	0.0
Contour Felling	1	9	44.4	44.4	11.2	0.0
	2	2	0.0	50.0	0.0	50.0
	3	6	50.0	16.7	16.7	16.6
	4	4	25.0	50.0	0.0	25.0
	5	6	16.7	50.0	0.0	33.3
	6	8	12.5	25.0	37.5	25.0

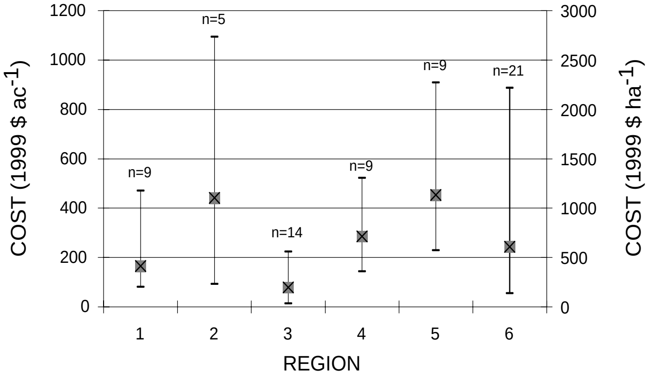


Figure 19—Cost per area for BAER spending on contour-felled logs by Region in 1999 dollars. Mean unit cost with range for each region is shown.

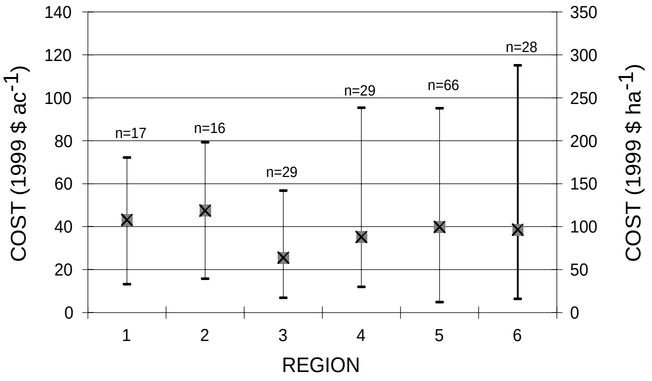


Figure 20—Cost per area for BAER spending on aerial seeding by Region in 1999 dollars. Mean unit cost with range for each region is shown.

Region 5 spent the most on debris basins (1990's) and channel debris clearing (1970's) (fig. 22). Straw bale check dams were used mostly by Regions 4, 5 and 6. There were far fewer interviewee comments recorded in our database for channel treatments (38) than for hillslope treatments (168), indicating a lower frequency of use in BAER projects.

Road and Trail Treatments—Only two road treatments, culvert upgrading and trash racks, received more than three effectiveness evaluations. The responses covered the range from "excellent" to "poor," although three-quarters of the interviewees rated culvert upgrading "excellent" or "good" in effectiveness (table 16). Interviewees were evenly split on their assessment of trash racks as "excellent," "fair," or "poor."

BAER spending on armored ford crossings was three times greater than for any other road treatment. This was due to the extensive use of armored crossing on the 1994 Tyee Fire, Wenachee National Forest in Washington (fig. 23). Culvert upgrades, ditch maintenance/cleaning and armoring, road ripping, drainage improvement and stabilization, and trail work accounted for the majority of funds spent. In the 1990's, more funds were spent on ditch maintenance than during the other two decades combined (adjusted to 1999 dollars). Spending on most other road treatments increased during the 1980's and again in the 1990's. Region 5 spent more on road treatments, other than armored ford crossing, than other regions (fig. 24). Region 4 invested the most on ditch cleaning and armoring.

Treatment Rankings

The composition of interviewees was examined to see if different disciplines would rank treatment

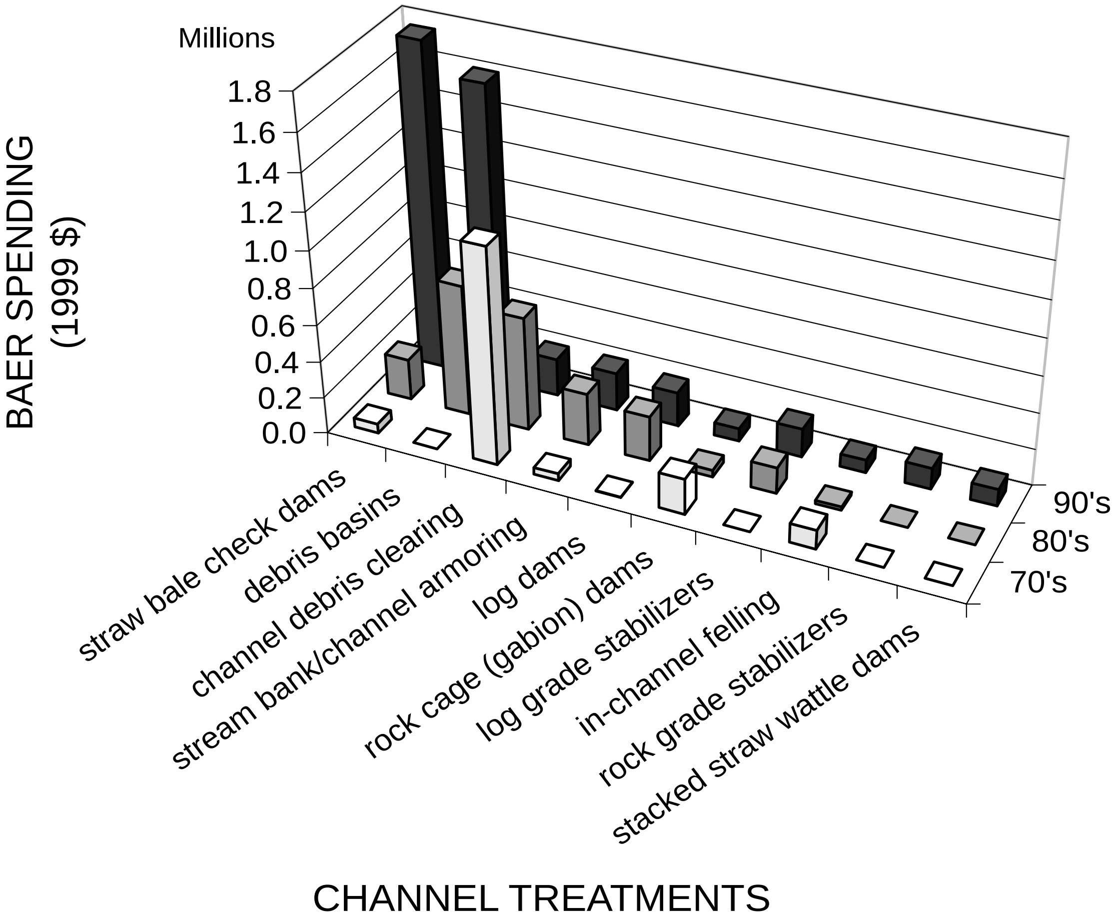


Figure 21—BAER spending on channel treatment by decade in 1999 dollars. Treatments are ordered by decreased spending.

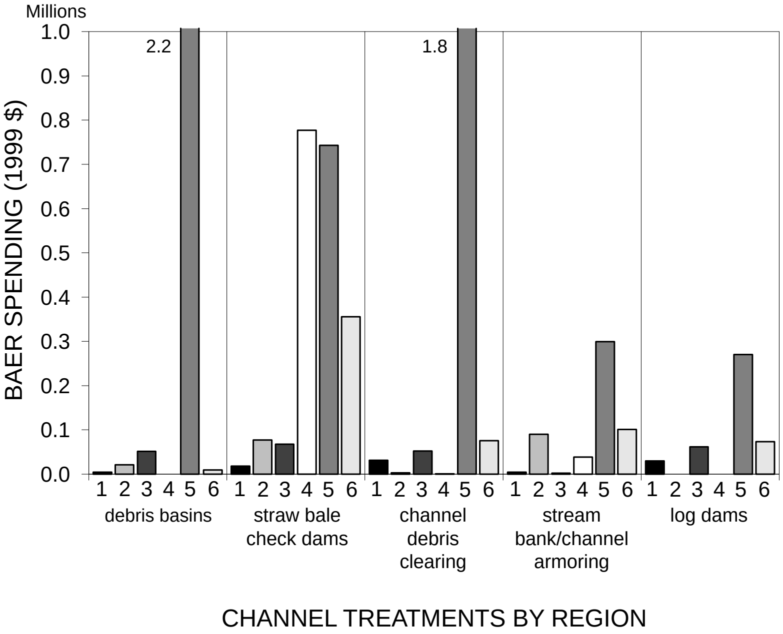


Figure 22—BAER spending on the five most expensive channel treatments by Region in 1999 dollars.

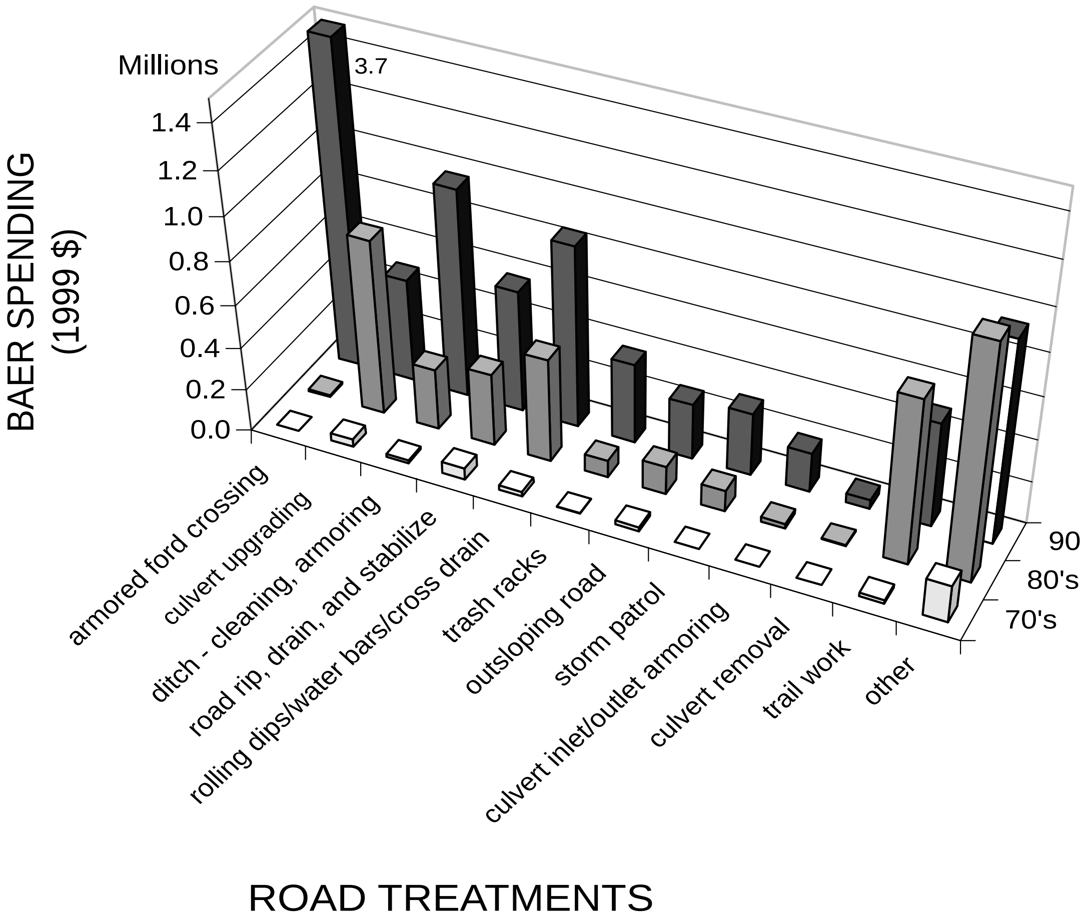


Figure 23—BAER spending on road and trail treatments by decade in 1999 dollars. Treatments are ordered by decreased spending except for trail work and other treatment that were not categorized.

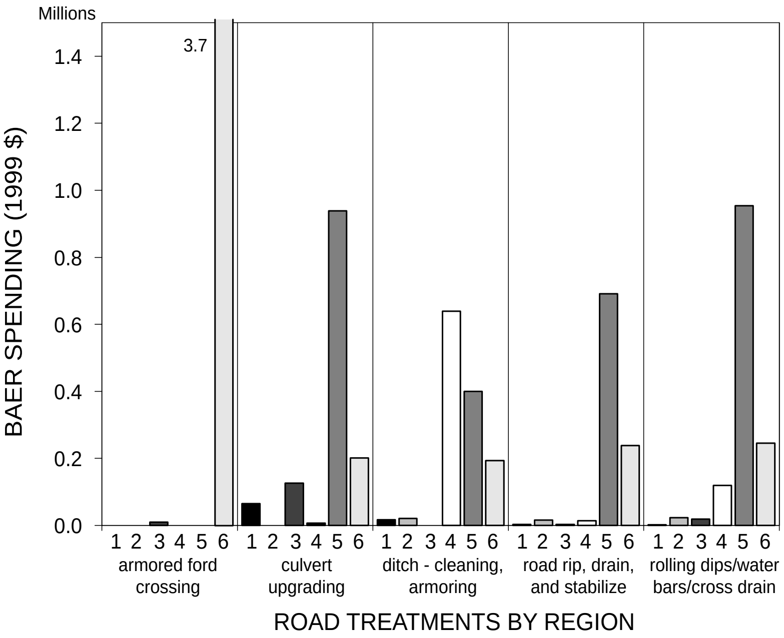


Figure 24—BAER spending on the five most expensive road and trail treatments by Region in 1999 dollars.

preferences differently. There was no difference in rankings from all interviewees (n = 105) compared to those of soil scientists (n = 29) or hydrologists (n = 21), who accounted for the majority of interviewees; therefore, rankings were not stratified by discipline. Interviewees did not name over- or underused treatments on every fire.

The overall rankings show that hillslope treatments are preferred methods for controlling erosion and runoff after fire, comprising five of the top 10 ranked treatments (fig. 25). Contour-felled logs and seeding had scores twice or more as high than any other treatment. These rankings are reflected in spending on these methods (fig. 17). Road treatments were next in overall preference, and only one channel treatment was highly ranked.

Aerial seeding had the highest ranking among hillslope treatments, followed by contour-felled logs, slash spreading, mulch, and temporary fencing. Other treatments received relatively low scores. The high rank for seeding is not surprising considering its high level of use (fig. 26). On the other hand, aerial seeding was listed as the most overused treatment by far, with ground seeding second (table 18). Seeding also garnered a few votes as underused, and it was most often mentioned (three times) as a treatment that should have been used on no-action fires. These seemingly contradictory results reflect the wide differences in opinion about seeding's effectiveness (table 17) and the on-going controversies surrounding the use of grass seeding as a rehabilitation treatment.

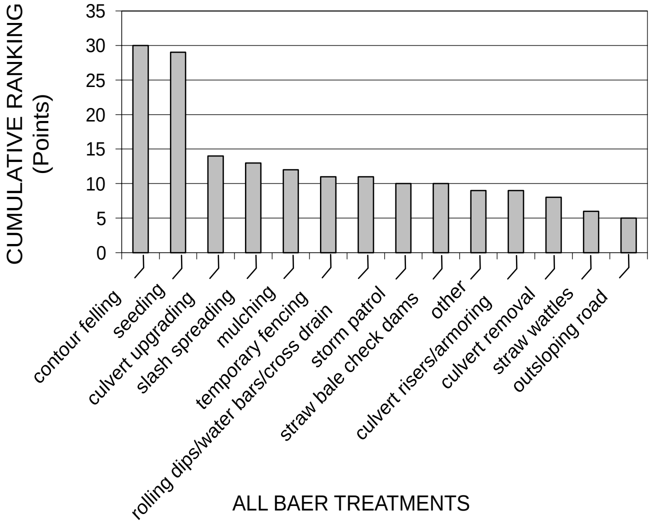


Figure 25—Cumulative ranking of treatment effectiveness for all treatments combined. Cumulative rankings are taken from interviewees ranking of their top three treatment preferences. The top 14 treatment preferences are shown out of a total of 26 treatments.

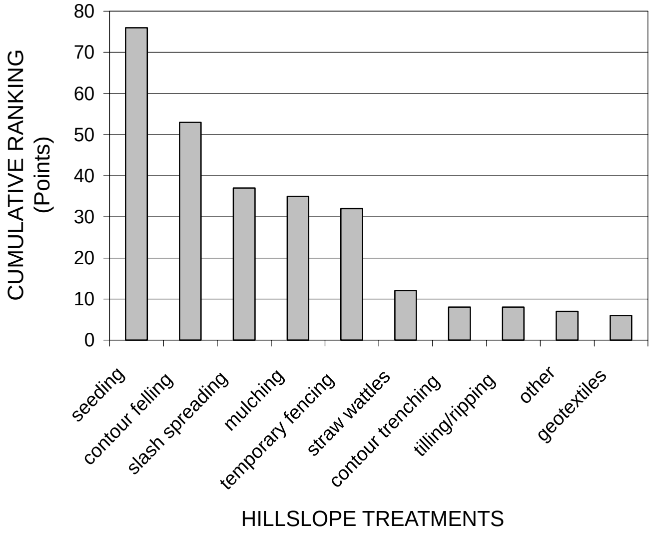


Figure 26—Cumulative ranking of treatment effectiveness for hillslope treatments. Cumulative rankings are taken from interviewees ranking of their top three treatment preferences. The top 10 preferences are shown out of a total of 16 treatments.

Contour-felled logs, the second highest ranked hillslope treatment, was also rated the most often underused treatment on project fires and second most on no-action fires. This treatment received the highest overall ranking (fig. 26), barely beating seeding, a trend reflected in its increasing popularity in recent years (fig. 17). However, it was listed as overused twice and, like seeding, received mixed ratings on effectiveness (table 17).

Among channel treatments, straw bale check dams received the highest ranking, followed by log grade stabilizers, rock grade stabilizers, channel clearing, bank and channel armoring, and in-channel felling (fig. 27). Straw bale check dams ranked ninth in overall preference, the only channel method falling within the top 10 (fig. 25). On the other hand, straw bale check dams were listed as overused twice, more than any other channel treatment, and were not listed as underused at all (table 18).

Rolling dips or water bars and culvert upgrading were by far the most preferred road treatments, with storm patrol next and other methods ranking lower (fig. 28). No road treatments were named as overused, but culvert upgrading was mentioned often as a treatment that should have been used on both project (second highest) and no-action (third highest) fires (table 18). It was the third highest ranked treatment overall. Storm patrol ranked eighth overall and was mentioned twice as a treatment that should have been used on no-action fires.

Table 18—Underused treatment on no action fires, underused treatment on BAER project fires, and overused treatments on BAER project fires from interviewees.

Treatment	Underused No Action Fires	Underused BAER Project Fires	Overused BAER Project Fires
Seeding, ground		1	3
Contour-felling	2	8	2
Straw bale checkdams			2
Seeding, aerial	3	1	10
Debris basins	1	1	1
Silt fence		2	1
Tilling/ripping		1	1
Geotextile fabrics		1	1
Stream bank/channel armoring			1
Seeding plus fertilizer			1
Culvert upgrading	2	4	
Storm patrol	2		
Mulching	1	4	
Cross drain ditches	2	1	
Exclusion	1		
Channel debris clearing		1	
Outsloping road		1	
Log dams		1	
Log grade stabilizers		1	
Ditch maintenance-cleaning, armoring		1	
Straw wattles		1	
Sand, soil, or gravel bags		1	

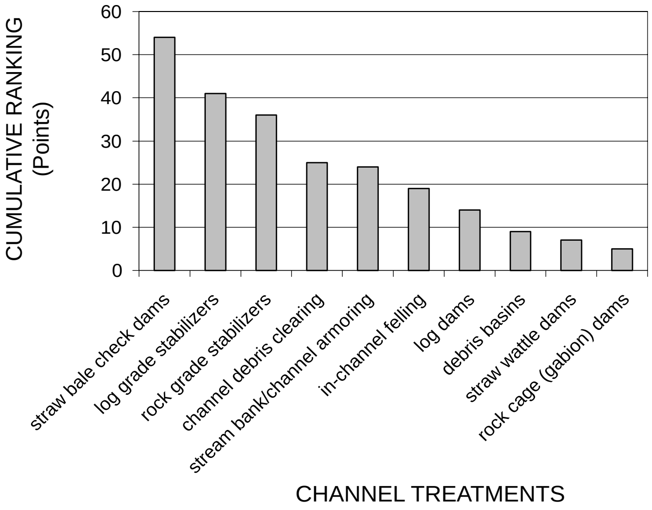


Figure 27—Cumulative ranking of treatment effectiveness for channel treatments. Cumulative rankings are taken from interviewees ranking of their top three treatment preferences. Rankings of all preferences are shown.

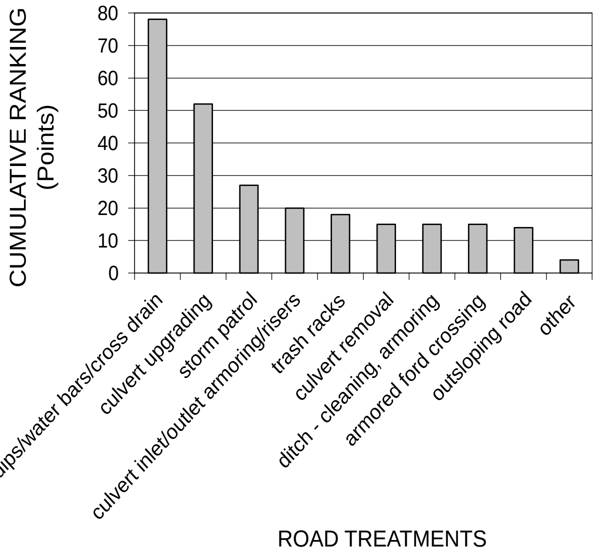


Figure 28—Cumulative ranking of treatment effectiveness for road treatments. Cumulative rankings are taken from interviewees ranking of their top three treatment preferences. The top 10 preferences are shown out of a total of 15 treatments.

Discussion

The BAER evaluation process provides a means to assess the postfire emergency and identify appropriate treatments. Although our original intent was to evaluate treatment effectiveness, our efforts to compile information on individual fires produced a large database of information on the BAER assessment process itself. Treatment effectiveness depends in part upon appropriate treatment selection, and that depends on accurately identifying the emergency condition. Our interviews revealed that some treatments are overused and others could be applied more often. We discuss the implications of our findings from review of BAER assessments, then evaluate treatment methods.

BAER Assessments

Total BAER expenditures during the last three decades (adjusted to 1999 dollars) were greater than $83 million, with over 60 percent occurring in the 1990's. This was due to several large fires, their proximity to urban/wildland interface, and increased values at risk, promoting greater protection. During the last three decades, over 3.8 million ac (1.5 million ha) of Forest Service land were burned. Of that, high severity burned areas has increased from 195,000 ac (79,000 ha) in the 1970's to over 655,000 ac (265,000 ha) in the 1990's. Flooding and sedimentation risk is greater from areas with high severity burns. Thus more money has been spent to try to reduce the threat to downstream values. Most of the increase in spending in the 1990's was due to high profile fires that threatened urban areas (table 9).

BAER teams assign erosion hazard ratings to various portions of a burned area based on local geology, soil type, topography, burn severity, expected storm duration and intensity, and local experience with postfire conditions. Improvements in erosion hazard rating could be accomplished by better fire severity mapping with infrared flights and satellite imagery after the fire (Lachowski and others 1997). These methods, though still in development, have shown promise for providing better burn area-wide severity assessment. Methods used to calculate erosion potential and sediment yields were not consistent, and in some cases the estimates made could be considered unreasonable. For example, erosion rates of 1000 t ac^{-1} (2200 Mg ha^{-1}) and sediment yields of 0.1 million yd^3 mi^{-2} (0.03 million m^3 km^{-2}) were projected on several fires. Considering that our review of published literature found reported erosion rates no higher than 165 t ac^{-1} (370 mg ha^{-1}) even from steep chaparral slopes (Hendricks and Johnson 1944). This suggests that assumptions about erosion potential used for those calculations are inaccurate. Uncritical review of the erosion potential estimates by the BAER team leaders must also have occurred. Refinement of the calculation methods and better training on how to do these calculations appears warranted.

Most BAER treatments were designed for a 10-year or 25-year return interval event indicating that treatments were designed for major storm events. Thus, the tolerance for high peakflows and excess sediment was low. Design storm estimated peakflow changes were not well correlated with infiltration reduction (fig. 15). A 10 percent reduction in infiltration is not likely to cause a 10,000 percent or great increase in peakflows. It is more realistic to expect that magnitude of increase from infiltration reduction of 80 to 100 percent. From our literature review, actual increases in peakflows due to wildfires can range over 3 to 4 orders of magnitude (Anderson and others 1976, Glendening and others 1961). Hibbart (1971) reported a 9,600 percent increase in peakflows in chaparral after a severe wildfire. Although high peakflow increases occur due to infiltration reduction and water repellent soil conditions in some forest types, design storm peakflow estimation techniques need to be refined and better documented to reflect the realities of watershed response to severe wildfire.

According to the Burned Area Reports we collected, water repellent soil conditions are more widespread after fire than previously reported (fig. 13; DeBano and others 1998). Existing research suggests that water repellency is usually found on coarse-textured soils, especially under chaparral or other vegetation with high levels of volatile organic compounds in the litter (DeBano and others 1979b, DeBano and others 1998). Our dataset included reports of water repellent conditions across all soil and vegetation types. Unfortunately, the information given on the Burned Area Reports did not allow us to analyze what methods were used to determine soil water repellent conditions (thus assessing the accuracy of the estimates) or how extensive the sampling was for the water repellent area determinations. These results identify a need for additional research on the extent and severity of water repellent soil conditions and its affect on infiltration after wildfire in the Western United States.

Quantifying the watershed degradation threat is difficult. Threats to life and property, water quality, and soil productivity were the main reasons given for proposing BAER treatments. The more urban Forest Service Regions listed threats to property as a reason for BAER treatment 50 percent of the time. As development in foothill areas increases, the need to treat burned areas to reduce the risk to property and life will likely increase as well. The role of flood plains during flood and debris flows needs to be emphasized.

Water quality issues include effects on aquatic habitat, sedimentation in channels and reservoirs, and effects on drinking water. Several monitoring studies found impacts to aquatic ecosystems that occurred in the first year after the fire or in the first major storm. Increases in stream turbidity with high rainfall were documented in Regions 1 and 6 (Amaranthus 1990, McCammon 1980, Story 1994). Large flood and debris flow events cleared streams of fish after the 1984 North Hills fire, Helena National Forest, Montana (Schultz and others 1986) and the 1990 Dude fire, Tonto National Forest, Arizona (Rinne 1996). In both cases the populations of at least some species recovered surprisingly quickly, however. Threats to developed water sources can be quantified relatively easily, because managers know how much it would cost to treat turbid water or remove sediment from a reservoir.

It is difficult to assess the potential for loss of soil productivity after fire, because there is no easy way of calculating a long-term productivity decline resulting from the loss of soil material or nutrients. This is particularly the case where there are not obvious losses of large amounts of organic matter and mineral soil. Depending on fire severity, soil productivity changes can be either beneficial or deleterious. Short-term increases in plant productivity can occur from soil changes such as the mineralization of nutrients tied up in organic matter (DeBano and others 1998, Neary and others 1999). Predicting productivity changes for long rotation forest stands is difficult, however, because of the many interacting factors which affect long-term productivity and the lack of adequate information to make long-range predictions (Powers and others 1990).

Site productivity changes can be long-term or temporary. If a fire is within the natural range of variation for an ecosystem, productivity changes should be short-term and acceptable since fire is a natural component in many ecosystems. If a fire is outside of the natural range of variation and intensity, particularly due to human interference with forest ecosystems, long-term soil productivity is more likely to be at risk.

Various methods have been used in the BAER process to estimate the cost of potential changes in soil productivity after fire. For example, the value of soil loss has been based on estimated site index changes due to the fire and the consequent potential loss in harvestable timber during the next regeneration cycle, or based on the cost of replacement top soil if purchased commercially. Most Burned Area Reports did not state how loss estimates were made. Methods that consider only the value of harvestable timber may underestimate the consequences of site productivity loss to other ecosystem components.

Instead of trying to justify BAER treatments by estimating some future loss in site productivity values (merchantable timber), a better approach would be to identify situations where future productivity is potentially threatened by the loss of large amounts of above ground organic matter in severe fires (Neary and others 1999) or losses of surface soil horizons (DeBano and others 1998). While both affect long-term productivity, only the latter can be affected in the short-term by BAER treatments. Until better methods can be developed to estimate long-term changes in productivity after wildfires, the professional judgment of soil scientists is the best tool for determining the need for treatments to mitigate soil productivity losses.

Probability of success stated in the BAER reports was always high (average 69 percent for hillslope treatments, 74 percent for a channel treatments, and 86 percent for road treatments the first year after fire; table 12). BAER teams are apparently very enthusiastic and optimistic that the BAER goals can be met and that the implemented treatments will work—a “can do” attitude, similar to that in fire fighting, prevails. This result should be expected, because only known effective treatments are supposed to be used for emergency watershed rehabilitation (USDA Forest Service 1995).

Results of our interviews suggest that these probabilities may be overestimated for some treatments. For example, only 52 percent of interviewees felt that aerial seeding, the most extensively used hillslope treatment was “good” or “excellent” in effectiveness (a reasonable definition of success), and only 56 percent of quantitative monitoring reports considered seeding effective the first year after fire. On the other hand, 79 percent of the nonquantitative reports considered it successful, justifying the high probability of success. Other treatments fared better in the effectiveness ratings. “Good” or “excellent” ratings were given to about 66 percent of contour-felled log projects, 83 percent of mulch projects, and a whopping 91 percent of ground seeding efforts. Monitoring reports also found contour-felled logs to be successful most of the time. These subjective results suggest that probability of success may be overstated for aerial seeding in many reports, but may be more realistic for other hillslope treatments. However, seeding is the only method for which a significant amount of post-fire research has been conducted (discussed further below). For other hillslope methods, hard data to evaluate effectiveness—and thus the probability of success—are scarce.

Among channel treatments, “good” or “excellent” ratings were given to 60 percent of straw bale check dam and log grade stabilizer projects, while channel debris clearing was closer to the Burned Area Report average with 71 percent. On the other hand, 69 percent of monitoring reports on straw bale check dams were favorable. For major channel treatments, BAER teams appear to be making fairly reasonable projections of success. Too few road treatments were rated for effectiveness or evaluated in monitoring or research reports to evaluate the reliability of success projections for those treatments.

Not only were BAER treatments expected to be successful, they were projected to save million of dollars in damages. For every $1 spent on treatments, $10 to $200 in losses was proposed to be saved (fig. 16). These estimates were made with very few data to verify the effectiveness of most BAER treatments. Based on our results, projected benefits from aerial seeding may need to be adjusted downward to reflect lower realistic probabilities of first-year success. Sullivan and others (1987) suggested that a high probability of success is required for a treatment to be economically cost effective.

As the cost of action or no action alternatives are based on professional judgment and past experience, they are very approximate. It might be better to use these estimates to rank treatment options. They do not provide real dollar values of what might happen, suggesting that an alternative ranking system might be preferable to compare treatment alternatives and no treatment options. Ranking could be based on actual damages that occurred in nearby similar watersheds.

BAER teams contained soil scientists and hydrologists most of the time, with a wide range of other disciplines represented as needed on particular fires. Although wildlife biologists were often on teams, ecologists were included relatively infrequently except in Region 4 (table 13). Many monitoring reports and interviewees identified a need for better information on the ecosystem impacts of fire and vegetation recovery potential (discussed further below) when evaluating the necessity for emergency treatments. In many cases, natural revegetation of burned areas occurred more quickly than expected. Including ecologists and botanists on BAER teams more frequently might help to better assess natural recovery potential.

BAER Project Monitoring

Monitoring of BAER projects has been done for a wide variety of reasons. Consequently, there was no standard format or content to the monitoring documents we collected. The most common type was a memo reporting on a trip to visually assess the results of BAER treatments or natural recovery after fire. These reports provided qualitative evaluations of treatment effectiveness and watershed condition, but relatively few quantitative data. Until 1998, there was no funding specifically available for postimplementation monitoring of BAER treatments. Any monitoring had to be done out of Forest Service appropriated funds. Thus the trip reports were probably all that could be squeezed into the normal plan of work on busy National Forests.

Most of the reports fell into the categories of "implementation" or "effectiveness" monitoring. They assessed whether treatments, especially structures such as straw bale check dams or contour-felled logs, were properly installed and operating as designed. In the case of structures, accumulation of sediment behind the barrier, structural integrity after the first winter, and lack of flooding or sedimentation problems downstream were generally regarded as indications of treatment success. Seeding operations were regarded as successful if the seeded species were observed to be growing well. Most monitoring was done a few months to 1 or 2 years after a fire. Only a few National Forests monitored projects lasted longer than that. The impacts of treatment on the emergency condition can be evaluated in this time period, but the ecosystems impacts of treatments, especially of seeding on native plant recovery, may not be adequately assessed.

Where quantitative data were collected, details other than the variables being measured were often omitted from reports (which were generally intended for internal use). For monitoring results to be informative for others with similar soils or vegetation types, details such as soil type and texture, slope angle, aspect, watershed or analysis area size, fire severity indicators, and other variables should be included in reports. Where treated areas are compared to untreated areas, it is especially important to know how comparable the sites are in other physical and biological attributes. These data are relatively easy to collect in most cases. Quantitative reports also often noted that measurements were made in "typical" areas, with no intention of providing statistical sufficiency. Some description of how "typical" was determined or how representative the sample plots were of the overall fire area would make the results more useful to future investigators, both on and off the specific National Forest. The low number of samples taken in most efforts may have resulted in overstatement of treatment impacts (as either effective or ineffective), because inherent site variability is not captured in the results. With greater funding available for monitoring, this limitation may be alleviated in the future.

Quantitative monitoring efforts were generally restricted to very small areas of a fire, while the qualitative trip reports analyzed a much larger proportion of the burned area in less detail. Both kinds of reports have obvious value for assessing the results of BAER projects. We found few cases where both kinds of monitoring were done on a given fire. This may be a result of the incompleteness of our record, or it could reflect the fact that National Forests could afford to do one or the other kind of monitoring, but not both. The interests of the personnel charged with monitoring may also have determined the type of monitoring that was done.

Because BAER treatments are generally designed to reduce erosion, sedimentation, and flooding, the most valuable assessments of treatment effectiveness would be those that actually quantify sediment movement and water yield. Relatively few reports measured sediment movement, and virtually none tried to quantify water yield. Methods used for measuring sediment movement ranged from erosion bridges, which measure change in the distance to ground surface from a fixed suspended bar, to height of erosion pedestals left after sediment movement occurred, to sediment traps such as troughs and silt fences installed below hillsides or in small swales. Erosion bridge results generally proved difficult to evaluate, because sediment was as likely to be deposited on a spot (eroded from above) as removed. Pedestal measurement was considered to overstate erosion, because it is measured only in places where sediment loss has obviously occurred and cannot easily be generalized to a larger area. Traps and silt fences provided the most informative results, although their tendency to overtop made many measurements minimum estimates rather than actual quantities. In addition, it is difficult to determine the size of the area actually contributing to a trap or fence. If fixed area plots above a trap are used, the plot boundaries may affect sediment movement. Most reports using these methods did not tell how contributing area was determined for the "tons per acre" sediment output calculation.

Because monitoring results can become the basis for future management decisions, it is critical that monitoring efforts and reports be as scientifically credible as possible. Whether defending a decision to seed or explaining why a flood occurred despite BAER treatments, Forests need to be able to support their work with good data from their own and other Forests' monitoring efforts. There is little published research on most BAER treatments. With the limitations of monitoring reports mentioned above, we did not feel that we could evaluate the validity of most reports, let alone generalize the results of monitoring done on one Forest to another area. There is a critical need for more and better monitoring of BAER treatments (discussed further in the Recommendations section).

Most monitoring focused on the most expensive (stream channel treatments, contour-felled logs), widespread (seeding), or controversial (seeding) treatment applied after a fire. The results from these efforts are incorporated into our discussions of specific treatment effectiveness.

Treatment Effectiveness

The basis for the BAER program is whether treatments effectively ameliorate postfire emergency conditions without compromising ecosystem recovery. For many treatment methods, effectiveness could only be determined qualitatively. From our interviews and the monitoring reports, it became apparent that treatment success often depended on appropriate implementation (see appendix B) and cooperative postfire weather. Quantitative data on effectiveness were available for relatively few treatments. We were able to analyze hillslope treatments in more detail than channel or road treatments.

Hillslope Treatments—Increasing infiltration of rain water and preventing soil from leaving the hillslope are considered the most effective methods to slow runoff, reduce flood peaks, retain site productivity, and reduce downstream sedimentation. Mulching and geotextiles were rated the most effective hillslope treatments by our interviewees, because they provide immediate ground cover to reduce raindrop impact and hold soil in place. Postfire research and monitoring reports showed dramatic decreases in sediment movement where mulch was applied (Bautista and others 1996, Faust 1998). However, both methods are relatively costly and are difficult or impossible to install in remote locations (appendix B). Mulch is most useful near roads or in critical areas at the tops of slopes. Geotextiles are generally applied to small areas, such as road cuts and fills. Aerial seeding and contour-felled logs are the two most common hillslope treatments. Their effectiveness in reducing erosion had mixed reviews from the published literature, monitoring reports, and interview results, even though the Forest Service spent over $25 million in the last three decades on each treatment.

Little contour-felling was implemented in the 1970's, and only $4 million was spent in the 1980's. Since then, however, contour-felled logs have gained in popularity as a hillslope treatment. Most interviewees thought the effectiveness was good or excellent. Monitoring studies did not evaluate runoff, infiltration, or sediment movement changes due to the contour-felled logs; they only reported sediment storage. Monitoring studies indicated that contour-felling could be about 60 percent efficient (DeGraff 1982) and could reduce downslope sedimentation by about 40 to 60 percent (Griffith 1989a). Maximum trapped sediment of 6.7 yd^3 ac^{-1} (13 m^3 ha^{-1}) or about 6.8 t ac^{-1} (17 Mg ha^{-1}) by contour-felled logs was reported by Miles and others (1989). McCammon and Hughes (1980), on the other hand, estimated storage at about 72 yd^3 ac^{-1}

(135 m^3 ha^{-1}), using a high density of logs. If first-year annual erosion rates vary from 0.004 to 150 t ac^{-1} (0.01 to 370 Mg ha^{-1}), then they could trap 5 to 47 percent of 150 t ac^{-1} (370 Mg ha^{-1}) of sediment, depending on the density of the logs. Beyond that they would not be cost effective from a sediment-holding capacity analysis. This wide range of effectiveness indicates the need of proper estimation techniques of the erosion potential, and for properly designing contour-felled log installations in terms of log numbers and spacing. For example, if you can trap 60 percent or greater then they are probably cost effective, but if you are only trapping 5 or 10 percent of the expected sediment production, then it may not be worth the effort for such small amount of sediment storage ability. Contour-felled logs do provide immediate benefits after installation, in that they trap sediment during the first postfire year, which usually has the highest erosion rates.

The ability of this treatment to reduce runoff, rilling, increase infiltration and decrease downstream time to peak (slowing velocities) has not been documented, even though these are reasons often given for doing contour felling. If contour-felled logs slow or eliminate runoff, sediment movement may not occur. Therefore, measuring sediment accumulation behind the logs may not be the best method for assessing their effectiveness. Quantifying sediment and water output from a watershed are the best ways to truly evaluate the effectiveness of contour-felled logs, but this kind of research and monitoring is expensive and difficult to do.

Contour-felled logs will channel flow if not installed correctly on the contour with good ground contact. Therefore, proper training, contract inspections, and close monitoring during installation are critical to success, as was repeatedly pointed out by interviewees (appendix B).

Grass seeding is the most widely used and best studied BAER treatment. Our interviewees ranked seeding second highest in overall treatment preference, despite giving it mixed reviews for effectiveness and citing it as overused more often than any other treatment. Expenditures for seeding declined somewhat in recent years (fig. 17). However, seeding remains the only method available to treat large areas at a reasonably low cost per acre.

How likely is seeding to increase plant cover or reduce erosion, in either the first growing season or later? We tabulated results from published studies (in tables 6 and 7) to determine rough probabilities of seeding "success" in the first and second years after fire (table 19). Only studies that evaluated comparable seeded and unseeded plots were included. Distinct research sites within a single paper were treated as unique "studies" for this comparison. Because few researchers measured erosion, we used vegetation cover as an indicator of potential erosion control effectiveness. Previous work found that 60 percent ground cover reduced sediment movement to negligible amounts, and 30 percent cover reduced erosion by about half compared to bare ground (Noble 1965, Orr 1970). We used these levels as indicators of effective or partly effective watershed protection, respectively, from seeded and/or natural vegetation.

Table 19—Numbers of published studies reporting measures of seeding "success" by native vegetation type during the first 2 years following fire.

Pubs. Showing Cover Measurements[1]	Those Showing Seeding Increased Cover	% of Pubs. Showing >30 % Cover		% of Pubs. Showing >60 % Cover		Pubs. Showing Erosion Measurements	Those Showing Seeding Reduced Erosion
		Seeded	Unseeded	Seeded	Unseeded		
No.		*Percent*				*No.*	
Postfire Year One							
Chaparral							
10	4	50	50	30	20	7	1
Conifer							
9	5	33	0	22	0	1	0
Combined							
19	9	42	26	26	10.5	8	1
Postfire Year Two							
Chaparral							
7	2	86	86	86	43	6	1
Conifer							
11	6	73	55	36	0	3	1
Combined							
18	8	78	67	56	17	9	2

[1] All studies contained seeded and unseeded plots and reported plant production as percent cover at the end of the growing season. Only statistically significant increases in cover or reductions in erosion are tabulated (Amaranthus 1989, Amaranthus and others 1993, Anderson and Brooks 1975, Beyers and others 1998a, Conard and others 1995, Gautier 1983, Geier-Hayes 1997, Griffin 1982, Rice and others 1965, Roby 1989, Taskey and others 1989, Van de Water 1998, Tiedemann and Klock 1973, 1976).

Seeding significantly increased total plant cover 47 percent of the time by the end of the first growing season after fire (table 19). Forty-two percent of seeded sites had at least 30 percent cover, compared to 26 percent of unseeded. Only 26 percent of seeded sites had at least 60 percent cover versus 10.5 percent of unseeded. Using vegetation cover as an indicator, therefore, the probability of seeding providing effective watershed protection by the end of the first growing season was just 26 percent, but that was more than twice the probability that an untreated site would be stable.

Erosion was decreased by seeding in only one out of eight first-year studies (12.5 percent). Erosion measurements have high variability, and several of the studies showed a trend toward lower sediment movement on seeded plots that was not statistically significant (e.g., Amaranthus 1989, Wohlgemuth and others 1998). The low occurrence of erosion effects is not surprising, however, considering that much of the sediment movement occurs before plant cover is established. Krammes (1960), in southern California, found that as much as 90 percent of first-year postfire hillslope sediment movement can occur as dry ravel before the first germination-stimulating rains even occur. Amaranthus (1989) measured most first-year sediment movement on his Oregon study site during several storms in December, before the seeded ryegrass had produced much cover.

In the second year after fire, seeded sites had greater total cover (plant and litter) than unseeded 42 percent of the time (table 19). Half of the studies measured erosion, which was significantly lower on seeded sites 22 percent of the time. Greater cover, therefore, did not always produce less erosion. The proportion of sites with at least 30 percent cover was 78 percent and 67 percent of seeded and unseeded plots, respectively. More than half (56 percent) of all seeded sites were essentially stabilized (at least 60 percent cover), compared to only 17 percent of unseeded sites. Thus seeded slopes were three times more likely to be stable after 2 years than unseeded slopes, though seeding still had only a 56 percent probability of "success" if success means "effective" (60 percent) cover.

Published reports from chaparral and conifer sites differed somewhat in response to seeding (table 19). Seeding was less likely to increase cover the first year on chaparral sites than conifer sites. Half of both seeded and unseeded chaparral sites had at least partially effective cover after 1 year, compared to only 33 percent of seeded conifer sites and none of the unseeded. However, the only study reporting less erosion on seeded plots the first year after fire was from a chaparral site seeded with annual ryegrass (Gautier 1983). The same trend was evident in studies reporting second-year results (table 19).

The study sites in these publications varied widely in soil type, percent slope (table 6, 7), annual precipitation, rainfall pattern, and prefire plant community, as well as seeding mix, so that lumping them together masks important factors affecting cover development and erosion. The total cover value tallied in the published studies sometimes included litter, sometimes not; thus, the number of partially and effectively stabilized sites in the second year could be underestimated.

We made several generalizations from this tabulation. First, plant cover developed relatively rapidly on the chaparral sites examined, so that seeding was less likely to make a difference in total cover in chaparral than on conifer sites. Second, most of the studied chaparral sites were seeded with annual ryegrass, while the conifer sites tended to be treated with a mixture of perennial pasture grasses, and increased cover due to seeding was more likely to show up in the first year on chaparral sites and in the second year on conifer sites. Third, even if treatment "success" is defined as at least 60 percent total cover at the end of the growing season, rather than as an actual measured reduction in sediment movement, seeding had a low probability of success during the first year after fire, when most of the erosion occurs (Robichaud and Brown 1999, Wells 1981), and continued to have a low probability of success on conifer sites in the second year. On the basis of these published results, Burned Area Reports that project 60 to 80 percent first-year success for seeding operations are greatly exaggerating the potential benefits of treatment.

A similar tabulation was made from quantitative monitoring reports, although most of them did not directly compare seeded and unseeded plots (table 20). Where they were directly compared, seeded plots had greater cover than unseeded plots 64 percent of the time at the end of the first growing season after fire, though the differences were not tested for statistical significance (table 14). A higher proportion of first-year monitoring studies, compared to published studies, showed apparent reductions in erosion (43 percent) as well, although, again, differences in sediment production were not analyzed statistically. Some of the comparisons involved only one or two monitoring points per treatment. Seeded plots were more likely to have at least 30 percent cover after one growing season in the monitoring studies than in the published studies (74 percent vs 42 percent), possibly because more of them reported on sites seeded with quick-growing cereal grains or annual ryegrass rather than perennial pasture grasses. The probability of finding "effective" (at least 60 percent) cover at the end of the first growing season was only slightly greater (35 percent) than in the published studies.

Table 20—Numbers of monitoring reports listing measures of seeding "success" by native vegetation type during the first 2 years following fire.

Reports Showing Cover Measurements[1]	Those Showing Seeding Increased Cover	% of Reports Showing >30 % Cover		% of Reports Showing >60 % Cover		Reports Showing Erosion Measurements	Those Showing Seeding Reduced Erosion
		Seeded	Unseeded	Seeded	Unseeded		
No.		*Percent*				*No.*	
Postfire Year One							
Chaparral							
7	4	85	25	38	12	3	1
Conifer							
4	3	60	60	30	0	4	2
Combined							
11	7	74	38	35	8	7	3
Postfire Year Two							
Chaparral							
2	0	67	67	33	33	2	0
Conifer							
0	0	80	100	20	100	1	1
Combined							
2	0	75	75	25	50	3	1

[1] The first two columns report only studies that contained both seeded and unseeded plots. The middle four columns summarize all studies that contained percent vegetation cover data. The last two columns report only studies that compared erosion between seeded and unseeded plots. Statistical significance was not tested in these studies.

Interviewees and monitoring reports alike acknowledged that the major benefits of seeding are not apparent until the second year after fire, because, as noted above (Amaranthus 1989), most of the growth by seeded grasses takes place after first year damaging storms have occurred. From the Los Padres National Forest: "As is typical, the seeding [annual ryegrass and lana vetch] did not significantly control erosion during the first rainy season. Seeds did not germinate until after steady precipitation, and did not grow significantly until after warm spring weather. The seeded species are expected to be of greatest value during the second and third rainy seasons" (Esplin and Shackleford 1978), when plant litter produced by the first year's growth covers the soil. Rainfall that first winter was the second highest on record and resulted in approximately 125 $yd^3\ ac^{-1}$ (240 $m^3\ ha^{-1}$) of soil eroded, despite the fact that seeding was "successful" by most criteria, tripling average plant biomass compared to unseeded areas by the end of the first growing season (Esplin and Shackleford 1978). One report suggested that measures other than seeding should be used in places where first-year control of sediment movement is critical (Ruby 1997). The increased use of contour-felled logs in recent years probably reflects this knowledge.

Seeding is often most successful where it may be needed least—on gentle slopes and in riparian areas. Janicki (1989) found that two-thirds of plots with more than 30 percent annual ryegrass cover were on slopes of less than 35 percent. He also noted "observations of grass plants concentrated in drainage bottoms suggest that seed washed off the slope with the first two storm events." Concentration of seeded species at the base of slopes was also observed by Loftin and others (1998). Some published papers and most monitoring reports did not give slope angles for study sites, making interpretation of varying success levels difficult. Several interviewees suggested that seeding was unnecessary in riparian areas, because native vegetation there usually recovers rapidly. On the other hand, other published papers and monitoring reports suggested quickly establishing strips of vegetation along the margins of streams as one of the best ways to reduce sediment transport into watercourses. Careful assessment of vegetation regrowth potential during the BAER evaluation could help resolve this apparent contradiction.

Interviewees observed that first-year seeding success is highly dependent on rainfall pattern. Gentle rain before the first intense storm is needed to stimulate germination; then enough rain is needed for seeded species to survive. These conditions are more likely to be met in some areas of the Western United States than others. Seeding may be particularly risky in the Southwest (Region 3), where intense monsoon rains follow the early summer fire season. Areas where seeding is more often considered "excellent" or "good" may be those where rainfall lasts longer through the year (e.g., all but July and August in the Pacific Northwest) or where a significant portion of the annual total occurs in summer (e.g., about 30 percent in areas such as Montana, northern Idaho, and northeastern Washington). California (Region 5) has a long dry season and unpredictable early fall rains, making grass establishment less likely to be successful.

Research, monitoring reports, and interview comments all suggest that "successful" grass establishment displaces some native plant regeneration. This was the goal of past range "reseeding" projects—producing useful livestock and wildlife forage on land that would not contain harvestable timber for decades and would otherwise produce nothing but "weeds"—and aggressive, persistent grass species were deliberately chosen for seeding (Christ 1934, Evanko 1955, Friedrich 1947, McClure 1956, Stewart 1973). Suppression of native plant regeneration could potentially reduce browse species for wildlife, reduce watershed protection in chaparral, and limit the seed bank contributions of annual and short-lived perennial "fire-followers" in chaparral and Southwestern ecosystems (Conard and others 1995, Keeler-Wolf 1995, Keeley and others 1981, Loftin and others 1998). There is no published research that quantifies the long-term impacts of postfire seeding on native plants, but one monitoring observed that weeping lovegrass (*Eragrostis curvula*) in the Southwest can effectively suppress native vegetation for years (Loftin and others 1998).

In our interviews, forest silviculturists expressed major concerns about the impacts of grass seeding on conifer regeneration. The dilemma between erosion reduction and conifer growth is well recognized: "Since granitics are inherently good tree-growing sites, as well as being extremely erodible when burned, the choice between immediate reforestation and long-term productivity can be a difficult one" (Van de Water 1998, p. 28). Better understanding of the impacts of fire and erosion on soil productivity would help address this problem.

Current USDA Forest Service guidelines promote the use of native species for revegetation projects wherever practical. Interviewees commented that native grasses are expensive and not widely available in the quantities necessary for postfire seeding projects, and developing seed sources that can provide a range of locally adapted genotypes is difficult (Van de Water 1998). In addition, well-adapted native perennial grasses could provide as much or more competition with conifers as the non-native species currently in use. For example, the native Southwestern grass Arizona fescue (*Festuca arizonica*) greatly reduced the growth of conifer seedlings (Pearson 1942, Rietveld 1975). One BAER team included the cost of using herbicide for seeded grass control in BAER calculations and, as a result, decided against using a well-adapted native grass and chose to seed cereal barley (*Hordeum vulgare*) instead (Griffith 1998). The barley died out after 1 year except where disturbed by salvage logging (Griffith 1993; tables 14, 15).

Seeded grasses can benefit conifer seedlings if they exclude more competitive vegetation, such as shrubs (Amaranthus and others 1993, McDonald 1986). Once conifer seedlings are well established, grass cover is less detrimental to their growth than shrub competition (McDonald and Oliver 1984, McDonald 1986). If grass cover is not too thick, it can potentially benefit tree seedlings. Green (1990) observed over 90 percent survival of Douglas fir seedlings on a site seeded after fire with cereal rye (*Secale cereale*). The rye, at a density of 9 plants ft^{-2} (100 plants m^{-2}), provided shade to the seedlings during the first year after fire. The rye decreased to less than 3 plants ft^{-2} (33 plants m^{-2}) the second year and essentially disappeared in the third.

Cereal grains such as barley, cereal rye, oats (*Avena sativa*), and winter wheat (*Tricium aestivum*) appear to show great promise for producing cover that does not persist. Annual ryegrass was expected to behave this way, but it proved persistent beyond a couple of years in some ecosystems (Barro and Conard 1987, Griffith 1998) and often produces maximum cover the second year after fire, rather than the first (Beyers and others 1998; compare Janicki 1989 with Conard and others 1991). A few reports cited initial concerns over the impacts of cereal grains on native regeneration that disappeared after further monitoring (e.g., Callahan and Baker 1997, Hanes and Callahan 1995, 1996, Van Zuuk 1997). Some cereal grains may exhibit allelopathy, inhibiting competing plant growth chemically (Went and others 1952), but this has not been investigated under field conditions. Clearly more research on and monitoring of postfire cereal grain seeding is needed, especially regarding the impacts on native herbaceous plants and conifer seedlings.

In many cases natural regeneration provided as much cover as seeded species during the first years after fire, but good methods for assessing native seed bank viability are lacking (Isle 1998, Loftin and others 1998). One standard test for seed bank viability only identifies large-seeded species (by sieving them from postfire soil samples) or those that germinate quickly (7 to 10 day greenhouse germination test) (Dyer 1995). Species that will provide cover later in the winter or in the second growing season—the same time that seeded grasses provide most of their cover—are not detected by this method if they have tiny seeds or cold requirements for germination. Better understanding of the natural range of vegetation response to fire would increase our ability to predict whether seeding is really necessary (Loftin and others 1998, Tyrrel 1981).

Several interviewees suggested that more flexibility in choosing seed mixes be allowed in BAER projects, including the use of quick-growing annuals for erosion control and slower growing native perennials for long-term ecosystem restoration, particularly native range. At present, BAER guidelines stress the use of only proven erosion-control species for emergency rehabilitation. Other interviewees expressed concern that grass seeding may introduce noxious weed species even in certified seed.

Little evidence suggests that fertilizer applied with seeded grass is effective in increasing cover or reducing erosion after fire. Flight strips from the aircraft that applied the fertilizer were visible as brighter green stripes on the ground in some areas, and seeded grasses were twice as tall in the fertilized strips than in missed areas (Herman 1971). Fertilizer increased native plant growth on low fertility granite soils in Idaho but did not increase cover of seeded grasses (Cline and Brooks 1979). Other research and monitoring studies found no significant effect of fertilizer on plant cover or erosion (Esplin and Shackelford 1980, Tyrrel 1981). After fire, plant growth responds to a flush of readily available nitrogen compounds deposited on the soil surface with the ashes (Christensen 1973, DeBano and others 1979a, DeBano and others 1998). Research that showed increased growth by seeded grass with fertilization was conducted on firelines, where the nutrient-rich ash layer had been scraped from the soil (Klock and others 1975). It could make more sense to apply fertilizer late in the first growing season or during the second year, after the initial flush of available nutrients has been used by plants or leached away.

Retention of soil onsite for productivity maintenance is an important BAER objective, but almost no evidence indicates whether seeding meets this goal. Two years after a fire, higher available soil nitrogen and higher cation exchange capacity were found in seeded areas than in adjacent swaths that had been missed (Griffith 1989b, 1998). Soil retention and nutrient uptake/release by the seeded grass were credited for the improvement. No other reports addressed soil fertility. Whether soil nutrient loss from the fire itself and from subsequent erosion are significant to long-term ecosystem productivity will depend on whether fire severity was within or far outside the natural range of variability for a given ecosystem. Although some nutrients are inevitably lost in a fire, they will be made up in time by natural processes (DeBano and others 1998). Loftin and others (1998) pointed out that sometimes postfire conditions are more "natural," from a long-term ecosystem perspective, than the prefire condition in many forests that have been subject to decades of fire suppression. More research and monitoring are needed to evaluate the need for and effects of seeding and other BAER treatments on soil productivity.

Monitoring reports and interviews noted that occasionally seeding is done mostly for "political" reasons, because the public and elected officials expect to see *something* done to restore a burned area "disaster" near their community (Anonymous 1987, Ruby and Griffith 1994). Smaller fires that burned under conditions not far out of the range of natural variation may have been seeded unnecessarily for this reason. Better public education on the natural role of fire in ecosystems and the inevitability of a postfire sediment pulse could reduce the need for "political" seeding.

Other hillslope treatments have been used, but little quantitative information has been published on their effectiveness. Thus effectiveness ratings are often based on visual assessment with no direct comparisons with other treatments. Hillslope treatments such as large contour trenching may increases infiltration and trap sediment during summer thunderstorms, but they are expensive to install and require machinery, thus limiting the slopes that they can work, and they have long-term impacts on hillslope appearance and hydrologic function. More recently, hand trenches have been used. Hand trenches are quicker to install and require less skilled crews. Straw wattles may detain surface runoff, reduce velocities, store sediment, and provide a seedbed for germination. Cattle exclusion with temporary fencing can be important for the first 2 years postfire. Ripping/tilling was effective on roads, trails, and firebreaks with slopes less than 35 percent. Slash spreading is effective if good ground contact is maintained. Most of these treatments cannot be applied to large areas but may be appropriate in critical areas of high risk. Monitoring of effectiveness is needed to determine if they are cost effective as well.

Channel Treatments—We conclude that channel treatments should only be used if downstream threat is great. Straw bale check dams are designed to reduce sediment inputs into streams. Collins and Johnston (1995) indicated that about 45 percent of the straw bales check dams installed were functioning properly after the first 3 months, whereas Miles and others (1989) reported that 87 percent of the straw bale check dams were functioning and Kidd and Rittenhouse (1997) reported that 99 percent were functioning. They often fill in the first few storms, so their effectiveness diminishes quickly and they can blow out during high flows. Thus their usefulness is short-lived.

Log dams can trap sediment by decreasing velocities and allowing coarse sediment to drop out. Fites-Kaufman (1993) indicated only a 3 percent failure rate. However, if these structures fail, they usually aggravate erosion problems. Log and rock grade stabilizers emphasis stabilizing the channel rather than storing the sediment. They tend to work for low and moderate flows, not high flows. No reports on channel stabilization effectiveness were found.

No estimates of erosion reduction were found by stream bank armoring. Channel clearing—removing logs and other organic debris—was rated "good" 71 percent of the time since it prevents logs from being mobilized in debris flow or floods. Since the value of in-stream woody debris to fish has been realized, this treatment has declined in popularity whereas in-channel felling has increased in popularity. No estimates on rock cage dams effectiveness were found but it is known that they provide grade stability and reduce velocities to drop out coarse sediment. Debris basins are designed to store runoff and sediment and are often the last recourse to prevent downstream flooding and sedimentation. They are often designed to trap 50 to 70 percent of the expected flows. No estimates of sediment trapping efficiencies for debris basins were found.

Road Treatments—Road treatments are designed to move water to desired locations and prevent washout of roads. There is little quantitative research evaluating and comparing road treatment effectiveness. A recent computer model, X-DRAIN, can provide sediment estimates for various spacings of cross drains (Elliot and others 1998), and the computer model, WEPP-Road, provides sedimentation estimates for various road configurations and mitigation treatments (Elliot and others 1999). Thus, effectiveness of various spacings of rolling dips, waterbars, cross drains, and culvert bypasses can be compared. By shortened flow paths and route water at specified crossings, erosion can be reduced. Upgrading culverts to larger sizes increases their flow capacity, which reduces the risk of blockage and exceeding capacity. Culvert armoring and adding risers allow sediment to settle out and prevent scouring. Trash racks prevent clogging of culverts or other structures which keeps the culverts opening as designed. Culvert removal, when appropriate, eliminates the threat of blockage. Storm patrol shows promise as a new cost effective method to keep culverts and drainage ditches clear, provide early warnings and close areas that could be threaten by a storm flows. Armoring ford crossings allows for low-cost access across stream channels, with the ability to handle large flows. Ditch cleaning and armoring provide for drainage of expected flows and reduce scouring. Outsloping prevents concentrated flow on road surfaces thus reducing erosion. Detail discussion of road related treatment effectiveness is beyond the scope of this report. The recent USDA Forest Service, San Dimas Technology and Development Program, Water/Road Interaction Technologies Series (Copstead 1997) provides design standards, improvement techniques, and evaluations of some surface drainage treatments for reducing sedimentation.

Conclusions

Relatively little monitoring of BAER treatments has been conducted in the last three decades. Published literature focused on seeding issues, with little information on any other treatments. Therefore, interview forms and monitoring reports were used to document our current knowledge on treatment options and their effectiveness. There were at least 321 BAER project fires during last three decades that cost the Forest Service around $110 million to rehabilitate. Some level of monitoring occurred on about 33 percent of these project fires. Our analysis of the literature, Burned Area Report forms, interview comments, monitoring reports, and treatment effectiveness ratings leads us to the following conclusions:

- Existing effectiveness monitoring efforts and research are insufficient to accurately compare treatment effectiveness and ecosystem recovery.
- Rehabilitation should be done only if the risk to life and property is high since the amount of protection provided is assumed to be small. In some watersheds, it would be best not to do any treatments. If treatments are necessary then it is more effective to reduce erosion onsite (hillslope treatment) rather than collected it downstream (channel treatment).
- Contour-felled logs show promise as a relatively effective treatment compared to other hillslope treatments. This is considered to be true for areas where erosion rates are expected to be high because they provide protection during the first-year postfire which has the highest erosion rates. In areas that do not have available trees, straw wattles may provide an alternative. However, the effectiveness of contour-felled logs or straw wattles has not been adequately documented in the scientific literature.
- Seeding has a low probability of reducing erosion the first wet season after a fire. There is a need to do other treatments in critical areas. Seeding can provide reasonable cover late in first season and in the second year. Most estimates of ground cover occur at the end of the first growing season, thus cover information is not appropriate for comparison for first year storm events.
- There is a need to better understand regeneration potential of natural vegetation. Seeding treatment may not be needed as often as currently thought.
- Because seeding is often not “successful,” it may have little impact on natural regeneration. Persistent perennials are least effective at providing first year cover and most likely to interfere with later regeneration. Cereal grains (annuals) offer better first-year protection than perennials but generally do not interfere with later regeneration of natural vegetation. Little is known about the effectiveness of native annual grasses.
- Evaluating postfire watershed conditions, treatment chance of success, cost-benefit ratios, and

risk assessments was difficult because various methods were used to estimate their values. Little information and research is available on risk assessment and cost-risk ratios of various BAER treatments.

- To reduce the threat of road failure, road treatments such as rolling dips, water bars, and relief culverts properly spaced provide a reasonable method to move water past the road prism. Storm patrol attempts to keep culverts clear and close areas as needed. This approach shows promise as a cost effective technique to reduce road failure due to culvert blockage.
- Straw bale checkdams, along with other channel treatments, should be viewed as secondary mitigation treatments. Sediment has already been transported from the slopes and will eventually be released though the stream system as the bales degrade, although the release is desynchronized.

Recommendations

Based on the findings from this study, we provide the following recommendations to further our knowledge and understanding of the role of emergency rehabilitation treatments:

- Streamline the Burned Area Report (FS-2500-8) form to address postfire watershed cost-benefit and risk analysis in an easily understandable manner. Provide information to assist decisionmakers to be able to compare treatment alternatives and understand that the consequences are only going to happen if we have storm events.
- Increase training on methods to calculate and use design storm intensity and frequency, probability of success, and erosion risk estimates. These can be targeted to soil scientists and hydrologists because they are involved with virtually every BAER effort.
- Increase the number of quantitative studies to document contour-felled logs effectiveness in reducing erosion. Additional research is needed to determine whether contour-felling can reduce rilling, increase infiltration, and decrease downstream time to peakflow (slow water velocities). Hand trenching effectiveness is another treatment that has not been documented, but may be effective and should also be evaluated.
- Increase monitoring efforts to determine if treatments are performing as planned and designed. Monitoring should include measuring effectiveness in reducing erosion, sedimentation, or downstream flooding, but may also include changes in infiltration, soil productivity, ecosystem recovery and water quality parameters. Two levels of monitoring are proposed. Extensive effectiveness monitoring can be accomplished at the forest level with little regional support, thus numerous sites/fires can be evaluated in different climate regimes. Intensive performance monitoring would need regional and research support and could be done on "demonstration" fires for each region (physiographic or Forest Service).

Effectiveness Monitoring: Silt fences placed at the bottom of hillslope plots are an economical method to compare hillslope treatments by determining how much sediment is trapped by each silt fence. Plots can be established to compare hillslope treatments such as seeding, contour-felled logs, hand trenches, etc. Silt fences have a very high trap efficiency (greater than 90-95 percent), and are easily maintained and serviced. For maximum information gain, treated replicated plots should be compared for physically similar untreated plots.

Performance Monitoring: To compare sedimentation responses of various treatments, small catchments need to be monitored for runoff and sediment. This is a costly and time-consuming technique but does provide the best results and would need to be conducted in conjunction with research in order to prevent shortcoming from past efforts. This method can be used to compare hillslope or road or channel treatments.

- Support Research efforts to improve methodologies to assess and predict long-term effects of wildfire on soil and site productivity.
- Develop a knowledge-base of past and current BAER projects that is easily accessible to others (i.e., Internet). This would include treatment design criteria and specifications, contract implementation specifications, example Burned Area Report calculations, and monitoring techniques.

References

Agee, J. K. 1993. Fire ecology of Pacific northwest forests. Island Press, Washington, DC. 493 p.

Amaranthus, Michael P. 1989. Effect of grass seeding and fertilizing on surface erosion in two intensely burned sites in southwest Oregon. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 148-149.

Amaranthus, Michael P. 1990. Siskiyou National Forest wildfire and recovery monitoring report. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Siskiyou National Forest, OR. 142 p.

Amaranthus, Michael P.; Trappe, James M.; Perry, David A. 1993. Soil moisture, native revegetation, and *Pinus lambertiana* seedling survival, growth, and mycorrhiza formation following wildfire and grass seeding. Restoration Ecology. 1(3): 188-195.

Ambos, Norm. 1992. Summary—Dude fire photo points. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Tonto National Forest, AZ. 6 p.

Anderson, William E.; Brooks, Lee E. 1975. Reducing erosion hazard on a burned forest in Oregon by seeding. Journal of Range Management. 28(5): 394-398.

Anderson, H. W.; Coleman, G. B.; Zinke, P. J., 1959. Summer slides and winter scour—wet-dry erosion in southern California mountains. Gen. Tech. Rep. PSW-36. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 12 p.

Anderson, H. W.; Hoover, M. D.; Reinhart, K. G. 1976. Forests and water: effects of forest management on floods, sedimentation, and water supply. Gen. Tech. Rep. PSW-18. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 115 p.

Anonymous. 1987. Oak Grove fire. Unpublished report on file at: Dixie National Forest, UT. 2 p.

Arndt, Arthur M. 1979. Emergency revegetation of burned watersheds in Los Angeles County. Riverside, CA: Chaparral Research and Development Program, CHAPS Newsletter, March 1979: 1-3.

Bailey, Reed W.; Copeland, Otis L. 1961. Vegetation and engineering structures in flood and erosion control. In: Proceedings, 13th Congress, September 1961, Vienna, Austria. International Union of Forest Research Organization Paper. 11-1: 23 p.

Baron, F. J. 1962. Effects of different grasses on ponderosa pine seedling establishment. Res. Note PSW-199. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Barro, Susan C.; Conard, Susan G. 1987. Use of ryegrass seeding as an emergency revegetation measure in chaparral ecosystems. Gen. Tech. Rep. PSW-102. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 12 p.

Bautista, S.; Bellot, J.; Vallejo, V.R. 1996. Mulching treatment for post-fire soil conservation in a semiarid ecosystem. Arid Soil Research and Rehabilitation. 10: 235-242.

Benda, L. E.; Cundy. T. W. 1990. Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal. 27: 409-417.

Best, D. W.; Kelsey, D. K.; Hagans, D. K.; Alpert, M. 1995. Role of fluvial hillslope erosion and road construction in the sediment budget of Garret Creek, Humboldt County, California. In: Nolan, K. M.; Kelsey, H. M.; Marron, D. C., eds. Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. Professional Paper 1454. Washington, DC: U.S. Geological Survey: M1-M9.

Beyers, Jan L.; Conard, Susan G.; Wakeman, Carla D. 1994. Impacts of an introduced grass, seeded for erosion control, on postfire community composition and species diversity in southern California chaparral. In: Proceedings of the 12th international conference on fire and forest meteorology, October 26-28, 1993, Jekyll Island, GA. Bethesda, MD: Society of American Foresters: 594-601.

Beyers, Jan L.; Wakeman, Carla D.; Wohlgemuth, Peter M.; Conard, Susan G. 1998a. Effects of postfire grass seeding on native vegetation in southern California chaparral. In: Proceedings, nineteenth annual forest vegetation management conference: wildfire rehabilitation, January 20-22, 1998. Redding, CA: Forest Vegetation Management Conference: 52-64.

Beyers, Jan L.; Wohlgemuth, Peter M.; Wakeman, Carla D.; Conard, Susan G. 1998b. Ryegrass seeding for postfire erosion control in chaparral—does it work? Fire Management Notes. 58: 30-34.

Biswell, H. H.; Schultz, A. M. 1965. Surface runoff and erosion as related to prescribed burning. Journal of Forestry. 55: 372-373.

Bitterroot National Forest. 1997. Forest plan monitoring and evaluation report, fiscal year 1997, Bitterroot National Forest, MT. 80 p.

Blanford, Robert H.; Gunter, Louis E. 1972. Emergency revegetation—a review of project evaluations 1956-1970. Forest, Range and Watershed Management Section, California Division of Forestry, Sacramento, CA. 21 p.

Blankenbaker, Gene; Ryan, Tom; Graves, Walt. 1985. Aguanga burn soil erosion and vegetation recovery administrative study. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Cleveland National Forest, CA. 9 p.

Bosch, J. M.; Hewlett, J. D. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology. 55: 3-23.

Boyd, Anne; McKay, Mary; Dailey, Scott. 1995. Field observations on the Cleveland Fire, January 10, 1995. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Eldorado National Forest, CA. 2 p.

Brooks, K. N.; Ffolliott, P. F.; Gregorsen, H. M.; DeBano, L. F. 1997. Hydrology and management of watersheds. Ames, IA: Iowa State University Press. 392 p.

Burroughs, Edward R., Jr., ; King, John G. 1989. Reduction in soil erosion of forest roads. Gen. Tech. Rep. INT-264. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.

Callahan, Karen; Baker, Blaze. 1997. Crystal burn analysis. Postfire succession and seeding monitoring: year three. Unpublished report on file at: U.S. Department of Agriculture, Forst Service, Tahoe National Forest, CA. 23 p.

Campbell, G. S.; Jungbauer, J. D., Jr.; Bristow, K. L.; Hungerford, R. D. 1995. Soil temperature and water content beneath a surface fire. Soil Science. 159(6): 363-374.

Campbell, R. E.; Baker, M. B., Jr.; Ffolliott, P. F. 1977. Wildfire effects on a ponderosa pine ecosystem: an Arizona case study. Res. Pap. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Cannon, Susan. 1999. Debris-flow response of watersheds recently burned by wildfire. Boulder, CO: University of Colorado. 200 p. Dissertation.

Chiun-Ming, L. 1985. Impact of check dams on steep mountain channels in northeastern Taiwan. In: El-Swaify, S.A.; Moldenhauer, W. C.: Lo, A., ed. Soil Erosion and Conservation: 540-548.

Christ, J. H. 1934. Reseeding burned-over lands in northern Idaho. University of Idaho Agricultural Experiment Station Bulletin 201. Moscow, ID: University of Idaho. 27 p.

Christensen, N. L. 1973. Fire and the nitrogen cycle in California chaparral. Science. 181: 66-68.

Cline, G. G.; Brooks, W. M. 1979. Effect of light seed and fertilizer application in steep landscapes with infertile soils after fire. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region Soil, Air, Water Notes 79-2. 6 p.

Collins, L. M.; Johnston, C. E. 1995. Effectiveness of straw bale dams for erosion control in the Oakland Hills following the fire of 1991. In: Keeley, J. E.; Scott, T., eds. Brushfires in California wildlands: ecology and resource management. Fairfield, WA: International Association of Wildland Fire: 171-183.

Conard, Susan G.; Beyers, Jan L.; Wohlgemuth, Peter M. 1995. Impacts of postfire grass seeding on chaparral ecosystems—what do we know and where do we go from here? In: Keeley, J. E.; Scott, T., eds. Brushfires in California wildlands: ecology and resource management. Fairfield, WA: International Association of Wildland Fire: 149-161.

Conard, S. G.; Regelbrugge, J. C.; Wills, R. D. 1991. Preliminary effects of ryegrass seeding on postfire establishment of natural vegetation in two California ecosystems. In: Andrews, Patricia L.; Potts, Donald F., eds. Proceedings of the 11th conference on fire and forest meteorology, April 16-19, 1991, Missoula, Montana. Bethesda, MD: Society of American Foresters: 314-321.

Conrad, C. Eugene. 1979. Emergency postfire seeding using annual grass. Riverside, CA: Chaparral Research and Development Program, CHAPS Newsletter, March 1979: 5-8.

Cooper, W. S. 1922. The broad-sclerophyll vegetation of California: an ecological study of the chaparral and its related communities. Carnegie Institution of Washington Publication 319. 145 p.

Copstead, R. 1997. The water/road interaction technology series: an introduction. No. 9777 1805-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology Center. 4 p.

Copeland, Otis L. 1961. Watershed management and reservoir life. Journal of American Water Works Association. 53(5): 569-578.

Copeland, Otis L. 1968. Forest Service Research in erosion control in the western United States. Presented at: Annual Meeting, American Society of Agricultural Engineers, June 18-21, 1968, Logan, UT. Paper 68-227. St. Joseph, MI: American Society of Agricultural Engineers. 11 p.

Corbett, E. S.; Green, L. R. 1965. Emergency revegetation to rehabilitate burned watersheds in southern California. Res. Pap. PSW-22. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 14 p.

Costales, E. F., Jr.; Costales, A. B. 1984. Determination and evaluation of some emergency measures for the quick rehabilitation of newly burned watershed areas in the pine forest. Sylvtrop Philippine Forestry Research. 9: 33-53.

Croft, A. R.; Marston, Richard B. 1950. Summer rainfall characteristics in northern Utah. Transactions, American Geophysical Union. 31(1): 83-95.

Davis, E. A. 1984. Conversion of Arizona chaparral increases water yield and nitrate loss. Water Resources Research. 20: 1643-1649.

DeBano, L. F.; Conrad, C. E. 1976. Nutrients lost in debris and runoff water from a burned chaparral watershed. In: Proceedings of the third interagency sedimentation conference, Denver, CO, March 1976. Water Resources Council. 3: 13-27.

DeBano, L. F.; Eberlein, G. E.; Dunn, P. H. 1979a. Effects of burning on chaparral soils. I. Soil nitrogen. Soil Science Society of America Journal. 43: 504-509.

DeBano, L. F.; Ffolliott, P. F.; Baker, M. B., Jr. 1996. Fire severity effects on water resources. In: Ffolliott, P. F.; DeBano, L. F.; Baker, M. B., Jr.; Gottfried, G. J.; Solis-Garza, G.; Edminster,C. B.; Neary, D. G.; Allen, L. S.; Hamre, R. H., tech. coords. Effects of fire on Madrean province ecosystems—A symposium proceedings. Gen. Tech. Rep. RM-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 77-84.

DeBano, L. F.; Neary, D. G.; Ffolliott, P. F. 1998. Fires's effects on ecosystems. New York: John Wiley & Sons. 333 p.

DeBano, L. F.; Rice, R. M.; Conrad, C. E. 1979b. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion and runoff. Res. Pap. PSW-145. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 21 p.

DeBlye, Norbert V. 1970a. Do contour trenches reduce wet-mantle flood peaks? Res. Note INT-108. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

DeByle, Norbert V. 1970b. Infiltration in contour trenches in the Sierra Nevada. Res. Note INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 5 p.

DeByle, N. V.; Packer, P. E. 1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. In: Csallany, S. C.; McLaughlin, T. G.; Striffler, W. D., eds. Watersheds in transition, proceedings, American Water Resources Association and Colorado State University, Fort Collins, CO. Urbana, IL: American Water Resource Association: 296-307.

DeGraff, J. V. 1982. Final evaluation of felled trees as a sediment retaining measure, Rock Creek Fire, Kings RD, Sierra National Forest, Fresno, CA. U.S. Department of Agriculture, Forest Service Special Report, Sierra National Forest. 15 p.

Department of Forester and Fire Warden. 1985. Emergency revegetation in Los Angeles County 1919-1984. Unpublished report on file at: County of Los Angeles, Fire Department, P.O. Box 3009, Terminal Annex, Los Angeles, CA 90051. 93 p.

Doty, Robert D. 1970. Influence of contour trenching on snow accumulation. Journal of Soil and Water Conservation. 25(3): 102-104.

Doty, Robert D. 1971. Contour trenching effects on streamflow from a Utah watershed. Res. Pap. INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 19 p.

Doty, Robert D. 1972. Soil water distribution on a contour-trenched area. Res. Note INT-163. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 6 p.

Ducummon, Sheryl L. 1987. Las Pilitas fire rehabilitation assessment project. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Los Padres National Forest, CA. 13 p. plus maps and photos.

Dyer, David A. 1995. Determining viability of soil seed banks after wildfires. Tech. Note TN-Plant Materials-36. Lockeford, CA: U.S. Department of Agriculture, Natural Resources Conservation Service. 8 p.

Dyrness, C. T. 1974. Grass-legume mixtures for erosion control along forest roads. Handout prepared for "Soil erosion prevention and sedimentation control short course," Olympia, Washington, February 6, 1974. 16 p.

Dyrness, C. T. 1976. Effect of wildfire on soil wettability in the High Cascades of Oregon. Res. Pap. PNW-202. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Edwards, L.; Burney, J.; DeHaan, R. 1995. Researching the effects of mulching on cool-period soil erosion in Prince Edward Island, Canada. Journal of Soil and Water Conservation. 50: 184-187.

Elliot, Katherine J.; White, Alan S. 1987. Competitive effects of various grasses and forbs on ponderosa pine seedlings. Forest Science. 33(2): 356-366.

Elliot, W. J.; Graves, S. M.; Hall, D. E.; Moll, J. E. 1998. The X-DRAIN cross drain spacing and sediment yields. No. 9877 1801-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology Center. 24 p.

Elliot, W. J.; Hall, D. E.; Scheele, D. L. 1999. WEPP-Road, WEPP interface for predicting forest road runoff, erosion and sediment delivery [Online]. Available: http://forest.moscowfsl.wsu.edu/fswep/docs/wepproaddoc.html.

Esplin, DeLoy H.; Shackleford, James R. 1978. Cachuma burn reseeding evaluation: coated vs. uncoated seed, first growing season. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Los Padres National Forest, CA. 24 p.

Esplin, DeLoy H.; Shackleford, James R. 1980. Cachuma burn revisited. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Los Padres National Forest, CA. 5 p.

Evanko, Anthony B. 1955. Species adaptability and seeding season for increased forage production in northeastern Washington. Res. Pap. INT-37. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Farmer, Eugene E.; Fletcher, Joel E. 1972. Some intra-storm characteristics of high-intensity rainfall burst. In: Distribution of Precipitation in Mountainous areas, Geilo Symposium, Norway July 31-August 5. Geneva, Switzerland: World Meteorological Organization. 2: 525-531.

Farmer, E. E.; Van Haveren, B. P. 1971. Soil erosion by overland flow and raindrop splash on three mountain soils. Gen. Tech. Rep. INT-100. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 14 p.

Faust, Robert. 1998. Lesson plan: Fork fire soil loss validation monitoring. Unit VIII, Long term recovery and monitoring. In: Burned area emergency rehabilitation (BAER) techniques, 1998. San Francisco: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. (course notebook).

Federal Reserve Bank. 1999. Consumer Price Index [online]. Available: http://woodrow.mpls.frb.fed.us/economy/calc/cpihome/ [June 16, 1999].

Ferrell, William R. 1959. Report on debris reduction studies for mountain watersheds. Los Angeles, CA: Los Angeles County Flood Control District, Dams and Conservation Branch. 164 p.

Fites-Kaufman, Russell. 1993. Survey of check dams in the Cleveland Fire Area. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Eldorado National Forest, CA. 3 p.

Flanagan, S. A.; Furniss, M. J. 1997. Field indicators of inlet controlled road stream crossing capacity. No. 9777 1808-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology Center. 5 p.

Forsling, C. L. 1931. Artificial reseeding on western mountain range lands. USDA Circ. No. 178. Washington, DC: U.S. Department of Agriculture. 48 p.

Friedrich, C. Allen. 1947. Seeding grass by airplane on western Montana's burned-over timberlands. Res. Note No. 52. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Rocky Mountain Forest and Range Experiment Station. 5 p.

Furniss, Michael J.; Ledwith, Tyler, S.; Love, Michael A.; McFadin, Bryan C. Flanagan, Sam A. 1998. Response of road-stream crossings to large flood events in Washington, Oregon, and Northern California. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Technology and Development Program, 9877 1806-San Dimas Technology Development Center. 14 p.

Gautier, Clayton R. 1983. Sedimentation in burned chaparral watersheds: is emergency revegetation justified? Water Resources Bulletin. 19(5): 793-802.

Geier-Hayes, Kathleen. 1997. The impact of post-fire seeded grasses on native vegetative communities in central Idaho. In: Greenlee, Jason M., ed. Proceedings: First conference on fire effects on rare and endangered species and habitats. Fairfield, WA: International Association of Wildland Fire: 19-26.

Gibbons, Boyd. 1995. Remarks on postfire seeding. In: Keeley, Jon E.; Scott, Tom, eds. Brushfires in California wildlands: ecology and resource management. Fairfield, WA: International Association of Wildland Fire: 211.

Gleason, C. H. 1947. Guide for mustard sowing in burned watersheds of southern California. San Francisco, CA: U.S. Department of Agriculture, Forest Service, California Region. 46 p.

Glendening, G. E.; Pase, C. P.; Ingebo, P. 1961. Preliminary hydrologic effects of wildfire in chaparral. In: Johnson, R., ed. Proceedings of the 5th annual Arizona watershed symposium, September 21, 1961, Phoenix, Arizona. Phoenix, AZ: Arizona Water Resources Committee and Wathershed Management Division, State Land Department: 12-15.

Goldman, S. J.; Jackson, K.; Bursztynsky, T. A. 1986. Erosion and sediment control handbook. San Francisco, CA: McGraw-Hill. 360 p.

Green, L. R. 1981. Burning by prescription in chaparral. Gen. Tech. Rep. PSW-51. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 36 p.

Green, Pat. 1990. 1989 soil monitoring report, Green Creek Point fire, Clearwater Ranger District. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Nez Perce National Forest, ID. 4 p.

Griffin, James R. 1982. Pine seedlings, native ground cover, and *Lolium multiflorum* on the Marble-Cone burn, Santa Lucia Range, California. Madroño. 29(3): 177-188.

Griffith, Robert W. 1989a. Memo, silt fence monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 4 p.

Griffith, Robert W. 1989b. Memo, soil productivity and burned area grass seeding. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 2 p.

Griffith, Robert W. 1991. Memo, Arch Rock burn area erosion monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 2 p.

Griffith, Robert W. 1993. Memo, Arch Rock burn area grass monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 2 p.

Griffith, Robert W. 1998. Burned area emergency rehabilitation. In: Proceedings, nineteenth annual forest vegetation management conference: wildfire rehabilitation, January 20-22, 1998. Redding, CA: Forest Vegetation Management Conference: 4-7.

Hanes, R. O.; Callahan, K. 1995. Summary of first monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, CA. 24 p.

Hanes, Richard; Callahan, Karen. 1996. Crystal burn analysis. Post-fire succession and seeding monitoring: year two. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest,CA. 23 p.

Hartford, R. A.; Frandsen, W. H. 1992. When it's hot, it's hot—or maybe it's not (surface flaming may not portend extensive soil heating). International Journal of Wildland Fire. 2: 139-144.

Heede, Burchard H. 1960. A study of early gully-control structures in the Colorado Front Range. Station Paper 55. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 42 p.

Heede, Burchard H. 1970. Design, construction and cost of rock check dams. Res. Pap. RM-20. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 24 p.

Heede, Burchard H. 1976. Gully development and control: the status of our knowledge. Res. Pap. RM-169. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 42 p.

Heede, Burchard H. 1981. Rehabilitation of disturbed watershed through vegetation treatment and physical structures. In: Proceeding, Interior West Watershed Management Symposium, April 1980, Spokane, WA. Pullman, WA: Washington State University Cooperative Extension: 257-268.

Helvey, J. D. 1975. Watershed behavior after forest fire in Washington. In: Proceedings of the irrigation and drainage division specialty conference, Fort Collins, Colorado, April 22-24, 1973. Washington, DC: United States Government Printing Office: 403-422.

Helvey, J. D. 1980. Effects of a north-central Washington wildfire on runoff and sediment production. Water Resources Bulletin. 16: 627-634.

Hendricks, B. A.; Johnson, J. M. 1944. Effects of fire on steep mountain slopes in central Arizona. Journal of Forestry. 42: 568-571.

Herman, Loren D. 1971. Review of Forks fire, Okanogan N.F., and fire on Wenatchee N.F. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Okanogan National Forest, OR. 18 p.

Hibbert, A. R. 1971. Increases in streamflow after converting chaparral to grass. Water Resources Bulletin. 7: 71-80.

Hibbert, A. R.; Davis, E. A.; Knipe, O. D. 1982. Water yield changes resulting from treatment of Arizona chaparral. Gen. Tech. Rep. PSW-58, Berkeley, CA: U.S. Department of Agriculture, Forest Service: 382-389.

Hungerford, R. D. 1996. Soils- fire in ecosystem management notes: unit II-I. Marana, AZ: U.S. Department of Agriculture, Forest Service, National Advanced Resource Technology Center.

Isle, David. 1988. 2,3445 acre 8/26/88 Powerhouse burn: Isle's follow-up observations notes. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Mendocino National Forest, CA. 6 p.

Isle, David W. 1998. Erosion control seeding and mulching treatments. Unit VIII, "Back to the future": long term recovery and monitoring. In: Burned area emergency rehabilitation (BAER) techniques, 1998 (course notebook). San Francisco: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region.

Janicki, Alex. 1989. Emergency revegetation of the Stanislaus Complex fire. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 17 p.

Janicki, Alex. 1992. Memo, Cotton burn area erosion monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Stanislaus National Forest, CA. 3 p.

Kay, B. L. 1983. Straw as an erosion control mulch. Agronomy Progress Report No. 140. Davis, CA: University of California Agricultural Experiment Station. 11 p.

Keeler-Wolf, Todd. 1995. Post-fire emergency seeding and conservation in southern California shrublands. In: Keeley, J. E.; Scott, T., eds. Brushfires in California wildlands: ecology and management. Fairfield, WA: International Association of Wildland Fire: 127-139.

Keeley, Jon E. 1991. Seed germination and life history syndromes in the California chaparral. The Botanical Review. 57: 81-116.

Keeley, J. E.; Keeley, S. C. 1988. Chaparral. In: Barbour, M. G.; Billings, W. D., eds. North American terrestrial vegetation. Cambridge: Cambridge University Press: 165-207.

Keeley, Jon E.; Carrington, Mary; Trnka, Sally. 1995. Overview of management issues raised by the 1993 wildfires in southern California. In: Keeley, Jon E.; Scott, Tom, eds. Brushfires in California wildlands: ecology and resource management. Fairfield, WA: International Association of Wildland Fire: 83-89.

Keeley, S. C.; Keeley, J. E.; Hutchinson, S. M.; Johnson, A. W. 1981. Postfire succession of herbaceous flora in southern California chaparral. Ecology. 62(6): 1608-1621.

Kidd, Jerry L.; Rittenhouse, Dave. 1997. Evaluation of storm effects on Eight Street Fire Rehabilitation. Unpublished report on file at: U.S. Department of the Interior, Bureau of Land Management, Boise, ID. 8 p.

Klock, Glen O.; Tiedemann, Arthur R.; Lopushinsky, William. 1975. Seeding recommendations for disturbed mountain slopes in north central Washington. Res. Note PNW-244. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Kozlowski, T. T.; Ahlgren, C. E., eds. 1974. Fire and ecosystems. New York: Academic Press. 542 p.

Krammes, J. S. 1960. Erosion from mountain side slopes after fire in southern California. Res. Note PSW-171. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 8 p.

Krammes, J. S.; Hill, L. W. 1963. "First aid" for burned watersheds. Res. Note PSW-29. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 7 p.

Lachowski, Henry; Hardwick, Paul; Griffith, Robert; Parsons, Annette; Warbington, Ralph. 1997. Faster, better data for burned watersheds needing emergency rehab. Journal of Forestry. 95(6): 4-8.

Liewer, Marvin. 1990. The big fire—one year later. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Black Hills National Forest, SD. 2 p.

Loftin, Sam; Fletcher, Reggie; Luehring, Peggy. 1998. Disturbed area rehabilitation review report. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM. 17 p.

Maloney, P. Cavan; Thornton, John L. 1995. Implementation and effectiveness monitoring of best management practices and soil and water protection measures within the Foothills Fire salvage logging area 1992-1995. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Boise National Forest, ID. 51 p.

McCammon, Bruce P. 1980. Bridge Creek fire rehabilitation status report. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Deschutes National Forest, OR. 12 p.

McCammon, B. P.; Hughes, D. 1980. Fire rehab in the Bend Municipal Watershed. In: Proceedings of the 1980 watershed management symposium, July 21-23, 1980, Boise, ID. New York: American Society of Civil Engineers: 252-259.

McClure, Norman R. 1956. Grass and legume seedings on burned-over forest lands in northern Idaho and adjacent Washington. Moscow, ID: University of Idaho. 125 p. Thesis.

McDonald, Philip M. 1986. Grasses in young conifer plantations—hindrance and help. Northwest Science. 60(4): 271-278.

McDonald, P. M.; Oliver, W. W. 1984. Woody shrubs retard growth of ponderosa pine seedlings and saplings. In: Coombes, D., ed. Proceedings, fifth annual forest vegetation management conference. Redding, CA; Forest Vegetation Management Conference: 65-89.

McNabb, D. H.; Swanson, F. J. 1990. Effects of fire on soil erosion. In: Walstad, J. D.; Radosevich, S. R.; Sandberg, D. V., eds. Natural and prescribed fire in Pacific northwest forests. Corvallis, OR: Oregon State University Press: 159-176.

Meeuwig, R. O. 1971. Soil stability on high-elevation rangeland in the Intermountain area. Res. Pap. INT-94. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Megahan, W. F. 1986. Recent studies on erosion and its control on forest lands in the United States. In: Richard, F., ed. Range basin sediment delivery: Proceedings; 1986 August; Albuquerque, NM. IAHS Pub. 159, Wallingford, Oxon, United Kingdom: 178-189.

Megahan, Walter F.; Molitor, Delbert C. 1975. Erosion effects of wildfire and logging in Idaho. In: Watershed management symposium: 1975 August, Logan, UT. New York: American Society of Civil Engineers Irrigation and Drainage Division: 423-444.

Miles, Scott R.; Haskins, Donald M.; Ranken, Darrel W. 1989. Emergency burn rehabilitation: cost, risk, and effectiveness. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 97-102.

Nadkarni, Nalini M.; Odion, Dennis C. 1986. Effects of seeding an exotic grass *Lolium multiflorum* on native seedling regeneration following fire in a chaparral community. In: DeVries, Johannes J., ed. Proceeding of the chaparral ecosystems research conference, May 16-17, 1985, Santa Barbara, California. Report No. 62, California Water Resources Center, University of California, Davis: 115-121.

Neary, D. G.; Hornbeck, J. W. 1994. Chapter 4: Impacts of harvesting and associated practices on off-site environmental quality. In: Dyck, W. J.; Cole, D. W.; Comerford, N. B., eds. Impacts of forest harvesting on long-term site productivity. London: Chapman & Hall: 81-118.

Neary, D. G.; Klopatek, C. C.; DeBano, F. F.; Ffolliott, P. F. 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management. 122: 51-71.

Niehoff, Jerry. 1995. Mary-mix monitoring trip. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Idaho Panhandle National Forest, ID. 3 p.

Noble, Edward L. 1965. Sediment reduction through watershed rehabilitation. In: Proceedings of the federal inter-agency sedimentation conference 1963. Washington, DC: U.S. Department of Agriculture, Misc. Publ. 970: 114-123.

Noble, Edward L.; Lundeen, Lloyd. 1971. Analysis of rehabilitation treatment alternatives for sediment control. In: Symposium on forest land uses and stream environment, October 19-21, 1971, Corvallis, OR. Corvallis, OR: Oregon State University, School of Forestry and Department of Fisheries and Wildlife, Continuing Education Publications: 86-96.

Norris, Logan A. 1990. An overview and synthesis of knowledge concerning natural and prescribed fire in the Pacific Northwest forest. In: Walstad, John D.; Radosevich, Steven R.; Sandberg, David V., eds. Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State University Press: 7-22.

Orr, Howard K. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. Res. Pap. RM-60. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Packer, P. E.; Christensen, G. F. 1977. Guides for controlling sediment from secondary logging roads. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, and Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 42 p.

Parsons, Annette. 1994. Field notes from burn rehab and soil erosion monitoring day trip to observe treatments at 2 years post-fire. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Eldorado National Forest, CA. 5 p.

Parsons, Annette; McDonald, Brandi. 1993. Preliminary results, Eldorado National Forest Cleveland fire emergency watershed treatment monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Eldorado National Forest, CA. 5 p.

Pase, P. C.; Ingebo, P. A. 1965. Burned chaparral to grass: early effects on water and sediment yields from two granitic soil watersheds in Arizona. In: Cooper, C. C., Jr., ed. Proceedings of the 9th annual Arizona watershed symposium, September, 1965, Tempe, AZ. Phoenix, AZ: Arizona Water Resources Committee and Watershed Management Division, State Land Department: 8-11.

Pase, C. P.; Lindenmuth, Jr., A. W. 1971. Effects of prescribed fire on vegetation and sediment in oak-mountain mahogany chaparral. Journal of Forestry. 69: 800-805.

Patric, J. H. 1976. Soil erosion in eastern forests. Journal of Forestry. 74: 671-676.

Pearson, G. A. 1942. Herbaceous vegetation: a factor in natural regeneration of ponderosa pine in the southwest. Ecological Monographs. 12: 316-338.

Powers, R. F.; Alban, D. H.; Miller, R. E.; Tiarks, A. E.; Wells, C. G.; Avers, P. E.; Cline, R. G.; Loftus, N. S., Jr.; Fitzgerald, R. O. 1990. Sustaining productivity of North American forests: Problems and prospects. In: Gessel, S. P.; Lacate, D. S.;Weetman, G. F.; Powers, R. F., eds. Sustained Productivity of Forest Soils, Proceedings of the 7th North American Forest Soils Conference, 24-28 July 1988, Vancouver, BC: University of British Columbia Faculty of Forestry: 49-79.

Pyne, S. J.; Andrews, P. L.; Laven, R. D. 1996. Introduction to wildland fire. New York: John Wiley & Sons. 769 p.

Radek, K. J. 1996. Soil erosion following wildfires on the Okanogan National Forest—initial monitoring results. In: International Erosion Control Association symposium, February 27-March 1, 1996, Seattle, WA. Steamboat, CO: International Erosion Control Association. 7 p.

Ratliff, Raymond D.; McDonald, Philip M. 1987. Postfire grass and legume seeding: what to seed and potential impacts on reforestation. In: Proceedings, ninth annual forest vegetation management conference, November 3-5, 1987. Redding, CA: Forest Vegetation Management Conference: 111-123.

Reid, L. M. 1993. Research and cumulative watershed effects. Gen. Tech. Rep. PSW-GTR-141. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 118 p.

Rice, Raymond M. 1974. The hydrology of chaparral watersheds. In: Rosenthal, ed. Symposium on living with the chaparral proceeding. San Francisco, CA: Sierra Club: 27-34.

Rice, R. M.; Crouse, R. P.; Corbett, E. S. 1965. Emergency measures to control erosion after a fire on the San Dimas Experimental

Forest. In: Proceedings of the federal inter-agency sedimentation conference 1963. Washington, DC: U.S. Department of Agriculture, Misc. Publ. 970: 123-130.

Rich, L. R. 1962. Erosion and sediment movement following a wildfire in a ponderosa pine forest of central Arizona. Res. Note 76. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Rietveld, W. J. 1975. Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine. Res. Pap. RM-153. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.

Rinne, J. N. 1996. Short-term effects of wildfire on fishes and aquatic macroinvertebrates in the southwestern United States. North American Journal of Fisheries Management. 16: 653-658.

Robichaud, P. R.; Brown, R. E. 1999. What happened after the smoke cleared: onsite erosion rates after a wildfire in eastern Oregon. In: Olsen, D. S.; Potyondy, J. P., eds. Proceeding, Wildland Hydrology Conference, June 1999, Bozeman, MT. Hernon, VA: American Water Resource Association: 419-426.

Roby, Kenneth B. 1989. Watershed response and recovery from the Will Fire: ten years of observation. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 131-136.

Rosgen, D. L. 1996. Applied river morphology. Pagosa Springs, CO: Wildland Hydrology. 364 p.

Ruby, Earl C. 1989. Rationale for seeding grass on the Stanislaus Complex burn. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 125-130.

Ruby, Earl. 1995. Tyee BAER report: findings of the post-BAER evaluation team, 8/21-23/95. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, WA. 6 p.

Ruby, Earl. 1997. Observations on the Dome fire emergency rehabilitation seeding. Unpublished report on file at: U.S. Department of Agriculture, Forest Service. Tonto National Forest, AZ. 3 p.

Ruby, Earl C.; Griffith, Rob. 1994. First-winter damage survey: Marre fire, burned area emergency rehabilitation, May-June 1994. Unpublished report on file at: Los Padres National Forest, CA. 19 p. plus data sheets and photos.

Ryan, K. C.; Noste, N. V. 1983. Evaluating prescribed fires. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W., tech. coords. Proceedings, symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 230-238.

Sampson, Arthur W. 1944. Plant succession on burned chaparral lands in northern California. California Agricultural Experiment Station Bulletin. 685. 144 p.

Sartz, R. S. 1953. Soil erosion on a fire-denuded forest area in the Douglas-fir region. Journal of Soil and Water Conservation: 279-281.

Schultz, A. M.; Launchbaugh, J. L.; Biswell, H. H. 1955. Relationship between grass density and brush seedling survival. Ecology. 36(2): 226-238.

Schultz, S.; Lincoln; Cauhorn, J.; Montagne, C. 1986. Quantification of erosion from a fire and rainfall event in the Big Belt Range of the Northern Rocky Mountains. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Helena National Forest, MT. 21 p.

Schumm, S. A.; Harvey, M. D. 1982. Natural erosion in the USA. In: Schmidt, B. L., ed. Determinants of soil loss tolerance. Madison, WI: American Society of Agronomy, Special Publication. 45: 23-39.

Souders, C. 1997. Soil loss pin method form, Gila National Forest: HB fire. (data sheets) Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Gila National Forest, NM. 2 p.

Stewart, William Lemley. 1973. Emergency rehabilitation of watersheds denuded by wildfire in the ponderosa pine and Douglas-fir zones of north-central Washington. Pullman, WA: Washington State University. 59 p. Thesis.

Story, Mark T. 1994. Water quality monitoring, Mill Creek timber sales and Thompson Creek fire. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Gallatin National Forest, MT. 10 p.

Story, Mark T.; Kracht, Richard. 1989. Memo: Emergency watershed stabilization, BMP implementation review Storm Creek fire. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Gallatin National Forest, MT. 16 p.

Sullivan, J.; Omi, P. N.; Dyer, A. A.; Gonzales-Caben, Armando. 1987. Evaluating the economics efficiency of wildfire rehabilitation treatments. Western Journal of Applied Forestry. 2(2): 58-61.

Swanson, F. J. 1981. Fire and geomorphic processes. In: Mooney, H.; Bonnicksen, T. M.; Christensen, N. L.; Lotan, J. E.; Reiners, W. A., tech. coords. Proceedings of the conference; Fire regimes and ecosystem properties, December 11-15, 1979, Honolulu, HI. Gen. Tech. Rep. WO-26. Washington, DC: U.S. Department of Agriculture, Forest Service: 410-420.

Sweeney, James R. 1956. Responses of vegetation to fire: a study of the herbaceous vegetation following chaparral fires. University of California Publications in Botany. 28: 143-249.

Taskey, R. D.; Curtis, C. L.; Stone, J. 1989. Wildfire, ryegrass seeding, and watershed rehabilitation. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management, October 26-28, 1988, Sacramento, California. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 149-161.

Taylor, Carl; Dalen, Ray; Ettner, Bob; Bates, Wes; Little, Harry; Allen, Larry; Knipe, Duane. 1979. Burned area rehabilitation activity review. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Southwestern Region, Albuquerque, NM. 68 p.

Tiedemann, Arthur R.; Klock, Glen O. 1973. First-year vegetation after fire, reseeding, and fertilization on the Entiat Experimental Forest. Res. Note PNW-195. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 23 p.

Tiedemann, Arthur R.; Klock, Glen O. 1976. Development of vegetation after fire, seeding, and fertilization on the Entiat Experimental Forest. In: Proceedings, annual Tall Timbers fire ecology conference, number 15: Pacific northwest. Tallahassee, FL: Tall Timbers Research Station: 171-191.

Tiedemann, A. R.; Helvey, J. D.; Anderson, T. D. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. Journal of Environmental Quality. 7(4): 580-588.

Tyrrel, Robert R. 1981. Memo, Panorama burn rehabilitation. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, San Bernardino National Forest, CA. 16 p.

U.S. Department of Agriculture, Forest Service. 1995. Burned Area Emergency Rehabilitation handbook FSH 2509.13.

Van de Water, Roberta. 1998. Post-fire riparian zone management: the Salmon River experience. In: Proceedings, nineteenth annual forest vegetation management conference: wildfire rehabilitation, January 20-22, 1998. Redding, CA: Forest Vegetation Management Conference: 25-40.

Van Zuuk, Kathy. 1997. Memo, Crystal burn monitoring. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Tahoe National Forest, CA. 2 p.

Wells, W. G., II. 1981. Some effects of brushfires on erosion processes in coastal southern California. In: Erosion and Sediment Transport in Pacific Rim Steeplands. Christchurch, New Zealand: IASH Publication No. 132: 305-342.

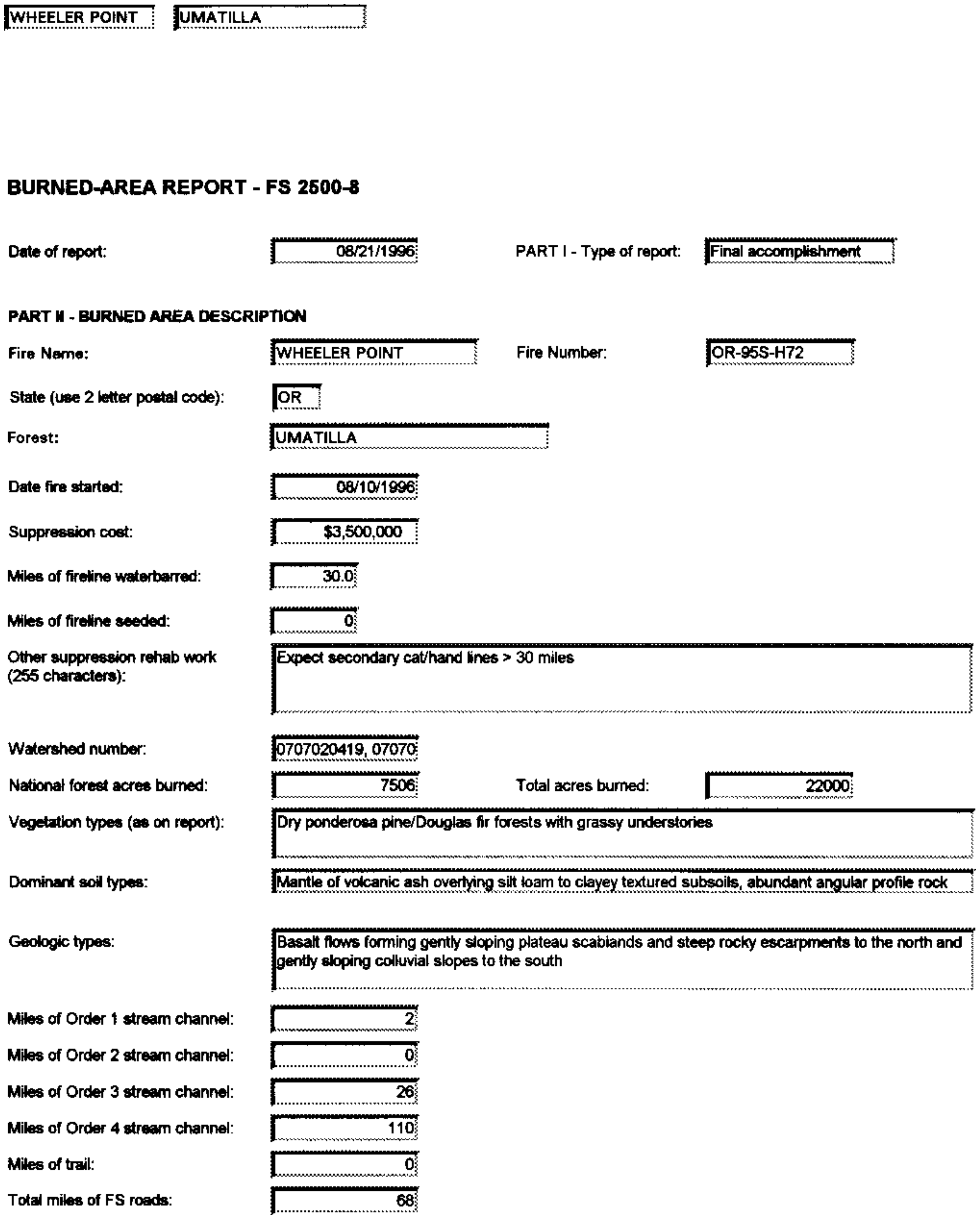
Went, F. W.; Juhren, G.; Juhren, M. C. 1952. Fire and biotic factors affecting germination. Ecology. 33(3): 351-364.

Wohlgemuth, Peter M.; Beyers, Jan L.; Wakeman, Carla D.; Conard, Susan G. 1998. Effects of fire and grass seeding on soil erosion in southern California chaparral. In: Proceedings, nineteenth annual forest vegetation management conference: wildfire rehabilitation, January 20-22, 1998. Redding, CA: Forest Vegetation Management Conference: 41-51.

Wright, H. A.; Churchill, F. M.; Stevens, W. C. 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in central Texas. Journal of Range Management. 29: 294-298.

Wright, H. A.; Churchill, F. M.; Stevens, W. C. 1982. Soil loss and runoff on seeded vs. non-seeded watersheds following prescribed burning. Journal of Range Management. 35: 382-385.

Appendix A—Example Data and Interview Forms



WHEELER POINT UMATILLA

BURNED-AREA REPORT - FS 2500-8

Date of report:	08/21/1996	PART I - Type of report:	Final accomplishment

PART II - BURNED AREA DESCRIPTION

Fire Name:	WHEELER POINT	Fire Number:	OR-95S-H72
State (use 2 letter postal code):	OR		
Forest:	UMATILLA		
Date fire started:	08/10/1996		
Suppression cost:	$3,500,000		
Miles of fireline waterbarred:	30.0		
Miles of fireline seeded:	0		
Other suppression rehab work (255 characters):	Expect secondary cat/hand lines > 30 miles		
Watershed number:	0707020419, 07070		
National forest acres burned:	7506	Total acres burned:	22000
Vegetation types (as on report):	Dry ponderosa pine/Douglas fir forests with grassy understories		
Dominant soil types:	Mantle of volcanic ash overlying silt loam to clayey textured subsoils, abundant angular profile rock		
Geologic types:	Basalt flows forming gently sloping plateau scabiands and steep rocky escarpments to the north and gently sloping colluvial slopes to the south		
Miles of Order 1 stream channel:	2		
Miles of Order 2 stream channel:	0		
Miles of Order 3 stream channel:	26		
Miles of Order 4 stream channel:	110		
Miles of trail:	0		
Total miles of FS roads:	68		

WHEELER POINT UMATILLA

PART III - WATERSHED CONDITION

Fire Intensity - Enter either acres or %. If you enter %, then acres will be calculated based on the total fire acres reported on page 1.

Fire intensity (acres):	Low	1388	Moderate	1813	High	4305
Fire Intensity (%, pre 1993 form)	Low		Moderate		High	

Water Repellent Soil - Enter either acres or %: Acres 0 %

Soil erosion hazard rating - Enter acres or %.

Low	840	Moderate	3600	High	3510
% Low:		% Moderate		% High	

Erosion Potential - Enter according to the units. Tons/acre average): 10 Cu yds/Sq mi:

Sediment potential (cubic yards/sq.mi): 105

PART IV - HYDROLOGIC DESIGN FACTOR

Estimated vegetative recovery period (yrs): 3
Design chance of success: 90
Equivalent design recurrence interval (yrs): 10
Design storm duration (hrs): 0.5
Design storm magnitude (inches): 0.5
Design flow (cfs per sq. mile): 0.9
Estimated reduction in infiltration (%): 25
Adjusted design flow (cfs per sq mile): 2.4

PART V - SUMMARY OF ANALYSIS

Check the boxes for the values threatened, and describe the threat in 255 spaces or less.
Yes is a check, no is a blank, and null is a shaded box.

▨ Life	
☑ Property	Risk to roads to sediment blocking road culverts triggering road washouts. Risk of noxious weed invasion onto forest lands.
☑ Water quality	Risk of sedimentation to streams
▨ Threatened, endangered, or sensitive species	
▨ Soil productivity	

PART V - SUMMARY OF ANALYSIS (cont)

C. Probability of completing treatment prior to first major damage-producing storm:

Land: 90 Channel: 90 Road: 90 Other: 90

D. Probability of treatment success: Years after treatment

	1	3	5
Land	90	95	95
Channel	90	95	95
Roads	90	95	95

E. Cost of no-action (including loss): $3,051,225

F. Cost of selected alternative (including loss): $541,690

G. Skills represented on burned-area survey team: Yes is a check, no is blank, null is shaded box

☑ Hydrology
☑ Timber
☐ Contractin
▨ Fisheries

☑ Soils
☑ Wildlife
☑ Ecology
Other: GIS, Public affairs

☐ Geology
☐ Fire Management
☐ Research

☑ Range
☑ Engineering
☑ Archaeology

Team Leader:

Phone: (541) 278-3762

WHEELER POINT UMATILLA

PART VI - PROJECT COSTS

For the upper part of this section you need to manually subtotal the spending by land, channel, road, other, or survey treatment category. Separate between BAER funds (EFFS-FW22 or FFF 092) and total. In the treatment costs subform, enter total spending by treatment.

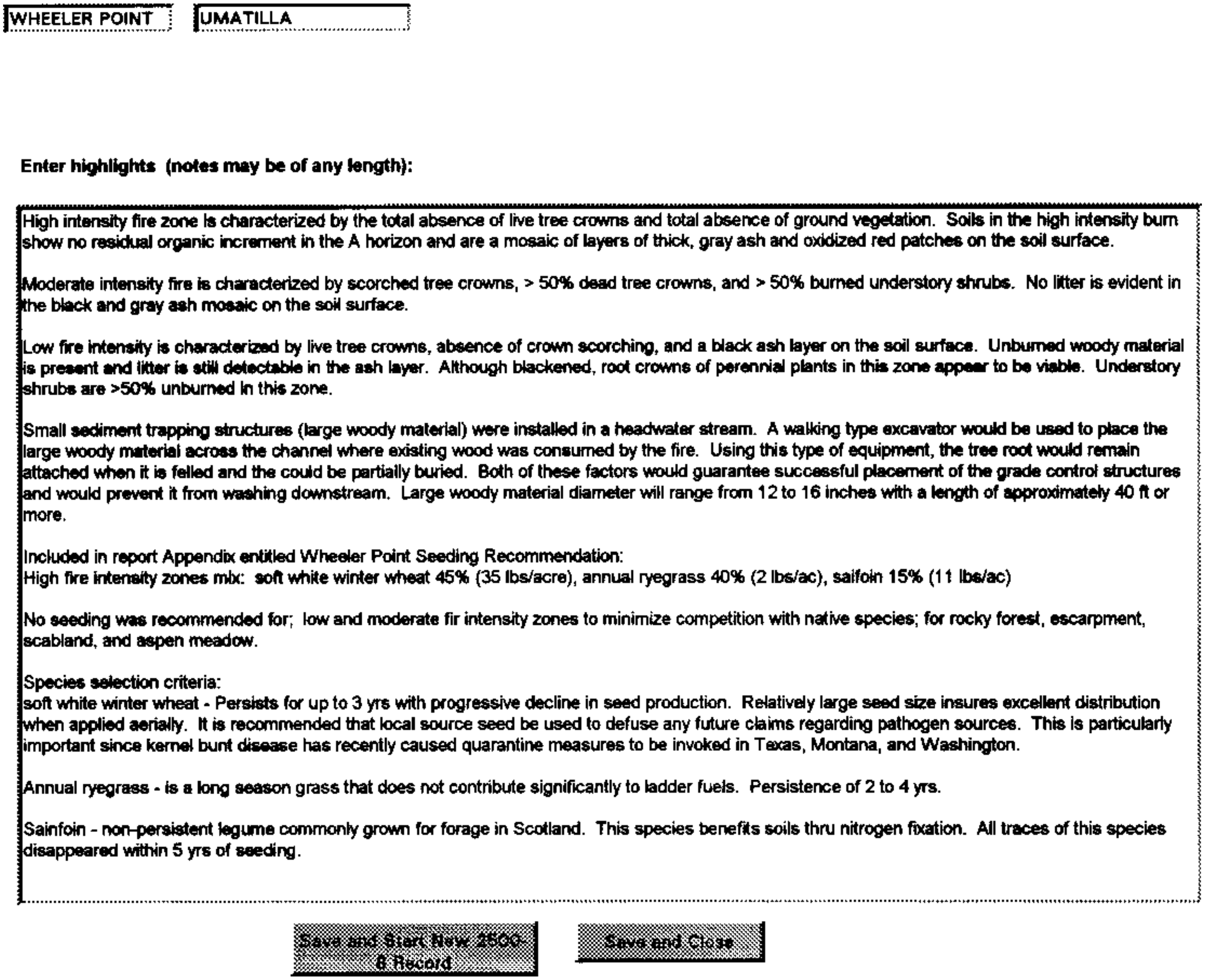
	NFS BAER funds	Total
Land treatments:	$95,470	$95,470
Channel Treatments:	$1,273	$1,273
Road\Trail Treatments:	$17,248	$17,248
Other :	$0	$0
BAER survey and Admin Support:	$19,860	$19,860
NFSTotal$:	$133,851	$133,851

Treatment Costs subform

Enter the individual treatments and costs from the 2500-8. Try to select a treatment name from the pull down list, but the treatment type is not limited to the list so if the list does not include a matching treatment you can enter an appropriate treatment name. Do not enter BAER evaluation and administrative support expenses in this subform - this is for spending on treatments alone..

WHEELER POINT Fire UMATILLA NF

Treatment	Unit of measurement (eg.acres ,	UnitCost	mberOfUnits	NFSCost	TotalCost
culvert upgrading	each	$255	5	$1,273	$1,273
channel debris cleari	channel	$53	24	$1,273	$1,273
cross drain ditches	each	$509	10	$5,090	$5,090
culvert removal	each	$260	20	$5,192	$5,192
road rip, drain, and s	acre	$49	115	$5,693	$5,693
seeding - aerial	acre	$25	3800	95,470	$95,470



Enter highlights (notes may be of any length):

High intensity fire zone is characterized by the total absence of live tree crowns and total absence of ground vegetation. Soils in the high intensity burn show no residual organic increment in the A horizon and are a mosaic of layers of thick, gray ash and oxidized red patches on the soil surface.

Moderate intensity fire is characterized by scorched tree crowns, > 50% dead tree crowns, and > 50% burned understory shrubs. No litter is evident in the black and gray ash mosaic on the soil surface.

Low fire intensity is characterized by live tree crowns, absence of crown scorching, and a black ash layer on the soil surface. Unburned woody material is present and litter is still detectable in the ash layer. Although blackened, root crowns of perennial plants in this zone appear to be viable. Understory shrubs are >50% unburned in this zone.

Small sediment trapping structures (large woody material) were installed in a headwater stream. A walking type excavator would be used to place the large woody material across the channel where existing wood was consumed by the fire. Using this type of equipment, the tree root would remain attached when it is felled and the could be partially buried. Both of these factors would guarantee successful placement of the grade control structures and would prevent it from washing downstream. Large woody material diameter will range from 12 to 16 inches with a length of approximately 40 ft or more.

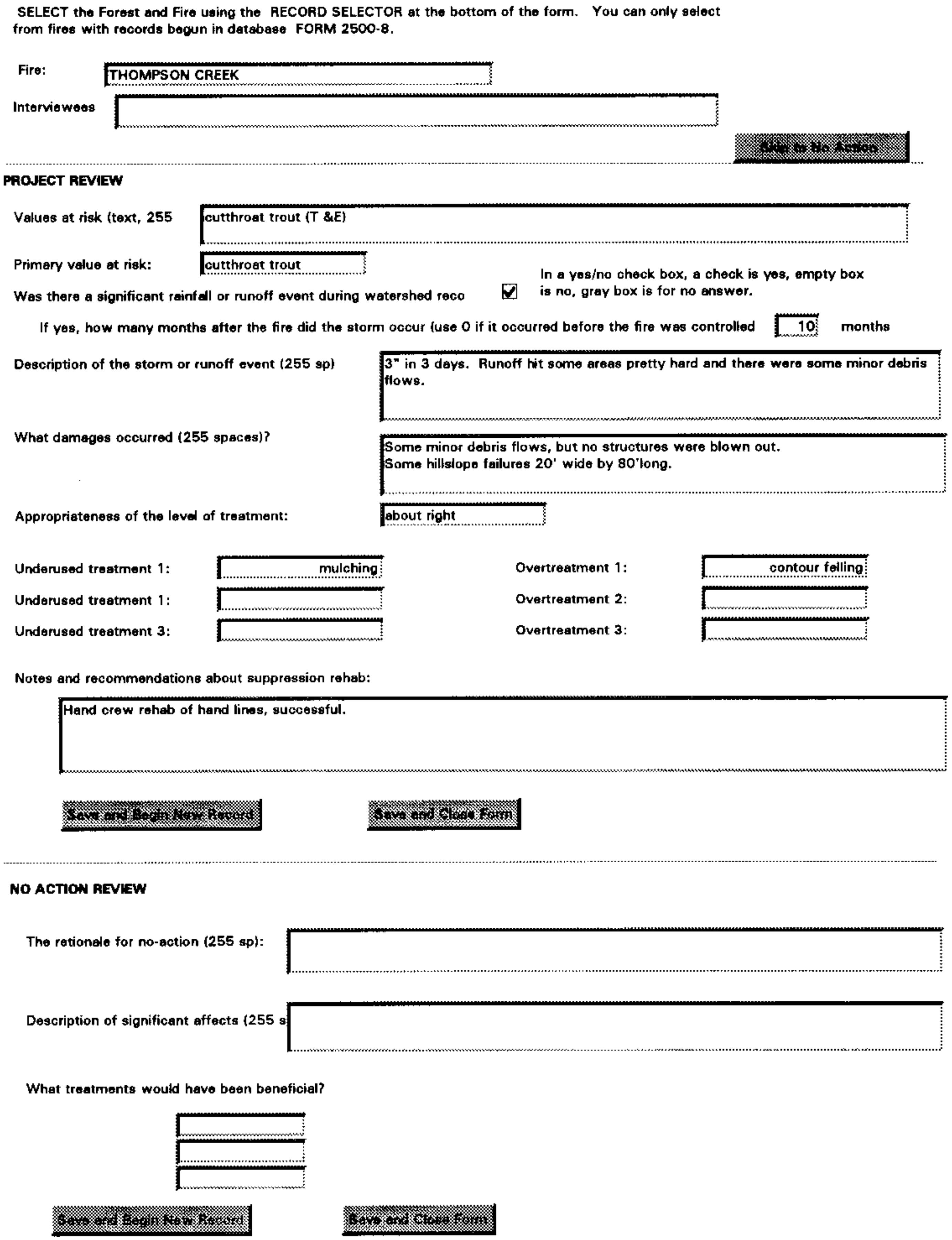
Included in report Appendix entitled Wheeler Point Seeding Recommendation:
High fire intensity zones mix: soft white winter wheat 45% (35 lbs/acre), annual ryegrass 40% (2 lbs/ac), saifoin 15% (11 lbs/ac)

No seeding was recommended for; low and moderate fir intensity zones to minimize competition with native species; for rocky forest, escarpment, scabland, and aspen meadow.

Species selection criteria:
soft white winter wheat - Persists for up to 3 yrs with progressive decline in seed production. Relatively large seed size insures excellent distribution when applied aerially. It is recommended that local source seed be used to defuse any future claims regarding pathogen sources. This is particularly important since kernel bunt disease has recently caused quarantine measures to be invoked in Texas, Montana, and Washington.

Annual ryegrass - is a long season grass that does not contribute significantly to ladder fuels. Persistence of 2 to 4 yrs.

Sainfoin - non-persistent legume commonly grown for forage in Scotland. This species benefits soils thru nitrogen fixation. All traces of this species disappeared within 5 yrs of seeding.



SELECT the Forest and Fire using the RECORD SELECTOR at the bottom of the form. You can only select from fires with records begun in database FORM 2500-8.

Fire: THOMPSON CREEK

Interviewees

PROJECT REVIEW

Values at risk (text, 255 cutthroat trout (T &E)

Primary value at risk: cutthroat trout

In a yes/no check box, a check is yes, empty box is no, gray box is for no answer.

Was there a significant rainfall or runoff event during watershed reco ☑

If yes, how many months after the fire did the storm occur (use 0 if it occurred before the fire was controlled 10 months

Description of the storm or runoff event (255 sp) 3" in 3 days. Runoff hit some areas pretty hard and there were some minor debris flows.

What damages occurred (255 spaces)? Some minor debris flows, but no structures were blown out. Some hillslope failures 20' wide by 80'long.

Appropriateness of the level of treatment: about right

Underused treatment 1:	mulching	Overtreatment 1:	contour felling
Underused treatment 1:		Overtreatment 2:	
Underused treatment 3:		Overtreatment 3:	

Notes and recommendations about suppression rehab:

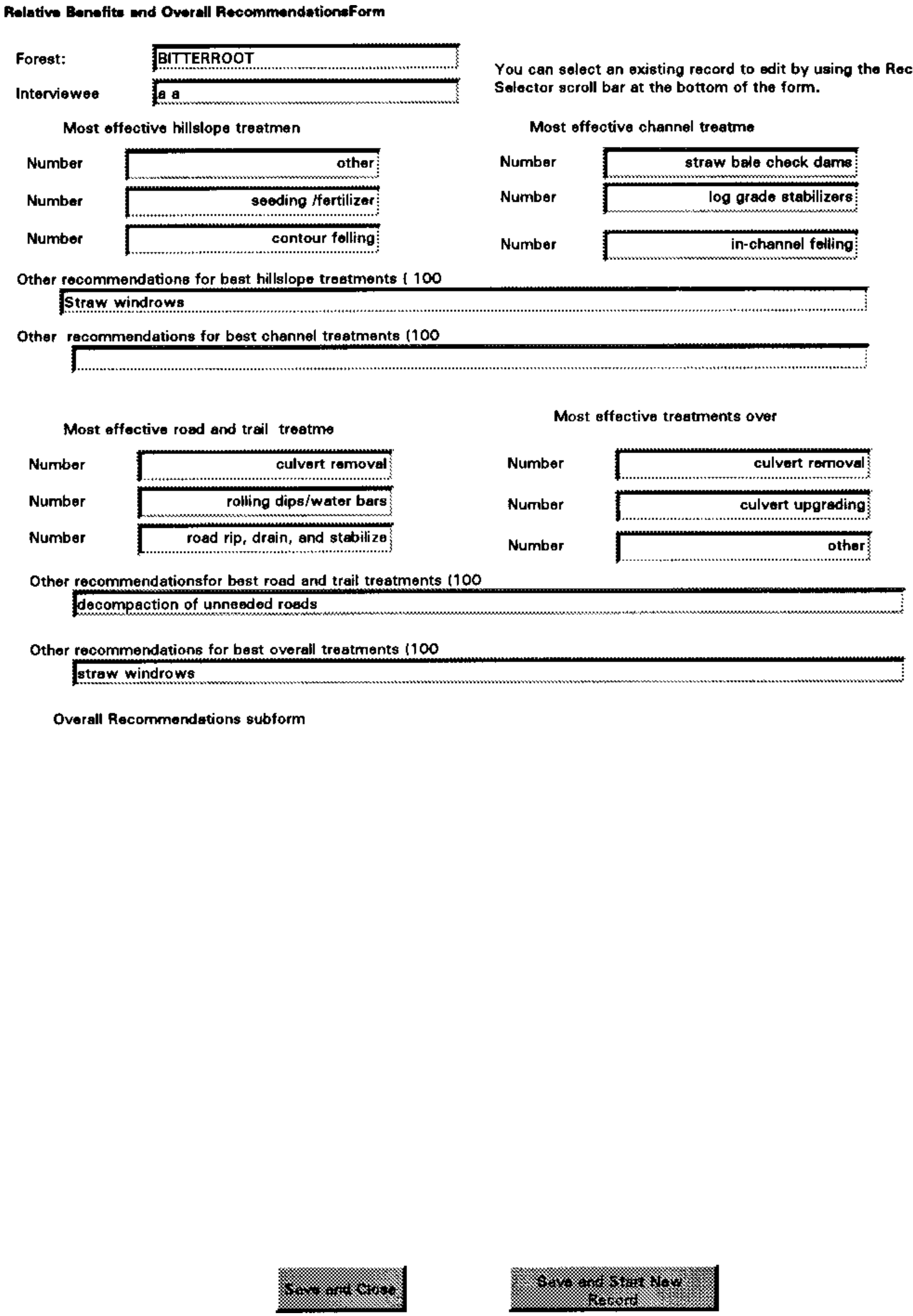
Hand crew rehab of hand lines, successful.

NO ACTION REVIEW

The rationale for no-action (255 sp):

Description of significant affects (255 s

What treatments would have been beneficial?



Relative Benefits and Overall RecommendationsForm

Forest: BITTERROOT

Interviewee a a

You can select an existing record to edit by using the Record Selector scroll bar at the bottom of the form.

Most effective hillslope treatmen

Number other

Number seeding /fertilizer

Number contour felling

Most effective channel treatme

Number straw bale check dams

Number log grade stabilizers

Number in-channel felling

Other recommendations for best hillslope treatments (100

Straw windrows

Other recommendations for best channel treatments (100

Most effective road and trail treatme

Number culvert removal

Number rolling dips/water bars

Number road rip, drain, and stabilize

Most effective treatments over

Number culvert removal

Number culvert upgrading

Number other

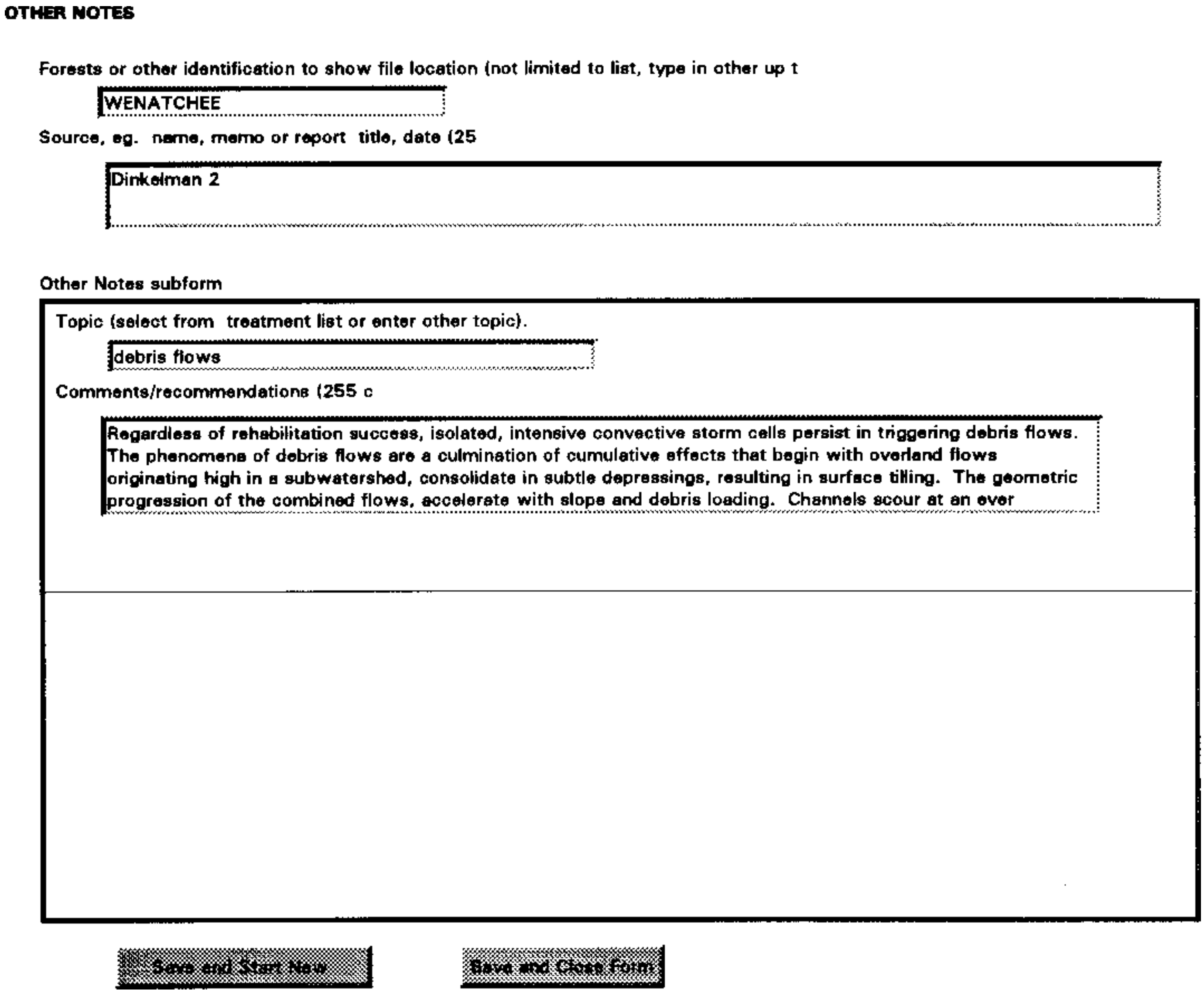
Other recommendationsfor best road and trail treatments (100

decompaction of unneeded roads

Other recommendations for best overall treatments (100

straw windrows

Overall Recommendations subform



OTHER NOTES

Forests or other identification to show file location (not limited to list, type in other up t

WENATCHEE

Source, eg. name, memo or report title, date (25

Dinkelman 2

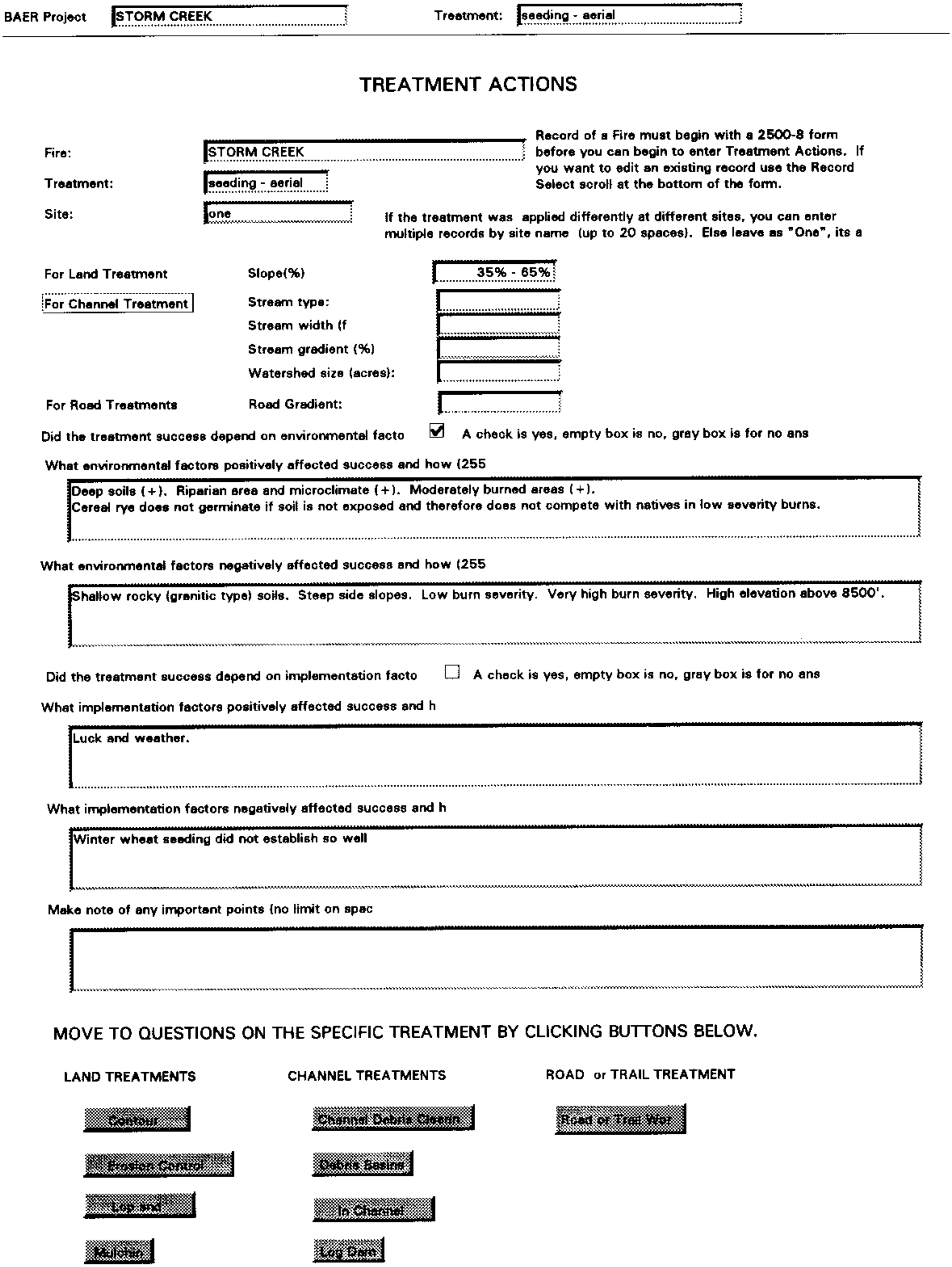
Other Notes subform

Topic (select from treatment list or enter other topic).

debris flows

Comments/recommendations (255 c

Regardless of rehabilitation success, isolated, intensive convective storm cells persist in triggering debris flows. The phenomena of debris flows are a culmination of cumulative effects that begin with overland flows originating high in a subwatershed, consolidate in subtle depressings, resulting in surface tilling. The geometric progression of the combined flows, accelerate with slope and debris loading. Channels scour at an ever



BAER Project: STORM CREEK

Treatment: seeding - aerial

TREATMENT ACTIONS

Fire: STORM CREEK

Treatment: seeding - aerial

Site: one

Record of a Fire must begin with a 2500-8 form before you can begin to enter Treatment Actions. If you want to edit an existing record use the Record Select scroll at the bottom of the form.

If the treatment was applied differently at different sites, you can enter multiple records by site name (up to 20 spaces). Else leave as "One", its a

For Land Treatment — Slope(%): 35% - 65%

For Channel Treatment — Stream type:

Stream width (f:

Stream gradient (%):

Watershed size (acres):

For Road Treatments — Road Gradient:

Did the treatment success depend on environmental facto ☑ A check is yes, empty box is no, gray box is for no ans

What environmental factors positively affected success and how (255

Deep soils (+). Riparian area and microclimate (+). Moderately burned areas (+).
Cereal rye does not germinate if soil is not exposed and therefore does not compete with natives in low severity burns.

What environmental factors negatively affected success and how (255

Shallow rocky (granitic type) soils. Steep side slopes. Low burn severity. Very high burn severity. High elevation above 8500'.

Did the treatment success depend on implementation facto ☐ A check is yes, empty box is no, gray box is for no ans

What implementation factors positively affected success and h

Luck and weather.

What implementation factors negatively affected success and h

Winter wheat seeding did not establish so well

Make note of any important points (no limit on spac

MOVE TO QUESTIONS ON THE SPECIFIC TREATMENT BY CLICKING BUTTONS BELOW.

LAND TREATMENTS

CHANNEL TREATMENTS

ROAD or TRAIL TREATMENT

BAER Project STORM CREEK Treatment: seeding - aerial

LAND TREATMENTS

SEEDING - AERIAL AND GROUND

Seeding rate (PLS/acre, rounded to whole numbe 30

Species seeded (no limit to spaces)

Riparian mix:. 20# cereal rye, 5#mountain brome, 3# orchard grass, 1# hard fescue, 1# dutch clover.
Hillside mix (used in area of contour felling): 20# cereal rye
Park boundary mix: 20# winter wheat grass

Natives (%) ☐ Annual rye (% ☐ Exotics (%): ☐
Native cultivars (% ☐ Regreen (%): ☐

☐ Was the seed inoculated
☒ Was the seed tested
☒ Was the residual seed bank in the soil teste
☐ Was fertilizer used

Seeding date:: 10/13/2015
Timeliness:: excellent

GO TO Monitoring and

MULCHING

Mulch rate (tons/acre)
Mulch type (50 sp
How was mulch spread, by hand or machin
Was tackifier used ☒
Was mulch application continuous or strip

GO TO Monitoring and

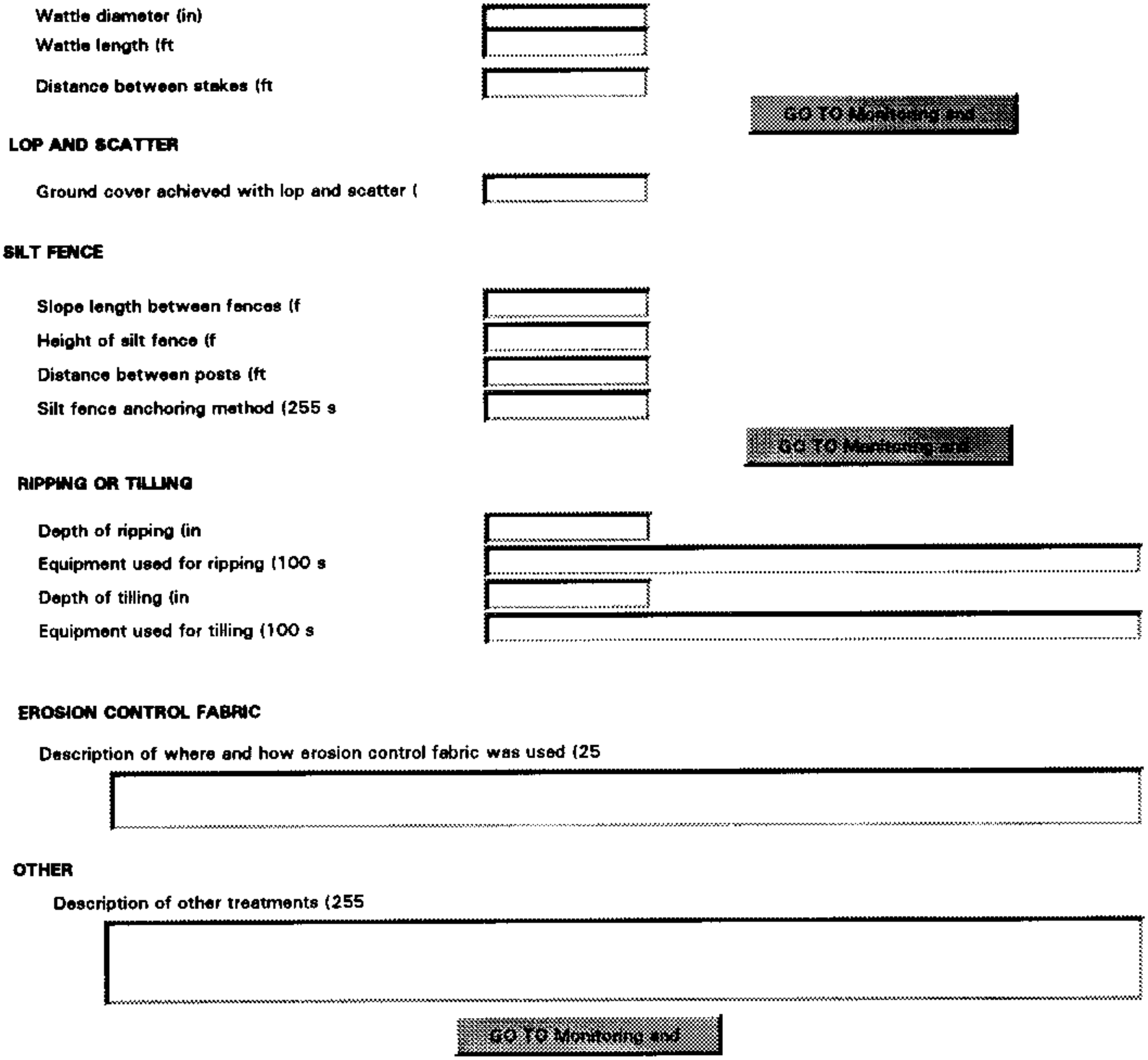
CONTOUR FELLING (LEB'S)

Horizontal distance between logs (f
Slope distance between rows of logs (f
Log dbh (in):
Average LEB log length (ft
Were LEB's bedded in or backfilled (yes or no) ☒

GO TO Monitoring and

STRAW WATTLES

Horizontal distance between wattles (
Distance on the slope between rows of wattles



Wattle diameter (in)
Wattle length (ft
Distance between stakes (ft

LOP AND SCATTER

Ground cover achieved with lop and scatter (

SILT FENCE

Slope length between fences (f
Height of silt fence (f
Distance between posts (ft
Silt fence anchoring method (255 s

RIPPING OR TILLING

Depth of ripping (in
Equipment used for ripping (100 s
Depth of tilling (in
Equipment used for tilling (100 s

EROSION CONTROL FABRIC

Description of where and how erosion control fabric was used (25

OTHER

Description of other treatments (255

BAER Project PONY **Treatment:** straw bale check dams

CHANNEL TREATMENTS

In a yes/no check box, a check is yes, empty box is no, gray box is for no answer.

STRAW BALE CHECK DAM

Check dam width (# of bales 4
Stakes per bale: 2
Type of bale: string

GO TO MONITORING AND RESULTS

Was the dam keyed in ☑
Was there an energy dissipator ☑

A check is yes, empty box is no, gray box is for no ans

LOG GRADE STABILIZER

Log grade stabilizer height (ft
Average log diameter (in)

Were logs keyed in? ▨
Did the log grade stabilizers have energy dissipators ▨

GO TO MONITORING AND RESULTS

ROCK GRADE STABILIZER

Rock grade stabilizer height (ft
Was the rock grade stabilizer keyed in ▨
Did the grade stabilizer have an energy dissipator ▨

LOG DAM

Log dam width (ft
Log dam height (ft
Log diameter (in)

GO TO MONITORING AND RESULTS

Was the log dam keyed in ▨
Did the log dam(s) have energy dissipators ▨
How were the logs fastened (100 s

IN CHANNEL FELLING

Size of logs used for in-channel felling (i

GO TO MONITORING AND RESULTS

DEBRIS BASIN

Volume of debris basin (cu yds
Cleaning interval for the debris basins (month
What type/design/construction was the debris basi

CHANNEL DEBRIS CLEARING

What type and size of material was cleared from the chann

STREAM BANK ARMORING

What size material was used for bank armoring (i
Was a fabric lining used with the bank armori ▨

GO TO MONITORING AND RESULTS

ROCK CAGE (GABION) DAM

Rock dam width (ft

Rock dam height (ft

Was the rock dam keyed in ▨

Did the rock dam have an energy dissipato ▨

SAND, SOIL, OR GRAVEL BAG CHECK DAM

Width of sand, soil, or gravel bag check dam (

Was the check dam keyed in place ▨

Did the check dam(s) have energy dissipators ▨

What was the bag constructed o

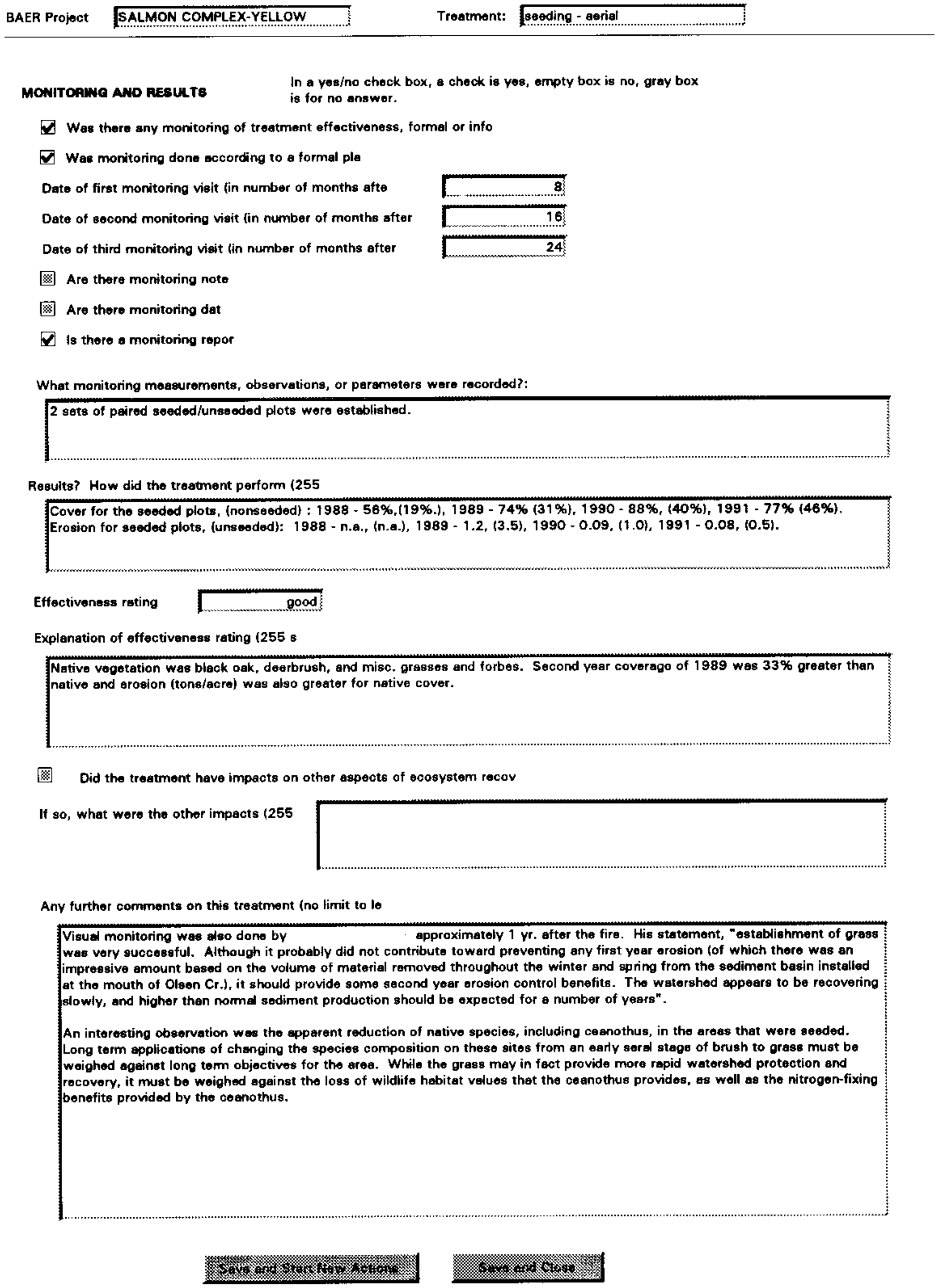
GO TO MONITORING AND RESULTS

ROAD TREATMENT or TRAIL TREATMENT

Description of road work (255 s

Description of trail work (255

GO TO MONITORING AND RESULTS



BAER Project: SALMON COMPLEX-YELLOW

Treatment: seeding - aerial

MONITORING AND RESULTS

In a yes/no check box, a check is yes, empty box is no, gray box is for no answer.

☑ Was there any monitoring of treatment effectiveness, formal or info

☑ Was monitoring done according to a formal pla

Date of first monitoring visit (in number of months afte: 8

Date of second monitoring visit (in number of months after: 16

Date of third monitoring visit (in number of months after: 24

▨ Are there monitoring note

▨ Are there monitoring dat

☑ Is there a monitoring repor

What monitoring measurements, observations, or parameters were recorded?:

2 sets of paired seeded/unseeded plots were established.

Results? How did the treatment perform (255

Cover for the seeded plots, (nonseeded) : 1988 - 56%,(19%.), 1989 - 74% (31%), 1990 - 88%, (40%), 1991 - 77% (46%).
Erosion for seeded plots, (unseeded): 1988 - n.a., (n.a.), 1989 - 1.2, (3.5), 1990 - 0.09, (1.0), 1991 - 0.08, (0.5).

Effectiveness rating: good

Explanation of effectiveness rating (255 s

Native vegetation was black oak, deerbrush, and misc. grasses and forbes. Second year coverage of 1989 was 33% greater than native and erosion (tons/acre) was also greater for native cover.

▨ Did the treatment have impacts on other aspects of ecosystem recov

If so, what were the other impacts (255

Any further comments on this treatment (no limit to le

Visual monitoring was also done by approximately 1 yr. after the fire. His statement, "establishment of grass was very successful. Although it probably did not contribute toward preventing any first year erosion (of which there was an impressive amount based on the volume of material removed throughout the winter and spring from the sediment basin installed at the mouth of Olsen Cr.), it should provide some second year erosion control benefits. The watershed appears to be recovering slowly, and higher than normal sediment production should be expected for a number of years".

An interesting observation was the apparent reduction of native species, including ceanothus, in the areas that were seeded. Long term applications of changing the species composition on these sites from an early seral stage of brush to grass must be weighed against long term objectives for the area. While the grass may in fact provide more rapid watershed protection and recovery, it must be weighed against the loss of wildlife habitat values that the ceanothus provides, as well as the nitrogen-fixing benefits provided by the ceanothus.

Appendix B—Treatment Effectiveness Summaries

In the course of conducting BAER team member interviews and reviewing monitoring reports, we acquired considerable information on the factors that make the various BAER treatments effective or not, as well as useful tips for implementation. Most of the information was not amenable to tabulation or other quantitative expression, so it was entered into our database in "comments" fields. This information has been summarized below, along with the effectiveness ratings developed from the interview forms.

The effectiveness and implementation information in these descriptions comes strictly from the comments and monitoring reports collected by us in this project. They are not intended to be comprehensive analyses of each treatment. Fully describing effective installation of treatments is beyond the scope of this report. The following comments should be used to supplement other sources of information on the various treatments.

Hillslope Treatments

Hillslope treatments are implemented to keep soil place and comprise the greatest effort in most BAER projects. Consequently, we obtained the most information on these treatments from our interviews and monitoring reports.

Aerial Seeding

Purpose: Aerial seeding, usually grasses but occasionally also legumes, is carried out to increase vegetative cover on a burn site during the first few years after a fire. It is typically done where erosion hazard is high and native plant seed bank is believed to have been destroyed or severely reduced by the fire. Seed is applied by fixed-wing aircraft or helicopter.

Relative Effectiveness: Excellent-24% Good-28% Fair-28% Poor-20% (Replies = 83)
Interviewees were almost evenly divided on the effectiveness rating of aerial seeding, with a slight majority regarding it as either "good" or "fair" (table 16). Respondents in Regions 1, 4, and 6 were more likely to rate seeding "excellent" or "good" than respondents in Regions 3 and 5.

Effectiveness depends on timeliness of seed application, choice of seed, pilot skill, 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 drop seed directly into dry ash, before any rain falls, to take advantage of the fluffy seedbed condition, while in others seed is best applied after the first snow so that it will germinate in the spring. Both conditions also reduce loss to rodents. Choice of seed determines how easily it can be applied – some grass species with long awns tend to clog in seeder buckets, and light seeds drift more than heavy ones – and how well it will grow, how long it will persist, and what impact it will have on natural regeneration. In general, legumes have not been found to be particularly effective at producing cover (there are exceptions). A skillful pilot will apply the seed evenly, rather than in strips with unseeded areas in between them, providing better ground cover once the seed germinates.

A few respondents also mentioned that straw mulch, needle cast, slope barriers such as straw wattles or contour-felled logs, or ripping the soil enhanced growth of seeded grasses. Maximum cover of seeded species is not attained until summer. Many respondents reported that seeding was not particularly effective at producing protection from the first year's storms (especially in the Southwest for fires that occur just before the monsoon season with its high intensity rains) but may provide effective cover during the second and subsequent years. Several respondents suggested that waiting to seed onto snow for spring growth would be the most effective course of action in the Southwest (Region 3), because they usually ended up having to do a second seeding anyway after the summer monsoon washed the first application away. Several respondents noted disappointing results from seeding with relatively expensive native species or Regreen (commercially available sterile wheatgrass hybrid) and would not use them again. On the other hand, cereal grains were generally reported to perform well the first growing season. Cereal grains that do not germinate in quantity the second year provide soil cover with the mulch from the dead first year growth. Both cattle and elk grazing were reported to reduce the effective cover of seeded grasses. Seeded grass cover tends to be higher on low angle slopes (less than 40 percent) than steep ones.

Implementation and Environmental Factors: Many respondents reported difficulties in contracting for seed and aircraft operators which, especially after fall fires, resulted in seed being applied too late for optimum conditions. Ground sampling, with sticky papers or by visual inspection, should be done to monitor seed application rate and evenness. Fixed wing aircraft may be less expensive per application but can be less accurate at directing seed than helicopters.

The use of native seed is a major issue on many Forests. Native grass seed can be hard to acquire in large quantities or in a timely manner compared to cereal grains or pasture grasses; it is also generally more expensive. Native seed should come from a nearby source area to preserve local genetic integrity. Cereal grains will germinate and grow the second year if the ground surface is disturbed by salvage logging or grazing. Many monitoring studies have found lower cover of native plants in areas with high seeded grass cover, even where seeding increased total cover. Sometimes this resulted in lower total cover after the seeded grass decreased in abundance. On the other hand, seeded grass may also inhibit growth of noxious weeds that invade sites after fire, a beneficial outcome. Rhizomatous (sod-forming) grasses make reforestation more difficult if they achieve significant cover. It is important to know the composition of prefire vegetation when proposing to seed – if the vegetation included many annuals or lots of perennial grass or sedge, there will usually be considerable cover established naturally after a fire.

Other factors: Many respondents noted that grass seeding was sometimes done primarily for "political" reasons, especially at the wildland-urban interface.

Ground Seeding

Purpose: Ground seeding is done in localized areas of high burn intensity where reestablishing plant cover quickly is essential, such as riparian areas, above lakes and reservoirs, or highly productive forest land. Annual or perennial grasses, usually non-native pasture grasses or cereal grains, and non-native leguminous forbs, are typically used. Ground seeding assures more even seed application than aerial seeding and sometimes includes treatments to cover the seed, which enhances germination. Seed is applied from all-terrain vehicles or by hand.

Relative Effectiveness: Excellent-9% Good-82% Fair-9% Poor-0% (Replies = 11)

Ground seeding was judged "good" in effectiveness by most interviewees. As with aerial seeding, the post-fire weather pattern frequently determines the effectiveness of cover production by seeded grass. High winds may blow seed off site. First rains can wash ash and seed from the hillslope, or they may be gentle enough to stimulate germination. Use of a rangeland drill, raking, or mulch to cover seed increases success. One forest used cattle to trample seed into the ground and break up a hydrophobic layer. Non-native species, especially perennial grasses, grow well, sometimes too well, and provide persistent cover. Cereal grains disappear in a few years.

Implementation and Environmental Factors: Timing of seed application is essential to success; optimum timing depends on local weather pattern. The seed mix must be adapted to the soil type. Awned or very light seeds spread more easily if rice hulls (or similar material) are included in the mix. Grass growth is best on lower angle slopes (less likely to wash away). Protection from cattle grazing the first year is considered by some to be the biggest factor in success; protection for 2 or 3 years is good. Elk may have a negative effect on seeded grasses as well.

Seeding Plus Fertilizer

Purpose: Seeding plus fertilization is done to increase total vegetation cover quickly on a burned slope. Occasionally fertilizer alone is applied to enhance natural regeneration.

Relative effectiveness: Excellent-25% Good-0% Fair-50% Poor-25% (Replies = 4)

Fertilization received mixed reviews among the four respondents. As with seeding, timing of application and post-fire weather pattern are important to success. Fertilization is mainly done in the Northwest and ammonium sulfate is most commonly used. One respondent reported that greener strips were apparent in the seeded area where the fertilizer had been applied. Pelleted seed, containing a small amount of fertilizer, may be easier to apply than uncoated seed.

Implementation and Environmental Factors: Along riparian areas slow release fertilizer has been used to minimize leaching into waterways. There is evidence that fertilizer may inhibit or depress mycorrhizae formation.

Contour-Felled Logs (Log Erosion Barriers, Log Terraces, Terracettes)

Purpose: Contour-felled logs reduce water velocity, break up concentrated flows, and induce hydraulic roughness to burned watersheds. Sediment storage is a secondary objective. The potential volume of sediment stored is highly dependent on slope, the size and length of the felled trees, and the degree to which the felled trees are adequately staked and placed into ground contact.

Relative Effectiveness: Excellent-29% Good-37% Fair-14% Poor-20% (Replies = 35)

The effectiveness of contour-felling covered the spectrum from "excellent" to "poor," although more ratings were "excellent" or "good" (66 percent) than "fair" or "poor" (34 percent) (table 16). Some personnel reported 100 percent of logs functioning, while others reported 0 percent functioning. Site conditions, installation quality, climate, and the quality of materials are major factors in determining relative effectiveness. In some instances contour-felled log barriers have filled with sediment following the first storm event after installation, while others have taken 1 to 2 years to fill.

Implementation and Environmental Factors: Good planning, proper implementation, and knowledge of environmental factors are crucial to the success of contour-felling. This BAER treatment is expensive, technically demanding, and dangerous work, so crew skill and experience and good supervision are important. Attention to felling and delimbing safety rules is paramount. Logs must be placed on the contour, put in contact with the ground, and properly anchored. If these three items are ignored, failure is assured. This treatment needs to be implemented in a very methodical and meticulous manner. Increased installation speed or area covered will not make up in effectiveness that can be lost by poor installation. Ground contact can be assured by adequate delimbing beneath each log, leaving branches downhill, trenching, and backfilling. In some instances machinery has been used to make ground contact trenches, but the usual method is to excavate with hand labor due to equipment and slope limitations. Trenching to seat contour-felled logs has an additional benefit in that it can help to break up hydrophobic layers in the soil. Anchoring can be done with wooden or re-bar stakes where slopes are steeper, but should be of sufficient frequency and depth to prevent movement of the logs.

Shallow, rocky soils that are very 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 extra implementation time required and limited stabilization of small amounts of soil. Gentler slopes and finer textured soils (except clayey soils) lead to better installation and greater sediment trapping efficiency. Slopes less than 40 percent are recommended for successful contour-felling. Slopes greater than 75 percent present significant installation safety hazards and should be avoided. In some instances, only the lower portions of slopes near ephemeral or perennial channels have been treated. 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 also affects this treatment. Specifications require logs from burned trees 15 to 20 ft (4.5 to 6 m) in length with diameters of 4 to 12 in (100 to 305 mm). Placing tree stems 10 ft (3 m) apart on slopes over 50 percent, 15 ft (4.5 m) apart for slopes of 30 to 50 percent, and 20 ft (6 m) apart for slopes less than 30 percent would require 2000 to 4000 linear ft ac^{-1} (1500 to 3000 linear m ha^{-1}) of tree bole on some sites. A shortage of dead timber or large numbers of small diameter trees could place limitations on the contour-felled treatment area. Crooked stems, such as oak, are often readily available, but they are not useable or cost-effective for contour-felling treatment. Cutting trees for contour-felled log barriers reduces the number of snags for birds to use. However, it often increases vegetation cover when plants become established in fine sediments trapped on the uphill sides of the felled logs. Contour-felled logs should be placed in a random pattern to ensure a more "natural" appearance and avoid patterns which might aggravate runoff.

Mulch

Purpose: Mulch is used to cover soil, reducing rain impact and soil erosion. It is often used in conjunction with grass seeding to provide ground cover in critical areas. Mulch protects the soil and improves moisture retention underneath it, benefitting seeded grasses in hot areas but not always in cool ones.

Relative Effectiveness: Excellent-66% Good-17% Fair-17% Poor-0% (Replies = 12)

Mulch was judged "excellent" in effectiveness by most interviewees, although many also noted that it is quite expensive and labor-intensive (table 16). It is most effective on gentle slopes and in areas where high winds are not likely to occur. Wind either blows the mulch offsite or piles it so deeply that seed germination is inhibited. On very steep slopes, rain can wash some of the mulch material downslope. Punching it into the soil, use of a tackifier, or felling small trees across the mulch may increase onsite retention. Mulch is frequently applied to improve germination of seeded grasses. In the past, seed germination from grain or hay mulch was regarded as a bonus, adding cover to the site. Use of straw from pasture introduces exotic grass seed. Forests are now likely to seek "weed-free" mulch such as rice straw. Mulch is judged most valuable for high value areas, such as above or below roads, above streams, or below ridge tops.

Implementation and Environmental Factors: Mulch can be applied most easily where road access is available because the mulch must be trucked in, although for critical remote areas it can be applied by helicopter or fixed wing aircrafts. Hand application is labor-intensive and can result in back or eye injuries to workers. Using a blower to apply the mulch requires considerable operator skill to get uniform distribution of the material. Effectiveness depends on even application and consistent thickness. Rice straw is not expected to contain seeds of weeds that could survive on a chaparral or forested site (too dry); however, weeds do germinate sometimes and could result in introducing new exotics to wildland areas. Other certified "weed-free" straws sometimes contain noxious weeds. There is concern that thick mulch inhibits native shrub or herb germination. Shrub seedlings have been observed to be more abundant at the edge of mulch piles, where the material was less than 1 in (25 mm) deep. Because of the weed and germination concerns, mulch should not be used in areas with sensitive or rare plants. Mulch can be applied in 100 to 200 ft (30 to 60 m) wide strips on long slopes, saving labor costs and also reducing the potential impact of the mulch on native plant diversity.

Slash Spreading

Purpose: Slash spreading covers the ground with organic material, interrupting rain impact and trapping soil. It is a common practice after timber sales, but can also be used on burned slopes where dead vegetation is present. Slash is more frequently used on firebreaks and dozer firelines.

Relative Effectiveness: Good–50% Fair–50% (Replies = 2)

Interviewees that used this treatment rated the effectiveness "good" and "fair." It is more effective on gentle slopes than steep ones. In accessible areas, the material can disappear as people collect it for firewood. One respondent was disappointed that not much sediment was trapped by spread slash.

Implementation and Environmental Factors: Slash needs to be cut so it makes good contact with the ground. It can be used in a moderately burned area, where there is more material to spread, or below an intensely burned slope or area of water repellent soil. There is concern that slash will attract or harbor insects, and it could act as fuel for a reburn.

Temporary Fencing

Purpose: Temporary fencing is used to keep grazing livestock and/or vehicles off of burned areas and riparian zones during the recovery period. Resprouting onsite vegetation and seeded species attract grazing animals and are initially very sensitive to disturbance. Fencing can speed up the recovery process by removing post-fire disturbance from grazers and vehicles.

Relative Effectiveness: Excellent-0% Good-68% Fair-33% Poor-0% (Replies = 3)

Temporary fencing was evaluated as "good" or "fair" by the limited number of interviewees that rated it (table 16). They noted that the effectiveness is dependent on the extent to which grazers are excluded from the burned areas. In some areas, elk grazing is as problematic as cattle grazing, and the use of the more costly high fences that exclude elk needs to be considered. The presence and intensity of native ungulate grazing will definitely affect the success of fencing. Elimination of grazing for 2 years was judged to be very important for achieving hillslope stability. One person noted that temporary fencing could have excellent effectiveness when done before winter, but the chance of fencing being completed before winter is often low due to the extensive time requirements of fence construction.

Implementation and Environmental Factors: Some BAER personnel recommend cattle exclusion if more than 50 percent of an allotment is burned. If a decision is made to employ temporary fences, installation needs to be timely and proper. Fence construction is slow relative to other BAER treatments so it is important that fence installation is not delayed. It is important to keep cattle out of burned areas before and during fence construction. Incursions by cattle can slow fence construction. Consideration should be given to installation of big game/elk exclosures where these animals have a significant impact on burned area recovery. The location of temporary fences should be coordinated with existing allotment fences.

Other Factors: Some personnel liked using BAER funds with Forest funds to achieve long-term fencing goals. Others apparently have had problems getting fencing put in with BAER funds. Electric fence is an option for excluding cattle. This option needs to be considered more in the future. It may be more cost-effective, easier, and quicker to install just after aerial seeding than other types of fences. Fencing is also a good tool for excluding off-road vehicles from sensitive recently burned areas.

Straw Wattles

Purpose: Straw wattles are permeable barriers used to detain surface runoff long enough to reduce flow velocity. Their main purpose is to break up slope length. They have also been used in small drainages or on side slopes for detaining small amounts of fine suspended sediment.

Relative Effectiveness: Excellent-33% Good-33% Fair-33% Poor-0% (Replies = 3)

The effectiveness rating of straw wattles ranges from "excellent" to "fair" depending on the circumstances in which they were used and the quality of the installation. Comments within one Region on straw wattle effectiveness ranged from being an "excellent" treatment at a reasonable cost and still functioning after 2 years, to that of exhibiting pronounced undercutting immediately on the downhill side. Visual monitoring has noted that straw wattles usually remain in place and often fill with soil material on the uphill side. Where that happens, good seed germination occurs. Straw wattles have been placed onto specific sites and randomly located on slopes. Some monitoring observations have noted that there does not appear to be a difference in overall vegetative recovery between contour-felled log areas and straw wattle treatment areas. Overall effectiveness can be affected by breakdown of the wattles and release of built-up sediment onto the rest of the slope or into drainages.

Implementation and Environmental Factors: Correct installation of straw wattles is crucial to their effectiveness. They are labor intensive because they need to have good ground contact and anchoring. Wattles can be anchored to the ground by trenching and backfilling or staking. An effective anchoring technique is to use "U" shaped 1/8 in (3 mm) re-bar. Re-bar can hold wattles to the ground without trenching and is less likely to break than wood stakes in shallow soils. Straw wattles can work well on slopes greater than 40 percent but they are difficult to carry and hard to install on steep terrain. Spotting the wattles with helicopters can solve some of this problem.

Other Factors: The cost of straw wattle installation is about one half that of contour-felled logs.

Tilling/Ripping

Purpose: Tilling and ripping are mechanical soil treatments aimed at improving infiltration rates in machine-compacted or water repellent soils. Both treatments may increase the amount of macropore space in soils by physical breakup of dense or water repellent soils, and thus increase the amount of rainfall that infiltrates into the soil.

Relative Effectiveness: Excellent-33% Good-33% Fair-33% Poor-0% (Replies = 3)

Tilling and ripping was judged to be an "excellent" treatment for roads, firebreaks, and trails but less effective on hillslopes (table 16). These techniques may add roughness to the soil and promote infiltration. They may be successful for site-specific circumstances like compacted or water repellent areas, but not economically feasible on large areas or safe to do on slopes greater than 30 to 45 percent. Size of the equipment and crawler tractor operator skill are also important effectiveness factors. Up- and down-hill tilling/ripping needs to be avoided because it can diminish the effectiveness of the treatment in reducing soil erosion by promoting rilling in the furrows. According to some personnel, this type of treatment was the most effective when done in combination with broadcast seeding. Others indicated that tilling/ripping can be successful accomplished at a high production rate on non-timbered areas without seeding.

Implementation and Environmental Factors: Shallow soils, rock outcrops, steep slopes, incised drainages, fine-textured soils, and high tree density create significant problems for tilling and ripping. These treatments work best where there is a good soil depth, the soils are coarse textured, slopes are less than 30 percent, and woody vegetation density is low. This type of treatment has a high logistics support requirement (fuel, transport carriers, access, and drainage crossing).

Other Factors: Since tilling and ripping are ground-disturbing activities, cultural clearances are required. Obtaining proper cultural clearances may significantly slow accomplishment of tilling/ripping projects.

Contour Trenching and Terraces

Purpose: Contour trenches are used to break up the slope surface, to slow runoff and allow infiltration, and to trap sediment. Rills are stopped by the trenches. Trenches or terraces are often used in conjunction with 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.

Relative Effectiveness: Excellent-67% Good-33% Fair-0% Poor-0% (Replies = 3)

Two of the three interviewees who rated trenching considered its effectiveness "excellent;" the other thought it "good" (table 16). Trenches trap sediment and interrupt water flow, slowing runoff velocity. They work best on coarse granitic soils. When installed with heavy equipment, trenches may result in considerable soil disturbance that can create problems.

Implementation and Environmental Factors: Trenches must be built along the slope contour to work properly; using baffles or soil mounds to divide the trench reduces the danger of excessive flow if they are not quite level. Digging trenches requires fairly deep soil, and slopes of less than 70 percent are best. Trenches are hard to construct in heavy, clay soils and are not recommended for areas prone to landslides. Hand crews can install trenches much faster than log erosion barriers (a similarly effective hillslope treatment), and crew skill is not quite as important to effective installation. Trenches have high visual impact when used in open areas (and thus may be subject to controversy), but tend to disappear with time as they are filled with sediment and covered by vegetation. On the other hand, more extreme (wide, deep) trenches installed several decades ago are still visible on the landscape in some areas.

Geotextiles, Geowebbing

Purpose: Matting is used to cover ground and control erosion in high risk areas where other methods will not work, such as extremely steep slopes, above roads or structures, or along stream banks. It is usually used in conjunction with seeding. Geotextiles come in different grades with ultraviolet inhibitors that determine how long they will last in the field.

Relative Effectiveness: No interviewees rated this treatment.

When geotextiles mats are applied over seed and mulch, they are very effective in stopping erosion. Because the cost is very high, they are used only where immediate ground cover is needed; large areas cannot be covered by this method. Geotextiles are particularly effective for steep upper slopes where other materials (seed, mulch alone) will blow off. Material must be anchored securely to remain effective, especially along streambanks.

Implementation and Environmental Factors: An experienced crew is needed to ensure that good contact is established between the fabric material and the ground, and that the fabric is securely anchored. Fabric matting is difficult to apply on rocky ground. Plastic netting on some geotextiles material can trap small rodents and birds. Jute netting does not provide complete ground cover but it has not been reported to trap animals. The complete cover provided by some geotextiles can reduce native plant establishment.

Silt Fences

Purpose: Silt fences are installed to trap sediment in swales, small ephemeral drainages, or along hillslopes where other methods cannot be used. They provide temporary sediment storage. Silt fences are also installed to monitor sediment movement as part of effectiveness monitoring.

Relative Effectiveness: Excellent–38% Good–62% Fair –0% Poor–0% (Replies = 8)

Silt fences were considered “good” or “excellent” by interviewees (table 16). Most respondents felt they worked well in ephemeral channels, but not all. The size of the watershed above the fence may be important, and silt fences cannot handle debris flows or heavy sediment loads. They work better on gentler slopes, such as swales. Silt fences can be installed on rocky slopes where log erosion barriers would not achieve good ground contact. Sealing the bottom of the fence to the ground well is critical to effectiveness and seems to work best if a trench is dug behind the fence to trap sediment. Silt fences also effectively catch small rocks and ravel on slopes above buildings.

Implementation and Environmental Factors: As noted above, silt fences must be anchored and sealed to the ground to be effective. Sandbags can be used as anchors. Burying the bottom of the fence in a trench is also useful. Rockiness of the soil affects how well the toe of the fence can be buried. When used in ephemeral channels, silt fences must be cleaned out or they can fail and release the stored sediment all at once. They are useful for monitoring sediment movement, and can last several years before failing.

Sand, Soil or Gravel Bags

Purpose: Sand, soil or gravel bags are used in small channels or on hillslopes to trap sediment and interrupt water flow.

Relative effectiveness: No interviewees rated this treatment.

Comments indicate that bags are useful in ephemeral channels or on slopes, where they are placed in staggered rows like contour felling in areas where there are no trees. Rows of bags break water flow and promote infiltration. They store sediment temporarily, then break down and release it.

Implementation and Environmental Factors: When bags are used in channels, installation sites must be selected by an experienced person. They are not appropriate for use in V-shaped channels. Installation of soil bags is labor-intensive, but they can be a relatively cheap treatment if volunteer labor is used. The bags are easy for volunteers to fill and install.

Channel Treatments

Channel treatments are implemented to modify sediment and water movement in ephemeral or small-order channels, and to prevent flooding and debris torrents that may affect downstream values at risk.

Straw Bale Check dams

Purpose: Straw bale check dams are used to prevent or reduce sediment inputs into perennial streams during the first winter or rainy season following a wildfire. Straw bales function by decreasing water velocity and detaining sediment-laden surface runoff long enough for coarser sediments to deposit behind check dams. The decreased water velocity also reduces downcutting in ephemeral channels.

Relative Effectiveness: Excellent-30% Good-30% Fair-30% Poor-10% (Replies = 10)

Straw bale check dams were judged to cover the range from “good” to “poor” effectiveness. They often fill in the first few storms, so their effectiveness can diminish rapidly. However, channel gradients can be easily stabilized, and sediment is stored and released at a slower or diminished rate. They appear to work well in front of culverts, and in semi-arid environments require little maintenance. Structural survival rates of 90 percent have been reported after 1 year with 75 to 100 percent sediment storage, and 95 percent survival after rainfall of 2.4 in hr^{-1} (60 mm hr^{-1}) for a 10-min duration. However, a common negative comment was that straw bale check dams tend to blow out in large storms. Failure can occur if the dams are poorly installed or put in locations where they can not contain runoff. Straw bale check dams are considered by many BAER project coordinators to be effective emergency rehabilitation treatments. Straw bale check dams appear to work better than contoured felled logs. Some Forests use straw bales below culverts to disperse flow and trap sediments. They appear to the most successful in channels small enough to require only three bales, but in narrow, steep drainages two-bale wide structures do not function as well.

Others do not recommend use of straw bales because they fill to capacity after small storms. They can be washed out later even when anchored with "U" shaped 1/8 in (3 mm) re-bar are useful only in the upper reaches of watersheds (1st or 2nd order drainages) that are often difficult to access, and can be easily undercut if energy dissipators are not installed. One of the comments on straw bale check dams was there is always a risk of failure in large events. These dams cannot be designed for large storms, and will fail during significant runoff events.

Implementation and Environmental Factors: A large number of comments were made about important implementation and environmental factors that affect the success of straw bale check dams. Regarding implementation, a key factor is having a skilled implementation leader and trained, experienced crews. Straw bale check dams are costly and labor intensive. With such a high investment, the dams must be well-designed, properly placed, and well built.

Generally speaking, straw bales work best in drier regions, on small drainage areas that have low gradients (less than 30 percent), and in channels that are not incised. The bales need to be placed so that they contact the channel bottom, are curved up to and keyed into banks, and are adequately staked or wired to stay in place. Inter-bale spaces need to be filed so that channelized flow does not occur. "U" shaped re-bar seems to work well in stabilizing bales but don't guarantee that the bales will remain in place. Geotextile fabric works well as an energy dissipator and should be placed starting on the uphill side running over the bales in the center of the channel and downstream in a splash pad. Chicken wire and staking should be used to keep the geotextile in place. Rock, wood, or other straw bales can also be used as energy dissipators but must be large enough or well-anchored to prevent movement during runoff. Straw bale check dams seem to work better and survive longer than silt fences, especially when reinforced with wire on the upstream side.

Other Factors: Because straw bales will break down over time and fail in high flows, maintenance during the first year is very important. Straw bales are not readily available early in the year. After August they are very available. Rice straw bales should be considered because they usually do not contain noxious weeds, and weeds associated with rice crops do not do well on dry hillslopes and ephemeral channels. Straw bale check dams can be destroyed by grazing animals such as cattle and elk. Bears also have a peculiar tendency to indulge in ripping straw bale check dams apart.

Log Grade Stabilizers

Purpose: The purpose of log grade stabilizers is much the same as log dams, except that the emphasis is on stabilizing the channel gradient rather than trapping sediment.

Relative Effectiveness: Excellent-30% Good-30% Fair-10% Poor-30% (Replies = 10)

Interviewees rated log grade stabilizers about equally across the spectrum from "excellent" to "poor." Like log dams, these structures are expensive and time-consuming. In situations where log grade stabilizers were rated "excellent," 70 to 80 percent of the structures were still functional after 1 year. "Poor" ratings usually resulted where the log grade stabilizers did not make a difference or they were lost to high stormflows.

Implementation and Environmental Factors: Log grade stabilizers have many of the same design, implementation, and environmental factors considerations that log dams do. Proper design and crew experience are critical in making these structures last and function effectively. Numerous small log grade stabilizers are preferable to a few larger ones. In some locations, there might not be adequate, straight, woody material left after a fire to build log grade stabilizers with onsite resources.

Rock Grade Stabilizers

Purpose: The purpose of rock grade stabilizers is the same as log grade stabilizers, except that they are made of rock. The emphasis is on stabilizing the channel gradient rather than trapping sediment although some sediment will be trapped by these structures.

Relative Effectiveness: Excellent-0% Good-33% Fair-67% Poor-0% (Replies = 3)

Only a few interviewees commented on rock grade stabilizers. They rated this technique as "good" to "fair." There were not many comments about this technique.

Implementation and Environmental Factors: Many comments on implementation and environmental factors pertaining to log grade stabilizers, apply to rock grade stabilizers. Proper design, adequate planning, and experienced crews often make the difference between "good" and "fair" effectiveness. Like log grade stabilizers, this technique is expensive and time consuming. A key implementation factor is the availability of rock for the grade stabilizers. A couple of important implementation factors that affect effectiveness are: (1) the use of rocks that are large enough to resist transport during runoff events, and (2) placement of organic debris or sediment screening on the upstream side of the grade stabilizer.

Channel Debris Clearing

Purpose: Channel clearing is the removal or size reduction of logs and other organic debris or the removal of sediment deposits to prevent them from being mobilized in debris flows or flood events or altering stream geomorphology and hydrology. This treatment has been done to prevent creation of channel debris dams which might result in flash floods, or aggravate flood heights or peakflows. Organic debris can lead to culvert failure by blocking inlets culverts, or reduce channel flow capacity. Excessive sediments in stream channels can compromise in-channel storage capacity and the function of debris basins.

Relative Effectiveness: Excellent-0% Good-71% Fair-0% Poor-29% (Replies = 7)

Channel debris clearing was rated as "good" in effectiveness by the majority of the interviewees, but nearly a third rated its effectiveness to be "poor." The latter rating came from situations where there was not enough post-fire organic debris in riparian areas or the channels to cause debris dam problems or stream hydrology was adversely altered by clearing. Because much of the debris from fire-killed trees does not enter channel system until 2 or 3 years later, this treatment was not considered by some to be a useful BAER treatment. Also, there has been a significant improvement in the understanding of the positive role of large woody debris in trapping sediment, dissipating the energy of flowing water, and providing aquatic organism habitat. In some instances the channel clearing has been more disruptive than the wildfire. So, in some areas the policy now is to avoid channel clearing.

Channel clearing is definitely an expensive, time-consuming operation, but it has been successful in certain situations such as locations where trash racks cannot be used to protect road culverts, where woody debris might move into reservoirs, and where sediment must be removed from debris basins and channels to provide adequate sediment storage capacity. Important factors in the relative effectiveness of channel clearing, when it is used, include a good analysis of risk and the value of resources at risk, knowledge of the size and quantity of material to remove, the clearing distances above roads needed to protect culverts, and understanding of the physical characteristics of the channels which might aggravate or reduce stormflows.

Implementation and Environmental Factors: Timing is an important factor which affects both the effectiveness and the assessment of the value of channel clearing. When sediment removal is the objective of channel clearing, operations must be done before seasons (usually winter) that produce the first or most significant stormflows. For large woody debris, the key question is if and when inputs of woody debris are likely to occur. In some areas, woody debris recruitment (greater than 2 years) may be beyond the timeframe of BAER projects. Crews conducting channel clearing must be well trained in order to recognize woody material that is too large to float or be firmly anchored, is part of the natural instream coarse woody debris load, or is a natural grade stabilizer. Where woody debris is cut up it must be sufficiently short to pass through culverts.

Other Factors: Channel debris clearing may produce significant, adverse riparian area impacts, destabilize the channel, reduce aquatic habitat, and alter stream hydrology. These side effects may negate any positive benefits derived from channel clearing in some situations.

Stream Bank Armoring/Channel Armoring

Purpose: Stream bank and channel armoring is done to prevent erosion of channel banks and bottoms during runoff events. In some hydrologic systems stream banks are a major source of sediment.

Relative Effectiveness: Not enough interviewees rated this treatment.

Comments on armoring indicated that it functions well in small, ephemeral drainages or near the heads of larger ephemeral drainages, and lower gradient areas. In steep terrain, sloughing of upslope materials can bury the bank armoring.

Implementation and Environmental Factors: Stream bank armoring requires proper design, a well-developed implementation plan, and experienced crews for maximum effectiveness. Other implementation factors that contribute to success include proper sized materials, use of geotextile fabric, avoiding overly steep areas, and the use of energy dissipators.

In-Channel Felling

Purpose: This BAER channel treatment is designed to replace woody material in drainage bottoms that have been consumed by wildfire. It is intended to trap organic debris and temporarily detain or slow down storm runoff. Woody material felled into channels will ultimately alter channel gradient, and may cause sediment deposition and channel aggradation.

Relative Effectiveness: Not enough interviewees rated this treatment.

It is difficult to assess the relative effectiveness of this treatment because no monitoring information was available and few visual observations have been made. Log jams created by felling trees into channels have the potential to detain sediment, but there is little credible confirmation of this potential.

Implementation and Environmental Factors: Good pre-planning, supervision, and a high level of crew experience are crucial to successful implementation of this treatment. Skilled tree fellers and chainsaw crews are vital to implementation of this treatment. Crews need to be able to judge correct log spacing, positioning, and adequate contact with the streambed. This treatment can be implemented only where there is a good supply of dead trees near the channels. Also, care must be taken not to use large trees because they do not work as well as smaller ones. Snags can be felled parallel to channels to support channel banks or in v-shaped or other patterns to retain woody debris above road culverts.

Log Dams

Purpose: Log dams, like straw bale check dams, are used to prevent or reduce sediment inputs into perennial streams during the first winter or rainy season following a wildfire. They are constructed of more durable material than straw bale dams. Log dams function by decreasing water velocity and detaining sediment-laden surface runoff long enough for coarser sediments to deposit behind check dams. Decreased water velocity also reduces downcutting in ephemeral channels.

Relative Effectiveness: Excellent-40% Good-60% Fair-0% Poor-0% (Replies = 5)

Log dams were rated "excellent" and "good" in their effectiveness as a BAER treatment by the limited number of interviewees who commented on log dams. Well-built log check dams can be 70 to 80 percent effective in trapping sediment and last 15 to 30 years. The amount of sediment trapped is highly variable depending on the size of the dam. In one location, individual log dams were reported to trap up to 40 yd^3 (40 m^3) of sediment without failure. They can be very effective in adding to channel stability and keeping sediment onsite. On the negative side, failures due to undercutting, bypassing, and complete blowout have aggravated erosion problems by producing deep scouring at dam sites and release of large amounts of sediment in pulses. Despite these potential problems and situations where 25 percent failed in the first storm, no one rated log dams as "fair" or "poor" in effectiveness.

Implementation and Environmental Factors: Like straw bale check dams, a key factor in log dam construction is having a skilled implementation leader and trained, experienced crews. Log check dams are costly and labor intensive, requiring six to eight times the labor for installation than straw bale check dams. Design features such as appropriate size of watershed, dam orientation, log sizes, lateral keying (1.5 to 3 ft (0.4 to 1 m) into banks), spillways, contact with the stream bed, plugging of gaps, and energy dissipaters are important implementation considerations. Some BAER coordinators recommend that log dams never be put in fully functional channels, but others recommend that log dams can be used to replace coarse woody debris burned out of small perennial channels. Often rocks are used in conjunction with log dams.

Other Factors: In some locations, there might not be adequate woody material after a fire to build log dams.

Debris Basins

Purpose: Debris basins are constructed to treat either the loss of control of runoff and deterioration of water quality, or threats to human life and property. The design of debris basins must be to a standard that they provide immediate protection from flood water, floatable debris, sediment, boulders, and mudflows. They are usually constructed in stream systems with normally high sediment loads. Their purpose is to protect soil and water resources from unacceptable losses or to prevent unacceptable downstream damage. Debris basins are considered to be a last resort because they are extremely expensive to construct and require commitment to annual maintenance.

Relative Effectiveness: Not enough interviewees rated this treatment.

In order for debris basins to function they must be able to trap at least 50 percent and preferably 70 to 80 percent of 100-year flows. A spillway needs to be constructed in the debris basin to safely release flow in excess of the design storage capacity. The downstream channel should be lined to prevent scour. In some instances excavated pits in ephemeral channels have been used as debris basins. These must be large enough to trap 50 to 90 percent of flood flow. They need to be cleaned annually until abandoned.

Implementation and Environmental Factors: Because debris basins are rather large, they require design by qualified engineers. They are built in depositional or runout areas that have large storage capacity. During construction it is important to maintain the channel gradient. Head cutting can result from improperly located or constructed debris basins.

Other Factors: Debris basins must be designed with large vehicle access to the basins so they can be cleaned out periodically. Maintenance is a key factor in effectiveness of this treatment. Although protection is immediate, maintaining debris basins may be a long-term commitment.

Straw Wattle Dams

Purpose: Straw wattle dams work on the same principal as straw bale check dams. They trap sediment on side slopes and in the upper ends of ephemeral drainages by reducing channel gradient. Straw wattles are easy to place in contact with the soil and provide a low risk barrier to soil movement.

Relative Effectiveness: Excellent-33% Good-67% Fair-0% Poor-0% (Replies = 3)

The limited number of interviewees that rated this treatment scored straw wattle dams as "excellent" or "good" in terms of controlling movement of sediment in channels. In one instance, only 10 of 3,300 wattles failed during the first storm after installation. Another reported an 80 percent first-storm survival rate, and excellent channel energy dissipation and trapping of sediment.

Implementation and Environmental Factors: Like any other channel treatment, good plans, designs, and experienced crews go a long ways to ensure successful implementation. Straw wattles work best on first order ephemeral channels with slopes less than 45 percent gradient. They can be easily placed by relatively untrained crews since they conform to the soil surface very well. This is a distinct advantage over rigid barriers like logs. Placement of straw wattle check dams is easiest on loamy sand soils that can be readily excavated. The closer together straw wattles are placed in steep terrain the more effective they are in detaining sediment. "U" shaped re-bar is very effective in keeping straw wattles fastened down but is another factor to consider in the logistics plans for this type of BAER project. Shallow or rocky soils can cause problems with re-bar usage, but hard pans can be penetrated by driving the re-bar. Straw wattle dams are a good alternative in burned areas where logs are absent, poorly shaped, or scarce. Wattles can be used quite effectively in combination with straw bale check dams. They also can be easily prepositioned by helicopters.

Other Factors: Straw wattles are relatively cheap to buy. They can be disturbed by grazing animals, decompose, and catch fire. Although the wattle netting is photodegradable, there are concerns that it persists long enough to pose hazards for small animals. Supply is a major problem, particularly for a large project. There are concerns among some users about the cost effectiveness of straw wattle dams since the material and labor costs are quite high.

Rock Cage (Gabion) Dams

Purpose: Also known as rock fence check dams, these structures are used in intermittent or small perennial channels to replace large woody debris that may have been burned out during a wildfire. The rock cage dams provide a degree of grade stability and reduce flow velocities long enough to trap coarse sediments.

Relative Effectiveness: Not enough interviewees rated this treatment.

Comments by some individuals indicated favorable results. On mild gradients these structures work well. Some failures occurred on steeper slopes when high velocity flows are greater than 3 ft s^{-1} (1 m s^{-1}). This is a common theme for all channel treatments. Most of the failures occur where treatments are imposed on steep gradient sections of ephemeral or first to second order perennial channels. Rock cage dams often last long enough and trap enough fine sediments to provide microsites for woody riparian vegetation to get reestablished. Rock cage dams on the Wenatchee National Forest were very successful, trapping 2000 to 10,000 yd^3 (1500 to 7600 m^3) of material after just one storm.

Implementation and Environmental Factors: Like most other BAER channel treatments, proper dam design and installation by experienced crews are crucial to success. The rock cage dams must be properly placed, keyed in, and anchored to stay in place during runoff events. Downslope energy dissipators are recommended because they reduce the risk of the rock cage dams being undercut.

Other Factors: Construction of these structures is dependent on the availability of adequate amounts and sizes of rocks. Rock cage dams need to be cleaned out periodically if they are to maintain their effectiveness.

Road Treatments

Road treatments are implemented to increase the water and sediment processing capabilities of roads and road structures. They are not meant to retain water and sediment, but rather to manage its erosive force.

Rolling Dips/Waterbars/Cross Drain/Culvert Overflow/Bypass

Purpose: These treatments are designed to provide drainage relief for road sections or water in the inside ditch to the downhill side of roads especially when the existing culvert is expected to be overwhelmed.

Relative Effectiveness: No interviewee rated this treatment.

Environmental/Implementation Factors: Rolling dips are easily constructed with road grader or dozer. Rolling dips or waterbars need to be deep enough to contain the expected flow and location carefully assessed to prevent damages to other portions of the road. Waterbars can be made out of rocks or logs. Armoring of fillslope at the outlet is often needed to prevent gullying.

Culvert Upgrade

Purpose: Culvert improvements increase the flow capacity which will prevent damage to roads.

Relative Effectiveness: Excellent-0% Good-80% Fair-0% Poor-20% (Replies = 5)

When sized properly and installed correctly, the results were rated "good." The "poor" rating was from culverts that were still not large enough and failed.

Environmental/Implementation Factors: Upgraded culverts need to be sized properly based on expected increased flows. They should be installed at the proper slope with appropriate approaches and exits. To be effective, upgraded culverts need to be installed before the first damaging rainfall. Flexible down spouts and culvert extensions often are needed to keep exiting water from highly erodible slopes.

Storm Patrol

Purpose: Patrol during storm events provides immediate assessment of flood risk, clear blocked culvert entrances, and drainage ditches and close access (gates) to areas that are at risk.

Relative Effectiveness: No interviewee rated this treatment.

Several interviewees indicated that storm patrol was a cost effective alternative to installing trash racks, or removing culverts.

Environmental/Implementation Factors: This treatment can include early warning systems such as radio-activated rain gauge or stream gauge alarms when flows are increasing. Storm patrols remove floating woody debris near culvert inlets and clean inlets after each storm event. Storm patrols can be activated during forecast events of weather which may trigger larger than normal water, sediment or woody debris flows.

Culvert Inlet/Outlet Armoring/Risers

Purpose: These treatments reduce scouring around the culvert entrance and exit. They allow heavy particles to settle out of sediment laden water and reduce the chance of debris plugging the culvert.

Relative Effectiveness: Not enough interviewees rated this treatment to make any statements about its effectiveness.

Environmental/Implementation Factors: Sometimes culvert risers can clog and may be difficult to clean.

Trash Racks

Purpose: Trash racks are installed to prevent debris from clogging culverts or down stream structures.

Relative Effectiveness: Not enough interviewees rated this treatment.

Comments included that in one watershed the third winter after the fire, a large storm detached considerable debris which blocked trash rack, causing complete culvert failure.

Environmental/Implementation Factors: These structures are generally built out of logs, but occasionally they are from milled lumber or metal. Sizes vary from small culverts to 30 ft (9 m) diameter. Several cage designs have been used with most of them allowing debris to ride up and to the side of the cage. Some cages have been set in concrete. Trash racks generally perform better in smaller drainages. They need to be cleared after each storm to be effective.

Culvert Removal

Purpose: This procedure removes undersized culverts which would probably fail due to increased flows, in a controlled fashion.

Relative Effectiveness: No interviewee rated this treatment.

Environmental/Implementation Factors: Removal needs to be completed before the first damaging storms. It is often done in conjunction with road obliteration.

Ditch Improvements: Cleaning/Armoring

Purpose: Cleaning and armoring provides adequate water flow capacity and prevents downcutting of ditches.

Relative Effectiveness: No interviewee rated this treatment.

Environmental/Implementation Factors: When maintenance does not occur, high water levels can overtop roadways leading to gully development in the road bed.

Armoring Ford Crossing

Purpose: Armored crossings provide low-cost access across stream channels that are generally capable of handling large flows.

Relative Effectiveness: No interviewee rated this treatment.

Environmental/Implementation Factors: Large riprap is placed upstream and downstream of actual road crossing area. Armoried crossings are often used for low traffic volume roads. Low water crossing were not used on one fire because they could attract an endangered toad species that would inhabit the crossing when wet and be killed by vehicle traffic.

Outsloping

Purpose: Outsloping prevents concentration of flow on road surfaces that produces rilling, gullying, and rutting.

Relative Effectiveness: Not enough interviewees rated this treatment.

One interviewee commented that this is one of the few treatments that has both immediate and long-term facility and resource benefits.

Environmental/Implementation Factors: Sometimes after regrading, compaction does not occur due to low traffic volume which may cause sheet and rill erosion. Both public and administrative traffic should be curtailed during wet road conditions to prevent rutting and road sub-grade damages.

Trail Work

Purpose: BAER treatments on trails are designed to provide adequate drainage and stability so trails remain functioning.

Relative Effectiveness: Not enough interviewees rated this treatment to make any statements about its effectiveness.

Environmental/Implementation Factors: Crew skill is important for this labor intensive treatment. Water bars need to be installed correctly, proper slope and depth, to be effective.

Other Treatments

Purpose: This category consists of various treatment solutions to specific problems. It includes wetting agents to reduce water repellency on high erosion hazard areas, gully plugs to prevent headcutting in meadows, flood signing installation to warn residents and visitors of flooding potential, and removal of loose rocks above roadways that were held in place by roots, forest debris, duff and were now in a precarious position due to the fire.

Relative Effectiveness: No interviewees rated these treatments.

Environmental/Implementation Factors: Treatment specific.

RMRS
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