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A synthesis of post-fire Burned Area Reports from 1972 to 2009 for western US Forest Service lands: trends in wildfire characteristics and post-fire stabilisation treatments and expenditures

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Abstract. Over 1200 post-fire assessment and treatment implementation reports from four decades (1970s–2000s) of western US forest fires have been examined to identify decadal patterns in fire characteristics and the justifications and expenditures for the post-fire treatments. The main trends found were: (1) the area burned by wildfire increased over time and the rate of increase accelerated after 1990; (2) the proportions of burned area assessed as low, moderate and high burn severity likely have remained fairly constant over time, but the use of satellite imagery that began *c*. 2000 increased the resolution of burn severity assessments leading to an apparent decreased proportion of high burn severity during the 2000s; (3) treatment justifications reflected regional concerns (e.g. soil productivity in areas of timber harvest) and generally reflected increased human encroachment in the wildland–urban interface; (4) modifications to roads were the most frequently recommended post-fire treatment type; (5) seeding was the most frequently used land treatment, but declined in use over time; (6) use of post-fire agricultural straw mulch has steadily increased because of proven success; and (7) the greatest post-fire expenditures have been for land treatments applied over large areas to protect important resources (e.g. municipal water sources).

Additional keywords: BAER, Burned Area Emergency Response, erosion control, post-fire assessment, rehabilitation, treatment expenditure, values-at-risk.

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Introduction

Wildfires have always been part of important natural processes that contribute to the ecology of the western US. In recent decades, substantial increases in wildfire activity have resulted in greater wildfire frequency, longer wildfire durations and seasons (Westerling *et al.* 2006), and greater area burned per fire (Stephens 2005), compared to historic fire regimes. There is a strong link between climate and area burned (Littell *et al.* 2009; Holz *et al.* 2012). Driven by recent global climate change and, in several ecosystems, high levels of fuel accumulation due to past wildfire suppression policy (Mouillot and Field 2005) and beetle-killed trees, the trend in western US forest fires is towards larger and more catastrophic events (Keane *et al.* 2002; Stephens 2005; Running 2006; Westerling *et al.* 2006; NIFC 2013). However, in the woody sagebrush scrublands that dominate large portions of the Great Plains and canyon lands of the western US, no overall upward trend in area burned has occurred (Baker 2013).

High-severity fires not only consume or deeply char all vegetation, but also affect the physical properties of soil. These changes alter watershed responses to rainfall, causing increased runoff, erosion and downstream sedimentation (DeBano *et al.* 1998; Neary *et al.* 2005; Úbeda and Outeiro 2009). The magnitude of these post-fire runoff and erosion responses is a function of soil burn severity, topography and the occurrence of hydrologic events. When a major, and particularly high-intensity, rainfall event follows a large, high burn severity fire, the runoff, peak flows, flooding and erosion are likely to be orders of magnitude greater than the pre-fire response to the same rain event (DeBano *et al.* 1998; Neary *et al.* 1999, 2005; Moody and Martin 2001). Mitigating the threats to public safety, property, infrastructure, cultural sites, natural resources and water quality from these secondary fire effects is an integral part of wildfire response in the western US (Robichaud and Ashmun 2013). Efforts to predict and mitigate the risks from secondary fire effects are catalogued in the US

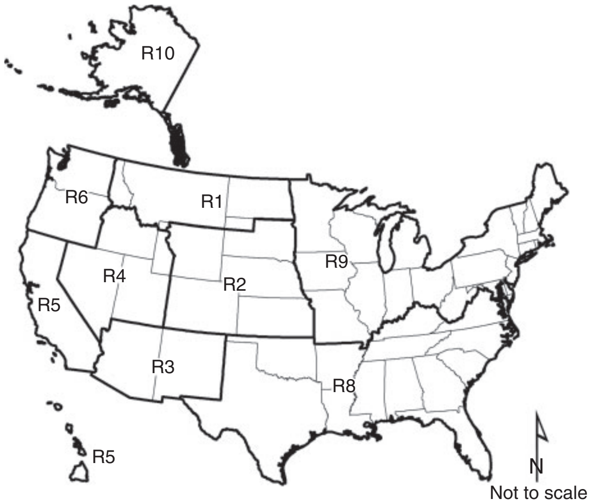

Fig. 1. USDA Forest Service administrative regions (modified from USDA Forest Service 2013).

Forest Service (USFS) Burned Area Reports that have been made over the past four decades.

The first Burned Area Reports on post-fire emergency watershed stabilisation and rehabilitation were prepared in the 1960s and early 1970s. The funds for these early post-fire watershed rehabilitation projects were obtained from fire suppression accounts, emergency flood control programmes or appropriated watershed restoration accounts. In 1974, a formal authority for post-fire rehabilitation activities, the Burned Area Emergency Rehabilitation (BAER) programme, was authorised to evaluate burn severity and treatment options, and established funding request procedures. In 1988–89, BAER policies and procedures were codified in the Forest Service Manual and the BAER Handbook, which standardised the assessments and reports filed within the programme.

The current Burned Area Emergency Response (BAER – same acronym with a new, more accurate word for the letter 'R') programme is an interagency effort involving four land management agencies within the US Department of Interior and US Department of Agriculture, Forest Service. The post-fire assessment protocols and Burned Area Reports examined in this study are specific to the USFS implementation of the BAER programme in the western US because the majority of the wildfires that have been evaluated through the BAER programme occurs on USFS land and of these, 1246 out of 1260 Burned Area Reports were from USFS Regions 1–6 (Fig. 1).

The BAER programme supports a limited range of post-fire activities: (1) identify post-wildfire threats to human life and safety, property and critical natural or cultural resources, and (2) take appropriate, immediate action to manage risks (FSM 2523.02, USDA Forest Service 2012). Assessments are conducted on burned areas following wildfires larger than 200 ha in size (FSM 2523.03, USDA Forest Service 2012), and are then summarised and reported using the Burned Area Report (US government form FS-2500–8). Burned area assessments are intended neither to provide a comprehensive evaluation of all fire and suppression damages nor to identify long-term rehabilitation and restoration needs (FSM 2523.1, USDA Forest Service 2012). Emergency stabilisation actions are normally temporary short-term measures that require little or no maintenance or that can be removed after objectives have been met (FSM 2523.2, USDA Forest Service 2012). BAER funds can be used only for emergency stabilisation for up to 1 year after fire containment, with the exception of monitoring treatment effectiveness, and maintaining, repairing or replacing emergency treatments where failure to do so would place significant risk on critical values, which can continue for up to 3 years following a fire (FSM 2523.03, USDA Forest Service 2012). This approach ensures that emergency stabilisation measures are effective and working as planned, but it precludes using the funding for longer-term rehabilitation.

Post-fire assessments and recommendations for actions and treatments are completed by *ad hoc* BAER teams that may include soil scientists, hydrologists, foresters, ecologists, engineers, archaeologists and other specialists as dictated by the location of the fire and values-at-risk. Once assembled, BAER teams: (1) assess fire-induced changes in the burned area; (2) estimate the risk for loss or damage posed by the post-fire conditions to the identified values-at-risk; (3) recommend cost-effective treatments to reduce the risk where possible and economically justified; and (4) implement selected treatments. BAER teams work under strict time constraints to accomplish the first three tasks within 2 weeks of fire containment, as public safety protection and burned area stabilisation measures need to be put into place as rapidly as possible. Their assessments, analyses, treatment recommendations and cost estimates are included in the Initial FS-2500–8 Burned Area Report (see sample Burned Area Report in the Supplementary material available online at http://www.publish.csiro.au/?act=view_file&file_id=WF13192_AC.pdf), which accompanies the request for funding of proposed treatments if needed. Because treatment implementation can take up to 1 year to complete, a BAER implementation team (separate from the BAER assessment team, although some members may be on both) oversees the treatment installation process. Inevitably, especially on large fires, the implementation process requires adjustments in terms of areas treated, contract costs and material substitutions. As changes affect costs, additional Interim FS-2500–8 Burned Area Reports may be filed. After 3 years, a Final FS-2500–8 Burned Area Report is filed, which contains the final costs, areas treated, implementation report and results of treatment effectiveness monitoring. The initial assessment information is included in all subsequent Burned Area Reports. Thus, the most complete post-fire assessment and treatment information is in the Final FS-2500–8 Burned Area Report, which is the Burned Area Report we used whenever possible for this study.

The Burned Area Report form includes fire characteristics, post-fire threats, values-at-risk, management objectives, treatment recommendations and cost estimates, analysis of expected treatment effectiveness, and a monitoring plan (FSM 2523.1, USDA Forest Service 2012). Although the Burned Area Report form has changed over the years, nearly all versions contain the fire name, location, dates of fire start and containment, size of the burned area and suppression cost. The affected watershed(s) is identified and described in terms of vegetation, soils, geology and stream channels. The post-fire conditions are generally described as the proportions of burned area designated as low, moderate and high burn severity and the estimated proportion of water-repellent soil (Parsons *et al.* 2010). Erosion hazard ratings based on a 2–5-year design storm and estimates of potential runoff, peak flows, erosion and sediment yields are made using various prediction models (Robichaud and Ashmun 2013). Values-at-risk for damage – specifically life, property, threatened and endangered species, water quality and soil productivity – are identified. The Burned Area Report describes the watershed emergency and justifies the need (or not) for immediate stabilisation treatments, as well as the estimated probabilities of their success. The report also provides treatment costs and an economic rationale for treatment implementation by estimating the costs of the potential losses that may occur if no action is taken (see sample Burned Area Report in the Supplementary material).

Burned Area Report information selected for analysis

The breadth of information contained in the Burned Area Reports, particularly in the forms used for the past 15 years, is extensive and not easily examined within a single study. We decided to focus on changes over time in fire size and burn severity, post-fire treatment selections and expenditures incurred in post-fire assessment and treatments.

Fire size and burn severity

The area within the fire perimeter generally has been reported as representing the fire size although this area is not burned throughout to the same degree. Instead, most wildfires leave a mosaic of unburned as well as low, moderate and high severity burned areas in various proportions and with variable levels of 'patchiness', or variation in spatial distribution within the fire's perimeter (Lentile *et al.* 2006).

In recent years, an attempt has been made to standardise severity definitions and classifications as they pertain to fire and its effects (Parsons *et al.* 2010). The term 'severity' is often used inconsistently, and fire severity and burn severity are regularly used interchangeably when describing wildfire effects on post-fire environments (Jain 2004; Lentile *et al.* 2006; French *et al.* 2008). Fire severity is defined as a measure of the immediate and direct effects of fire on the environment (Lentile *et al.* 2006; French *et al.* 2008); whereas burn severity is defined by the degree to which an ecosystem has changed owing to the fire (Morgan *et al.* 2001; Lentile *et al.* 2006; French *et al.* 2008). Although post-fire assessments and Burned Area Reports use the term 'burn severity' to describe the magnitude of ecological change caused by fire, newer resources, such as the 'Field Guide for Mapping Post-fire Soil Burn Severity' (Parsons *et al.* 2010), focus on the condition of the soil to classify burn severity. Burn severity is often assessed by comparing pre- and post-fire vegetative and soil characteristics using satellite imagery and ground measurements (Parsons *et al.* 2010). Near-infrared and mid-infrared bands from the Landsat satellite sensor are used to calculate the Normalised Burn Ratio (NBR) for pre- and post-fire satellite images and the differences in the pre- and post-fire NBR values to determine the dNBR of each pixel in the image (Orlemann *et al.* 2002). The dNBR values are categorised into unburned, low, moderate and high burn severity and shown on a Burned Area Reflection Classification (BARC) map (Clark and Bobbe 2006). Ground assessments include post-fire vegetative characteristics, such as aboveground vegetation consumption, mortality and scorch, together with an estimate of potential recovery (Morgan *et al.* 2001), and soil characteristics, based on char depth, ash colour, bare soil exposed, organic matter and fine root loss, altered soil structure, reduced infiltration and soil water repellency (Ryan and Noste 1985; DeBano *et al.* 1998; Neary *et al.* 1999, 2005; Parsons *et al.* 2010). Given that the soil components of burn severity affect post-fire runoff, erosion and sedimentation potential more than the vegetative components, the BAER teams focus more specifically on assessing *soil* burn severity (Robichaud and Ashmun 2013).

Post-fire treatment justifications and selections

Treatments are categorised into four groups: (1) protection of public safety, (2) land, (3) channel and (4) road and trail (Napper 2006). All treatments aim to mitigate adverse effects from the burned area on values-at-risk, such as life, property, and critical natural and cultural resources. Public safety treatments, such road closures, flood warning systems and signage are used to protect the public from hazards such as flooding, dangerous trees, falling rocks and landslides. Land treatments stabilise burned soils by providing ground cover, reducing erosion and trapping sediment, and may also be implemented to minimise an influx of invasive plants. Channel treatments reduce channel down-cutting, slow water velocity, trap sediment and help maintain channel characteristics. Road and trail treatments improve the drainage capacity to handle potential increased flows and debris from burned areas.

Not all treatments are equally effective and their effectiveness can vary by region. In the 2000s, many treatment effectiveness studies were carried out (e.g. Beyers 2004; Raftoyannis and Spanos 2005; Robichaud *et al.* 2006; Wagenbrenner *et al.* 2006; Yanosek *et al.* 2006; deWolfe *et al.* 2008; Robichaud *et al.* 2008; Dodson and Peterson 2009; Foltz and Copeland 2009; Foltz *et al.* 2009; Robichaud *et al.* 2010; Stella *et al.* 2010; Prats *et al.* 2012; Robichaud *et al.* 2013*a*, 2013*b*). The findings from these and other studies support the development of new post-fire treatment products and application techniques, which in turn are evaluated for their effectiveness (Table 1) (Napper 2006).

Post-fire assessment and treatment costs

Although it is known that expenditures within the BAER programme have increased over time, there has been little analysis of the driving factors. Given the much larger costs of fire suppression compared to post-fire response costs it is not surprising that fire suppression expenditures, which have steadily increased since the mid-1980s, are much better understood (Calkin *et al.* 2005; Prestemon *et al.* 2008; Abt *et al.* 2009). The increase in suppression costs is mostly due to the increase in area burned, not the increase in suppression cost per unit area (Calkin *et al.* 2005; Liang *et al.* 2008). In addition, a small number of large fires are generally responsible for most of the area burned (Cramer 1959; Minnich and Chou 1997; Heyerdahl *et al.* 2001; Rollins *et al.* 2001) and consequently the amount of money spent on suppression. Although there is an expectation that post-fire response expenditures are increasing for the same reasons as the suppression costs, this has not been well studied.

Robichaud *et al.* (2000) compiled a database (BAERDAT) of Burned Area Reports from 470 fires (321 had post-fire treatments) that occurred in 1973–98 in the western US (USFS

Table 1. Frequently used post-fire treatments by category
Robichaud *et al.* (2000); Napper (2006); Foltz and Copeland (2009); Robichaud *et al.* (2010)

Category	Treatment	Description
Road	Armouring	Covering road, hillslope surface or ditch with aggregates and rocks to protect the surface
	Culvert modifications	Upsizing existing culverts; armouring inlet and outlet areas; attaching metal end sections
	Culvert removal	Removing cross-drain culverts that are too small (≤60 cm (24 inch)) for expected increased flows
	Culvert risers	Vertical extension of upstream culvert to sieve debris and to allow passage of water
	Debris racks or deflectors	Barrier (trash rack) across stream channel to hold debris and keep culverts open
	Low-water stream crossing	Temporary fords and low-water overflows when culverts cannot handle increased flows
	Out-sloping	Shaping a road surface to divert water off the surface to the road fill
	Overflow structures	Structures to control runoff across the road surface and to protect the road fill
	Road closure	Closing roads with gates, jersey barriers, barricades, signs and closure enforcement
	Rolling dips or water bars	Road grade reversal to direct surface flow across the road
	Storm patrol	Checking and cleaning drainage structure inlets between or during rain events
Land	Contour-felled logs (LEB)	Burned tree trunks installed on slope contour to trap sediment
	Silt fences	Geotextile fabric installed to form an upright fence to trap sediment
	Mulching	Materials spread over burned soil using aerial or ground application technologies
	Agricultural straw mulch	Wheat, barley and rice straw are most frequently used for post-fire mulching
	Hydromulch	Fibrous material (wood, paper, etc.), tackifiers and optional materials mixed with water into slurry for application; hydromulch adheres to the soil surface after it dries
	Wood shreds	Green or burned trees shredded by a horizontal grinder to produce a coarse mulch
	Wood strands (WoodStraw[A])	Narrow slats of wood of various lengths manufactured from scrap veneers
	Seeding (and fertilising)	Plant seeds spread over burned area; usually applied aerially; occasionally with added fertiliser
	Slash spreading	Trees and brush scattered over burned area
	Soil scarification or drilling	Tilling burned soils with a rake or disc to break up water-repellent soil layer
Channel	Channel-debris clearing	Removal of woody debris from channels
	Channel deflectors	Structures that direct stream flow away from unstable banks or high values-at-risk
	Check dams	Small structures placed perpendicular to the flow that store sediment on the upstream side; made of logs, straw bales, rocks, etc.
	Debris basins	Constructed basin to trap and hold sediment and debris
	Grade stabilisers	Structures installed at channel grade to decrease incision; made of rocks, logs and wood
	In-channel tree felling	Felled trees placed at a diagonal angle along channel reaches to slow flow and trap sediment
	Stream bank armouring	Rock reinforcement of the stream bank

[A]In this study, the wood strand material (WoodStraw) was produced by Forest Concepts, Inc., Auburn, WA.

Regions 1–6; Fig. 1). They found that USFS BAER programme expenditure increased by US$48 million (in 1998 dollars) from 1991 to 1998 primarily due to several large fires, whereas in the early 1980s annual expenditures were less than $2 million. Peppin *et al.* (2011) reviewed 380 Burned Area Reports from fires in the western US occurring between 1970 and 2007, primarily to analyse post-fire seeding trends. They found that 2000 to 2007 expenditures for post-fire seeding increased by 192% compared to the average spent during the previous 30 years. Although the percentage of burned area seeded decreased from 21% in the 1970s to only 4% during 2000–07, the cost per unit area seeded increased greatly due to the high costs of flight time for aerial seeding and specialised seed.

The objectives of this study were to review all available USFS Burned Area Reports from wildfires in the western US to determine trends in fire size, burn severity, treatment justification, types of treatments used, and expenditures on post-fire assessment and treatments. By examining post-wildfire trends we show how changes in the post-fire assessment process influenced treatment decisions and expenditure.

Methods

The existing BAERDAT (created in Microsoft Access) database used in Robichaud *et al.* (2000) was updated with the USFS Burned Area Reports database from 1999 to 2009. The resulting BAER Burned Area Reports contained a total of 1246 Burned Area Reports that were filed during 1972–2009 (http://forest.moscowfsl.wsu.edu/BAERTOOLS/baer-db, accessed 28 August 2013). We used accomplishment (after treatments were implemented) or final (when project is completed) Burned Area Reports whenever possible, to ensure that the treatments actually implemented were analysed. If no accomplishment or final Burned Area Report was available for a fire, an initial or interim Burned Area Report was used.

The elements of the Burned Area Reports that were analysed included: (1) total area burned and the proportional area of each burn severity class (low, moderate and high); (2) the identified values-at-risk (life, property, threatened and endangered species, water quality and soil productivity) and the economic justification of the post-fire treatments; (3) expenditure by three treatment (land, channel and road) and other (assessment, administrative and monitoring) categories; (4) expenditure by specific land treatment (contour-felled logs, agricultural straw mulch, hydromulch, wood strand mulch and seeding); and (5) a separate analysis of the 10 fires with the greatest expenditures for post-fire assessment and treatment. We included all Burned Area Reports, regardless of any treatment recommendations, for burned area, burn severity and economic justification analyses (points 1 and 2 above). Only the Burned Area Reports with actual treatment expenditures were analysed for post-fire expenditures, individual land treatments and most expensive fires (points 3, 4, and 5 above). To compare expenditures over time, all costs were converted to 2009 US dollars using the Consumer Price Index (Federal Reserve Bank of Minneapolis, see www.minneapolisfed.org, accessed 17 April 2014).

Burned area and burn severity

The reported fire areas were summed annually. The proportions of the areas burned according to each of the three burn severity classifications compared to the total area burned were calculated to determine the percentage of burned area in each burn severity class (low, moderate and high) for each fire. The decadal mean percentages of area burned in each burn severity classification were calculated and analysed for changes over time. The BAER protocol for determining soil burn severity changed in 2000 when quantitative analysis of satellite imagery replaced aerial observations. Satellite imagery data used in the Monitoring Trends in Burn Severity (MTBS) project (Eidenshink *et al.* 2007; MTBS Project, www.mtbs.gov/dataaccess.html, accessed 28 August 2013) were also compared to the values derived from the Burned Area Reports.

Justification of post-fire treatment needs

Post-fire treatments are justified by comparing the cost of no action given a damaging storm event (i.e. the economic value of damage or loss to the identified values-at-risk) *v.* the cost of the proposed treatment and expected reduction of damage or loss if a damaging storm event occurs. The percentage of Burned Area Reports that cited each of the five value-at-risk categories (life, property, threatened and endangered species, water quality and soil productivity) was compared by decade. The total post-fire expenditure was compared to the projected economic loss if no action was taken and these data were compared by decade to discern changes over time; however, this comparison was limited to approximately half (602 of the 1246) of the Burned Area Reports used in the study because only those reports that included monetary values for both the values-at-risk and treatment expenditures could be included.

Post-fire treatment expenditure by category

BAER programme treatment expenditures were categorised into road, land or channel treatments (Table 1), or other (assessment, monitoring and administration). Treatment category frequency (the percentage of all the Burned Area Reports that prescribed treatment(s) of each category), total treatment category expenditures, and treatment category expenditure per fire and per unit area were calculated. Mean treatment category values were calculated by decade for land, channel and road categories and analysed for changes over time.

Individual land treatment expenditures

When the Burned Area Reports from the 1970s–1998 were analysed, Robichaud *et al.* (2000) found that over two-thirds of the treatment expenditures were for land treatments, with the greatest expenditures being made for contour-felled logs, agricultural straw mulch and seeding treatments. Since 2000, new

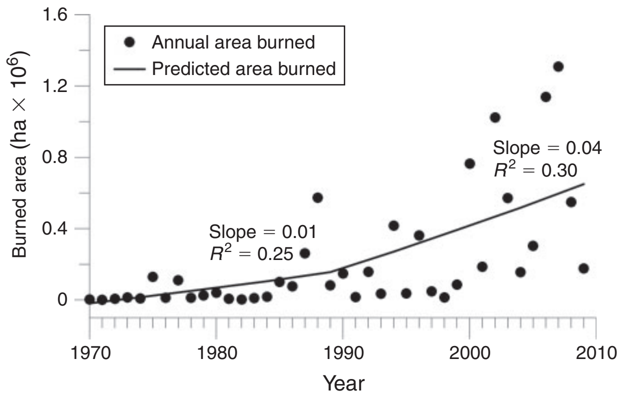

Fig. 2. Total burned area by year from 1970 to 2009 as reported in Burned Area Reports. Note the predicted (loess fit) line for the 1970–89 data has a slope of 0.01 and the predicted (loess fit) line for 1990–2009 data has a four-times-greater slope of 0.04.

land treatments have been introduced, such as hydromulch and wood strand mulch, and changes in techniques for producing and applying treatments, such as aerial application of mulches, have influenced the use and expense of land treatments. For this study, contour-felled logs (also called log erosion barriers, or LEBs), agricultural straw mulch, hydromulch, wood strand mulch and seeding (occasionally combined with fertiliser) were selected for investigation. Frequency of use, total expenditure, and expenditure per individual fire and per unit area were calculated for each of the individual treatments. Individual treatment costs per year and per unit area were calculated and decadal means were compared to determine changes over time.

Most expensive fires for treatment expenditure

The 10 fires on USFS lands with the highest BAER programme costs were analysed separately to determine the influence of these large fires on the overall BAER programme. The area burned, total BAER expenditure and proportion of the total annual BAER expenditure that was encompassed by the individual fire's BAER expenditure were compared from these 10 fires. Pearson correlation coefficients were calculated between the area burned and expenditure for the top 10 most expensive fires (SAS 2003).

Statistical analyses

Annual area burned was plotted using a loess fit (locally-weighted quadratic least-squares regression) to estimate the trend in annual burned area. In addition, the data were frequently divided into decadal groupings to compare changes over time. Differences among decadal mean values were compared using the least-squares means. A Tukey adjustment was used to compare multiple least-squares means at a significance level of $\alpha = 0.05$ (SAS 2003).

Results and discussion

Burned area and severity

The annual total area burned by wildfire has increased over time, with the rate of increase from 1990 to 2009 being nearly three times greater than from 1970 to 1989 (Fig. 2). Similar wildfire trends have been reported by other researchers working with

Table 2. Proportions of land classified as unburned, low, moderate and high burn severity within fire perimeters in the western US by decade

Data from the Monitoring Trends in Burn Severity (MTBS) project were used to calculate the proportions for all fires on western US lands and for fires on western US Forest Service lands (www.mtbs.gov, accessed 28 August 2013). Unburned area within the fire perimeter was not reported in the Burned Area Reports and was generally included as low burn severity

Decade	Unburned (%)	Low (%)	Moderate (%)	High (%)
Based on MTBS summary data for all fires[A] on western US lands				
1984–89	24	40	22	14
1990–99	20	45	24	11
2000–09	20	39	26	15
Based on MTBS summary data for fires[A] on western US Forest Service lands				
1984–89	27	29	22	22
1990–99	25	39	22	14
2000–09	18	39	27	16
Based on the Burned Area Reports from western US Forest Service fires assessed by BAER teams[B]				
1980–89		35[A]	33[A]	32[A]
1990–99		41[A]	30[A]	29[A]
2000–09[C]		51[A]	33[A]	16[A]

[A]All fires ≥405 ha (1000 acres) included.
[B]Decadal mean values for the Burned Area Reports within a column (within a burn severity class) followed by the same superscript letter are not significantly different based on Tukey comparisons ($P < 0.05$).
[C]Burn severity assessment methodology changed *c*. 2000 when BAER teams began to use burn severity maps derived from pre- and post-fire satellite data as the starting point for burn severity assessments.

other data sources and time divisions. For example, Stephens (2005) reported an increase in area burned from 1940 to 2000 and Westerling *et al.* (2006) reported that the annual area burned during 1987–2003 was more than six and a half times the average for 1970–1986.

The proportion of burned area in each burn severity class, as reported in the Burned Area Reports, was similar in the 1980s and 1990s (Table 2). However, when comparing the change from the 1990s to the 2000s, the proportion of low burn severity significantly increased from 41 to 51% and the proportion of high burn severity significantly decreased from 29 to 16%, whereas the proportion of moderate burn severity was virtually unchanged (Table 2). Until the last decade, BAER assessment teams mostly relied on low-level aerial survey (helicopter) to map general areas of concern followed by some ground survey and observation when possible. In addition, there was no consistent definition of 'severity' or standardised methods for determining the burn severity (Lentile *et al.* 2006). Since 2000, the BAER programme has refined the process used to classify burn severity within the perimeter of a wildfire to take advantage of the BARC maps produced from satellite imagery (Orlemann *et al.* 2002). BAER teams use field observations and measurements to make needed adjustments in the classification parameters used to produce the BARC map so that the final burn severity map more closely reflects the 'soil burn severity' (Parsons *et al.* 2010). The change in methodology from broad visual assessments to quantitative analysis of remotely sensed data made it incongruous to compare the pre- and post-2000 proportions of burned area in each burn severity class reported in the Burned Area Reports.

Recently, the MTBS Project – a joint venture of between the Earth Resources Observation Systems (EROS) Data Center (USDI Geological Survey) and the Remote Sensing Applications Center (RSAC) (USDA Forest Service) – has used archived satellite data to map the burn severity within fires across all lands of the US since 1984 (Eidenshink *et al.* 2007; www.mtbs.gov/dataaccess.html). Given that the same methodology for classifying burn severity was applied to all these data, changes over time can be quantitatively assessed. Using the MTBS data, the proportion of burned area classified as unburned, low, moderate or high burn severity were determined for each decade available (1984–89, 1990–99, and 2000–09) for all fires greater than 405 ha (1000 acres) in the western region of the US and specifically for fires that burned western US Forest Service lands (Table 2). A data summary provided by the MTBS Project reported that (a) there was no consistent trend towards more high severity across all fires and (b) that large fires (>20 230 ha [50 000 acres]) had slightly higher proportions of high burn severity in the last decade (MTBS Project 2009). Given the consistent methodology applied to create the MTBS data, the changes in the proportions of low and high burn severity after wildfires in the last decade were more accurately assessed by the MTBS data than by the Burned Area Reports.

The proportions of burned area in each of the burn severity classifications reported in the Burned Area Reports after 2000 were not directly comparable to MTBS data for the same period despite being generated by a similar analysis of pre- and post-fire satellite data. The satellite images used to generate the MTBS data were taken at different times relative to the fire (pre-fire high growth period and the first post-fire high growth period – generally ~1 year after the fire) than those used to create the BARC maps for the BAER teams (pre-fire high growth compared to immediate post-fire). In addition, the MTBS database, even when filtered for USFS lands only, includes more fires than those assessed by USFS BAER teams. BAER teams are not called in to assess small fires, prescribed

Table 3. The proportion of Burned Area Reports that selected each of the five values-at-risk categories as justification for post-fire treatment expenditures by decade or by region

Burned Area Reports often place values-at-risk in more than one justification category, such that the sum of the percentages may exceed 100%. Regional values are for the four decades combined. Values in bold highlight those individual values that are greater than the mean of the six regional values. T and E species, Threatened and Endangered species

	Values-at-risk category				
	Life (%)	Property (%)	T and E species (%)	Water quality (%)	Soil productivity (%)
Decade					
1970s	3	41	1	39	24
1980s	2	36	6	40	31
1990s	16	45	19	44	42
2000s	42	61	25	40	63
Region					
1	48	**28**	39	**61**	24
2	43	4	35	55	17
3	42	11	25	40	23
4	**58**	**29**	36	**63**	**36**
5	**59**	16	**45**	45	**32**
6	**56**	**26**	**59**	**64**	**31**
Mean	51	19	40	55	27

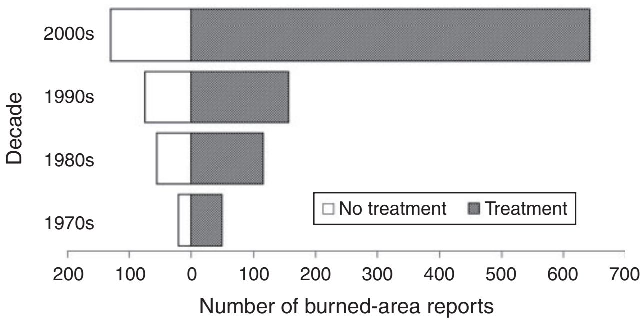

Fig. 3. The number of Burned Area Reports recommending no post-fire treatment (no shading, left-facing bar) and treatments (shading, right-facing bar) in each of the four decades of this study.

burns or fires that pose little risk of damage from post-fire responses, but these fires were included in the MTBS data. Consequently, greater proportions of unburned and low burn severity were, as expected, reported in the MTBS Project data as compared to the Burned Area Reports. In the 2000s, the MTBS data showed that the combined proportion of unburned and low burn severity was 59% on all western fires and 57% on USFS fires, both of which were slightly more than the 51% low burn severity from the Burned Area Reports. However, the proportion of high burn severity was the same (16%) for the MTBS data for USFS lands and the Burned Area Reports (Table 2), which reflects the fact that BAER teams assessed nearly all the fires that included areas burned at high severity.

Justification of post-fire treatment expenditure

Of the five value-at-risk categories (life, property, threatened and endangered species, water quality and soil productivity), property, water quality and soil productivity were consistently cited as justification for treatment expenditures during the four decades of the study (Table 3). Although both property and soil productivity were cited more often in the last decade, water quality has been consistently named as a value-at-risk in ~40% of the Burned Area Reports in all decades. Comparing the 2000s to the previous three decades, more wildfires occurred in or near the wildland–urban interface (WUI) (Calkin *et al.* 2005; Prestemon *et al.* 2008) and there was a four-fold increase in the number of fires receiving treatments (from 157 to 642) whereas the number of fires with no-treatment recommendations only increased by ~50% (from 75 to 130) (Fig. 3). Although protection of property and soil productivity were the primary justifications for treatment expenditures in the 2000s, protection of life (public safety) increased 24%, rising from 16% in the 1990s to 42% in the 2000s (Table 3).

Threatened and endangered species was least frequently cited as a value-at-risk to justify post-fire treatments, but this varied significantly among USFS Regions. USFS Region 6 (Oregon and Washington) justified post-fire treatments for protection of threatened and endangered species in 59% of their reports – the highest of any region – and USFS Region 5 (California) was second with 45% (Table 3). Several species of salmonid fish are listed as threatened or endangered in the Pacific salmon habitats of the western US (excluding Alaska), which are mostly located in Oregon, Washington and northern California (Augerot and Foley 2005). Protection of bull trout (*Salvelinus confluentus*), a threatened salmonid species mostly found in Idaho, Montana, Nevada, Oregon and Washington, influenced post-fire treatment justifications in USFS Regions 1,4 and 6, which encompass most of their habitat (USDOI Fish and Wildlife Service 2013). Bull trout have exacting habitat demands, such as cold water temperatures and very low amounts of silt, both of which can be affected by wildfire. Protection of bull trout habitat likely contributed to the frequent selection of water quality as a treatment justification in the three regions (Table 3).

As part of the economic justification for post-fire treatments, their costs were compared to the expected monetary loss if no action was taken. Most (98%) of the Burned Area Reports showed the monetary value of the potential loss or damage to values-at-risk was more than 15 times greater than the total treatment expenditures ($y = 15.5x$, $R^2 = 0.48$) (Fig. 4). Some values-at-risk, such as life and public safety, were too important to be subjected to economic justification. Other non-market values-at-risk, such as water quality, habitat for threatened and endangered species, and culturally significant areas, were not easily assigned a value in economic terms. Generally, members of the assessment team, sometimes with the help of an economist, used their collective professional judgment to assign a monetary value to a non-market value-at-risk for comparison in the treatment cost evaluation.

Of the nearly 600 Burned Area Reports that contained monetary value of both the values-at-risk and the treatments implemented to protect them, 15 had treatment costs that exceeded (by 6–500% or US$5000–$3.5 million) the cost reported for the value-at-risk (Fig. 4); ten of the 15 Burned Area

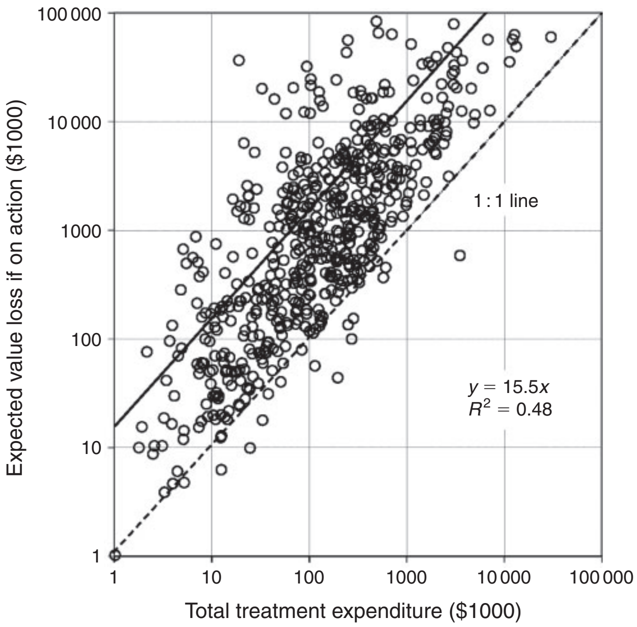

Fig. 4. The costs of post-fire treatments were compared to those of the potential damage or loss to the identified values-at-risk if no action (no treatment) was taken. The dashed 1 : 1 line indicates equal cost of treatment and loss of values-at-risk. The solid regression line indicates that values-at-risk amounted to 15 times the cost of treatments. In only 15 (2%) of the Burned Area Reports were recommended treatments more expensive than the assessed value of the values-at-risk (data point below the 1 : 1 line). All monetary values are converted to 2009 US dollars. Logarithmic scale is used for both axes.

Reports were for fires that occurred in the 2000s. Given that approval of any post-fire treatment implementation plan is based on the justification, values-at-risk, expected value loss and estimated treatment expenditure, the justifications for these treatments had to carry more weight than the economics alone for the treatment projects to be approved. Common elements among these 15 reports were: (1) high costs of monitoring (mostly for noxious weeds); (2) high assessment and administration costs because of high public interest; and (3) difficulty in applying monetary values for risk factors. Recently, there have been efforts to develop guidelines to systematically formulate an implied minimum value of non-market values-at-risk in the post-fire environment (Calkin *et al.* 2007, 2008); however, these economic tools were unavailable during the years considered in this study.

Post-fire treatment expenditure

Frequency of implementing post-fire treatments increased during the study period and 91% of the Burned Area Reports had some post-fire treatment expenditure in the 2000s – up from 65 to 70% of the reports in the three prior decades. Total post-fire treatment expenditure followed the same trends and increased dramatically from one decade to the next with the largest decadal increase occurring in the 2000s (Table 4). Total expenditure per fire followed a slightly different trend: BAER spending per fire was approximately the same in the 1970s and 1980s, increased by ~50% from the 1980s to the 1990s (US$296 000–$433 000 per fire), and remained approximately the same in the 2000s (Table 4). Given that the number and treated area of fires tended to increase over time and that post-fire expenditure per fire stayed nearly the same during the 1990s and 2000s, it is not surprising that the post-fire expenditure per unit area decreased in the same interval (Table 4). This was likely due to a combination of more standardised assessment procedures, more rigorous education of post-fire assessment teams and the restricted budgets of the last decade. The particularly high expenditure per unit area in the 1970s (Table 4) resulted from the uncharacteristically intense treatment of 4000 ha for two 1976 fires – Crum Canyon (Okanogan–Wenatchee NF, Washington) and Skinner Mill (Shasta–Trinity NF, California) – which was motivated by severe post-fire flooding in nearby areas having occurred a few years earlier.

BAER assessment

It is difficult to determine the BAER assessment expenditures (i.e. BAER team costs) in the 1970s and 1980s as they were not reported separately from other categories. Starting in the 1990s, more than 70% of the Burned Area Reports included 7–10% of the post-fire expenditure to pay for the work and support of the BAER team (Table 4). Average expenditure of BAER assessment per fire peaked in the 1990s (US$57 000 per fire), but as budgets were reigned in during the past decade the cost per fire dropped to ~$37 000 per fire even though the total BAER costs tripled (Table 4). In the 2000s, it is likely that per fire BAER team expenditures were reduced by the use of satellite imagery for post-fire burn severity mapping, which decreased the amount of helicopter flight time and BAER team member time committed to burn severity mapping. Increased training and experience of many BAER team members has also increased the efficiency and expertise of BAER team members.

Public safety

Although protection of life and safety has always been the highest priority for BAER teams, treatments aimed at public safety never exceeded 5% of the decadal BAER expenditures. The proportion of Burned Area Reports that included public safety recommendations rose from 17% in the 1990s to 45% in the 2000s (Table 4), which coincides with the rapid expansion of the WUI in the western US. Public safety treatments often include mechanisms to restrict public access to areas that pose danger, provision for adequate warning of impending floods, and removal of hazardous trees from areas around trails, roads and recreation areas. Despite the importance of this category of treatments, the costs of implementing road closures, installing fences, gates and flood warning systems, and removing hazardous trees have been significantly less than for other treatments. Arguably, treatments that reduced flooding and erosion also contributed to public safety; however, this category was mostly applied to those treatments designed to reduce public exposure to hazards in the post-fire environment.

Land treatments

During all four decades covered by this study, land treatments were applied most often and accounted for the largest proportion of post-fire treatment expenditures (57–72%).

Table 4. The proportion of Burned Area Reports, expenditure, percent of total expenditure and mean expenditure by fire disaggregated by treatment category and decade

All expenditures reported in 2009 US dollars. Among treatment categories not all treatment categories were used in the Burned Area Reports before 2000; this is indicated by n.a. (i.e. not available)

Treatment category		Decade			
		1970s	1980s	1990s	2000s
Total	Proportion[A] (%)	66	65	71	91
	Total expenditure ($)	11 100 000	32 900 000	71 000 000	310 800 000
	Expenditure per fire ($)	242 000	296 000	433 000	444 000
	Expenditure per unit area ($ ha^{-1})	73	46	88	72
BAER assessment	Proportion of reports[B] (%)	n.a.	n.a.	74	84
	Category expenditure ($)	n.a.	n.a.	6 900 000	21 700 000
	Portion of total expenditure (%)	n.a.	n.a.	10	7
	Category expenditure per fire ($)	n.a.	n.a.	57 000	37 000
Public safety	Proportion of reports (%)	n.a.	n.a.	17	45
	Category expenditure ($)	n.a.	n.a.	700 000	16 100 000
	Portion of total expenditure (%)	n.a.	n.a.	1	5
	Category expenditure per fire ($)	n.a.	n.a.	24 000	52 000
Land	Proportion of reports (%)	98	91	82	73
	Category expenditure ($)	6 300 000	23 800 000	48 000 000	188 300 000
	Portion of total expenditure (%)	57	72	68	61
	Category expenditure per fire ($)	140 000	235 000	356 000	371 000
Road	Proportion of reports (%)	33	58	55	64
	Category expenditure ($)	2 700 000	6 100 000	9 000 000	69 200 000
	Portion of total expenditure (%)	24	19	13	22
	Category expenditure per fire ($)	179 000	95 000	100 000	155 000
Channel	Proportion of reports (%)	37	49	51	24
	Category expenditure ($)	2 100 000	2 600 000	6 300 000	7 800 000
	Portion of total expenditure (%)	19	8	9	3
	Category expenditure per fire ($)	122 000	48 000	76 000	46 000
Monitoring (implementation)	Proportion of reports (%)	n.a.	n.a.	n.a.	68
	Category expenditure ($)	n.a.	n.a.	n.a.	7 700 000
	Portion of total expenditure (%)	n.a.	n.a.	n.a.	2
	Category expenditure per fire ($)	n.a.	n.a.	n.a.	16 000

[A]Percentage of Burned Area Reports that included treatment expenditures.
[B]Percentage of Burned Area Reports that included this particular treatment category.

However, the proportion of Burned Area Reports that included land treatments decreased in each successive decade (98–73%), whereas total post-fire land treatment expenditures and mean expenditure per fire increased each decade (Table 4). These trends reflect the transition in terms of treatment from broadcast seeding, a relatively inexpensive land treatment and virtually the only land treatment used in the 1970s, to the use of both seeding and contour-felled log erosion barriers (higher cost due to labour-intensive installation) throughout the 1980s and 1990s, and the increasing use of more expensive aerially applied mulches in the past decade.

Road treatments

Road treatments were second in terms of treatment expenditure after land treatments, and unlike the latter, the proportion of Burned Area Reports that included recommendations for road treatments generally increased between the 1970s (33%) and the 2000s (64%). Total road treatment expenditures also increased between the 1970s (US$2.7 million) and the 2000s ($69.2 million) (Table 4). However, the proportion of decadal post-fire expenditure (24% in the 1970s and 22% in the 2000s) did not follow the same trend. Expenditures on road treatments increased from $9 million in the 1990s to $69 million in the 2000s; yet road treatment expenditures per fire only increased by ~50% over the same two decades (Table 4). This suggests that the increasing number and extent of wildfires of the past decade drove the increased spending on post-fire road treatments. The post-fire treatments implemented on the 2006 Tripod Complex Fires (Washington) cost over $30 million, the most spent on any one fire in this study; over $6.9 million (23%) of those expenditures were for road treatments.

Forest roads were generally unaffected by wildfire, but the increased runoff and peak flows that often occur after a fire led to damaged road water passage structures, such as culverts, and the road structure itself. Thus, the purpose of most post-fire road treatments was to improve the road drainage capacity to handle increased flows and debris from burned areas (Foltz *et al.* 2009). Given that road treatment costs and the potential losses to the values-at-risk (the roads) were based on well-known road construction costs, it was fairly straightforward to propose, justify and approve road treatment recommendations.

Channel treatments

Channel treatments were recommended in almost half of the Burned Area Reports in the 1980s and 1990s, but less than 10% of the post-fire expenditures were used for channel treatments (Table 4). In the 2000s, only a quarter of the Burned Area Reports recommended channel treatments and just 3% of the expenditures were used for them (Table 4). Expenditures per fire for channel treatments decreased from the 1990s to the 2000s (from US$76 000 to $46 000 per fire), yet the large increase in the number of fires resulted in increased channel treatment expenditures (from $6.3 to $7.8 million) during the same period.

The limited research on the effectiveness of emergency treatments to stabilise channels has been inconclusive (Robichaud *et al.* 2000). Check dams made of straw bales or log structures were found to be less costly and relatively easy to install, but were prone to failure and quickly filled with sediment, negating their effectiveness (Goldman *et al.* 1986; Collins and Johnston 1995; Storrar 2013). Larger, sturdier structures such as rock dams and gabions were generally more effective long-lived stabilisers, but were more costly and difficult to install (Heede 1970, 1981; Chiun-Ming 1985). In the past decade, as land treatments evolved to include aerial mulching, BAER teams often decided to treat hillslopes rather than channels. They reasoned that keeping the sediment on the hillslopes and out of the channels would be more successful and cost effective than installing channel treatments. As a result, there were more land treatments and fewer channel treatments in the 2000s.

Monitoring

Monitoring was not separately budgeted for until the last decade when more than two-thirds of Burned Area Reports included monitoring expenditures that totalled US$7.7 million (Table 4). Application of treatments, particularly land and road treatments, often involved multiple contractors and contracts with complex and geographically diverse specifications. Costs were incurred in administering these contracts and inspecting the materials used and the treated areas for contract compliance. The time needed for the processes of contracting, treating and verifying compliance extended beyond the tenure of the BAER assessment team and required personnel to be hired for these tasks. In addition, treatments were monitored for up to 3 years after the fire to ensure that they were maintained and performed as expected. Prior to 2000, post-fire treatment performance and effectiveness reports often consisted of images and qualitative descriptions of the treatment and treatment effectiveness (e.g. good ground cover, little rilling observed) (Robichaud *et al.* 2000). Given that quantitative evaluation of treatment effectiveness required measurement of rainfall characteristics and responses (e.g. amount of sediment per unit area) over several years, BAER teams often collaborated with research personnel to determine treatment effectiveness.

Individual land treatment expenditure

Seeding

Seeding was the most frequently used land treatment in each decade of the study. In the 1970s and 1980s more than 75% of all fires that received any treatment were seeded (Table 5). The proportion of fires treated with seeding fell to 68% in the 1990s and then decreased to 30% in the 2000s (Table 5). In the late 1990s, researchers and land managers began questioning the effectiveness of seeding for hillslope stabilisation, especially in the first post-fire year, when erosion and flooding are usually greatest. Several studies found that seeding reduced year 1 post-fire erosion for less than 25% of the rain events, but when favourable rainfall allowed the seeds to germinate and grow, seeding could effectively reduce erosion for 1 to 2 years (Dean 2001; Robichaud *et al.* 2006; Wagenbrenner *et al.* 2006; Groen and Woods 2008; Dodson and Peterson 2009; Peppin *et al.* 2011). Because of this research and the availability of stabilisation treatments that were more likely to be successful, seeding was recommended by BAER teams less often in the 2000s compared to earlier decades (Table 5). Despite being more selectively used, seeding remained the most implemented post-fire land treatment over the entire study period. Seeding's long history of use, relatively low cost and perceived success in reducing erosion from burned hillslopes made it an easy choice for remote hillslopes that qualified for post-fire treatment, especially in the early part of the decade when aerial application of mulches was not well proven.

Expenditures for seeding increased through the 1980s, decreased slightly in the 1990s and increased again in the 2000s. The large expenditures in the 1980s were due to the abnormally high cost of aerial seeding after two 1988 fires; US$2.3 million was spent to treat 9300 ha after the Clover Mist Fire in Wyoming and $1.1 million was spent to treat 8100 ha after the Brewer Fire in Montana. In the 2000s, seeding was prescribed for less than a third of the treated fires, yet total expenditures for seeding nearly doubled from the 1990s (Table 5). This increased expenditure for seeding treatments reflected the combined effects of the four-fold increase in the number of fires receiving post-fire treatments (Fig. 3) and a doubling of the cost of post-fire seeding per unit area in the 2000s compared to the 1990s (Table 5). This increase in cost per unit area was due to the high costs of flight time for aerial seeding and specialised seed mixtures.

Fertiliser and seeding

Fertiliser, when used as a post-fire treatment, was always applied in combination with seeds (but not *vice versa*). This treatment was used most often in the 1970s (20%) and decreased over time to less than 1% in the 2000s with expenditures being commensurate (Table 5). Fertilisation to facilitate seeded plant growth was never shown to be effective and did not justify the additional cost (Dean 2001; Robichaud *et al.* 2006; Dodson and Peterson 2009); thus, the treatment fell into disuse unless a specific need was known to exist.

Contour-felled logs

Contour-felled logs, also known as LEBs, were widely used in the 1990s; one-third of Burned Area Reports with treatment expenditures included contour-felled logs and 60% of the total land treatment expenditures (US$28.6 million of $48 million) were spent to apply contour-felled logs (Table 5). In 1994, $15.3 million (53% of the decadal total expenditure) was spent on contour-felled log treatment for two fires – Rabbit Creek

Table 5. The proportion (%) of Burned Area Reports that included the treatment category, the total expenditure on the treatment category, the mean expenditure per fire and per unit area disaggregated by treatment category and decade

All expenditures reported in 2009 US dollars. Among land treatment categories only the Burned Area Reports from fires that included post-fire treatment expenditures were analysed. Not all treatments were available in all decades; this is indicated by n.a. (i.e. not available)

Land treatment category		Decade			
		1970s	1980s	1990s	2000s
Seeding	Proportion of reports[A] (%)	76	78	68	30
	Total expenditure ($)	3 500 000	13 500 000	12 100 000	21 100 000
	Expenditure per fire ($)	99 000	155 000	108 000	100 000
	Expenditure per unit area ($ ha^{-1})	280	340	230	470
Fertiliser and seeding[B]	Proportion of reports (%)	20	11	4	<1
	Total expenditure ($)	2 200 000	2 900 000	1 300 000	1 418 000
	Expenditure per fire ($)	243 000	243 000	179 000	1 418 000
	Expenditure per unit area ($ ha^{-1})	290	210	110	280
Contour-felled logs	Proportion of reports (%)	2	19	33	7
	Total expenditure ($)	211 000	6 300 000	28 600 000	8 300 000
	Expenditure per fire ($)	211 000	300 000	529 000	173 000
	Expenditure per unit area ($ ha^{-1})	n.a.	800	920	1520
Agricultural straw mulch	Proportion of reports (%)	2	10	15	18
	Total expenditure ($)	<100 000	200 000	3 400 000	79 700 000
	Expenditure per fire ($)	4000	18 000	142 000	618 000
	Expenditure per unit area ($ ha^{-1})	150	3290	3000	2570
Hydromulch	Proportion of reports (%)	n.a.	n.a.	n.a.	5
	Total expenditure ($)	n.a.	n.a.	n.a.	41 000 000
	Expenditure per fire ($)	n.a.	n.a.	n.a.	1 171 000
	Expenditure per unit area ($ ha^{-1})	n.a.	n.a.	n.a.	5980
Wood strand mulch[C]	Proportion of reports (%)	n.a.	n.a.	n.a.	3
	Total expenditure ($)	n.a.	n.a.	n.a.	2 900 000
	Expenditure per fire ($)	n.a.	n.a.	n.a.	163 000
	Expenditure per unit area ($ ha^{-1})	n.a.	n.a.	n.a.	8390
Total land	Total expenditure ($)	6 300 000	23 800 000	48 000 000	188 300 000
	Expenditure per fire ($)	140 000	235 000	356 000	371 000

[A]Percentage of Burned Area Reports that included this particular treatment category.
[B]No fertiliser treatment was prescribed without seeding. Expenditure amounts include both the fertiliser and the seed.
[C]In this study, the wood strand material (WoodStraw) was produced by Forest Concepts, Inc., Auburn, WA, and was shipped to the sites where it was used.

Complex in Idaho ($9.3 million to treat nearly 13 000 ha) and Tyee Creek Complex in Washington ($6.0 million to treat 6100 ha). In the 2000s, contour-felled logs were prescribed for only 7% of the treated fires and most of these were in the early years of the decade. The precipitous decline in contour-felled log use was in response to research based on post-fire observations from nine wildfires in western US that occurred between 1998 and 2002, which showed contour-felled logs to be fairly effective as a post-fire runoff and erosion mitigation treatment for lower-intensity rainfall events but ineffective for high-intensity rainfall events (Wagenbrenner *et al.* 2006; Robichaud *et al.* 2008). Additionally, Robichaud *et al.* (2008) found that greater care was needed during installation, such as adding end berms and backfilling underneath each log, thus increasing the time per log and associated unit area costs in the 2000s (Table 5). These research findings were disseminated before formal publication through BAER team meetings and technical training sessions, and drastically reduced the use of contour-felled logs after 2003.

Agricultural straw mulch

The use of agricultural straw mulch as a post-fire stabilisation treatment has continuously increased from the 1970s to 2000s (2% to 18%), and in the last decade, only seeding was prescribed more frequently. Agricultural straw mulch has been found to be a highly effective post-fire stabilisation treatment (Kay 1983; Miles *et al.* 1989; Edwards *et al.* 1995; Wagenbrenner *et al.* 2006; Groen and Woods 2008; Robichaud *et al.* 2013*a;* 2013*b*), but its increase in the last decade was the result of not only its proven effectiveness in reducing runoff and erosion but also, and perhaps more importantly, the development of aerial application techniques for dry mulch material (Robichaud *et al.* 2010). Prior to 2000, the application rate for straw mulch was considered 'slow' as it depended on ground-based dispersal (Miles *et al.* 1989) and seeding was the only post-fire land treatment that could be aerially applied on remote and inaccessible hillslopes. However, when straw mulch was successfully applied by helicopters on some fires in 2000, it became a viable treatment for the inaccessible burned areas that are frequently encountered in the western US (Robichaud *et al.* 2010). With the increased use of agricultural straw mulch in burned areas it became apparent that even certified weed-free straw can bring non-native plant seeds into the burned area (Olliff *et al.* 2001; Graham 2003) and the resulting plants could be invasive and pervasive, and compete with native vegetation (Beyers 2004; Kruse *et al.* 2004).

Table 6. The 10 fires on USFS lands with the greatest post-fire expenditures
The name of the fire, location by state, year it occurred and burned area are included as well as the total post-fire expenditure for the individual fire and the proportion of the total annual post-fire treatment expenditure that was spent on the individual fire (%). All expenditures reported in 2009 US dollars

Fire name	State	Year	Burned area (ha)	Expenditure (US$)	Proportion of annual expenditure (%)
Tripod Complex	Washington	2006	60 200	30 100 000	59
Hayman	Colorado	2002	47 300	24 900 000	30
Cerro Grande	New Mexico	2000	10 400	15 300 000[A]	35
Rodeo Chediski Complex	Arizona	2002	71 800	13 300 000	16
Foothills	Idaho	1992	56 600	12 600 000	79
Rabbit Creek	Idaho	1994	38 400	12 200 000	43
Valley–Skalkaho Complex	Montana	2000	76 300	12 200 000[B]	28
Biscuit	Oregon	2002	197 900	11 000 000	13
Tyee Creek Complex	Washington	1994	42 700	8 900 000	31
Gap	California	2008	1900	7 000 000	29

[A]Excludes additional expenditures made by the US Department of Energy to protect critical values-at-risk.
[B]Based on additional BAER expenditure information from Regional BAER coordinator not included in the Burned Area Report.

Although the cost of applying agriculture straw mulch has declined over time (from US$3290 ha^{-1} in the 1980s to $2570 ha^{-1} in the 2000s and even less in 2013 – $1200–$1600 ha^{-1}), aerial seeding was always less expensive. Consequently, in the last decade, 42% of the total land treatment expenditure was committed to agricultural straw mulching ($80 million of $188 million), despite seeding being prescribed more often. In addition, agricultural straw mulch accounted for most of the hillslope treatment expenditures associated with the most expensive fires (Table 6). Given that the use of agricultural straw mulch increases the need for weed monitoring, some forest managers have suggested that the cost of monitoring should be included in the overall cost of using straw mulch when comparing post-fire treatment costs.

Hydromulch

Hydromulch comprises a mixture of wood or paper fibres, tackifiers, suspension agent, soil stabiliser and often seeds, combined with water and applied as a slurry on the soil surface. The components of a hydromulch formulation can be modified to enhance specific performance characteristics and some companies are striving to produce a mix for post-fire applications that will stabilise burned hillslopes for more than 1 year. It was first used for post-fire hillslope stabilisation in 2000 and infrequently since then. Only 5% of the Burned Area Reports from the 2000s included hydromulch as a prescribed treatment (Table 5), but the expense per unit area (~US$6000 ha^{-1}) resulted in $41 million (27% of the total land treatment expenditures) being spent on hydromulch. Because it was used on only a few fires, the average expenditure per fire ($1.2 million) was higher than for any other land treatment. In addition to the high cost, the hydromulch mixes that have been tested were found to be short lived on the soil surface – often disappearing within months of their application – and failed to significantly reduce erosion (Hubbert *et al.* 2012; Robichaud *et al.* 2013*a*, 2013*b*). On the other hand, preliminary data from a hydromulch effectiveness study in southern California suggest that the paper-based hydromulch applied after three wildfires (occurring 2007–09) was moderately successful in reducing erosion (P. Wohlgemuth, pers. comm.).

Wood strands

The wood strand mulch used in the 2000s was a manufactured material (WoodStraw; Forest Concepts, Inc., Auburn, WA) made from veneer and wood manufacturing waste (Foltz and Dooley 2003; Foltz 2012). Wood strand mulch was first used in 2005 and had limited use on 18 fires included in this study. The expense of manufacturing and shipping wood strand mulch adds to the treatment cost, making the expenditure per unit area (US$8390 ha^{-1}) the greatest among all land treatments (Table 5). Wood strand mulch has been found to be at least as effective as agricultural straw mulch in mitigating post-fire erosion (Foltz and Dooley 2003; Yanosek *et al.* 2006; Foltz 2012; Robichaud *et al.* 2013*a*) without the risk of introducing non-native plant seeds. In addition, wood strands remain on the soil surface longer (i.e. have greater persistence) and have less tendency to be displaced by the wind than agricultural straw (Copeland *et al.* 2009; Foltz 2012; Robichaud *et al.* 2013*a*). There is high interest in developing wood-based mulches that embody the positive characteristics of wood strand mulch but at a lower cost. Wood shreds, a wood product that can be produced on or near a burned area from burned or green trees, has been tried and has shown promise as a post-fire mulch treatment (Foltz and Copeland 2009; Foltz 2012; Robichaud *et al.* 2013*c*, 2013*d*).

Most expensive fires for treatment expenditure

The post-fire treatments that were implemented on the 2006 Tripod Complex fires (Washington) were the most expensive of any fire and cost over US$30 million – 59% of the total annual BAER expenditure on National Forest Service lands that year (Table 6). Three of the 10 most expensive post-fire treatment fires occurred in the 1990s with the other seven in the 2000s (Table 6). Although seeding was generally applied to the largest area, it was the high-cost treatments, such as contour-felled logs in the 1990s and aerial straw mulching in 2000s that pushed these particular fires into the top 10 in terms of BAER expenditure. In addition, these costly fires often were those with the highest BAER expenditure for the year in which they occurred (Table 6). Although a small number of large fires generally accounted for most of the area burned in any given year (Cramer 1959; Strauss *et al.* 1989; Calkin *et al.* 2005), the largest fires did not always result in the largest BAER expenditure; in fact there was no statistical relationship between fire size and BAER expenditure ($r = -0.03$, $P = 0.93$) for the 10 fires with the highest BAER expenditures. BAER expenditures were not driven by amount of area burned, but rather by the values-at-risk for damage or loss. Protecting source water areas for municipal drinking water supplies has justified large expenditures for post-fire treatments throughout the western US. For example, in the 2002 Hayman Fire, a large proportion of the Denver municipal water supply was threatened when a large, steep area surrounding a major reservoir was burned at high severity. Protection of the water quality draining into the reservoir was a prominent component of the post-fire treatment plan (Graham 2003).

Conclusions

The 1246 Burned Area Reports analysed for this synthesis related to fires on National Forest lands in the western US that occurred over four decades (early 1970s through the year 2009). Although they were not the only wildfires that occurred, the reports cover the majority evaluated through the BAER programme.

We found that the annual total area burned has increased over time, and the rate of increase accelerated *c*. 1990, such that the decadal total area burned in the 2000s was four times as much as that in the 1990s. Similar wildfire trends were reported by other researchers working with other data sources and time divisions. Burned Area Report data showed that in the 1980s and 1990s the proportion of burned area classified as low, moderate and high burn severity remained relatively stable with approximately half of the burned area classified as unburned or low severity and the remaining half fairly evenly divided between moderate and high severity. The BAER programme protocol for classifying burn severity was improved *c*. 2000 when low-level aerial surveys were replaced with an analysis of pre- and post-fire satellite imagery. The quantitative analysis of remote sensing products was applied at a high resolution over the entire burned landscape, and as a result, was not comparable to the more subjective assessments of the previous two decades.

Treatment justifications generally reflected regional concerns, such as protection of aquatic habitat for threatened and endangered species in the Pacific Northwest, protection of soil productivity in areas that support a robust timber industry and protection of municipal water supplies where fires surrounded source water watersheds. In the last decade, BAER treatments were more often justified using life and property values-at-risk compared with the earlier three decades, which reflected the overall increase in number and the area of wildfires and the expansion of development into the WUI, where people and property are more at risk from wildfires.

Road treatments were the most frequently recommended category of treatments, yet the largest decadal treatment expenditures were for land treatments. In the 2000s, US\$188 million was spent on post-fire land treatments in the western US. Seeding was the most frequently used treatment during all four decades of the study, particularly in the 1970s and 1980s when it was used on 96 and 89% of the treated fires. However, as post-fire treatment effectiveness research showed that seeding only reduced erosion ~20–25% of the time (and rarely in the first post-fire year when erosion rates were often greatest), the frequency of post-fire seeding decreased to 72% in the 1990s and to 30% in the 2000s. Even though agricultural straw mulch was more expensive than seeding, its use continuously increased from the 1970s to the 2000s (2 to 18%). In the last decade, 42% of the total land treatment expenditure was used to aerially apply straw mulch on hillslopes burned at high severity. Unlike seeding, straw mulch has been found to be quite effective at reducing post-fire erosion, which has led to the development and use of other mulches, such as hydromulch and wood strands, for post-fire stabilisation. The unit costs of hydromulch and wood strands were respectively 2.3 and 3.3 times more than agricultural straw mulch. High-cost land treatments applied over large areas to protect values-at-risk, such as municipal drinking water sources, were generally responsible for the majority of expenditures in the 10 most expensive fires for the BAER programme. Five of the ten most expensive fires occurred in the last decade and each had large expenses for aerial mulching.

The trends discerned in the Burned Area Reports fit into the broader explanations of wildfire trends coming from global research efforts, which couples with our increased understanding of the effects of climate change on potential wildfire, wildfire behaviour and post-fire vulnerabilities. This information is needed for planning the most appropriate and effective post-fire management response.

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Supplementary material

A synthesis of post-fire Burned Area Reports from 1972 to 2009 for western US Forest Service lands: trends in wildfire characteristics and post-fire stabilisation treatments and expenditures

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Example Burned Area Report

Sample Interim 2500-8 Burned Area Report from the 2008 Panther Fire in California

The original BAER assessment and initial Burned Area Report (funding request) for the Panther Fire were completed before the fire was fully contained. This interim report was filed to update the initial funding request based on more complete site data, design analysis and treatment contract specifications. Working from the initial report, the additions, changes and explanations were printed in blue italicised text.

US customary units were used in this report. Some potentially helpful conversions include:

1 inch = 25.4 mm

1 mile = 1.6 km

1 acre = 0.404 ha

1 sq. mile (mi^2) = 2.6 km^2 or 259 ha

1 cubic foot (ft^3) = 0.028 m^3

Note: cfs, cubic feet per second

1 cubic yard (yd^3) = 0.76 m^3

1 ton $acre^{-1}$ = 2.2 Mg ha^{-1}

BURNED-AREA REPORT
(Reference FSH 2509.13)

PART I – TYPE OF REQUEST

A. Type of report

[X] 1. Funding request for estimated emergency stabilization funds
[ ] 2. Accomplishment report
[ ] 3. No treatment recommendation

B. Type of action

[ ] 1. Initial request (Best estimate of funds needed to complete eligible stabilization measures)

[X] 2. Interim report # 1 *CHANGES IDENTIFIED IN BLUE*
[X] Updating the initial funding request based on more accurate site data or design analysis
[ ] Status of accomplishments to date

[ ] 3. Final report (following completion of work)

PART II – BURNED-AREA DESCRIPTION

A. Fire name: Panther Fire

B. Fire number: KNF-3624

C. State: CA

D. County: Siskiyou

E. Region: 05

F. Forest: Klamath National Forest & portions administered by Six Rivers National Forest

G. District: Ukonom and Happy Camp

H. Fire incident job code: P5EC9P

I. Date fire started: July 22, 2008; *new 10/01/08*

J. Date fire contained: no containment to-date

K. Suppression cost: $15 900 000 for Panther & Ukonom

L. Fire suppression damages repaired with suppression funds:
1. Fireline waterbarred (miles): 10 miles dozer line; 61 miles handline
2. Fireline seeded (miles):
3. Other (identify):

M. Watershed number: 18010209030202, 18010209030202, 18010209030203, 18010209030204, 18010209050301, 18010209050302, 18010209050401, 18010209050402, 18010209050403, 18010209050404, 18010209050503, 18010209070101, 18010209070102, 18010210040403, 18010210040403 *18010209030101, 18010209030102, 18010209030103, 18010209030104, 18010209030105, 18010209030201, 18010209030202, 18010209030203*

N. Total acres burned:
NFS acres (~~27 029~~ **37 994**) Other Federal ( ) State ( ) Private (6)

O. Vegetation types: Douglas-fir, canyon live oak, ponderosa pine, tanoak, black oak, madrone, deerbrush, manzanita

P. Dominant soils: Deadwook, Neuns, Kindig, Chaix, Dome, Holland, Chawanakee, Nanny

Q. Geologic types: Granitic rock (diorite), ultramafic rock, along with metavolcanic and metasedimentary rock (including slate-argillite of the Galice Formation), and marble.

R. Miles of stream channels by order or class: perennial: 48, ephemeral: 87; perennial: 19, intermittent: 25

S. Transportation system
Trails: 53 miles; *12.5 miles* Roads: 15 miles; *19 miles*

PART III – WATERSHED CONDITION

A. Burn severity (acres): 11 884 unburned; 7834 (low); 5896 (moderate); 1421 (high)
B. Water-repellent soil (acres): 3000
C. Soil erosion hazard rating (acres): 16 628 (low); 6673 (moderate); 3101 (high); 624 (very high)
D. Erosion potential: 0.2 to 15 tons/acre average = 3.2 tons/acre
E. Sediment potential: 123 cubic yards / square mile

A. Burn severity (acres): 1655 unburned; 1646 (low); 4099 (moderate); 3565 (high)
B. Water-repellent soil (acres): 5000
C. Soil erosion hazard rating (acres): 3301 (low); 1442 (moderate); 3857 (high); 2365 (very high)
D. Erosion potential: 0.2 to 25.6 tons/acre average = 7.4 tons/acre
E. Sediment potential: 1728 cubic yards / square mile

PART IV – HYDROLOGIC DESIGN FACTORS

A. Estimated vegetative recovery period (years):		
B. Design chance of success (%):	60	
C. Equivalent design recurrence interval (years):	5	
D. Design storm duration (h):	6	
E. Design storm magnitude (inches):	3.0	
F. Design flow (cubic feet / second / square mile):	191	*186*
G. Estimated reduction in infiltration (%):	22	*24*
H. Adjusted design flow (cfs per square mile):	245	

PART V – SUMMARY OF ANALYSIS

A. Describe critical values/resources and threats:

The expansion of the Panther Fire into the Elk Creek watershed created a new emergency as follows:

1. *Increase in landslide and debris flow potential, particularly in steep granitic watersheds burned at high and moderate severity. Landslide model runs suggest that landslide sediment production could more than double as a result of the fire in several seventh field tributaries to Elk Creek. The model assumes a 10 year return interval winter storm.*
2. *Increase in surface erosion potential (see soils report);*
3. *Increase in peak flows (see hydrology report);*
4. *Large increase in risk of culvert failure on roads 15N06, 15N03, 16N05, and 15N08A due to debris flows from upstream.*
5. *Increase in risk of sedimentation in Elk Creek above Sulphur Springs Campground. This could adversely affect water quality in Elk Creek, the water supply for the town of Happy Camp, and a prime anadromous*

fishery.

6. *Failure of road fills would deliver sediment directly into Elk Creek, Buckhorn Creek, and Bear Creek.*
7. *Debris flows will threaten a municipal drinking water system that diverts water for Happy Camp, CA near the mouth of Elk Creek at its confluence with Klamath River.*

Watershed response to the wildfire was modeled using the SCS curve number method described in the previous BAER assessment. Watersheds with the highest proportion of high severity burn were modeled in addition to Elk Creek just downstream of the burned sub-watersheds. Buckhorn Creek is a sub-watershed of Elk–Bear Creek 7th -field. Burney Creek is a sub-watershed of Elk–Granite Creek 7th -field. Elk Creek below the confluence of Doolittle Creek is composed of eight 7th-field watersheds affected by the Panther wildfire. Buckhorn Creek was used for the following Hydrologic Design Factors since it has existing culverts on FS road 15N06 with a large proportion of high severity burn.

Burney Creek had the highest modeled increase in peakflow due to the wildfire at 57%, followed by Buckhorn Creek at 31% (see Table 1). Both these watersheds had the largest proportion of high burn severity. Bear Creek and Elk Creek had a 23 and 15% peakflow increase, respectively (see Table 1). The lower peakflow increase in Elk Creek is due to longer distance for peakflow routing and larger watershed area without wildfire. Several face drainages of mainstem Elk Creek in Middle Elk and Stanza–Bishop 7th -field watersheds are expected to have similar peakflow increase as the watersheds shown in Table 1. These face drainages have very steep channel gradients and side slopes (>70%) in deeply weathered and dissected granitic parent material. Field evidence of sediment bulking and debris flow scarps along with historic information indicates that there will be debris flows transported into Elk Creek when rainfall intensities meet or exceed the design storm magnitude.

Table 1. Modeled Peakflow increases using the SCS curve number method

		Peakflow (cfs)		
Watershed Name	***Acres***	***Before Wildfire***	***After Wildfire***	***% Increase***
Buckhorn Creek	*1179*	*343*	*451*	*31*
Bear Creek	*6704*	*2378*	*2923*	*23*
Burney Creek	*2346*	*841*	*1324*	*57*
*Elk Creek**	*40 494*	*14 366*	*16 514*	*15*

**below Doolittle Creek confluence*

Proportion of Riparian Reserves burned by the wildfire was analyzed to address loss in stream temperature buffering and sediment filtering capacity. The buffer widths were based on the KNF Forest Plan. The Elk–Granite Creek 7th-field had nearly 250 out of 650 acres of Riparian Reserves burned at high burn intensity. The Panther Fire burned 965 acres of Riparian Reserve at high intensity.

Miles of burned intermittent and perennial streams indicate how much Riparian Reserves have been totally consumed. Elk–Granite Creek had 9.85 miles of burned intermittent streams. Elk–Bear had 5.39 miles of burned perennial streams. The Panther fire burned over 15 miles of intermittent and over 6 miles of perennial streams at high intensity.

Elk Creek is one of the most important Klamath River tributaries for supporting natural; non-hatchery influenced anadromous salmonid populations and has been designated a Key watershed for conservation of 'at-risk' salmonid stocks under the Northwest Forest Plan. Within the Panther Fire, Elk Creek is the most productive stream for anadromous salmonids, providing many miles of habitat for five distinct runs of salmon and steelhead. Elk Creek supports Southern Oregon–Northern California Coast ESU Coho Salmon (SONCC) (Oncorhynchus kisutch), Upper Klamath–Trinity River (UKTR) fall- and spring-run Chinook salmon (Oncorhynchus tshawytscha), and Klamath Mountains Province (KMP) winter- and summer-run steelhead (Oncorhynchus mykiss). Non-game fish species supported by Elk Creek include: Pacific lamprey, Klamath River lamprey, speckled dace, marbled sculpin, and Klamath largescale sucker.

SONCC coho salmon are listed as threatened species (62 FR 24588 and 70 FR 37160) under the Endangered Species Act*. Critical habitat (64FR24049) for the SONCC coho salmon ESU encompasses accessible reaches of all rivers (including tributaries) between the Mattole River in California and the Elk River in Oregon. The Klamath River and its' tributaries fall within this range. Elk Creek is one of the strongholds for coho salmon in that coho salmon spawn and rear every year in Elk Creek (all three cohorts are represented), the stream provides ~11 miles of habitat for coho salmon, and hundreds to thousands of juvenile coho are produced each* *year. Coho salmon occur in mainstem Elk Creek from the mouth to approximately the vicinity of the confluence with the Lick Creek tributary. The only Elk Creek tributaries that support coho salmon is the lower half-mile of East Fork Elk Creek and the lower few hundred feet of Cougar Creek. The uppermost limit of coho salmon range in mainstem Elk Creek approximately coincides the downstream section of the area of the Elk Creek watershed that burned in the Panther Fire.*

The noxious weeds present in or adjacent to the fire perimeters are:

Cytisus scoparius*, Scotch broom – an unconfirmed population is located at the fire edge on Forest Service Rd 15N13;*

Isatis tinctoria*, Dyer's woad – two populations are present within the fire perimeter, ISTI-33 at Norcross Campground and ISTI-53 at Stanza creek near Sulfur Springs Campground.*

Lathyrus latifolius*, Sweet Pea – one population, LALA4-1, can be found at an old homestead site off the trail near Sulfur Springs in the burned area.*

In addition, Centaurea solstitialis*, Yellow star thistle; Centaurea pratensis, Meadow knapweed; and Cytisus scoparius, Scotch broom occur along the road 16N05 going into the fire area. The State of California classification of these species can be found on the Klamath National Forest Noxious weed list.*

No weed washing was conducted prior to suppression and rehabilitation efforts in this area. An emergency exits with respect to the spread of known noxious weeds into the fire perimeters and the possible introduction of new noxious weed species due to lack of weed prevention measures.

There were ~19 miles of road that were within the perimeter of the new burned area of the Panther Fire. Some of these roads, mostly within the Buckhorn drainage of the Elk–Bear watershed, have large fills with small 18 inch culverts draining intermittent drainages. This poses a very real threat of failure in the changed watershed condition. Small drainages or tributaries to Buckhorn Creek experienced severe fire effects and large increases in streamflow are expected. These small culverts are at a great risk of failure, which would compound debris flow impacts to Elk Creek fish habitat. It is expected that an initiation of debris flow events above this road system, if unmitigated, would cause unacceptable impacts to downstream beneficial uses.

Multiple trails (12.5 miles), two trailheads, a campground, and two corrals were burned during this new fire activity. The Norcross Campground was almost entirely consumed and lies in an area that received severe fire effects. Two toilets, two corrals, most of the picnic tables, and many signs were destroyed. Trails lie below severely burned hillsides and trailhead signing is destroyed. Both toilet vaults are now entirely exposed and unsafe to visitors.

The soil resource will experience very high increased erosion within high burn severity areas with a lesser amount in the moderate severity burned areas. Sandy loam soils in the granitic terane have and will experience dry ravel of soil material into intermittent draws. These sandy loam soils in high burn severity areas will also experience water repellency induced soil surface mud flows during storms with moderate to intense rainfall rates. Where high severity burn areas are adjacent to stream channels and inner gorge locations the potential for increased sediment is very high which will increase turbidity within Elk Creek and the Klamath River.

Soils that were burned in the 2002 Stanza Fire have experience another high erosion event. Soil loss was 2 to 3 times the soil formation rate for 2 to 3 years after the Stanza Fire. The Panther Fire soil erosion rate will also have soil loss rates at 2 to 3 times the soil formation rate. There is a high probability that these sandy loam soils have lost site productivity due to excessive soil erosion rates within the prevous 6 years.

Several resource values were assessed including: long-term soil productivity, water quality beneficial uses and associated aquatic habitat for T&E fish species, roads, and culverts were assessed as to their upstream/upslope hazard and associated potential risk from post-wildfire watershed conditions. Field investigations and subsequent analyses/models were used to determine their post-wildfire hazard and associated risk from potential debris flows, flooding, soil erosion and accelerated sedimentation.

A sequential evaluation process assessed the post-fire watershed conditions starting at the hillslopes and moving downslope or down the stream channels to determine potential hazards and associated risks to the various resource values. First the hillslope and stream channel burn severities were identified and mapped. A debris flow initiation and transport map was developed that is based on inherent soil-hydrologic characteristics. Based on the findings of the burn severities, the post-fire watershed stream flows were modeled and combined with the debris flow map to assist with determining the potential hazard and associated risk to the aforementioned resource values. Further field investigations of these resource values were conducted to determine if they were at risk from the post-fire induced hazards.

The soil erosion rates will increase with amounts varying based on burn severity and characteristics of individual landtypes. There are several areas that have an increased hazard of rill and gully erosion, sheet flooding, flash flooding and debris flows. Erosion rates may reach or exceed soil loss tolerances in the 2 to 8 years following the fire. Unacceptable soil loss is dependent on several factors including burn severity, inherent soil characteristics, steepness of hillslopes, and climatic triggers. Long-term productivity may be negatively affected on steep hillslopes with high burn severities that experience high intensity rainfall from thunderstorms. At a minimum there will be a substantial increase in sedimentation to the drainages within the Panther Fire. There is a direct relationship of higher sedimentation associated with adjacent areas of high burn severities on steep hillslopes. Dry soil ravel has already been extensive on these areas. Sedimentation will increase dramatically depending on increasing rainfall intensities and initiation of debris torrents. In the short-term it is very likely that there will be negative effects to aquatic habitat within the analysis area due to increased sediment delivery from severely burned areas and increased temperatures from a reduction in stream channel shading. In the long-term, effects will be largely dependant on the climatic triggers and the spatial coverage of these storms that may occur over the next 3 to 5 years.

Fisheries – Southern Oregon–Northern California Coast ESU Coho Salmon (SONCC) (*Oncorhynchus kisutch*) are listed as threatened species (62 FR 24588 and 70 FR 37160) under the *Endangered Species Act*. Critical habitat (64FR24049) for the SONCC coho salmon ESU encompasses accessible reaches of all rivers (including tributaries) between the Mattole River in California and the Elk River in Oregon. The Klamath River and it tributaries fall within this range.

California Department of Fish and Game has subdivided each coho salmon ESU into watershed recovery units (recovery units). The recovery units are groups of smaller drainages related hydrologically, geologically, and ecologically, and that are thought to constitute unique and important components of the ESU. The Panther Fire occurs in the Ukonom hydrologic subarea (HSA). There is limited use of streams within the Ukonom HAS by coho that were burned in the Panther Fire. Coho have been occasionally found in the summer in low densities in lower gradient, more accessible reaches in Independence, King, and Ukonom Creeks. Coho use lower tributaries to likely escape high water temperatures in the Klamath River that can often exceed 80°F in some summers and cause occasional fish kills.

Summer steelhead (*Oncorhynchus mykiss*) is a sensitive species on both the Klamath and Six Rivers National Forest. This means these species must be managed to contribute to healthy, viable populations. Several other runs (e.g. winter, fall) of steelhead that are not sensitive also occur within tributaries or downstream of each fire. Fall and spring-run steelhead are the most widely distributed anadromous fish species within the subbasin, often occupying small tributaries and steeper gradient channels not commonly utilized by coho and chinook.

Within the Panther Fire winter and summer steelhead have been found in more accessible reaches in Independence, King, and Ukonom Creeks. Independence Creek provides the most habitat for winter steelhead (2.8 miles), followed by King Creek (1.7 miles) for winter steelhead, and Ukonom (0.72 miles) for summer steelhead.

Spring Chinook (*Oncorhynchus tshawytscha*) are sensitive species on both the Klamath and Six Rivers National Forest. This means these species must be managed to contribute to healthy, viable populations. Essential Fish Habitat (EFH) has been designated for spring and fall-run Chinook salmon under the Magnuson-Stevens Act. The act requires measures to conserve and enhance the habitat needed by fish to carry out their life cycles. Congress defined EFH as 'those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.' Within the Panther Fire fall-run chinook have only been found in the lower portion of Independence Creek.

The North Coast Regional Water Quality Control Board is in the process of developing total maximum daily loads (TMDLs) for the Klamath River in California. The Klamath River and their tributaries are listed on 303(d) for nutrients organic enrichment, dissolved oxygen, and water temperature.

The Klamath River beneficial uses that are impaired include: Cold Freshwater Habitat (COLD), Rare, Threatened, or Endangered Species (RARE), Migration of Aquatic Organisms (MIGR), Spawning, Reproduction, or Early Development (SPWN), Native American Culture (CUL).

The CUL beneficial use covers 'uses of water that support the cultural or traditional rights of indigenous people such as subsistence fishing and shellfish gathering, basket weaving and jewelry material collection, navigation to traditional ceremonial locations, and ceremonial uses. The CUL beneficial use in the Klamath River in California is currently impaired due to the decline of salmonid populations and degraded water quality resulting in changes to or the elimination of ceremonies and ceremonial practices and risk of exposure to degraded water quality conditions during ceremonial bathing and traditional daily activities.

Subsistence fishing (FISH) is also listed in the Basin Plan as a beneficial use of the waters in the region. Although, the specific areas in which this use exists has not yet been designated in the Basin Plan, this does not alter the need to protect this existing beneficial use. The FISH beneficial use is currently impaired in the Klamath River basin in California due to the decline of salmonid populations and other Tribal Trust fish populations resulting in decreased use, abundance, and value of subsistence fishing locations, altered diet and associated physical and mental health issues, and increased poverty.

Engineering – The reconnaissance of the roads during the field investigations found several issues pertaining to emergency stabilization. The issues associated with the findings requiring emergency stabilization included burned warning signs, burnt bridge, and road drainage problems (i.e. plugged culverts, filled in catchment basins and ditches, ruts in the road, etc.). The result of these field investigations identified threats to public safety and deterioration of water quality through possible road failures.

Most of the issues are typical of what is found on or above roads within the burned areas. These issues pertaining to most of the roads are a result of the roads template and location. To further elaborate, the roads template are constructed on steep mountain terrain which crosses steep side ‘V’ channels. Roads that are not maintained eventually have their catchment basins and ditches filled in from sediment that is washed down from normal storm events and spring runoff. The ‘V’ shape channels contain channel bottoms and side slopes with grades ranging 50º to 75º. These steep grades are able to deliver high erosive runoffs which can carry large amounts of sediment and debris in a short time span. With the landscape now burned, the runoff flows will be greater in intensity and more debris is available for transport above these crossings.

Noxious weeds – The fire has created suitable habitat for the spread of noxious weeds. While weed washing was required of vehicles used for fire suppression and rehabilitation, information on weed washing during the initial attack phase of the fire is unknown. Vehicles could have come from weed infested areas and weeds introduced through mud and debris. Water tenders used during the fire may have used drafting sites that contained weeds. Seeds may have been carried to the road system via water tenders. Monitoring will reduce the potential for establishment of new noxious weed sites.

B. Emergency treatment objectives:

The primary objectives of the Klamath Theater Burned Area Emergency Stabilization Plan were:

- To insure the BAER team’s personal safety and provide for public safety during our assignment
- To coordinate with the NRCS, State, and County on private lands, if appropriate
- To assess the risk to human life and property or natural or cultural resources from impaired watershed conditions and to recommend appropriate stabilization actions to protect the following values:
    - Roads
        - All major or minor routes as identified
    - Administrative sites
    - Fish
        - Listed Coho, Spring & Fall Chinook, and Summer Steelhead
    - Water quality
        - TMDL
        - Nutrients
        - Essential fish habitat
    - Increased infestations of noxious weeds

The BAER assessment evaluated the above objectives for possible mitigation using an array of treatment options or actions allowable by Department of Agriculture (USDA) policy. A list of issues specific to the Panther Fire is listed below. Treatments will be designed specifically to mitigate the following list of issues:

- An increased threat to roads, culverts, and a bridge because of higher runoff and the likelihood that these facilities will plug, overtop, or wash away.
- Increase erosion and sediment delivery associated after fires will occur along the hillslopes and increase the likely hood for potential landslides. Especially in the areas containing erodible granitics.

- An increase to the streams TMDL's due to the increased sediment delivery and reduced upstream shade as a result of the increased runoff and loss of vegetation on the hillslopes. These increases will impact the fish habitat residing in the streams within and below the fire perimeter.
- The loss of vegetation increases the potential for introducing weeds.

C. Probability of completing treatment prior to damaging storm or event:

Land **70** % Channel **NA** % Roads/trails **70** % Protection/safety **90** %

D. Probability of treatment success

	Years after treatment		
	1	3	5
Land	*70*	*80*	*NA*
Channel	*70*	*70*	*70*
Roads/trails	*80*	*75*	*60*
Protection/safety	100	90	70

Note: The Panther Fire – October Addendum created a unique risk to downstream values based on compounding threats. A large portion of the Elk Creek watershed burned with moderate and high severity putting a very important fishery and downstream municipal drinking water system at risk. However, much of the area that burned is either in wilderness or is unroaded. The portion of the burned area that is roaded includes the Elk/Bear watershed. These roads were installed at very steep grades (>7%) and straightened using large fills across intermittent channels. Many of these intermittent stream crossings have small, 18 inch culverts installed at the bottom of each fill. Our assessment of cost/risk involves the following rationale:
It is necessary to temporarily control road drainage during the next three years due to the expected increase in flow and debris as a result of the fire. The temporary control would include culvert risers and other treatments, but due to the gradient of the road, it is near impossible to also install rolling dips to control flow over the fill in the case of a plugged riser/culvert. Therefore, the diversion potential remains high. Another compounding factor in considering treatments was storm patrols. Storm patrols are considered unsafe on this road system immediately following rainstorms because of slippery conditions on such a steeply graded road. Therefore, it is expected that storm patrols would have to provide enough time (at least a week) after large rainstorm events to allow the road to dry and ensure safety of personnel and contractors.
These channels draining to the road were burned at moderate and high severity and high intensity leaving very little standing vegetation. It is assumed for other, unroaded portions of the watershed, that it is not necessary to complete hillslope treatments to protect fisheries habitat. The potential for unmeasureably large debris flows because of fill failure warrants treatment of hillslopes to reduce the threat. While unmeasureable, field observation indicated that the fills are large enough to cause at least a doubling effect to scouring debris flows from the intermittent drainages upslope of the road system. This doubling effect would cause unacceptable degradation to fisheries habitat, damage municipal drinking water collection systems, and potentially threaten downstream private property.
The loss of the fills is unacceptable and catastrophic to the road, fishery, life and property, and municipal water system. This risk of fill loss is extremely high due to the small culverts and high probability of storm events that would threaten these small culverts/risers. The road treatment alone is estimated to be effective, unless clogged. In-channel tree felling is proposed to reduce delivery of large debris that would damage or clog the culvert inlet/riser. The aerial mulching treatment would reduce the volume of sediment delivered to the culvert inlet. This reduction of sediment volume would maintain the inlet catch basin capacity for a longer period of time and therefore allow for safe access following storms, even if the storm patrols cannot safely enter the road system until a week or more later.

E. Cost of no-action (including loss): **$1 832 475**

The values at risk directly lost through No-Action includes: damage to fish and their habitat below roads, loss of soil productivity (as impacted by noxious weed potential), impact of ground water quality below roads, impacts to system roads due to changed hydrologic conditions.

F. Cost of selected alternative (including loss): **$683 660**

It was assumed the primary treatments would be successful in reducing resource values lost through No-Action by 70%. The remaining resource values lost (as a factor of success) were added to the cost of the primary land treatment.

G. Skills represented on burned-area survey team:

[X] Hydrology	[X] Soils	[X] Geology	[ ] Range	[X] Recreation
[ ] Forestry	[ ] Wildlife	[ ] Fire Mgmt.	[X] Engineering	[ ]
[ ] Contracting	[ ] Ecology	[X] Botany	[ ] Archaeology	[ ]
[X] Fisheries	[ ] Research	[ ] Landscape Arch	[X] GIS	

Team Leader: [redacted]

Email: [redacted] Phone: [redacted] FAX: [redacted]

H. **Treatment narrative:**

(Describe the emergency treatments, where and how they will be applied, and what they are intended to do. This information helps to determine qualifying treatments for the appropriate funding authorities. For seeding treatments, include species, application rates and species selection rationale.)

Land treatments:

Noxious weed detect and treatment

General description:

Monitor known weed populations and all areas within the perimeter of the Panther fire for weeds introduced or spread during fire suppression or rehabilitation. Dozer line and burn areas adjacent to roads or areas used for fire suppression or rehabilitation activities are high priority sites for monitoring. Treat and map any new or expanded weed populations.

Location (suitable) of sites:

All roads used within the Panther Fire for travel – 54 miles total. Areas used for fire suppression activities including dozerline (10.0 miles), drop points, helispots, spike camps, and staging areas. Scotch Broom, Dyer's Woad, and Star Thistle are present on FS road 14N14. Dyer's Woad is present on FD road 15N17Y (pop. num. 06ISTI-126). Star Thistle is present on FS road 15N10 near junction with 15N17Y. (Calculation of acres assumes 4 acres per mile)

All roads used within the new Panther fire perimeter for travel. Areas used for fire suppression and rehabilitation. Scotch Broom, Dyer's Woad, and Star Thistle are present on FS road 16N05. Scotch Broom has been reported on FS road 15N13 near fire perimeter. Sweet Pea is present at an old homestead site near the Sulfur Springs campground.

Design/construction specifications:

1. Monitoring will occur at multiple times during the growing season to catch both early and late maturing species. It is assumed that this treatment is conducted by personnel on the Klamath National Forest.
2. Monitoring will be conducted by a botanist or a technician under direction of a botanist qualified to identify target species. Weeds of primary concern are Meadow Knapweed, Spotted Knapweed, Yellow Starthistle, Scotch Broom, Dyer's Woad, and French Broom.
3. New population locations will be mapped using a GPS or 1:24 000 quad map and flagged on the ground. NRIS and Klamath survey and treatment forms will be filled out and entered into national database.
4. If new populations are small, plants will be hand dug and bagged for removal at time of discovery. Larger populations will be flagged for later treatment and a request for additional funding will be submitted.

5. Equipment washing for weed prevention is mandatory on all equipment or vehicles that may be harboring soil and debris prior to entering burned area for rehab or any other related activity.

Purpose:

- The fire has created suitable habitat for the spread of noxious weeds. While weed washing was required of vehicles used for fire suppression and rehabilitation, information on weed washing during the initial attack phase of the fire is unknown. Vehicles could have come from weed infested areas and weeds introduced through mud and debris.
- Water tenders used during the fire may have used drafting sites that contained weeds. Seeds may have been carried to the road system via water tenders.
- Monitoring will reduce the potential for establishment of new noxious weed sites.

Aerial mulch

General description:

Apply agricultural straw mulch to the ground surface by helicopter (and spread with hand crews as necessary) to achieve a continuous cover of uniform thickness, as specified below, to replace ground cover consumed by the fire. Ground cover is needed to maintain soil moisture, accelerate recovery of native vegetation, and to protect any seed remaining onsite. In addition, the organic mulch will protect soil from solar heating and drying, thereby improving the ability of seeds to germinate.

Location (suitable) of sites:

The treatment unit totals 908 acres that contains ~681 acres of treatable hillslopes. The location of this treatment is in drainages above roads and road crossings in the Buckhorn, Stanza, and Elk Creek watersheds. Refer to BAER Treatment Map for exact locations.

Design/construction specifications:

1. *Treat areas in designated units with 'High' and 'Moderate' soil burn severity that are less than 70% slope. Do not treat areas that have needles in trees, exposed rock outcrops, or slopes greater than 70%.*
2. *Straw application rate: Apply mulch to achieve a continuous cover of uniform thickness over 70% of treatment area at a depth of less than 2.0 inches. Application rate will be ~1.0 ton/acre (2000 pounds). This is ~0.25 inches or 3 straw shafts deep. Aerial application may not achieve desired ground cover, therefore ground crews will likely be needed to spread straw clumps by hand in select locations in each treatment unit.*
3. *Straw must conform to State Department of Agriculture (SDA), Certified Noxious Weed Free Standards for Noxious Weed Free Forage and Straw (NWFFS). All straw provided will have been planted, and harvested during the 2008 growing season. Straw shaft length will not exceed 12 inches. Suitable straw includes barley, rice, and wheat grasses.*
4. *The straw must be applied dry (less than 12% internal moisture content) to ensure proper dispersal during aerial applications. The Forest Service will randomly test bales using a moisture probe.*

Purpose:

This treatment is intended to achieve three sequential objectives:

1. *Improve conditions to protect soil productivity by replacing ground cover burned in the fire. Replacing ground cover will: a) decrease erosion by interrupting raindrop impact and surface soil detachment; and b) increase hillslope obstructions to decrease slope lengths which mitigate accelerated overland flow, thereby decreasing sediment delivery, and c) reduce the potential for soil repellency induced soil surface mudflows. Mulching also helps to protect the native seedbed and retain moisture on the burned slopes to facilitate vegetative recovery of the treatment areas.*
2. *Decrease overland flow and erosion from high soil burn severity areas upslope of roads, which can intercept surface runoff and result in damage or loss of the road infrastructure.*
3. *Decrease sedimentation from burned areas and roads upslope of streams that provide important spawning and rearing habitat for federally listed aquatic species.*

The mulching treatments are predicted to lower the estimated soil erosion and subsequent sediment delivery to the streams by ~75%. Mulching will also reduce downstream peak flows by absorbing and slowly releasing overland runoff which is likely to be increased due to reduced soil cover and hydrophobic soil conditions. Mulching treatments in the headwaters of the streams can protect a much larger *downstream area from cumulative runoff and sedimentation.*

The purpose of the mulching treatment is to reduce the delivery of sediment from severely burned hillslopes to avoid sediment bulking of flows entering road culverts and causing failures that would then directly deliver to Elk Creek. Due to the large fillslope size and inadequate culvert size, any excess debris or surface erosion is likely to clog culverts resulting in fillslope failure and related channel scour below the roads. Elk Creek is one of the most important Klamath River tributaries for supporting natural; non-hatchery influenced anadromous salmonid populations and has been designated a Key watershed for conservation of 'at-risk' salmonid stocks under the Northwest Forest Plan. Within the Panther Fire, Elk Creek is the most productive stream for anadromous salmonids, providing many miles of habitat for five distinct runs of salmon and steelhead. Elk Creek supports threatened Southern Oregon/Northern California Coast ESU Coho Salmon (SONCC) (Oncorhynchus kisutch), Upper Klamath/Trinity River (UKTR) fall- and spring-run Chinook salmon (Oncorhynchus tshawytscha), and Klamath Mountains Province (KMP) winter- and summer-run steelhead (Oncorhynchus mykiss).

The mulching treatments were determined to be the minimum necessary to prevent unacceptable loss of occupied critical habitat in Elk Creek, as defined in FSM 2523.2.2.C. Based on pre-fire monitoring data, the Oregon/Northern California Coast ESU Coho Salmon occupy Elk Creek from its mouth to just below Lick Creek, which is just downstream of the burned area. Elk Creek provides critical spawning and rearing habitat all three cohorts of SONCC.

Spot mulch & erosion control

General description:

Apply agricultural straw mulch to the ground surface by hand or helicopter (and spread with hand crews as necessary) to achieve a continuous cover of uniform thickness, as specified below, to replace ground cover consumed by the fire. Ground cover is needed to maintain soil moisture, accelerate recovery of native vegetation, and to protect any seed remaining onsite. In addition, the organic mulch will protect soil from solar heating and drying, thereby improving the ability of seeds to germinate. This treatment will protect loss of important cultural sites.

Location (suitable) of sites:

The treatment unit totals 2 acres as determined and delineated by the Forest Service Archeologist. The location of this treatment is just upslope and east of Norcross campground. Refer to BAER Treatment Map for exact locations.

Design/construction specifications:

1. *Apply mulch to achieve a continuous cover of uniform thickness over 70% of treatment area at a depth of less than 2.0 inches. Application rate will be ~1.0 ton/acre (2000 pounds). This is ~0.25 inches or 3 straw shafts deep. Aerial application may not achieve desired ground cover, therefore ground crews will likely be needed to spread straw clumps by hand in select locations in each treatment unit.*
2. *Straw must conform to State Department of Agriculture (SDA), Certified Noxious Weed Free Standards for Noxious Weed Free Forage and Straw (NWFFS). All straw provided will have been planted, and harvested during the 2008 growing season. Straw shaft length will not exceed 12 inches. Suitable straw includes barley, rice, and wheat grasses.*
3. *The straw must be applied dry (less than 12% internal moisture content) to ensure proper dispersal during aerial applications. The Forest Service will randomly test bales using a moisture probe.*
4. *Wattles must be placed on the slope just above the area end to end. Each wattle should be 'smiled' with the ends slightly higher then the center. The entire wattle must be placed perpendicular to slope and leveled except for the ends. Each wattle must have 5 stakes driven through the center and evenly spaced out to the ends. The wattles should also be made to be flush with the soil surface, even if you must scrape the soil surface to fill in gaps.*

Purpose:

This treatment is intended to achieve three sequential objectives:

1. *Improve conditions to protect soil productivity by replacing ground cover burned in the fire. Replacing ground cover will: (a) decrease erosion by interrupting raindrop impact and surface soil detachment and (b) increase hillslope obstructions to decrease slope lengths which*

mitigate accelerated overland flow, thereby decreasing sediment delivery. Mulching also helps to protect the native seedbed and retain moisture on the burned slopes to facilitate vegetative recovery of the treatment areas.

2. *Decrease overland flow and erosion from high soil burn severity areas upslope of resources to protect, which can prevent damage or loss of the resource.*
3. *Decrease sedimentation from burned areas upslope of cultural sites.*

The mulching treatments are predicted to lower the estimated soil erosion and subsequent sediment delivery to the streams by ~75%.

Channel treatments:

In-channel tree felling

General description:

In-channel tree felling is prescribed to maintain channel stability and provide fish habitat. In-channel tree felling replaces woody material consumed by the fire. It also is used to treat steep drainages to reduce the risk of in-channel debris flow bulking for several years after a fire (Fitzgerald, unpublished paper).

In-channel tree felling involves directionally felling trees upstream so the tops of the trees are in the channel. The trees are felled at a diagonal along designated channel reaches. The trees are staggered from side to side along the stream in a herringbone design (Ruby, unpublished paper; Fitzgerald, unpublished paper).

Location (suitable) of sites:

This treatment totals ~30 000 feet of 0- to 1st-order channels located above road drainage features on the 15N03 and 15N06 roads. The location of this treatment is in drainages above roads and road crossings in the Buckhorn, Stanza, and Elk Creek watersheds. Refer to BAER Treatment Map for exact locations.

1. *Treat areas in designated drainages with 'High' and 'Moderate' soil burn severity where woody material has been consumed.*
2. *Channels where energy dissipation is necessary.*
3. *Channels with high values at risk such as road crossings or sensitive aquatic species.*
4. *Channels with unstable bedload and high sediment-loading potential.*

Design/construction specifications:

1. *Locate in channels with upslope watersheds no larger than 200 acres in size that have debris and floatable material that would accumulate and clog downstream culvert inlets. Refer to treatment map for specific locations.*
2. *Channels should be burned at moderate to high severity/intensity.*
3. *Use trees large enough to hold the expected runoff and debris load. Fall trees that are 12 inch diameter or greater at an angle from hillslope to channel, pointing upstream. Angle may vary between 15 degrees and 45 degrees depending on available trees and sideslope gradients.*
4. *Leave felled trees in one piece with the top attached. If necessary, slash the tree halfway through from underside to aid in the tree laying more flush to the ground surface. Slash cuts should not be distances any less than 25 feet apart.*
5. *Space 2 trees per 50 to 100 feet of channel, with 1 tree on each side of the channel for ~106 to 212 trees per mile.*
6. *Fell two trees from each side of the channel on top of each other to improve stability. The upper 1/3 of each tree should be in the channel and slightly on the opposite bank then the butt of the tree. The butt of each tree should be 'locked' from rolling down the hillslope by another standing tree just downslope.*
7. *Fell trees such that the top quarter to half of the tree is within the high-water level for that channel (Ruby, unpublished paper).*
8. *Fell the second tree just upstream from the first tree from the opposite bank or hillslope so that they cross in the upper 1/3 of their length.*

Purpose:

In-channel tree felling traps floatable debris and suspended sediment. Over time, woody material can *cause sediment deposition and channel aggradation. For seasonal channels the in-channel trees serve as dams to stabilize existing prefire bed material and to trap and store post fire sediment in the short term, while providing long-term channel stability (Fitzgerald, unpublished paper). In-channel tree felling reduces effects to critical natural resources (sensitive aquatic species) or downstream values (water quality and or road crossings) by restoring large woody debris to the channel and dissipating stream energy.*

The ultimate purpose of the in-channel felling treatment is to reduce the delivery of debris from severely burned hillslopes to road culvert entrances to reduce risk of road fill failure and direct delivery to Elk Creek. Due to the large road fill size and inadequate culvert size, any excess debris or surface erosion is likely to clog culverts resulting in fillslope failure and related channel scour below the roads. Elk Creek is one of the most important Klamath River tributaries for supporting natural; non-hatchery influenced anadromous salmonid populations and has been designated a Key watershed for conservation of 'at-risk' salmonid stocks under the Northwest Forest Plan. Within the Panther Fire, Elk Creek is the most productive stream for anadromous salmonids, providing many miles of habitat for five distinct runs of salmon and steelhead. Elk Creek supports threatened Southern Oregon/Northern California Coast ESU Coho Salmon (SONCC), Upper Klamath/Trinity River (UKTR) fall- and spring-run Chinook salmon, and Klamath Mountains Province (KMP) winter- and summer-run steelhead.

<u>Roads and trail treatments:</u>

Road drainage reconstruction

General description:

The roads surveyed within the Panther fire were found to have issues with their drainage system due to the expected increase in flows. The minimal treatments required to remedy these issues are:

1. Drain dips (with or without armor) – Roadway dips modify the road drainage by altering the template and allowing surface flows to run off the road to prevent any excessive erosion of the surface. The armor consisting of rip rap is placed where runoff could possibly cause erosion to the road surface and fillslope.
2. Culvert cleaning – Includes the cleanout of catch basin culvert inlets, outlets, and the drop inlets. Also included is the replacement of lids covering the drop inlets. Cleaning culvert pipes and replacing the missing and damaged lids over the drop inlets will enable the drainage system to pass flows more intended design flow and reduce the chance of plugging.
3. Culvert repair – Using mechanical means to open up culverts to improve flow or cutting off sections too damaged to repair. This will improve culvert flow and reduce the chance of plugging.
4. Catch basin expansion – Expanding existing catch basins in size and remove debris in the channel above the inlet. The expanded catch basins will handle more sediment and removing debris will reduce the chance of the culvert plugging.
5. *Install slotted risers – Install slotted risers on the inlets of culverts to allow the culvert to pass water as the catch basin fills with sediment.* ~~Fill size reduction – Reduce the fill volume over undersized culverts and construct a channel over the culvert. The channel will normally have rip rap to protect the remaining fill. This keeps the flow and sediment in the channel and reduces road related sediment and total fill failure.~~
6. Fill slope protection – Place geotextile and rip rap on fill slopes where water flow over the fill is expected. This will reduce erosion and sediment delivery down stream.
7. Ditch cleaning – The cleanout of drainage ditches is required to remove debris that impede the flow or deflect it out of the ditch onto the road surface. Clean ditches will ensure that the flow reaches drainage structures.
8. *Grading roadway – Removing wheel ruts in the road surface, re-establishing the road cross slope, out slope or in slope to ensure the flow goes into a drainage structure or is allowed to sheet off outside edge of the road without concentrating the water. This reduces road related sediment.* ~~Roadway slope improvement – Out sloping or in sloping the road surface to ensure the flow goes into a drainage structure or is allowed to sheet off outside edge of the road without concentrating the water. This reduces road related sediment~~.
9. Culvert additions – Add additional culverts to drainage fills or upsize the existing culvert where

the expected increased flow is more than the existing culvert can handle. Reduces the chance of fill failure and associated sediment delivery down stream. Also allows replacement of fire damaged pipes and down drains to maintain existing drainage capacity and flow dissipation.

Location (suitable) of sites:

The treatments listed next to each road identified below are those treatments found during the initial survey and are not all inclusive to these sites. Also, additional roads within the fire perimeter still need to be assessed for any additional drainage issues. These additional roads shall be treated to eliminate the drainage concerns found during the survey.

<u>ROADS</u>

- 15N06
  - Grade roadway: 5.8 miles
  - Ditch cleaning: 5.8 miles
  - Clean catch basin: 52 each
  - Install slotted riser: 12 each
  - Fill slope protection: 25 cubic yards
- 15N03
  - Clean catch basin: 25 each
  - Install slotted riser: 2 each
  - Fill slope protection: 40 cubic yards
  - Culvert addition: 10 linear feet
- 16N05
  - Grade roadway: 2 Miles
  - Ditch cleaning: 2 Miles
  - Drain dips: 1 Each
  - Culvert cleaning: 12 each
  - Fill slope protection: 44 cubic yards
- 15N75
  - Ditch cleaning: 1 mile
  - Grade roadway: 1 mile
  - Culvert cleaning: 5 each
- 15N08A
  - Clean culverts: 8 each

Design/construction specifications:

1. Drain dips (with or without armor) – Construct rolling dips per Forest Service standards. Place rip rap across the roadway and on the fill slopes where potential runoff can occur if flow was to overtop the roadway from a plugged culvert or excessive runoff.
2. Overside drains – Install overside drains onto existing culverts that are extended out from the fillslope over steep grades. Place rip rap below the drain outlet to dissipate the energy from the flow. Overside drains may consist of drain pipe that lays flat along when no storm water is flowing through the pipe.
3. Ditch cleaning – All catchment-basins and drain ditches along the length of the roads shall have all existing silt and debris removed and either hauled away or spread out such that the material can not reenter the drainage structure during a runoff event.
4. Culvert removal/replacement – Removing and replacing culvert consists of removing the culvert and replacing it with an equal or larger culvert that is capable of handling the predicted increase flows.
5. *Grading roadway – Use a motor grader to grade the roadway in accortance with Forest Service road matinenace specifications. Removing ruts, berms, rocks and debris from the road surface and maintain road surfacing material.* ~~Roadway slope improvement – Outsloping and insloping typically 3% to 5%.~~
6. Culvert Repair – Replace the damaged inlet or outlet sections of pipe or cutoff the damaged end sections without compromising the pipes designed functionality . Pipe requiring cutting may require a cutting torch or an abrasive cutting wheel.

7. *Install slotted riser – Place a 36-inch diameter slotted riser on the inlet of culverts per Forest Service standards to allow the culvert to pass water as the catch basin fills with sediment.*

Purpose:

The purpose of this road treatment is to protect road infrastructure and minimize sediment delivery. The treatment measures proposed will help prevent unacceptable erosion, and minimize degradation to water quality, T&E anadramous fish habitat, and spawning habitat. These watersheds contain FS Sensitive steelhead and Chinook, essential fish habitat for Chinook, and Federally Threatened Coho and their critical habitat.

Protection/safety treatments:

Road burned area warning signs

General description:

This treatment is for the installation of burned area warning signs. Burned area signs consist of a warning to the public identifying of the possible dangers associated with a burned area. It shall contain language specifying of items to be aware of when entering a burn area such as falling trees and limbs, rolling rocks, and flash floods.

Location (suitable) of sites:

Burned area signs – These signs shall be installed at all entries into the fire perimeter. The location of these signs shall be along roads. All signs will be placed facing the direction of travel entering the burn area. The locations of these signs are listed below:

- Elk Creek Road at the 5 mile gate
- Norcross Trailhead
- Sulphur Springs Trailhead
- Johnsons Hunting Ground Trailhead

Design/construction specifications:

- Burned area warning signs along the roads shall measure, at a minimum, 4 feet by 4 feet and consist of 0.08' aluminum, sheeted in high intensity orange with black letters. The BURNED AREA lettering shall be a minimum of 5 inches in height and all remaining lettering, indicating the hazards, shall be a minimum of 3.5 inches in height.
- Ensure maximum visibility and readability of signs warning visitors of the hazards to human life and safety that exist in burned areas.

Purpose:

The purpose of the burned area signs is to warn the public of potential hazards resulting from the effects of the fire, such as rolling rocks, falling trees, road washouts, and flash floods.

Patrols for storm induced runoff

General description:

Roads within the Klamath Theater contain drainage structures that cross streams located in watersheds that have a high to moderate burn severity. These streams now have the potential for increased runoff and debris flows. These increases in flows pose a threat to the existing crossings which may result in plugging culverts or exceeding their maximum flow capacity. If these flows plug drainage structures the result could be massive erosion and debris torrents further down the drainage due to the failure of the fill slope. Also, there is an immediate and future threat to travelers along these roads within the burned area due to the increased potential for rolling and falling rock from burned slopes and increased potential for flash floods and mudflows. With the loss of vegetation normal storm frequencies and magnitudes can more easily initiate rill and gully erosion on the slopes and it is likely that this runoff will cover the roads or cause washouts. These events make for hazardous access along steep slopes and put the safety of users at risk. The patrols are used to identify those road problems such as plugged culverts and washed out roads and to clear, clean, or block those roads that are or have received damage. The storm patrollers shall have access to at least a backhoe and dump truck that can be used when a drainage culvert is plugged or soon to be plugged and to repair any road receiving severe surface erosion.

Location (suitable) of sites:

The patrols should focus on, but not be limited to, the following roads: 16N05, 15N06, 15N03, 15N03A, 15N75, 15N08A. Additional roads within the fire perimieter may be added if a concern for drainage issues occurs.

The patrols should focus on, but not be limited to, the following roads: 13N05, 14N01, 14N01B, 14N05, 15N07, 15N17, 15N17Y. Additional roads within the fire perimieter may be added if a concern for drainage issues occurs.

Design/construction specifications:

1. FS personnel will identify and direct the work. Immediately upon receiving heavy rain and Spring snowmelt the FS will send out patrols to the roads identified in section 'B' to identify road hazard conditions – obstructions such as rocks, sediment, washouts – and plugged culverts so the problems can be corrected before they worsen or jeopardize motor vehicle users. **Note:** Access for storm patrols may be restricted due to snow or Port Orford Cedar concerns.
2. Authorized Forest Service personnel shall bring in equipment necessary to mechanically remove any obstructions from the roads and culvert inlets and catch basins where necessary.
3. All excess material and debris removed from the drainage system shall be placed outside of bank-full channel where it cannot re-enter stream channels.

Purpose:

The purpose of the monitoring is to evaluate the condition of roads for motorized access and to identify and implement additional work needed to maintain or repair damage to road surfaces and flow conveyance structures across roads. These patrols are needed to provide safe access across FS lands and minimize deterioration of water quality due to road failures. Engineering and District personnel will survey the roads within the fire perimeter after high-intensity summer thunderstorms and high intensity winter rains in 2009, 2010 and 2011 and Spring 2009 and 2010 snow-melt. Survey will inspect road surface condition, ditch erosion, and culverts/inlet basins for capacity to accommodate runoff flows.

Norcross safety mitigation

General description:

Norcross Trailhead and Campground burned at high intensity -- none of the facilities remain in functioning condition. The corrals have burned at the bottoms and are unstable, debris from the toilet buildings, including nails, and partially burned picnic tables still remain, presenting a safety hazard. This project would fund a crew to remove remaining corrals and burned debris

The two toilet buildings burned to the ground leaving the underground 750 gallon vaults exposed. This project would pump, fill and crush the vaults.

Location (suitable) of sites:

Norcross Trailhead and Campground was a six site campground with corrals, 2 toilet buildings, picnic tables, fire rings and a water system. It is a popular entry point into the Marble Mountain Wilderness.

Design/construction specifications:

Replacement of permanent structures is not part of this treatment. The project would remove the burned remains of campground facilities including: corrals, picnic tables and toilet buildings. Material would be hauled to the district compound in Happy Camp.

Replacement of permanent structures is not part of this treatment. The project would decommission two toilet vaults, according to county standards:

1. *pump vaults*
2. *fill with rock or sand*
3. *crush and bury the vaults*

Purpose:

Corrals remain standing but posts are burned at the bottom, making them unstable. This could present a safety hazard for anyone leaning on the posts or children playing on or swinging on the posts.

The toilet buildings almost entirely burned – nails and roofing material remain and present a safety hazard for tripping or puncture wounds.

Picnic tables partially burned and are unstable – in this condition they could collapse and present a hazard to anyone trying to use them.

Toilet vaults, filled with human waste, that were left exposed after the structures burned could impact water quality and human safety if they are left untreated.
Norcross Campground is adjacent to Elk Creek, which is a key watershed under the Northwest Forest Plan and is the municipal watershed for the town of Happy Camp. Elk Creek provides habitat for Threatened coho salmon, Sensitive Chinook salmon, and Sensitive steelhead trout. If the vaults are left exposed, they will overflow with winter precipitation, bringing human waste to the surface and potentially into the creek.
The exposed vaults also pose a safety hazard. Open vaults, ~750 gallons, each present a significant hazard for falling into the vault.

I. **Monitoring narrative:**

(Describe the monitoring needs, what treatments will be monitored, how they will be monitored, and when monitoring will occur. A detailed monitoring plan must be submitted as a separate document to the Regional BAER coordinator.)

Part VI – Emergency stabilization treatments and source of funds Interim # 1

			NFS lands			Other lands				All
Line items	**Units**	**Unit cost**	**# of units**	**BAER $**	**Other $**	**# of units**	**Fed $**	**# of Units**	**Non-Fed $**	**Total $**
A. Land treatments										
Noxious weed detect & treat	Acres	38	96	$3648	$0		$0		$0	$3648
Aerial mulch	Acres	1214	681	$826 734	$0		$0		$0	$826 734
Spot mulch & erosion control	Acres	1955	2	$3910	$0		$0		$0	$3910
Insert new items above this line!				$0	$0		$0		$0	$0
Subtotal land treatments				$834 292	$0		$0		$0	$834 292
B. Channel treatments										
In-channel tree felling	Site	150	293.85	$44 078	$0		$0		$0	$44 078
				$0	$0		$0		$0	$0
				$0	$0		$0		$0	$0
Insert new items above this line!				$0	$0		$0		$0	$0
Subtotal channel treat.				$44 078	$0		$0		$0	$44 078
C. Road and trails										
Road drainage reconstruction	Miles	4661	16	$74 576	$0		$0		$0	$74 576
Storm patrols	Days	4198	5	$20 990	$0		$0		$0	$20 990
				$0	$0		$0		$0	$0
Insert new items above this line!				$0	$0		$0		$0	$0
Subtotal road & trails				$95 566	$0		$0		$0	$95 566
D. Protection/safety										
Road warning signs	Each	643	5	$3215	$0		$0		$0	$3215
Norcross Safety Mitigation	Each	12526	1	$12 526	$0		$0		$0	$12 526
				$0	$0		$0		$0	$0
Insert new items above this line!				$0	$0		$0		$0	$0
Subtotal structures				$15 741	$0		$0		$0	$15 741
E. BAER evaluation	Days	1750	5	$8750						
				---			$0		$0	$0
Insert new items above this line!				---	$0		$0		$0	$0
Subtotal evaluation				---	$0		$0		$0	$0
F. Monitoring										
				$0	$0		$0		$0	$0
Insert new items above this line!				$0	$0		$0		$0	$0
Subtotal MONITORING				$0	$0		$0		$0	$0

			NFS lands					Other lands			All
Line items	**Units**	**Unit cost**	**# of units**	**BAER $**	**Other $**		**# of units**	**Fed $**	**# of Units**	**Non-Fed $**	**Total $**
G. Totals				$989 677	$0			**$0**		**$0**	**$989 677**
Previously approved				$130 020							
Total for this request				**$859 657**							

PART VII – APPROVALS

_/s/ [redacted]_______________ ____Oct. 15, 2008______________

Forest Supervisor (signature) Date

_/s/ [redacted]_______________ ____10/20/2008________________

Regional Forester (signature) Date