Post-Fire Roadside Design Strategies: Survey of Practice

Requested by
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Executive Summary

Background

California is increasingly threatened by wildfire that is a result of climate change, drought and other factors. Fire-damaged areas must be repaired and restored quickly to prevent subsequent erosion, ensure proper drainage and preserve water quality. California Department of Transportation's (Caltrans') internal web site currently provides general information and remediation guidance to help practitioners who must respond to roadside fire damage.

To enhance its current offerings, the agency would like to expand this guidance with additional roadside design strategies that maintain safety and limit the costly environmental and infrastructure damage that is the result of fire. Design strategies along roadsides might include guidelines or design tools for landscape design, use of materials and treatments, plant selection and setbacks that can be employed to design a fire-resilient roadside and to rehabilitate a roadside after a fire.

To assist Caltrans in developing this guidance, CTC & Associates conducted an online survey of state departments of transportation (DOTs) to learn about their experience with roadside design strategies for post-fire rehabilitation. A selected group of California fire management experts were also consulted to learn about effective post-fire strategies. Supplementing the survey findings is a sampling of publicly available resources about national and state practices and guidance.

Summary of Findings

Survey of Practice

An online survey was distributed to members of two American Association of State Highway and Transportation Officials (AASHTO) committees:

- Committee on Design.
- Committee on Maintenance.

Respondents representing design and maintenance units from 20 state transportation agencies responded to the survey. Respondents from five states—Arizona, Colorado, Nevada, New Mexico and Virginia—reported that their agencies have developed or adopted roadside-specific treatments and strategies to repair and restore areas damaged by fire. Most of these respondents represented design functional units within their agencies; the respondent from Virginia DOT provided a maintenance perspective. Other transportation agency respondents noted that fires are not an issue in their states that requires implementing post-fire design strategies.

Findings from the five state transportation agencies are presented in the following topic areas:

- Post-fire road treatments.
- Policies and practices in a post-fire response.
- Post-fire roadside rehabilitation projects and guidance.

Post-Fire Road Treatments

Effectiveness of Post-Fire Road Treatments

Using a rating scale of extremely effective, moderately effective or ineffective, respondents evaluated the effectiveness of the following post-fire road treatments:

- Channel debris cleaning (catchment basin cleanout).
- Cross drain/culvert overflow/bypass (drainage relief for road sections or water in the inside ditch to the downhill side of roads especially when the existing culvert is expected to be overwhelmed).
- Culvert inlet/outlet armoring (reduction in scouring around the culvert entrance and exit).
- Culvert removal (planned removal of undersized culverts that would probably fail due to increased flows).
- Culvert replacement (removal and replacement of damaged ditch relief or drainage culverts).
- Culvert riser pipes (allowance for sediment accumulation while allowing water to flow through the culvert).
- Culvert upgrading (increase in flow capacity).
- Ditch armoring (use of gravel or riprap to reduce erosion potential).
- Ditch relief culvert (conduits buried beneath the road surface to relieve drainage in longitudinal ditches at the toe of back slopes).
- Harden drainage features (new or existing corrugated metal pipe armored with riprap to protect the catch basin on inlet and dissipate energy from outlet).
- Hydromulch on road cuts and fills (competition for invasive plants and erosion control on roads).
- Road ditch cleaning (cleaning or reconstruction of ditches to accommodate anticipated increased runoff conditions and construction of new drainage structures to improve existing drainage systems).
- Storm patrol (culvert and drainage structures kept functional by cleaning sediment and debris from the inlet between or during storm events).
- Surface repair (for example, pulling specific ditchline sections, removing outside berms and outslope where appropriate to improve road surface drainage, and removing rock and woody debris blocking ditchline).
- Trash racks (prevention of debris from culverts or downstream structures).

Ratings for these treatments varied significantly among survey respondents. Six treatments received the highest ratings: culvert inlet/outlet armoring, ditch armoring, harden drainage features, road ditch cleaning, storm patrol and surface repair. Three treatments received the lowest ratings: culvert riser pipes, ditch relief culvert, and hydromulch on road cuts and fills.

The respondent from Colorado DOT identified additional post-fire road treatments that were developed to control roadside erosion and debris accumulation following a fire along Highway 550 in southwestern Colorado:

- Install debris fences at the top of a highway slope.

- Reshape channel rundowns with existing boulders and soil.
- Use H-piles as trash racks in channels.
- Revegetate cut slopes, debris fill areas and roadside ditches in between storm events.
- Estimate new runoff flow at culvert crossings to increase pipe and/or channel capacity.

Essential Post-Fire Road Treatments

Respondents from Arizona, Colorado and Nevada DOTs described post-fire road treatments that their agencies found to be the most important elements of a post-fire response to address roadside damage. Essential practices were erosion and sediment control, seeding and reseeding, replacement of damaged roadside features, and debris and trash removal.

Policies and Practices in a Post-Fire Response

Burned Area Emergency Response Program Guidance

The Burned Area Emergency Response (BAER) program supports efforts to stabilize soil to prevent erosion, preserve water quality and mitigate other issues that occur following a fire. Administered by the U.S. Forest Service, BAER facilitates "suppression activity damage repair, burned area rehabilitation and long-term restoration." Of the transportation agencies participating in this survey, Arizona DOT is the only organization that employs BAER guidance in its post-fire program.

The Colorado DOT respondent was unaware of specific projects that implemented BAER guidance, but reported that the agency is part of a cooperative interagency agreement that establishes procedures for coordinating activities affecting the state transportation system and U.S. Forest Service land, including issues of importance such as fire. The agency completed a cooperative strategy for post-fire treatment with the Bureau of Land Management (BLM) following a recent forest fire in Colorado DOT Region 2 near Colorado Springs. The strategy included treatments for erosion control, seeding and planting.

Predictive Modeling of Post-Fire Rehabilitation

None of these five state agencies employs a predictive model that guides future responses to post-fire rehabilitation of roadsides.

Replacing Damaged Roadside Features

Responsibility for rapidly replacing guardrail, sign posts and other roadside equipment following a fire is part of the state and local maintenance response in Arizona, Colorado, Nevada and New Mexico. Nevada DOT has "an active 3R program that identifies roadway needs and upgrades." (The Nevada 3R program is designated for "resurfacing, restoring, rehabilitation or reconstructing" any route or portion of a route on the National Highway System.)

To ensure roadside equipment is replaced as part of a post-fire response, New Mexico DOT inventories the loss, stockpiles materials and warning signs when elements are damaged, and replaces equipment when needed.

Post-Fire Roadside Rehabilitation Projects and Guidance

Colorado DOT established guidelines that addressed roadside erosion along Highway 550 after a fire in southwestern Colorado. Guidance from this successful post-fire roadside rehabilitation project included treatments such as ditch checks, regrading roadside ditches to reduce channel

gradient and divert stormwater, debris cleanout of trash racks and drainage structures, and seeding methods.

Consultation With Fire Management Experts

Fire management experts from California Department of Forestry and Fire Protection (CAL FIRE) and Sierra Pacific Industries were contacted to gain a broader perspective of effective post-fire roadside design strategies. The Sierra Pacific Industries representative did not respond to requests for information. Gianni Muschetto, staff chief of Law Enforcement and Civil Cost Recovery at CAL FIRE, commented on the agency's involvement in a post-fire response, noting that CAL FIRE undertakes fire suppression repair work after a wildfire to repair the damage caused by the suppression work, not by the fire itself. According to Muschetto, the goals of these efforts are to repair any damage CAL FIRE incurred during a wildfire and to prevent further resource damage. Tasks that CAL FIRE typically conducts follow:

- Trees that threaten roads or habitable structures are flagged, mapped and removed by professional fallers. Roads plugged with trees or rocks are opened as soon as possible. Downed power and phone lines are flagged, mapped and reported to the appropriate utility company.
- Public road and traffic signs damaged by the fire are recorded and reported to the appropriate public agency for replacement. Those damaged by suppression crews may need to be replaced by CAL FIRE before completing repair work. Suppression damage to hard surfaced roads is recorded, and the appropriate agency liaison officer is notified. Damage to paved roads is addressed through the compensation claims process.
- Each year, CAL FIRE and the California Geological Survey (CGS) co-lead interagency teams called Watershed Emergency Response Teams (WERTs) to determine values-at-risk and emergency protection measures for a few selected fires with a high risk of post-fire debris flows, flooding and/or rockfall. Protection measures can be communicated quickly to local emergency management agencies (such as flood control districts).

<u>Post-Fire Road Treatments</u>

Muschetto reviewed the effectiveness of several post-fire road treatments that may be considered in CAL FIRE's post-fire rehabilitation and restoration efforts, some of which are standard WERT recommendations:

- **Extremely effective:** Channel debris cleaning, cross drain or culvert overflow or bypass, culvert replacement or upgrading, ditch relief culvert, road ditch cleaning, storm patrol and surface repair.
- **Moderately effective:** Trash racks.
- **Not used:** Culvert inlet/outlet armoring, culvert removal, culvert riser pipes, ditch armoring, harden drainage features, and hydromulch on road cuts and fills.

The five most important post-fire road treatments to address roadside fire damage are:

- After fire suppression repair work, re-establish road drainage structures (such as waterbars and rolling dips) for native surface roads.
- Grade native surface roads to the original road prism when possible, applying water from water tenders as needed.
- Breach or remove berms created by suppression activities to facilitate road drainage.

- Clean culverts that became plugged with soil or slash during suppression work.
- If the road was previously outsloped, re-establish the outslope to the previous condition.

Policies and Practices in a Post-Fire Response

Muschetto described the following policies and practices that are part of a CAL FIRE post-fire response:

- CAL FIRE uses BAER guidance, specifically the 2006 BAER treatments catalog, in its post-fire response. WERTs coordinate post-fire evaluation work with BAER teams when both are deployed to the same fire.
- Modeling is used for WERT activities, such as post-fire flood flows, debris flows and surface erosion, but not to determine when to conduct fire suppression repair.
- Technical specialists record the location of damaged public road and traffic signs, and report the information to the appropriate public agency for replacement. CAL FIRE may need to replace safety features damaged by suppression crews.
- Fire suppression repair workshops are held for CAL FIRE foresters and others conducting fire suppression repair.

A WERT training guide provides procedures for conducting post-fire hazard evaluations, including predictive modeling and practices for post-fire debris flow.

Related Research and Resources

BAER Guidance

Several BAER resources describe road treatments and emergency response tools, in particular the 2006 Burned Area Emergency Response Treatments Catalog, which includes the primary use for each treatment, the purpose and objective of the treatment, suitable locations for treatment implementation and cost factors. The 2010 BAER tools web page summarizes these treatments and provides links to more details in the catalog; a related U.S. Forest Service web site examines various methods to estimate post-fire peak flow and erosion. A 2013 report assesses the effectiveness of BAER road treatments used in three wildfires, and a 2009 report synthesizes post-fire road treatment information to assist BAER specialists in making road rehabilitation decisions.

Post-Fire Road Treatments and Tools

A 2015 primer for New Mexico communities highlights a range of road, hillslope and channel treatments and also provides a series of treatment selection tables to assist decision-makers when choosing the appropriate treatments for various applications.

In addition, a sampling of citations looks more closely at specific road treatments, including debris flow modeling, erosion and sediment control, hydrology and slope stabilization. A U.S. Geological Survey web site provides post-fire debris flow hazard assessments for selected fires in the western United States using geospatial data related to basin morphometry, burn severity, soil properties and rainfall characteristics to estimate the probability and volume of debris flows. A 2010 journal article evaluates empirical models used to predict the probability and volume of post-fire debris flows in the Intermountain West. A 2015 University of Idaho Extension report for forest landowners and managers describes the impact of fire on forest ecosystems, addressing the mechanics of fire and its effects on vegetation, soils and watersheds. Peak flow modeling is

described in a 2016 U.S. Forest Service report, and a 2016 journal article describes an online spatial database that rapidly generates modelling data sets modified by user-supplied soil burn severity maps to assist remediation teams with post-fire wildfire flooding and erosion control. A 2010 U.S. Forest Service synthesis of post-fire treatment effectiveness reviews research, monitoring and product development related to post-fire hillslope emergency stabilization treatments.

General Guidance

A 2013 journal article describes post-fire treatments and decision tools developed to assist land managers with post-fire assessment and treatment decisions, such as prediction models, research syntheses, equipment and methods for field measurements, reference catalogs and tools for calculating resource valuation and cost–benefit analysis. A 2019 Caltrans report summarizes a vulnerability assessment that was developed to demonstrate the long-term impacts of climate change and extreme weather on the state highway system. Although the report does not provide post-fire guidelines, it demonstrates the effectiveness of weather-responsive decisions for road closure actions by maintenance crews. An online resource hosted by CAL FIRE provides a current map of all major emergency incidents in California, including wildfires, floods, earthquakes and hazardous material spills.

Gaps in Findings

Although several state transportation agencies responding to the survey are from high-fire states, their experience with post-fire design is very limited. Only five participating states reported having developed post-fire roadside design strategies or practices. Among these five agencies, experience with BAER guidance was limited. None of these states uses a predictive model to address future responses to post-fire roadside rehabilitation.

Next Steps

Moving forward, Caltrans could consider:

- Examining the post-fire roadside design strategies and resources provided by respondents for application in California.
- Following up with survey respondents, specifically:
    - Arizona DOT for information about the agency's use of BAER practices.
    - Colorado DOT Region 2 and Region 5 staff for information about the strategies and post-fire response to two separate fires, specifically for a November 2018 presentation that detailed treatments for erosion control, seeding and planting after a fire in the Colorado Springs area.
- Gathering information from agencies that did not respond to the survey to obtain further guidance and perspectives.
- Reviewing the information from the CAL FIRE representative about the agency's involvement in a post-fire response.
- Examining the BAER guidance materials and other resources on post-fire roadside design strategies for potential design practices and tools.
- Gathering land surveying data that shows existing fiber optic lines to allow Caltrans to map the locations of third-party utilities.

Detailed Findings

Background

California is increasingly threatened by wildfire that is a result of climate change, drought and other factors. Remediation efforts that repair and restore areas damaged by fire are becoming more and more commonplace. These measures must be put into action quickly and effectively to prevent subsequent erosion, restore proper drainage and preserve water quality. The California Department of Transportation (Caltrans) would like to expand the general information and remediation guidance currently available on its internal web site to assist practitioners tasked with responding to roadside fire damage. While a number of fire remediation resources are available through the U.S. Forest Service, California Department of Forestry and Fire Protection (CAL FIRE) and Federal Emergency Management Agency, Caltrans is interested in identifying roadside-specific treatments and strategies that can be summarized and presented in an easily accessible toolbox format.

To inform the development of this toolbox, Caltrans is seeking information from other state departments of transportation (DOTs) that have specific design guidance or tools related to post-fire roadside rehabilitation. Also of interest are specific DOT projects that exemplify successful practices in post-fire rehabilitation, and the plans, specifications and cost estimates for those projects. In addition to querying state DOTs, Caltrans is interested in learning from California fire experts about their experiences with post-fire roadside rehabilitation.

To assist Caltrans in this information-gathering effort, CTC & Associates conducted an online survey of state DOTs that examined roadside design strategies used by these agencies for post-fire rehabilitation. In addition, a selected group of California experts in fire management were consulted to learn about post-fire strategies to repair and restore roadside areas damaged by fire. To supplement the findings from the survey and consultation with subject matter experts, researchers conducted a literature search that included domestic in-progress and completed research and other resources that describe the strategies employed by federal, state and other agencies for post-fire roadside rehabilitation. Findings from these efforts are presented in this Preliminary Investigation in three areas:

- Survey of practice.
- Consultation with fire management experts.
- Related research and resources.

Survey of Practice

An online survey was distributed to members of two American Association of State Highway and Transportation Officials (AASHTO) committees:

- Committee on Design.
- Committee on Maintenance.

Survey questions are provided in Appendix A. The full text of survey responses is presented in a supplement to this report.

Summary of Survey Results

Respondents representing design and maintenance units from 20 state transportation agencies responded to the survey:

- Alabama.
- Arizona.
- Colorado.
- Connecticut.
- Delaware.
- Florida.
- Idaho.
- Illinois.
- Kansas.
- Maryland.
- Michigan.
- Montana (two responses).
- Nevada (two responses).
- New Mexico.
- North Dakota.
- Oklahoma.
- Pennsylvania.
- Utah.
- Virginia.
- Wisconsin.

In five of these states—Arizona, Colorado, Nevada, New Mexico and Virginia—respondents reported that their agencies have developed or adopted roadside-specific treatments and strategies to repair and restore areas damaged by fire. Most of these respondents represented design functional units within their agencies; the respondent from Virginia DOT provided a maintenance perspective. Respondents from some of the state transportation agencies that have not developed or adopted formal roadside-specific strategies noted that fires are not an issue in their states that requires implementing remediation strategies.

Survey results from the five state transportation agencies are summarized below in the following topic areas:

- Post-fire road treatments.
- Policies and practices in a post-fire response.
- Post-fire roadside rehabilitation projects.
- Guidance for post-fire roadside design strategies.

When available, supplementary resources are provided at the end of each topic area. These resources were received from survey respondents or sourced through a limited literature search.

Post-Fire Road Treatments

Effectiveness of Post-Fire Road Treatments

Respondents evaluated the effectiveness of the following post-fire road treatments using a rating scale of extremely effective, moderately effective or ineffective:

- Channel debris cleaning (catchment basin cleanout).
- Cross drain/culvert overflow/bypass (drainage relief for road sections or water in the inside ditch to the downhill side of roads especially when the existing culvert is expected to be overwhelmed).
- Culvert inlet/outlet armoring (reduction in scouring around the culvert entrance and exit).
- Culvert removal (planned removal of undersized culverts that would probably fail due to increased flows).

- Culvert replacement (removal and replacement of damaged ditch relief or drainage culverts).
- Culvert riser pipes (allowance for sediment accumulation while allowing water to flow through the culvert).
- Culvert upgrading (increase in flow capacity).
- Ditch armoring (use of gravel or riprap to reduce erosion potential).
- Ditch relief culvert (conduits buried beneath the road surface to relieve drainage in longitudinal ditches at the toe of back slopes).
- Harden drainage features (new or existing corrugated metal pipe armored with riprap to protect the catch basin on inlet and dissipate energy from outlet).
- Hydromulch on road cuts and fills (competition for invasive plants and erosion control on roads).
- Road ditch cleaning (cleaning or reconstruction of ditches to accommodate anticipated increased runoff conditions and construction of new drainage structures to improve existing drainage systems).
- Storm patrol (culvert and drainage structures kept functional by cleaning sediment and debris from the inlet between or during storm events).
- Surface repair (for example, pulling specific ditchline sections, removing outside berms and outslope where appropriate to improve road surface drainage, and removing rock and woody debris blocking ditchline).
- Trash racks (prevention of debris from culverts or downstream structures).

Ratings for individual treatments varied significantly among survey respondents. Treatments that received the highest ratings were culvert inlet/outlet armoring, ditch armoring, harden drainage features, road ditch cleaning, storm patrol and surface repair. Treatments that received the lowest ratings included culvert riser pipes, ditch relief culvert, and hydromulch on road cuts and fills. Table 1 summarizes survey responses.

Table 1. Effectiveness of Post-Fire Road Treatments

State	Channel Debris Cleaning	Cross Drain/Culvert Overflow/Bypass	Culvert Inlet/ Outlet Armoring	Culvert Removal	Culvert Replacement
Arizona	Ineffective	Ineffective	Moderately effective	Not used	Ineffective
Colorado	Moderately effective	Moderately effective	Moderately effective	Moderately effective	Extremely effective
Nevada	Extremely effective	Extremely effective	Extremely effective	Extremely effective	Extremely effective
New Mexico	Moderately effective	Moderately effective	Moderately effective	Ineffective	Moderately effective
Virginia	Moderately effective	Moderately effective	Moderately effective	Moderately effective	Moderately effective

Table 1. Effectiveness of Post-Fire Road Treatments, continued

State	Culvert Riser Pipes	Culvert Upgrading	Ditch Armoring	Ditch Relief Culvert	Harden Drainage Features
Arizona	Not used	Ineffective	Moderately effective	Not used	Moderately effective
Colorado	Not used	Moderately effective	Moderately effective	Not used	Moderately effective
Nevada	Extremely effective	Extremely effective	Extremely effective	Extremely effective	Extremely effective
New Mexico	Not used	Extremely effective	Moderately effective	Not used	Moderately effective
Virginia	Moderately effective	Moderately effective	Extremely effective	Moderately effective	Moderately effective

Table 1. Effectiveness of Post-Fire Road Treatments, continued

State	Hydromulch on Road Cuts/Fills	Road Ditch Cleaning	Storm Patrol	Surface Repair	Trash Racks
Arizona	Not used	Moderately effective	Moderately effective	Moderately effective	Extremely effective
Colorado	Ineffective	Moderately effective	Extremely effective	Moderately effective	Moderately effective
Nevada	Extremely effective	Extremely effective	Extremely effective	Extremely effective	N/R
New Mexico	Ineffective	Moderately effective	Moderately effective	Moderately effective	Moderately effective
Virginia	Extremely effective	Extremely effective	Moderately effective	Moderately effective	Moderately effective

N/R No response.

Additional Post-Fire Road Treatments

The respondent from Colorado DOT identified additional post-fire road treatments that were used to control roadside erosion and debris accumulation following a 2018 fire along Highway 550 in southwestern Colorado (see Supporting Document):

- Installing debris fences at the top of a highway slope.
- Reshaping channel rundowns with existing boulders and soil.
- Using H-piles as trash racks in channels.
- Revegetating cut slopes, debris fill areas and roadside ditches in between storm events.
- Estimating new runoff flow at culvert crossings to increase pipe and/or channel capacity.

Essential Post-Fire Road Treatments

Respondents from three of the states participating in the survey—Arizona, Colorado and Nevada—described post-fire road treatments that their agencies found to be the most important elements of a post-fire response to address roadside damage. Erosion and sediment control, seeding and reseeding, replacing damaged roadside features, and debris and trash removal were essential practices. The respondent from Nevada DOT noted that the agency does not have a lot of vegetation requirements for roadsides. Most of the seeding is placed outside of the clear zone using native species. Rock mulch and shouldering material are used from the edge of the pavement to the clear zone. Table 2 summarizes recommended post-fire road treatment strategies.

Table 2. Essential Road Treatments in a Post-Fire Response

Treatment	State	Description
Drainage Maintenance	Arizona	N/R
Erosion Control	Arizona	Temporary erosion control.
Pavement Patching and Restriping	Nevada	N/R
Replacement of Damaged Roadside Features	Nevada	Damaged guardrail, sign posts, shouldering material and other roadside features.
Sediment Control	Arizona, Colorado	*Colorado*: • Ditch checks and sediment control measures. • Stormwater runoff velocity reduction through regrading roadside swales to reduce gradient.
Seeding/Reseeding	Arizona, Colorado, Nevada	*Arizona*. Reseeding. *Colorado*. Seeding with site-appropriate native seed mix, possibly with soil scarification, and soil retention blanket, bonded fiber matrix, turf reinforcement mat or other erosion control treatments. *Nevada*. Most seeding placed outside the clear zone using native plants.
Slope Stabilization	Colorado	Using on-site boulders to stabilize slopes, especially at concentrated flow areas such as at outlets and inlets.
Trash Control	Arizona, Colorado	*Arizona.* Roadside cleanup. *Colorado*. Trash and debris removal from drainage structures such as inlets, culverts, catch basins and trash racks.

N/R No response.

Supporting Document

Colorado

Highway 550 Burn Restoration, Colorado Department of Transportation, October 2018. https://drive.google.com/file/d/1VAMd6qqvnsmXv81wA02IZlEHQ900-oyF/view?usp=sharing
Colorado DOT prepared an informal set of guidelines for Region 5 staff in Durango, Colorado, in response to roadside erosion issues with a Highway 550 right of way following a fire in 2018. The agency recommended the following strategies for consideration:

- Install debris fences at the top of the highway slope.
- Reshape channel rundowns with existing boulders and soil.
- Use H-piles as trash racks in channels.
- Revegetate cut slopes, debris fill areas and roadside ditches in between storm events.
- Estimate new runoff flow at culvert crossings to increase capacity of pipe and/or channels.

Policies and Practices in a Post-Fire Response

Some respondents from the five states that have adopted post-fire roadside design strategies briefly described policies and practices implemented by their agencies in the following areas:

- Burned Area Emergency Response (BAER) program guidance.
- Predictive modeling of post-fire rehabilitation.
- Replacing damaged roadside features.

Burned Area Emergency Response Program Guidance

Arizona DOT is the only agency participating in the survey that employed guidance associated with the BAER program, which is the U.S. Forest Service's post-fire program. The respondent was unable to provide specific details about Arizona DOT's use of these practices, noting that the agency "generally follows" BAER guidance.

The Colorado DOT respondent was unaware of specific projects that implemented BAER guidance, but provided information about other state and federal interagency efforts:

- Colorado DOT is part of a cooperative interagency memorandum of understanding (MOU) that establishes procedures for coordinating activities affecting the state transportation system and U.S. Forest Service land, including issues of importance such as fire (see Supporting Document below).
- The agency completed a cooperative strategy for post-fire treatment with the Bureau of Land Management (BLM) following a recent forest fire in Colorado DOT Region 2 near Colorado Springs. A joint-agency fire treatment presentation was made to Colorado DOT Environmental staff in November 2018 about treatments for erosion control, seeding and planting in the Colorado Springs area. (*Note*: A request to the Colorado DOT Region 2 office for the presentation was unanswered. See **Post-Fire Roadside Rehabilitation Projects**, page 14, for follow-up contact information.)

Predictive Modeling of Post-Fire Rehabilitation

None of these five state agencies employs a predictive model that guides future responses to post-fire rehabilitation of roadsides.

Replacing Damaged Roadside Features

State and local maintenance crews in Arizona, Colorado, Nevada and New Mexico are responsible for ensuring the rapid replacement of guardrail, sign posts and other roadside equipment as part of a post-fire response. The Nevada DOT respondent noted that the agency has "an active 3R program that identifies roadway needs and upgrades." (The Nevada 3R program is designated for "resurfacing, restoring, rehabilitation or reconstructing" any route or portion of a route on the National Highway System.) The respondent added that Nevada roadways are constantly maintained and serviced by the agency's maintenance crews, keeping roadway clear zones free of trash and debris during pre- and post-construction.

To ensure roadside equipment is replaced as part of a post-fire response, New Mexico DOT inventories the loss, stockpiles materials and warning signs when elements are damaged, and replaces equipment when needed.

Supporting Document

Colorado

Memorandum of Understanding Related to Activities Affecting the State Transportation System, National Forest System Lands and Bureau of Land Management National System of Public Lands in the State of Colorado, Bureau of Land Management, Colorado Department of Transportation, Federal Highway Administration and Forest Service, U.S. Department of Agriculture, 2016.
https://www.codot.gov/programs/environmental/documents/federal-lands-mou-2016
The purpose of this MOU is to "establish procedures for coordinating activities affecting the state transportation system and lands administered by U.S. Forest Service/BLM within the State of Colorado." The MOU includes general processes for coordinating projects among agencies, from design through construction, operations and maintenance.

Post-Fire Roadside Rehabilitation Projects

Only the Colorado DOT respondent addressed successful post-fire roadside rehabilitation projects, pointing to the previously mentioned project that addressed roadside erosion along Highway 550 after a fire in 2018 in southwestern Colorado (see Supporting Document, page 13), and the 2018 project that addressed erosion control, seeding and planting treatments in response to a Colorado Springs area fire. (*Note*: The Colorado DOT Region 2 office did not respond to a request for the presentation about the Colorado Springs area fire.) The respondent recommended contacting the following regional and headquarters maintenance staff for more information about these projects and Colorado DOT's fire strategies and response:

Colorado DOT Headquarters: Maintenance

Tyler Weldon
Project Manager
tyler.weldon@state.co.us

Ken Howlett
Roadside Vegetation Specialist, Water Quality
kenneth.howlett@state.co.us

Colorado DOT Region 2 (near Colorado Springs)

Lesley Mace
Project Manager/Engineer
lesley.mace@state.co.us

Colorado DOT Region 5 (southwestern Colorado)

Danielle Wilkinson
Water Quality Specialist
danielle.wilkinson@state.co.us

Guidance for Post-Fire Roadside Design Strategies

While Colorado DOT does not have formal plans or specifications for successful projects that repaired roadside fire damage, the respondent noted the informal guidelines developed in response to the 2018 fire along Highway 550 in southwest Colorado (see Supporting Document, page 13). Treatments suggested in these guidelines include ditch checks, seeding methods, regrading roadside ditches to reduce channel gradient and divert stormwater, and debris cleanout of trash racks and drainage structures.

Consultation With Fire Management Experts

To gain a broader perspective of effective post-fire roadside design strategies, we contacted fire management representatives from CAL FIRE and Sierra Pacific Industries. Although we did not receive feedback directly from the initial CAL FIRE contacts, a senior representative from the organization provided information on behalf of CAL FIRE; those comments are summarized below. The Sierra Pacific Industries representative did not respond to requests for information.

California Department of Forestry and Fire Protection (CAL FIRE)

Gianni Muschetto, staff chief of Law Enforcement and Civil Cost Recovery at CAL FIRE, noted that CAL FIRE undertakes fire suppression repair work after a wildfire to repair the damage caused by the suppression work, not by the fire itself. Suppression repair applies to damage done by suppression forces only. According to Muschetto, the goals of these efforts are to repair any damage CAL FIRE incurred during a wildfire and to prevent further resource damage.

Because of public safety concerns, hazard trees threatening roads or habitable structures are flagged, mapped and removed by professional fallers. Roads plugged with trees or rocks are opened as soon as possible. Downed power and phone lines are flagged, mapped and reported to the appropriate utility company.

Public road and traffic signs damaged by the fire are recorded and reported to the appropriate public agency for replacement. Those damaged by suppression crews may need to be replaced by CAL FIRE before completing repair work. Suppression damage to hard surfaced roads is recorded, and the appropriate agency liaison officer is notified. Damage to paved roads is addressed through the compensation claims process.

For a few selected fires per year that have a high risk of post-fire debris flows, flooding and/or rockfall, CAL FIRE and the California Geological Survey (CGS) co-lead interagency teams called Watershed Emergency Response Teams (WERTs) to determine values-at-risk and emergency protection measures that can be rapidly communicated to local emergency management agencies (such as flood control districts). WERTs are somewhat like BAER teams except that biological and cultural resources are not inventoried. Roads and highways are often considered values-at-risk, and protection measures are recommended, such as storm patrol during strong winter storm events.

Post-Fire Road Treatments

Effectiveness of Post-Fire Road Treatments

Muschetto addressed the effectiveness of several post-fire road treatments that may be considered in CAL FIRE's post-fire rehabilitation and restoration efforts, briefly noting CAL FIRE's involvement in some of them:

Extremely Effective

- Channel debris cleaning (WERT recommendations only).
- Cross drain or culvert overflow or bypass (after fire suppression work has impacted the road surface, reinstall waterbars or rolling dips on native surface roads for adequate road drainage).
- Culvert replacement (if damaged by fire suppression work).
- Culvert upgrading (could be a WERT recommendation).
- Ditch relief culvert (replace if damaged).
- Road ditch cleaning (may be a suppression repair).
- Storm patrol (standard WERT recommendation).
- Surface repair (standard suppression repair task).

Moderately Effective

- Trash racks (could be a WERT recommendation; requires effective winter maintenance).

Not Used

- Culvert inlet/outlet armoring.
- Culvert removal.
- Culvert riser pipes.
- Ditch armoring.
- Harden drainage features.
- Hydromulch on road cuts and fills.

Essential Post-Fire Road Treatments

The five most important post-fire road treatments to address roadside fire damage follow:

- After fire suppression repair work, re-establish road drainage structures (such as waterbars and rolling dips) for native surface roads.

- Grade native surface roads to the original road prism when possible, applying water from water tenders as needed.
- Breach or remove berms created by suppression activities to facilitate road drainage.
- Clean culverts that became plugged with soil or slash during suppression work.
- If the road was previously outsloped, re-establish the outslope to the previous condition.

Policies and Practices in a Post-Fire Response

As part of the post-fire road repair and restoration, CAL FIRE uses guidance from BAER, specifically the 2006 BAER treatments catalog (see page 19 for this citation). WERTs coordinate post-fire evaluation work with BAER teams when both are deployed to the same fire.

Modeling is used for WERT activities, such as post-fire flood flows, debris flows and surface erosion, but it is not used to determine when to conduct fire suppression repair. Muschetto noted that only a few fires have WERT deployments per year.

Fire suppression repair technical specialists record where public road and traffic signs were damaged by the fire and report the information to the appropriate public agency for replacement. CAL FIRE may need to replace safety features damaged by suppression crews.

Muschetto added that fire suppression repair workshops are held for CAL FIRE foresters and others conducting fire suppression repair. During these trainings, CAL FIRE uses a detailed WERT guidance document that is updated annually (see Supporting Document below).

Supporting Document

Procedural Guide for Watershed Emergency Response Teams, California Natural Resources Agency, California Department of Forestry and Fire Protection, and California Geological Survey, April 27, 2020.
See Attachment A.
This WERT training reference provides procedures for conducting post-fire hazard evaluations.
From page 12 of the guide:

> The primary goal of a Watershed Emergency Response Team (WERT) effort is to reduce risk by reporting observations made during rapid, limited and general geologic and hydrologic hazard assessment. These observations are not intended to be comprehensive or conclusive, but rather to serve as a preliminary tool to assist emergency management agencies in development of more detailed post-fire emergency response plans. The WERT effort consists of a rapid assessment that (1) identifies on-site and downstream significant threats to lives and property from debris flows, flooding, rockfall, erosion, road hazards and other fire-related problems; and (2) provides general findings that emergency management agencies can use to complete their own more detailed evaluations, and develop comprehensive emergency action plans (EAPs) and mitigations.

Predictive modeling and practices for post-fire debris flow are detailed in the appendices, specifically screening criteria (Appendix B, beginning on page 30 of the guide, page 33 of the PDF) and methods (Appendix D, beginning on page 38 of the guide, page 42 of the PDF).

Related Research and Resources

The following citations present a sampling of completed research and other resources about post-fire roadside design strategies in the following topic areas:

- BAER guidance.
- Post-fire road treatments and tools.
- General guidance.

Citations may be further organized as national or state guidance.

BAER Guidance

What is BAER?, Burned Area Emergency Response, National Interagency Fire Center, undated.
https://www.nifc.gov/BAER/
The National Interagency Fire Center (NIFC) "support[s] many different kinds of emergency responses, including floods, hurricanes, earthquakes, volcano eruptions, riots, terrorist attacks (9/11 and Oklahoma City bombing) [and] radios to Haiti. However, [the center's] primary focus is on wildland firefighting." Among the fire programs administered by the NIFC is the BAER program. *From the web site*:

> Wildfires can cause complex problems, from severe loss of vegetation and soil erosion, to a decrease in water quality and possible flash flooding. The Burned Area Emergency Response [p]rogram addresses stabilization and rehabilitation of these and other post-wildfire problems, in order to protect public safety and prevent further degradation of the landscape and to mitigate post-fire damages to cultural resources.
>
> Emergency stabilization is part of a holistic approach to address post wildfire issues, which also includes suppression activity damage repair, burned area rehabilitation and long-term restoration. In order to facilitate this process, a designated BAER team will begin the process by assessing an area post-fire.
>
> BAER assessment team composition is determined both by the size of the fire and the nature of values potentially threatened by post-fire effects. Generally, specialists in soils, hydrology, geology, engineering, wildlife, botany and archeology assess the fire's effects and predict the post-fire effects. Each resource specialist brings a unique perspective to the BAER process, to help the team rapidly determine whether the post-fire effects constitute urgent threats to human life, safety, property or critical natural and cultural resources and to produce an integrated plan to respond to those threats.

Effectiveness of Post-Fire Burned Area Emergency Response (BAER) Road Treatments: Results From Three Wildfires, Randy Foltz and Peter Robichaud, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, October 2013.
https://www.fs.fed.us/rm/pubs/rmrs_gtr313.pdf
From the abstract:

> Little information is available on the effectiveness of various post-fire road treatments [after wildland fires], thus this study was designed to evaluate common treatments implemented after fire. The 2006 Tripod Complex, 2007 Cascade Complex and the 2008 Klamath Theater Complex Fires were selected because of their large size and extensive use of road treatments. Two of the three locations had below average precipitation and all three had

precipitation that did not achieve the post-fire road treatment design storms. With this amount of precipitation testing, all of the treatments we monitored met the design objectives. All three of the locations had large soil loss in the first year after the fire followed by a quick recovery of ground cover to 40% to 50% at the end of year one. Soil loss from roadside hydromulch was not statistically significant from control (no treatment) on the Tripod Complex sites. Soil loss at the Cascade Complex sites was a statistically significant difference on the straw mulch compared to the control (no treatment), but there were no different pairwise differences among straw mulch, Polyacrylamide (PAM) and Woodstraw. This suggests that the amount of cover is more important than the type of cover. Three studies and five years after beginning the studies, we think the best approach to assessing the effectiveness of post-fire BAER road treatments is to gain a limited knowledge of many sites along a road system rather than a detailed knowledge of a few sites.

Post-fire road treatments used at each location follow:

- Tripod Complex Fire: armored dips, culvert replacement, ditch cleaning, drain dips, harden drainage features and hydromulch (beginning on page 2 of the report, page 8 of the PDF).
- Cascade Complex Fire: cutslope mulch treatments (beginning on page 23 of the report, page 29 of the PDF).
- Klamath Theater Complex Fire: culvert and catch basin characteristics (beginning on page 30 of the report, page 36 of the PDF).

The effectiveness of these treatments is addressed following the discussion of each site.

BAER Road Treatments: Burned Area Emergency Response Tools, Forest Service, U.S. Department of Agriculture, last modified August 2010.
https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Treatments/
From the web site: The BAER specialists have been using various road treatments to increase flow and debris flow capacity of road drainage structures due to wildland fires. Depending on regional climate and fire regimes, different road treatments were preferred. Chapter 4 of Napper (2006) describes implementation details of most of these treatments, including primary use, description, purpose, suitable sites, cost and construction specifications. A discussion of each of the BAER specialist's preferred treatments is discussed below: culvert inlet/outlet modification (culvert modifications), culvert removal, culvert upgrading (culvert modifications), relief culvert, armored ford crossing (low-water stream crossing), channel debris cleaning (catchment-basin cleanout), ditch cleaning/armoring, culvert risers (riser pipes), debris/trash rack, road closure, road decommissioning, rolling dip/water bar, storm patrol (storm inspection and response), hazard/warning sign and outsloping road. Terms within parentheses were used by Napper (2006).

Related Resource:

Burned Area Emergency Response Treatments Catalog, Carolyn Napper, National Technology and Development Program, Forest Service, U.S. Department of Agriculture, December 2006.
https://www.fs.fed.us/eng/pubs/pdf/BAERCAT/lo_res/06251801L.pdf
From the introduction:

> BAER treatments for land, channels, roads/trails, and protection and safety are discussed in the catalog. Readers will learn the primary treatment use, the purpose and

objective of the treatment, suitable locations for treatment implementation and cost factors. Available treatment effectiveness information is provided to share known benefits and limitations of the treatments, although such information may be limited or anecdotal. BAER teams should validate specific treatment effectiveness in the affected area prior to recommending its use.

Chapter 4 provides detailed guidance about the following road treatments:

- Outsloping (beginning on page 105 of the report, page 113 of the PDF).
- Rolling dips (beginning on page 109 of the report, page 117 of the PDF).
- Overflow structures (beginning on page 113 of the report, page 121 of the PDF).
- Low-water stream crossings (beginning on page 121 of the report, page 129 of the PDF).
- Culvert modifications (beginning on page 127 of the report, page 135 of the PDF).
- Debris racks and deflectors (beginning on page 131 of the report, page 139 of the PDF).
- Riser pipes (beginning on page 139 of the report, page 147 of the PDF).
- Catchment-basin cleanout (beginning on page 145 of the report, page 153 of the PDF).
- Storm inspection and response (beginning on page 149 of the report, page 157 of the PDF).
- Trail stabilization (beginning on page 153 of the report, page 161 of the PDF).
- Road decommissioning (beginning on page 159 of the report, page 167 of the PDF).

Guidance for each treatment includes a discussion of suitable sites, design, construction specifications, cost, effectiveness and monitoring recommendations.

Post-Fire Peak Flow and Erosion Estimation: Burned Area Emergency Response Tools, Forest Service, U.S. Department of Agriculture, last modified May 2009.
https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/
From the web site:

There is a general consensus that post-fire streamflow increases, often with orders of magnitude larger than pre-fire events, especially for watersheds of high and moderate burn severity. Burned watersheds can yield runoff that quickly produces flash floods. The largest post-fire peak flow often occurs in smaller watersheds. Increased post-fire flow may transport debris that was produced by the fire. Often, the post-fire flow is a combination of water flow and debris, called bulking. Road treatments should be prescribed and implemented if existing drainage structures cannot handle the post-fire runoff increase.

The following methods are used by BAER specialists to estimate post-fire runoff. The description of each method includes the input requirements, process steps, advantages, disadvantages and example results.

- USGS regression methods (https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/USGS/).

- Curve number (CN) methods (https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/CN/).
- Rule of Thumb by Kuyumjian (https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/Rule_Thumb/).
- TR-55 (https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/TR55/).
- ERMiT (Erosion Risk Management Tool, https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/ERMiT/).
- FERGI (Fire Enhanced Runoff and Gully Initiation (FERGI) Model, https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/FERGI/).
- WATBAL (Watershed Response Model for Forest Management (WATBAL), https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/WATBAL/).

A Synthesis of Post-Fire Road Treatments for BAER Teams: Methods, Treatment Effectiveness and Decisionmaking Tools for Rehabilitation, Randy Foltz, Peter Robichaud and Hakjun Rhee, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, 2009.
https://www.fs.fed.us/rm/pubs/rmrs_gtr228.pdf
From the abstract:

> We synthesized post-fire road treatment information to assist BAER specialists in making road rehabilitation decisions. We developed a questionnaire; conducted 30 interviews of BAER team engineers and hydrologists; acquired and analyzed gray literature and other relevant publications; and reviewed road rehabilitation procedures and analysis tools. Post-fire road treatments are implemented if the values at risk warrant the treatment and based on regional characteristics, including the timing of first damaging storm and window of implementation. Post-fire peak flow estimation is important when selecting road treatments. Interview results indicate that USGS [U.S. Geological Survey] methods are used for larger watersheds (>5 mi^2) and NRCS [Natural Resources Conservation Service] [c]urve [n]umber methods are used for smaller watersheds (<5 mi^2). These methods are not parameterized and validated for post-fire conditions. Many BAER team members used their own rules to determine parameter values for USGS regression and NRCS CN methods; therefore, there is no consistent way to estimate post-fire peak flow. Many BAER road treatments for individual stream crossings were prescribed based on road/culvert surveys, without considering capacities of existing road structure and increased post-fire peak flow. For all regions, rolling dips/water bars, culvert upgrading and ditch cleaning/armoring are the most frequently used road treatments. For U.S. Forest Service Regions 1 and 4, culvert upgrading is preferred, especially for fish-bearing streams. For U.S. Forest Service Region 3, culvert removal with temporary road closure and warning signs is preferred. Except for culverts, insufficient data is available on other road treatments to estimate their capacity and to evaluate their effectiveness.

To better understand road treatment effects in a post-fire environment, researchers made the following recommendations:

- Post-fire peak flow estimation methods vary. Further research is needed to ensure that the BAER specialists can easily compare pre- to post-fire peak flow changes.
- There exists insufficient knowledge of the capacity of BAER road treatments to pass estimated flood and debris flows. Design tools should be developed to estimate flood and debris flow capacity of BAER road treatments (e.g., ford crossings and ditch

cleaning) so that the BAER specialists can select road treatments based on post-fire peak flow changes and the road treatment capacities.
- Insufficient data is available to evaluate road treatment effectiveness. More systematic monitoring and further research are recommended to evaluate road treatment effectiveness.

Post-Fire Road Treatments and Tools

The citations below are organized into the following topic areas:

- General guidance.
- Debris flow modeling.
- Erosion and sediment control.
- Hydrology.
- Hydromulching.
- Slope stabilization.
- Soil burn severity.
- Vegetation management.

General Guidance

National Research and Practices

Chapter 4.3—Post-Wildfire Management, Jonathan Long, Carl Skinner, Susan Charnley, Ken Hubbert, Lenya Quinn-Davidson and Marc Meyer, *Science Synthesis to Support Socioecological Resilience in the Sierra Nevada and Southern Cascade Range*, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, 2014.
https://ucanr.edu/sites/fire/files/288116.pdf
From the introduction:

> Wildfires trigger management decisions about post-fire interventions to mitigate potentially undesirable outcomes. Because uncharacteristically large patches of high-severity wildfire are expected to occur in the synthesis area in coming decades, these post-fire decisions may have significant implications for the resilience of socioecological systems. Post-fire situations entail several types of responses, including a short-term response through the Burned Area Emergency Response (BAER) program to protect life, property, water quality and ecosystems; potential salvage logging of burned trees; and longer term restoration efforts.

This technical report provides information to “inform forest managers, stakeholders, and interested parties concerned with promoting socioecological resilience.” Short-term management actions and recommendations are discussed (beginning on page 189 of the chapter, page 3 of the PDF) and include hillslope erosion and sedimentation mitigation, debris flows and road treatment guidance.

State Research and Practices

New Mexico

Post-Fire Treatments: A Primer for New Mexico Communities, New Mexico State University, Forest Service, U.S. Department of Agriculture, U.S. Army Corps of Engineers, Natural Resources Conservation Services, New Mexico State Forestry and High Water Mark LLC, 2015.
https://www.afterwildfirenm.org/additional-resources/site-pdfs/post-fire-treatments-pdf
A range of road, trail, hillslope and channel treatments are described in this guide, with a discussion of suitable sites, costs and effectiveness for each treatment. A series of treatment selection tables begins on page 36 of the guide, ranking the applicability of each treatment for various functions such as erosion and sediment control, drainage relief for culverts and debris flow.

Debris Flow Modeling

Emergency Assessment of Post-Fire Debris-Flow Hazards, U.S. Geological Survey, undated.
https://landslides.usgs.gov/hazards/postfire_debrisflow/
From the web site:

> Wildfire can significantly alter the hydrologic response of a watershed to the extent that even modest rainstorms can produce dangerous flash floods and debris flows. The USGS conducts post-fire debris-flow hazard assessments for select fires in the [w]estern U.S. We use geospatial data related to basin morphometry, burn severity, soil properties and rainfall characteristics to estimate the probability and volume of debris flows that may occur in response to a design storm.

Maps at the site show the "likelihood of debris-flow generation and estimates of flow magnitude in locations where debris flows initiate [but] do not predict downstream impacts, potential debris-flow runout paths and the areal extent of debris-flow or flood inundation."

"Predicting the Probability and Volume of Postwildfire Debris Flows in the Intermountain Western United States," Susan Cannon, Joseph Gartner, Michael Rupert, John Michael, Alan Rea and Charles Parrett, *Geological Society of America Bulletin*, Vol. 122, pages 127-144, 2010.
https://www.researchgate.net/publication/249527492_Predicting_the_probability_and_volume_of_postwildfire_debris_flows_in_the_intermountain_western_United_States
From the abstract: Empirical models to estimate the probability of occurrence and volume of postwildfire debris flows can be quickly implemented in a geographic information system (GIS) to generate debris-flow hazard maps either before or immediately following wildfires. Models that can be used to calculate the probability of debris-flow production from individual drainage basins in response to a given storm were developed using logistic regression analyses of a database from 388 basins located in 15 burned areas located throughout the U.S. Intermountain West. The models describe debris-flow probability as a function of readily obtained measures of areal burned extent, soil properties, basin morphology, and rainfall from short-duration and low-recurrence-interval convective rainstorms. A model for estimating the volume of material that may issue from a basin mouth in response to a given storm was developed using multiple linear regression analysis of a database from 56 basins burned by eight fires. This model describes debris-flow volume as a function of the basin gradient, aerial burned extent and storm rainfall. Applications of a probability model and the volume model for hazard assessments are illustrated using information from the 2003 Hot Creek fire in central Idaho. The predictive strength of the

approach in this setting is evaluated using information on the response of this fire to a localized thunderstorm in August 2003. The mapping approach presented here identifies those basins that are most prone to the largest debris-flow events and thus provides information necessary to prioritize areas for postfire erosion mitigation, warnings and prefire management efforts throughout the Intermountain West.

Erosion and Sediment Control

California

San Diego 2007 Fire Restoration, California Department of Transportation, 2018.
https://design.onramp.dot.ca.gov/downloads/design/files/lastandards/2007 San Diego Fire Remediation.pdf
This presentation largely comprises photographs of fire damage and erosion control practices along with maps of the Rice, Witch and Harris fires. Revegetation guidelines are provided as part of an erosion control treatment, including a quick cover seed list for hydroseeding (slide 6), erosion control materials and applications (slide 7), and a seed application analysis (slide 8).

"After the Fire," WHR Southwest, Inc., *The Monthly Dirt*, October–November 2017.
https://design.onramp.dot.ca.gov/downloads/design/files/lastandards/The Monthly Dirt -Oct-Nov 2017.pdf
This publication for property owners and municipalities presents measures to prepare and safeguard fire-damaged soils and slopes during stormwater runoff events. Practices of interest are summarized below:

1. Protect existing plant cover and establish vegetative cover on all bare or disturbed soil and slopes around your property before the winter rains. Plant materials and different types of mulches can be used to protect soil and slopes from the impact of falling rain and storm water runoff. *Note*: Seeding and/or mulching are not recommended in wild land areas, only on disturbed soils on fire breaks, around structures, and alongside access roads and driveways. Grass and/or plantings should be native or non-invasive non-native plant materials.
2. Do not disturb soil and slopes during the rainy season.
3. Evaluate stormwater conveyances, swales, ditches, roadways, long driveways, and even fire breaks, especially in fire damaged areas.
4. Monitor and maintain all existing and planned runoff, erosion and sediment control measures.
5. Use emergency/temporary practices such as sand bags, brush and slash, plastic sheeting and hand dug drainage ditches, etc., with extreme caution or don't use at all.
6. Prune or remove high hazard fire damaged trees capable of falling onto structures or roads.
7. Prepare for an increased threat of rockfall in some areas because of damage to vegetation and shallow rocky soils and slopes in affected watersheds.

Additional dos and don'ts for post-fire restoration include:

Dos

- Evaluate and map out locations of existing and/or pre-fire subsurface drainage, irrigation and utility facilities on your property, including underground pipe drains and

outlets, roof runoff/gutter drain outlets, culverts, irrigation systems, utilities, etc. Determine if they are still operable and/or degree of damage, if any.

- Install sediment control measures, such as straw wattles, mulching, plantings, slash, sediment traps and/or other properly designed and located sediment control measures, if necessary.
- Replant damaged landscapes with drought tolerant, fire retardant native plants with resprouting ability.
- Monitor and maintain fire and fuel breaks that may have been created by firefighters on your property. Waterbars/breaks should be provided and maintained on these fire control measures so that runoff water does not concentrate and cause erosion.
- Monitor and maintain all existing and planned erosion, sediment and drainage control measures, including vegetative treatments, before, during and after all future rainfall events.

Don’ts

- Don’t be too quick to remove fire damaged vegetation, including trees that were not completely burned.
- Don’t’ use materials such as broken asphalt or concrete, inorganic debris or other objects as an emergency or permanent erosion control measure, especially if these materials can come in contact with runoff water, natural drainages and stream courses.
- Don’t cover fire-damaged slopes with plastic sheeting in an attempt to prevent slope failure and protect bare or disturbed soil from next year’s rainfall.
- Don’t disturb the hydrophobic soil layer that forms on some soils following fire on slopes susceptible to land sliding.
- Don’t disturb potentially unstable slopes, especially those in fault areas and/or with signs of previous movement or known historic instability.

Idaho

After the Burn: Assessing and Managing Your Forestland After a Wildfire, Yvonne C. Barkley, University of Idaho Extension, August 2015.
https://www.uidaho.edu/-/media/UIdaho-Responsive/Files/Extension/topic/forestry/After-the-Burn-2015.pdf
This report for forest landowners and managers describes the impact of fire on forest ecosystems, addressing fire mechanics in general as well as its effects on vegetation, soils and watersheds. Erosion control is discussed in Appendix II (beginning on page 62 of the report, page 33 of the PDF), including a brief discussion of road treatments (pages 73-74 of the report, pages 38-39 of the PDF).

Hydrology

Post-Wildfire Hydrology, Bob Hassmiller, Pacific Northwest Region 6, Forest Service, U.S. Department of Agriculture, 2016.
https://design.onramp.dot.ca.gov/downloads/design/files/lastandards/Post wildfire hydrology B Hassmiller.pdf
With a focus on wildfire incidents in the western United States, this presentation addresses the BAER program, post-fire hydrology and erosion. Creating a watershed model (beginning on slide 22) requires:

- Step 1: Pour point watersheds on critical values.
- Step 2. Finalize burn severity map (based on the Burned Area Reflectance Classification (BARC)).
- Step 3. Complete GIS identity process to stamp hydro soil group, burn severity and watershed area as inputs to peak flow model.

An example of peak flow modeling begins on slide 27, including the following process steps:

1. Storm characteristics: Pick design storm (convective versus snowmelt) for each pour point.
2. Rainfall excess: Input area (acres) of hydrologic soil group.
3. Time of concentration: Channel length$^{1.15}$/7700$*$(elevation difference)$^{0.38}$.
4. Post-fire runs: Change CN by burn severity.

"Rapid-Response Tools and Datasets for Post-Fire Remediation: Linking Remote Sensing and Process-Based Hydrological Models," M.E. Miller, W.J. Elliot, M. Billmire, P.R. Robichaud and K.A. Endsley, *International Journal of Wildland Fire*, Vol. 25, pages 1061-1073, 2016.
https://www.fs.fed.us/rm/pubs_journals/2016/rmrs_2016_miller_m002.pdf
From the abstract: Post-wildfire flooding and erosion can threaten lives, property and natural resources. Increased peak flows and sediment delivery due to the loss of surface vegetation cover and fire-induced changes in soil properties are of great concern to public safety. Burn severity maps derived from remote sensing data reflect fire-induced changes in vegetative cover and soil properties. Slope, soils, land cover and climate are also important factors that require consideration. Many modelling tools and datasets have been developed to assist remediation teams, but process-based and spatially explicit models are currently underutilized compared with simpler, lumped models because they are difficult to set up and require properly formatted spatial inputs. To facilitate the use of models in conjunction with remote sensing observations, we developed an online spatial database that rapidly generates properly formatted modelling datasets modified by user-supplied soil burn severity maps. Although assembling spatial model inputs can be both challenging and time-consuming, the methods we developed to rapidly update these inputs in response to a natural disaster are both simple and repeatable. Automating the creation of model inputs facilitates the wider use of more accurate, process-based models for spatially explicit predictions of post-fire erosion and runoff.

Related Resource:

> **Rapid Response Erosion Database: Spatial WEPP Model Inputs Generator**, Michigan Tech Research Institute, Forest Service, U.S. Department of Agriculture and NASA, undated.
> https://geodjango.mtri.org/geowepp/
> The previous citation referred to this spatial database, which was designed to rapidly merge soil burn severity maps from BAER teams with spatial land cover and soils data to support post-fire remediation.

Hydromulching

"Post-Fire Mulching for Runoff and Erosion Mitigation, Part I: Effectiveness at Reducing Hillslope Erosion Rates," Peter Robichaud, Sarah Lewis, Joseph Wagenbrenner, Louise Ashmun and Robert Brown, *Catena*, Vol. 105, pages 75-92, June 2013.
https://www.sciencedirect.com/science/article/abs/pii/S0341816212002524?via%3Dihub
Part I of this two-part study evaluated the effectiveness of various mulches in reducing post-fire runoff and erosion rates. Part II examined the effects of wheat straw mulch and hydromulch on reducing runoff and erosion rates in small matched catchments. *From the introduction*:

> Specific objectives for part I were to: 1) determine if mulches of wheat straw, wood strands, wood-based hydromulch, needle cast or native seeding result in smaller sediment yields from treated hillslope plots than untreated plots in the first post-fire year; 2) determine if any of the treatments affected sediment yields beyond the first post-fire year; 3) relate rainfall characteristics (amount and intensity) to post-fire hillslope erosion rates; and 4) compare mulch treatment application and performance characteristics (ground cover, longevity, and effects on vegetation recovery) for potential links to any measured reduction in erosion rates. Part II of this study (Robichaud et al., 2013) explores the effects of wheat straw mulch and hydromulch on reducing runoff and erosion rates in small matched catchments.

Highlights of the study's conclusions follow:

- Wheat straw mulch, wood strand mulch and hydromulch treatments initially increased total ground cover to more than 60% but not all the mulches reduced sediment yields nor did the effectiveness of the mulches last the same amount of time. Wood strands reduced annual sediment yields by 79% and 96% during the first post-fire year at the two fires where it was tested and also reduced sediment yields in various later post-fire years at both fires. Wheat straw mulch reduced annual sediment yields by 97% to 99% in the first post-fire year at two of the four fires where it was tested, and, to a lesser degree, in the third and fourth post-fire years at one of the fires. Hydromulch did not reduce sediment yields compared to the controls at either of the fires where it was studied. In general, the effects of these mulches on sediment yields corresponded with their longevity. The measured reductions in sediment yields mostly were attributed to the increase in total cover, which included the persistent straw or wood strand mulch cover as well as the increases in litter and vegetation.
- Post-fire year and total precipitation were significantly related to sediment yields. The erosion rates decreased with the amount of time since fire and increased with higher rainfall intensities.
- Vegetative cover in the control plots increased over time, as did total ground cover, although the increase was much less pronounced at one of the four fires. The increase in vegetation over time was not linear or consistent on all fires, and the amount of

vegetation was influenced by the amount of precipitation as well as the fire characteristics and general conditions.

Hydromulching, Natural Resources Conservation Services, U.S. Department of Agriculture, 2012.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_061752.pdf
From the fact sheet:

When is hydromulching used?
Hydromulch is used on severely burned or otherwise highly erosive areas with 20% to 60% slopes. Hydromulching is an expensive erosion control method and therefore is generally limited to treating high risk areas to protect valuable properties, surface water supply sources or important habitat. Due to its expense conventional mulching is generally used on slopes less than 20%. Use of ground applied hydromulch is limited to areas within 300 feet of the roads or trails that are necessary to provide access for the application equipment.

Uniform aerial application of hydromulch is difficult to accomplish and as a result has proven less effective for erosion control, so it is seldom recommended. Hydromulch is generally not recommended where there is more than 25% surface rock cover, in areas where there is appreciable needlecast or where there is good potential for regrowth of vegetation within the first year after a fire.

Methods and materials?
The type and amount of mulch and tackifier is selected to provide a minimum of 70% surface cover that will remain in place for at least one growing season.

Hydroseeding?
When seed is applied with the mulch (hydroseeding), split applications are generally more effective than applying all materials in one pass. About 500 pounds of mulch per acre is applied with the seed (and fertilizer if recommended) in the first pass followed by a second application of 1,500 to 2,000 pounds of mulch and tackifier.

Slope Stabilization

Reducing Post-Fire Hillslope Erosion, Peter Robichaud, Science Briefing, Forest Service, U.S. Department of Agriculture, February 26, 2014.
https://www.fs.fed.us/rm/boise/AWAE/briefing/AWAE_Science_Briefings-ReducingPostFireHillslopeErosion.pdf
From the brief: The effectiveness of post-fire treatments at reducing sediment yields was measured with sediment fences on hillslope plots for 4 to 7 years after four wildfires in the western United States. Wheat straw mulch, wood strand mulch and hydromulch treatments initially increased total ground cover to more than 60%, but not all the mulches reduced sediment yields nor did the effectiveness of the mulches last the same amount of time. Wood strands reduced annual sediment yields by 79% and 96% during the first post-fire year at the two fires where it was tested and also reduced sediment yields in various later post-fire years at both fires. Wheat straw mulch reduced annual sediment yields by 97% to 99% in the first post-fire year at two of the four fires where it was tested. Wheat straw mulch was also effective in the third and fourth post-fire years at one of the fires. Hydromulch did not reduce sediment yields compared to the controls at either of the fires where it was studied. In general, the effects of these mulches on sediment yields corresponded with their longevity. The additional proportion of ground cover provided applied mulch is the primary treatment factor that appears to control reductions in sediment yields and hillslope erosion.

Post-Fire Treatment Effectiveness for Hillslope Stabilization, Peter Robichaud, Louise Ashmun and Bruce Sims, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, August 2010.
https://www.fs.fed.us/rm/pubs/rmrs_gtr240.pdf
From the abstract:

> This synthesis of post-fire treatment effectiveness reviews the past decade of research, monitoring and product development related to post-fire hillslope emergency stabilization treatments, including erosion barriers, mulching, chemical soil treatments and combinations of these treatments. In the past 10 years, erosion barrier treatments (contour-felled logs and straw wattles) have declined in use and are now rarely applied as a post-fire hillslope treatment. In contrast, dry mulch treatments (agricultural straw, wood strands, wood shreds, etc.) have quickly gained acceptance as effective, though somewhat expensive, post-fire hillslope stabilization treatments and are frequently recommended when values-at-risk warrant protection. This change has been motivated by research that shows the proportion of exposed mineral soil (or conversely, the proportion of ground cover) to be the primary treatment factor controlling post-fire hillslope erosion. Erosion barrier treatments provide little ground cover and have been shown to be less effective than mulch, especially during short-duration, high-intensity rainfall events. In addition, innovative options for producing and applying mulch materials have adapted these materials for use on large burned areas that are inaccessible by road. Although longer-term studies on mulch treatment effectiveness are ongoing, early results and short-term studies have shown that dry mulches can be highly effective in reducing post-fire runoff and erosion. Hydromulches have been used after some fires, but they have been less effective than dry mulches in stabilizing burned hillslopes and generally decompose or degrade within a year.

Three types of post-fire treatments are addressed: emergency stabilization, rehabilitation and restoration. A discussion of erosion barrier treatments begins on page 10 of the report (page 16 of the PDF) and includes methods to quantify barrier performance. Mulch treatments (dry and hydromulches) are presented beginning on page 15 of the report (page 21 of the PDF) in addition to chemical soil surface treatments (page 27 of the report, page 33 of the PDF) and treatment combinations (page 29 of the report, page 35 of the PDF). Summaries of related research are part of the discussion, including mulch impacts on soil temperature (page 16 of the report, page 22 of the PDF) and on post-fire revegetation (page 23 of the report, page 29 of the PDF). Guidance also includes management implications, such as choosing and monitoring post-fire treatments (beginning on page 30 of the report, page 36 of the PDF).

Soil Burn Severity

Field Guide for Mapping Post-Fire Soil Burn Severity, Annette Parsons, Peter Robichaud, Sarah Lewis, Carolyn Napper and Jess Clark, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture, October 2010.
https://www.fs.fed.us/rm/pubs/rmrs_gtr243.pdf
From the abstract:

> Following wildfires in the United States, the U.S. Department of Agriculture and U.S. Department of the Interior mobilize Burned Area Emergency Response (BAER) teams to assess immediate post-fire watershed conditions. BAER teams must determine threats from flooding, soil erosion and instability. Developing a post-fire soil burn severity map is an important first step in the rapid assessment process. It enables BAER teams to prioritize field reviews and locate burned areas that may pose a risk to critical values within or downstream of the burned area. By helping to identify indicators of soil conditions that

> differentiate soil burn severity classes, this field guide will help BAER teams to consistently interpret, field validate and map soil burn severity.

The guide presents representative ground conditions, soil characteristics and vegetation density models to help users determine the soil burn severity classification at a specific location. Topics discussed for mapping soil burn severity include the role of remote sensing and GIS (beginning on page 4 of the guide, page 8 of the PDF), assessment guidelines (beginning on page 7 of the guide, page 11 of the PDF) and soils assessment for soil burn severity classes (beginning on page 9 of the guide, page 13 of the PDF). Additional resources available in the guide include a discussion of common post-fire hydrology and erosion prediction models (beginning on page 31 of the guide, page 35 of the PDF) and considerations for mapping soil burn severity (beginning on page 37 of the guide, page 41 of the PDF).

Vegetation Management

California

Post-Fire Revegetation, California Department of Transportation, July 2019.
https://maintenance.onramp.dot.ca.gov/directors-orders/major-damage-and-directors-orders
Guidance for site analysis, culvert areas and soil stabilization are included. *From the introduction*:

> The purpose of this guidance is to provide information for Caltrans [l]andscape [a]rchitects and [e]ngineers to quickly respond to emergency projects to prevent erosion control damage to the highway system after a wild fire.

Fire Recovery Guide, California Native Plant Society, 2019.
https://www.cnps.org/wp-content/uploads/2019/08/cnps-fire-recovery-guide-2019.pdf
From the introduction: California has experienced its deadliest and most severe wildfire seasons in recent history. Although wildfire is a natural part of California's ecosystems, the changing fire regimes are something new—a "new normal" that demands forward-thinking and thoughtful solutions. Municipalities, state leaders, scientists and neighbors are working quickly to advance our knowledge, protect human life, minimize property damage and carefully manage our sensitive natural resources.

This updated statewide guide is intended to support California's ongoing efforts to skillfully address our wildfire challenges. With input from leading experts, it offers science-based guidance for those working toward recovery of their land while reducing risk going forward.

Idaho

Weed Suppressive Soil Bacteria to Reduce Cheatgrass and Improve Vegetation Diversity on ITD Rights-of-Way, Ann Kennedy, Idaho Transportation Department, June 2017.
https://rosap.ntl.bts.gov/view/dot/34952
Weed-suppressive bacteria (WSB) *Pseudomonas fluorescens* strain ACK55 was evaluated as a treatment for reducing downy brome (cheatgrass) on roadsides along Interstate 84 (I-84), I-86 and US-95 in Idaho. Weed management is briefly addressed as a best management practice in post-fire restoration (page 68 of the report; page 86 of the PDF):

> Post-fire restoration can be successful when WSB are included in the restoration plan. The removal of the thick residue that can build up from these weeds exposes a large quantity of

weed seed ready to germinate. When coupled with herbicides, perhaps surface tillage, and drill seeding of natives, WSB can be an integral part of the restoration of these lands.

Seasonal actions are listed for using WSB in post-fire restoration on Idaho roadsides.

General Guidance

National Research and Practices

"Tools to Aid Post-Wildfire Assessment and Erosion-Mitigation Treatment Decisions," Peter R. Robichaud and Louise E. Ashmun, *International Journal of Wildland Fire*, Vol. 22, pages 95-105, 2013.
https://forest.moscowfsl.wsu.edu/engr/library/Robichaud/Robichaud2013g/2013g.pdf
This article includes a discussion of post-fire treatment assessment and decision tools. *From the abstract*:

> A considerable investment in post-fire research over the past decade has improved our understanding of wildfire effects on soil, hydrology, erosion and erosion-mitigation treatment effectiveness. Using this new knowledge, we have developed several tools to assist land managers with post-wildfire assessment and treatment decisions, such as prediction models, research syntheses, equipment and methods for field measurements, reference catalogues and databases of past-practice, and spreadsheets for calculating resource valuation and cost–benefit analysis. These tools provide relevant science to post-fire assessment teams and land managers in formats that often can be directly entered into assessment and treatment decision-making protocols.

State Research and Practices

California

Caltrans Climate Change Vulnerability Assessments, Technical Report, District 10, California Department of Transportation, 2019.
https://merritt.cdlib.org/d/ark%3A%2F13030%2Fm5rj9rdm/1/producer%2Fd10-technical-report.pdf
This report summarizes a vulnerability assessment that was developed to demonstrate the long-term impacts of climate change and extreme weather on the state highway system (SHS). Although the pilot did not result in fire prevention guidelines, it demonstrates the effectiveness of weather-responsive decisions for road closure actions by Caltrans maintenance crews. The assessment "is the first step in a multi-part effort to identify SHS exposure to climate change, to identify the consequences and impacts of climate change to the system, and to prioritize actions based upon those impacts. A final prioritization step will be key to identifying which assets are at the greatest risk and should be prioritized first for more detailed, [Adaptation Decision-Making Assessment Process] style assessments and risk-based design responses."

Section 6 (beginning on page 36 of the report, page 37 of the PDF) describes the impact of wildfire on California infrastructure and includes a discussion of ongoing wildfire modeling efforts. Section 9 (beginning on page 59 of the report, page 60 of the PDF) describes District 10's emergency response after the 2018 Ferguson Fire, specifically to flooding and debris flows. Repair and restoration efforts "consisted of rebuilding and repairing the failed slope areas and roadway sections, replacing existing damaged culverts and inlets, installing flume down drains at various locations, and overlaying the roadway with asphalt."

Recovering From Wildfire: A Guide for California's Forest Landowners, Kristen Shive, Division of Agriculture and Natural Resources, University of California, July 2017.
https://anrcatalog.ucanr.edu/pdf/8386.pdf
Among the topics discussed in this publication for landowners is protecting property from damage due to erosion. Post-fire management assessment and mitigation are discussed (beginning on page 6 of the publication), including revegetation (beginning on page 6 of the publication), soil erosion (beginning on page 10 of the publication) and roads (beginning on page 12 of the publication). Seeding, contour log felling and mulch are mitigation options discussed for soil erosion. Road mitigation options are summarized below:

To protect the road system:

- Armor culvert inlets or bridge abutments.
- Patrol roads during significant rain events to clean out clogged ditches and culverts.

To slow and divert water:

- Construct rolling dips or waterbars for limited-use roads.
- Evaluate road shape and remove berms on the outside edge of the road's driving surface to allow dispersal of water.

To trap sediment and debris:

- Install sediment traps below culverts to prevent sediment from leaving the site.
- Install trash racks at culvert inlets to block woody debris from plugging the culvert. These will need to be regularly checked for debris and cleared if necessary.

To increase drainage:

- Enlarge the current ditch system.
- Replace damaged culverts or install larger culverts where debris flows are likely to exceed existing capacity.

Incidents Overview, California Department of Forestry and Fire Protection, undated.
https://www.fire.ca.gov/incidents/
This web page provides a current map of all major emergency incidents in California, including large, extended-day wildfires (10 acres or greater); floods; earthquakes; and hazardous material spills. Incidents reported at the web site include those managed by CAL FIRE and other partner agencies. The total number of wildfires in the state, acres burned, fatalities and structures damaged or destroyed are also summarized. The web page also provides access to the state incident database and to a forecast of the 2020 fire season.

Contacts

CTC contacted the individuals below to gather information for this investigation.

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Appendix A: Survey Questions

The following survey was distributed to members of two American Association of State Highway and Transportation Officials (AASHTO) committees:

- Committee on Design.
- Committee on Maintenance.

Post-Fire Roadside Design Strategies

(Required) Has your agency developed or adopted roadside-specific treatments and strategies to repair and restore areas damaged by fire?

- Yes (directs the respondent to the questions below)
- No (directs the respondent to the **Wrap-Up** section)

1. The following are possible post-fire road treatments. For each treatment, please indicate which statement applies to your agency:
    - Extremely effective
    - Moderately effective
    - Ineffective
    - Not used

Post-Fire Road Treatments

- Channel debris cleaning (catchment basin cleanout)
- Cross drain/culvert overflow/bypass (designed to provide drainage relief for road sections or water in the inside ditch to the downhill side of roads especially when the existing culvert is expected to be overwhelmed)
- Culvert inlet/outlet armoring (reduce scouring around the culvert entrance and exit)
- Culvert removal (planned removal of undersized culverts that would probably fail due to increased flows)
- Culvert replacement (removal and replacement of damaged ditch relief or drainage culverts)
- Culvert riser pipes (allow for sediment accumulation while allowing water to flow through the culvert)
- Culvert upgrading (increase flow capacity)
- Ditch armoring (use of gravel or riprap to reduce erosion potential)
- Ditch relief culvert (conduits buried beneath the road surface to relieve drainage in longitudinal ditches at the toe of back slopes)
- Harden drainage features (armor new/existing corrugated metal pipe with riprap to protect the catch basin on inlet and dissipate energy from outlet)
- Hydromulch on road cuts and fills (provide competition for invasive plants and minimize erosion on roads)
- Road ditch cleaning (clean or reconstruct ditches to accommodate anticipated increased runoff conditions and construction of new drainage structures to improve existing drainage systems)
- Storm patrol (keep culvert and drainage structures functional by cleaning sediment and debris from the inlet between or during storm events)

- Surface repair (could include pulling specific ditchline sections, and removing outside berms and outslope where appropriate to improve road surface drainage; also removing rock and woody debris blocking ditchline)
- Trash racks (installed to prevent debris from clogging culverts or downstream structures)

2. Does your agency employ post-fire road treatments to repair roadside fire damage that are not identified in Question 1?
   - No
   - Yes (please describe these treatments)
3. Please describe the five post-fire road treatments your agency has found to be the most important elements of a post-fire response to address roadside fire damage.

   Treatment One:

   Treatment Two:

   Treatment Three:

   Treatment Four:

   Treatment Five:
4. Does your agency employ guidance associated with the U.S. Forest Service's post-fire program, Burned Area Emergency Response (BAER)?
   - No
   - Yes (please describe how your agency employs the BAER guidance)
5. Does your agency employ a predictive model that guides future responses to post-fire rehabilitation of roadsides?
   - No
   - Yes (Please name and describe this model and provide documentation about it, if available, by providing links or sending any files not available online to carol.rolland@ctcandassociates.com.)
6. Please describe your agency's practices for ensuring the rapid replacement of guardrail and sign posts as part of a post-fire response.
7. Please describe one or two of your agency's most successful post-fire roadside rehabilitation projects.
8. Does your agency have plans, specifications and estimates (or something similar) you can provide for successful projects that repaired roadside fire damage?
   - No
   - Yes (Please provide links to documents or send any files not available online to carol.rolland@ctcandassociates.com.)
9. Has your agency developed formal, written guidance for post-fire roadside design strategies?
   - No
   - Yes (Please provide links to documents or send any files not available online to carol.rolland@ctcandassociates.com.)

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.