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

<u>California</u>

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.

<u>Idaho</u>

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.

PROCEDURAL GUIDE
FOR

WATERSHED EMERGENCY RESPONSE TEAMS

California Natural Resources Agency
California Department of Forestry and Fire Protection
California Geological Survey

April 27, 2020

Table of Contents

List of Abbreviations

ALERT	Automatic Local Evaluation in Real Time
BAER	USFS Burned Area Emergency Response
BARC	Burned Area Reflectance Classification
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BOF	California State Board of Forestry and Fire Protection
CAL FIRE	California Department of Forestry and Fire Protection
Cal OES	California Office of Emergency Services
Caltrans	California Department of Transportation
CEG	Certified Engineering Geologist
CGS	California Geological Survey
DEM	Digital Elevation Model
DWR	California Department of Water Resources
EAP	Emergency Action Plan
EHR	Erosion Hazard Rating
EIA	Emergency Incident Awareness
ERMiT	Erosion Risk Management Tool
EWP	Emergency Watershed Protection
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPS	Global Positioning System
ICS	Incident Command System
IMT	Incident Management Team
JFO	Joint Field Office
LiDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
PG	Professional Geologist
PE	Professional Engineer
PPE	Personal Protective Equipment
RPF	Registered Professional Forester
RWQCB	Regional Water Quality Control Board
SOC	State Operations Center
SRA	State Responsibility Area
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VARs	Values-at-Risk
WERT	Watershed Emergency Response Team
WPP	CAL FIRE Watershed Protection Program

1. Introduction

The following is a procedural guide for initiating and conducting post-fire hazard evaluations by State Watershed Emergency Response Teams (WERTs). The WERT process represents a decades-long evolution in how the California Department of Forestry and Fire Protection (CAL FIRE) and the California Geological Survey (CGS), along with other state, federal and local cooperators, identify and mitigate hydrologic and geologic risk following wildfire. The WERT process leverages the best professional judgement of technical specialists (e.g., engineering geologists, hydrologists, and civil engineers) with spatially-explicit data and model results to strategically focus post-fire evaluations. Post-fire risk reduction must be achieved in a timely fashion, and prior to stressing storm events. This goal is rapidly accomplished by following an explicit, step-wise process that is scalable to the size of the incident and to the magnitude of risk. These procedural steps are contained herein.

2. Background Information

Post wildfire evaluation work on non-federal lands in California has been conducted by the California Department of Forestry and Fire Protection (CAL FIRE) in numerous ways over the past 60+ years, beginning with Emergency Watershed Protection (EWP) assessments. As per statute, CAL FIRE can conduct post burn rehabilitation work as part of its EWP program. Public Resources Code Sections 4675 and 4676 authorize CAL FIRE to establish and maintain vegetative cover on watershed lands and to maintain watercourse channels free of natural impediments or destructive materials during peak flood flows. The intent of activities conducted under this authority is to (1) conserve water and soil, and (2) prevent destructive floods. Examples of past work include post-fire seeding for erosion control in high hazard areas and channel clearance to prevent overbank flooding in populated areas.

Early CAL FIRE EWP efforts generally consisted of aerial applications of annual ryegrass seed to create surface cover following large wildfires. However, emphasis shifted after 2000 toward deployment of interagency teams of hydrologists and geologists to conduct post-fire evaluations of risk to lives, property, and critical infrastructure. The emergency protective measures recommended by these teams has likewise evolved. Aerial seeding has given way to utilization of early warning systems (e.g., use of ALERT rain gauge and NWS radar data), and notifications to ensure timely warning and evacuation of residents who could be impacted by post-fire debris flows and flooding.

State agency teams, patterned after USFS Burned Area Emergency Response (BAER) teams, were formed in 2007 for numerous large fires in southern California, and in 2008 for fires throughout the state (denoted as “State Emergency Assessment Teams” or

"SEATs"). This process, however was viewed as expensive and slow in developing emergency protection measures. Little post-fire evaluation work was conducted from 2009 to 2014, largely due to a limited number of large fires in southern California, lack of Presidential major disaster declarations, and limited funding for this type of work.

In 2007, CAL FIRE Watershed Protection Program staff developed a draft prioritization form for use in identification of fires that could present the highest risk to lives and property. This approach was revisited in 2015, and has become the basis for WERT deployment.

3. Watershed Emergency Response Teams (WERT) Goals and Objectives

Watershed Emergency Response Teams (WERTs) are assembled and deployed to better coordinate local assistance to ensure a rapid response in identification of significant life-safety and property hazards resulting from wildfires.[1] The primary goal is to avoid or reduce the risk posed by post-fire hazards downslope or downstream of burn areas.

WERT objectives are completed in a rapid step-wise manner to achieve the goal of risk reduction. Figure 1 provides an overview of WERT objectives and these are explained in greater specificity in the detailed procedures portion of the document. A fundamental step in the WERT process is the identification and characterization of significant Values-at-Risk (VARs). VARs are the values or resources at risk of damage or loss by post-wildfire geologic and/or hydrologic hazards (Calkin et al., 2007, Figure 2). The WERT process utilizes a qualitative approach for evaluating risk to these values. It relies on a combination of modeling and best professional judgement to guide relative risk determination and the development of emergency protection measures. The final step in risk reduction is to communicate the evaluation findings to local jurisdictions responsible for emergency planning and preparedness.

[1] The term significant is defined as at least a moderate risk to either life-safety or property associated with post-fire debris flows, flooding, or rockfall based on the rapid evaluation approach of the WERT; effects produced from these events will be greater than those broadly defined as "nuisance impacts."

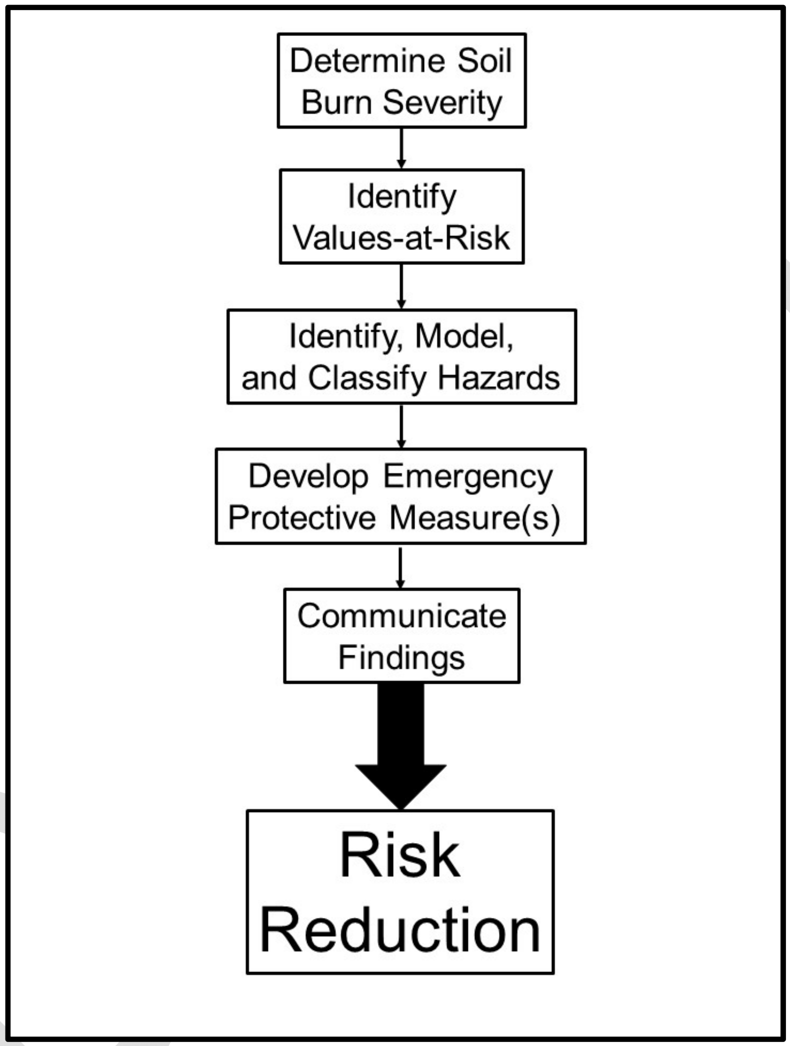

Figure 1. WERT goals and objectives.

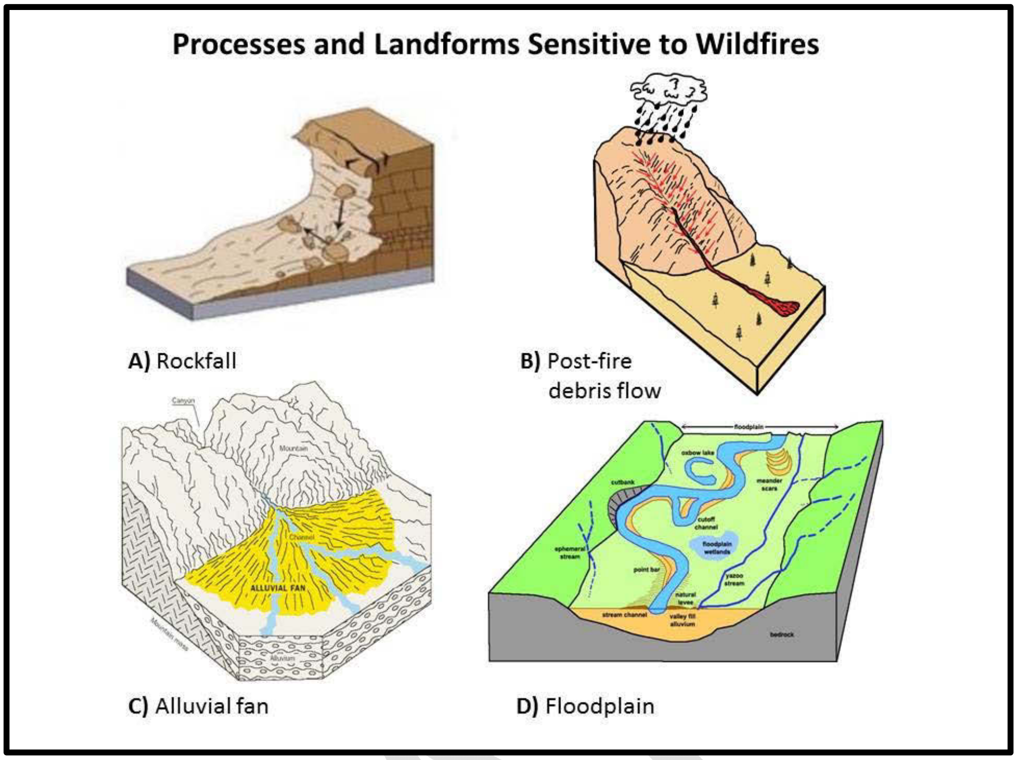

Figure 2. Potential landforms posing a risk to VARs.

4. <u>WERT Expectations</u>

The WERT is tasked with performing and communicating highly technical work in a rapid time frame. The following are WERT expectations for all cooperating agencies:

- All cooperating agencies and organizations shall make every effort to be all-inclusive, maintain open communication, cooperation, transparency, and efficiency.
- The primary focus is to (1) identify significant hazards that represent an immediate threat to life, public health and safety, and public and private property, and (2) develop and facilitate implementation of appropriate emergency protection measures. WERT findings can be used as the basis for more detailed evaluations of post-fire impacts, but this is beyond the scope of the initial WERT deployment.
- Each agency cooperating with the WERT effort will take actions based on their statutory authority, expertise, and jurisdictional responsibilities.

- In order to avoid duplication of efforts and make the most of funding opportunities, it is critical that WERT efforts coordinate with and compliment the efforts underway by federal and local agencies.

5. Criteria for WERT Deployment and Prioritization

The necessity for a WERT deployment depends upon several factors. These include:

- The presence of life-safety-related VARs (e.g., homes, businesses, schools, hospitals, other infrastructure) downslope and/or downstream of steep hillslopes and catchments burned at moderate to high soil burn severity.
- Significant likelihood of debris flow and flooding hazards based on soil burn severity, geology, topography, and likely rainfall rates.
- Historical occurrence of debris flows and flooding during burned and/or unburned conditions.
- Transportation networks (e.g., highways, rail lines), water supply systems, power generating plants and conveyance systems, campground/resorts, parks and hiking trails, and other high value sites expected to be at risk due to post-fire debris flows and/or flooding.
- A high percentage of State Responsibility Area (SRA) included in the fire area.

When these factors are considered, most fires will not require a formal WERT evaluation.

The key question to address is whether post-fire effects will pose a large enough threat to life, safety, and property to mobilize the WERT process. This question of whether a WERT is needed will be posed by either the Director, the Incident Management Team (IMT) Incident Commander (IC), the Agency Administrator, the Unit Chief, or the affected local jurisdiction. CAL FIRE Unit Foresters and/or the incident Fire Suppression Repair Lead can determine if a fire appears to be a candidate for a WERT deployment, and provide this information to the IC or Unit Chief. WERT members will also provide an office screening of incidents to determine if they meet the criteria for elevated post-fire watershed hazards (see Appendix F). If the level of hazard is unclear following office review, a small one or two-person team comprised of at least one CGS licensed geologist can conduct a rapid field review to determine whether a formal WERT evaluation is necessary. In cases where a WERT evaluation is recommended, a subsequent determination is needed to decide what specialist positions are necessary.

During fire sieges, prioritization for WERT evaluations are to be based on the magnitude of life-safety risk, particularly areas subject to flood and debris flow hazards (see Appendix B). The capacity to perform multiple WERT evaluations is limited. This will necessarily focus initial evaluations on areas with large concentrations of life-safety VARs. Additionally, the acquisition of remote sensing imagery for soil burn severity mapping may impose time delays for WERT deployment. This should be anticipated in the prioritization and scheduling of WERT deployments.

6. WERT Staffing and Organization

WERT staffing is flexible and scalable based on the size of the fire, number/frequency of potential VARs, and the anticipated magnitude of risk (Table 1). Typical staffing requirements are described below (modifications are to be made as appropriate).

Table 1. Suggested WERT staffing levels for varying fire sizes/VARs frequency levels.

WERT Type	**Criteria**	**Time Frame until Report Submittal**	**Minimum Staff Requirements**
Very Small	< 1,000 acres; VAR frequency variable	≤1 week	1 CAL FIRE WPP RPF (Hydrology) 1 CGS CEG 1 trainee (optional) Remote GIS Support
Small	1,000 - 10,000 acres; Low to moderate VAR frequency	≤ 1 week	1 CAL FIRE WPP RPF (Hydrology) 1 CAL FIRE Liaison 1 CAL FIRE Forester RPF 2-3 CGS CEG 1 DWR/RWQCB PE (optional) 1 GIS 1 trainee (optional) 1 CAL FIRE Finance
Medium	50,000 - 150,000 acres; Moderate to high VAR frequency	< 2 weeks	1-2 CAL FIRE WPP RPF (Hydrology) 1 CAL FIRE Liaison 3 CAL FIRE Foresters RPF 3 CGS CEG 3 DWR/RWQCB PE 1-2 GIS 2 trainees (optional) 1-2 CAL FIRE Finance
Large	>150,000 acres; Moderate to high VAR frequency	<3 weeks	2 CAL FIRE WPP RPF (Hydrology) 1 CAL FIRE Liaison 4-7 CAL FIRE Foresters RPF 4-7 CGS CEG 4-7 DWR/RWQCB PE 1-2 GIS 2-3 trainees (optional) 2 CAL FIRE Finance

The WERT Team Leader, with assistance from CAL FIRE and CGS Managers, should assemble a team with appropriate licensed and experienced professionals to evaluate threats to life-safety and property.

- At a minimum for a medium fire-impacted area, the team should include: a CAL FIRE Forester III or II with hydrology and/or post-fire evaluation knowledge acting as the Team Lead, one CGS Senior Engineering Geologist to act as the Co-Lead and primary technical lead; two CGS and/or Water Board Engineering Geologists; one DWR or Water Board Water Resources Engineer; one CAL FIRE Forester; one CAL FIRE or CGS GIS specialist; a resource professional from a state or federal agency (e.g., NRCS) with local knowledge; a CAL FIRE liaison; and a CAL FIRE Purchasing Agent (Table 1).

- It is necessary to designate an overall WERT CAL FIRE Team Lead, WERT technical Co-Lead (CGS Senior Engineering Geologist with considerable post-fire evaluation knowledge), as well as the WERT team members as soon as possible.

- The licensed professionals (RPF, PG, CEG, PE) should be experienced in evaluating potential risks associated with post-fire debris flows, flooding, rockfall, and erosion, and should have received training prior to team assignment. A minimum of six (6) individuals are recommended so that the teams can divide into two working sub-groups with three members to expedite data collection in the field.

- A CAL FIRE safety-trained licensed Forester should accompany field teams. Two Engineering Geologists, or an Engineering Geologist and a Professional Engineer, must be included on each sub-group in order to make evaluations regarding public safety.

- The Team Leader must make team members aware of field logistics prior to deployment.

- The CAL FIRE liaison should be deployed to the incident prior to the arrival of the full team, so that contacts can be made with incident staff, local governments, and affected stakeholders.

WERT roles and responsibilities are to be based on size and complexity of the incident. The span of control should be between 3 and 7 people. Brief descriptions of WERT member roles are displayed in Table 2.

Table 2. WERT member roles.

Team Member	Team Member Role
Team Lead	Overall Team management and communication Typically filled by CAL FIRE Forester II or III
Co-Team Lead	Overall Team management and communication consistent with Team Lead direction. Primary technical lead for the Team, and assists Team Lead in coordination of WERT evaluation and reporting Typically filled by CGS Senior Engineering Geologist (CEG)
Home Office Coordinator	Overall coordination between Home Office, Team leads, and remote support staff (e.g., GIS) Typically, CAL FIRE Sacramento Management with support from CGS Sacramento Management
Home Office GIS	GIS support to onsite GIS, and often initial GIS preparation
CAL FIRE WPP RPF (Hydrology)	Supplemental technical assistance, typically with hydrology background. Can be the Team Lead for small or moderate-sized fires
CAL FIRE Liaison	Overall Liaison between WERT Team Leads and local emergency management agencies
CAL FIRE Foresters (RPFs)	Safety Trained Foresters to accompany each field team, and contribute to post-fire assessment in their areas of expertise
CGS and RWQCB Geologists (CEGs)	California Licensed Engineering Geologists with post-fire experience to serve as geologic technical experts
DWR/RWQCB/CGS Civil Engineer (PE)	Licensed Civil Engineers with post-fire experience to serve as civil and or hydrologic engineering technical experts
GIS	Onsite GIS management, data development, and data presentation
Trainees	Any of the above to learn on-site WERT processes while assisting the team in their area of expertise
CAL FIRE Purchasing Agent	Experienced field team based finance specialists responsible for all WERT team financial logistics and support. Additionally, support report preparation (e.g., Word, Excel, report editing, etc.)

All agencies participating in the WERT effort are considered part of the emergency response team. Each agency has specialized resources necessary for post-fire emergency response. All agencies involved have roles and responsibilities based on statutory authority that should focus their objectives. The intent is to efficiently provide accurate, complete, and timely information on significant hazards, emergency protective measures, and risk reduction.

CAL FIRE acts as the lead agency coordinating the WERT in cooperation with all contact agencies. Specialized personnel with qualifications in civil engineering, engineering geology, hydrology, GIS, forestry (including fire line safety), and water quality are required to rapidly identify significant life-safety and property hazards. Personnel with prior experience and local knowledge are also recommended. Cal OES staff initiate the coordinated implementation of emergency protective measures based on available funding. In Presidential major disaster declarations, FEMA also assists with emergency protection measure funding and implementation. For fires that have received State or Federal Disaster Declarations, CAL FIRE, CGS, and other WERT agencies may be asked to provide staff to assist in interagency coordination at the State Operations Center (SOC) and/or Joint Field Office (JFO). These staff will act as liaisons between the WERT and representatives from OES, FEMA, and other associated State and Federal agencies.

WERT Contact Agencies

California State Agencies

- California Department of Forestry and Fire Protection (CAL FIRE)
- California Geological Survey (CGS)
- California Office of Emergency Services (Cal OES)
- California Department of Water Resources (DWR)
- Regional Water Quality Control Boards (RWQCBs)
- California Department of Transportation (Caltrans)

Local Agencies

- County Flood Control District/Department of Public Works
- County Office of Emergency Management
- City Department of Public Works

Federal Agencies (see Table A-3)

- United States Geological Survey (USGS)
- National Weather Service (NWS)
- Federal Emergency Management Agency (FEMA)
- Natural Resource Conservation Service (NRCS)
- USDA Forest Service (USFS)
- Bureau of Land Management (BLM)
- US Army Corps of Engineers (USACE)

- Bureau of Indian Affairs (BIA)
- National Park Service (NPS)

7. WERT Personnel Training

Fireline safety and WERT technical skills training is required for all WERT personnel. Until such time as a comprehensive wildland firefighter training program has been developed for cooperating agency and CAL FIRE non-safety personnel (expected to be by 2021), the following minimum training requirements shall apply:

- Completion of online Incident Command System (ICS) 100--Introduction to Incident Command System https://training.fema.gov/is/courseoverview.aspx?code=IS-100.b),
- ICS 200--ICS for Single Resources and Initial Action Incidents (https://training.fema.gov/is/courseoverview.aspx?code=IS-200.b) and
- IS-700—National Incident Management Introduction (https://emilms.fema.gov/IS700aNEW/index.htm) (recommended).
- Completion of 8-hour short course titled “Emergency Incident Awareness (EIA).” This class is provided to non-safety personnel wishing to fill overhead assignments on incidents. It provides an ICS overview, explanation of hazardous situations, fire shelter deployment, proper use of personal protective equipment (PPE), and other basic safety information.
- Mobile and hand held Handie-Talkie (HT) radio training (annual).
- Technical training (soil burn severity evaluation, ArcGIS Collector use, etc.) is to be scheduled as required.

8. WERT Safety Procedures

- All WERT personnel assigned to an incident shall receive a detailed safety briefing conducted by a qualified CAL FIRE Battalion Chief, Assistant Chief, or other Chief Officer familiar with the local fire conditions present (mandatory).
- All WERT personnel assigned to an incident shall receive a detailed safety briefing conducted by a qualified CAL FIRE Helitack Fire Captain or Air Operations Chief regarding helicopter flight safety procedures prior to any helicopter flight assessments (mandatory).
- All WERT personnel assigned to an incident shall receive a detailed briefing by the Team Leader on communication systems to be used by the WERT team (cell phones, CAL FIRE HT radios, etc.) (mandatory).
- All WERT personnel will be required to have basic safety equipment, including Nomex shirt and pants, hard hat, gloves, safety glasses, and leather boots with Vibram soles (key PPE components).

- All non-fireline qualified WERT personnel shall be accompanied by CAL FIRE fireline qualified personnel during field operations within the incident perimeter where the fire is not fully contained.

9. WERT Command and Control

Qualified WERT personnel shall be ordered by the incident ordering manager, or hosting Unit, in coordination with the Sacramento Command Center (Sac CC) and CAL FIRE WERT Liaison, through the Resource Ordering System of Record. WERT personnel assigned to one or more incidents may be tracked on the appropriate incident number or a separate CDF number as incident conditions warrant.

Where feasible and appropriate, orders for WERT personnel shall be filled by the Sac CC using ICS position qualification mnemonics appropriate to forestry, geology, hydrology, soil science, engineering, Geographic Information Systems (GIS), and document production. WERT members and support resources from the California Geological Survey (CGS), California Department of Water Resources (DWR), and the Regional Water Quality Control Boards (RWQCBs) shall be ordered as “fill with agreement” consistent with memoranda of understandings (MOUs) or contracts with CAL FIRE.

CAL FIRE resources assigned to WERT operations may be released, and/or reassigned, to higher priority incidents if necessary.

Mission Tasking

Mission tasking of cooperating state agencies through the California Office of Emergency Services (Cal OES) will no longer be utilized for WERT assignments. Where Cal OES objectives are outside the scope of a WERT assignment, mission tasking of CAL FIRE and other cooperating agencies may be appropriate. In such instances, tangible and achievable objectives for the mission task shall be clearly identified, and milestones or timeframes to achieve the objectives shall be delineated.

10. WERT Detailed Procedures

Introduction

Severe wildfire causes several impacts to wildland watersheds, including loss of vegetation, loss of surface cover, hyper-dry soil conditions, and often the formation of a water repellent layer that reduces infiltration. These physical changes lead to an increased risk of accelerated hillslope runoff, surface soil erosion, rockfall, debris flows, and flooding. How much occurs the first few winters after the fire is dependent on soil burn severity, geologic and soil conditions, topography, and rainfall intensities and durations. Post-fire debris flows and flooding can occur with very little warning and move very rapidly, producing destructive impacts to downstream life-safety, property, and infrastructure in the flow path. As such, identification of areas where this may occur is information needed by emergency management agencies in order to develop post-fire response plans and mitigations.

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.

If a wildfire affects significant amounts of US Forest Service land (>500 acres), or is smaller but has high resource threats, a Burned Area Emergency Response (BAER) Team will be deployed by the USFS. The Department of Interior (DOI) also assembles BAER teams composed of professionals from several different federal agencies (e.g., NPS, USFS, USFWS, BLM, BIA, and NOAA). The BAER teams conduct generally similar assessments to the WERT effort (http://www.nifc.gov/BAER/Page/NIFC_BAER.html), but they include assessment of natural and cultural resources, and they do not conduct detailed VAR inventories below federal land boundaries. Therefore, some fires may have both BAER and WERT evaluations, each focusing on their respective geographic areas (e.g., federal and non-federal lands). In these cases, it is imperative for the two teams to work closely and collaboratively to share information and data, and to not perform redundant assessments.

<u>Tasks for the Post-Fire Evaluation</u>

1. **Prior to leaving for the fire area**:

    a. The WERT Team Leader, with assistance from CAL FIRE and CGS Managers, should assemble an appropriately sized team with appropriate licensed and experienced professionals to evaluate threats to life and property. Home office support, such as GIS assistance, should be coordinated and initial communication with other relevant agencies (e.g. BAER, NWS, Incident Management, etc.) should occur. Appendix A, Table A-3 contains USFS BAER, NWS, and NRCS contact information.

    b. The Team Lead and/or Liaison will arrange for office space that is accessible 24/7 and has (1) large tables, (2) WiFi for high speed internet access, (3) sufficient power outlets, (4) printers, and (5) access to a plotter so that maps can be printed out at a large scale. The Team Lead may delegate this task to the CAL FIRE Liaison.

c. The Liaison, if necessary, will deploy to the incident and obtain relevant information from the fire Incident Commander (IC) regarding potential post-fire life and property concerns, as well as other information pertinent to the post-fire assessment (e.g., access limitations, etc.). The Liaison will establish contacts with local government officials and affected entities.

d. The Team Lead will begin planning specifics of data and information needs with the Co-Team Lead.

e. The GIS team member and Home Office GIS staff will obtain ArcGIS data consisting of:

    i. A Burned Area Reflectance Classification (BARC) map from CAL FIRE or the USFS BAER Team. The GIS layers (classified into four burn severity classes – unburned/very low, low, moderate, and high) should contain raster data that can then be layered onto a variety of maps generated by the team GIS specialist.

    ii. A composite map showing combined overlapping polygons of slope ≥ 43% and BARC categories for moderate to high burn severity for preliminary high hazard area identification.

    iii. A digital Erosion Hazard Rating (EHR) map, using BOF Technical Rule Addendum No. 1 (procedure for estimating surface soil erosion hazard rating) from CAL FIRE GIS staff in Santa Rosa or Sacramento.

    iv. Final fire perimeter ArcGIS data from the incident (note that it may have changed depending on when the BARC map was generated).

f. The GIS team member and Home Office GIS staff will obtain office maps, ArcGIS layers, and reports related to assessment of post-fire debris flow risk, flooding, and erosion for the fire area. Use of a checklist such as that is included in Appendix C will be helpful to ensure consistency and reduce critical data gaps. The purpose of each data type, their limitations, underlying assumptions, and their inter-relationships should be articulated as GIS metadata. The data may include, but are not limited to, topographic maps (current and historical); published geology maps; LiDAR (where available); Digital Elevation Models (DEMs); USGS peak flow information and reports; FEMA floodplain maps; DWR flood awareness maps; and fire history, CalVeg, GIS road, parcel, and hydrography layers.

g. The GIS team member and Home Office GIS staff will generate and print on a plotter large scale (4 x 5 foot) paper maps (at least three copies for field teams and office planning) showing BARC soil burn severity classes, the complete road layer, and other features aiding in field identification. In addition to field work use, these maps are to be placed on a wall or table to allow team members to (1) collectively discuss how the burn areas will be accessed, and (2) discuss findings at the end of each field day, and (3) reference specific sites observed to locations on the printed map in the office. Geo-referenced pdf maps or equivalent base maps are to be made and loaded onto iPads/tablets and smart phones with the Avenza PDF Maps application and the ArcGIS Collector application.

h. The GIS team member will work with the Team to divide the fire area into pour point watersheds based on identified VARs for hydrologic analysis. Pour points for watersheds are established to obtain a better understanding of hydrologic response for areas potentially at risk from flooding. They represent a sampling of the fire and are not assigned for all the VAR sites. Most pour points are relatively close to the fire perimeter, yielding greater post-fire flow increases than those far below the perimeter. The GIS specialist will extract relevant data as part of this process (e.g., watershed drainage acreage, acreage burned at each soil burn severity category, etc.). This method should be set up as an automated GIS process. Potential limits include restricting pour point drainage areas to locations with >20% increases in the 10-year recurrence interval (RI) flow, and >50% for the 2-year RI flow, particularly if areas are already mapped for FEMA 100-year floodplain, DWR floodplain awareness delineation, or local floodplain delineation.

i. The GIS team member will make arrangements for Batch ERMiT or other surface erosion modeling method and USGS debris flow modeling to be conducted once the BARC map is field checked and refined. Team geologists, hydrologists, and engineers will field check areas of concern as determined by the models and review their validity.

j. The GIS team member and Home Office GIS staff will follow established data management procedures to include: file names, locations, metadata, versioning or archiving, and preserving the availability of final GIS data and products for retrospective studies (Appendix C).

k. The GIS team member and Home Office GIS staff will ensure that appropriate computer programs are available to conduct the field assessment, including ArcGIS and Adobe Acrobat Pro. Additionally, iPad and iPhones or Android smart phones are essential when conducting field work. Smart phones are necessary for field safety, field work, and allow for easy transfer of data points and geo-referenced photos to the team GIS specialist (alternately Garmin GPS units and digital cameras can be used, but they are significantly less desirable). iPads or other GPS-equipped tablets are desirable for similar reasons, as well as the ability to input more detailed field information. The GIS team member will ensure that appropriate software/apps, such as Avenza Maps, ArcGIS Collector, and Google Earth, are installed on the smart phones and tablets and are available for unfettered use. The GIS team member will ensure that field personnel are trained for proper data collection and data transfer. The GIS team member will be responsible for data management.

l. If available, the GIS team member will incorporate data collection schema (fields) for field data collection software such as PDF Maps and ArcGIS Collector. These are to be based on information provided in Appendix C.

m. The Team Lead will be responsible for securing the items listed in Appendix A, Table A-1 (as well as notifying team members to bring required personal items).

2. The Team Lead and Co-Lead shall provide an initial briefing with the Team members to relay pertinent information regarding the assignment, as well as clarify and reinforce the roles of each team member.

3. The Team Lead and/or Liaison will arrange for and conduct an initial meeting with County and city officials, engineers, GIS analysts; local flood control district/ department of public works representatives; federal agency representatives (e.g., USFS, BLM, NPS, NRCS, NWS); and other appropriate local and regional agency staff (Appendix A, Table A-3). It is important to have open communications with these officials who will likely be leading post-fire response planning. Officials are to be queried regarding specific WERT products that will benefit post-fire response planning so that local needs are met. Useful GIS layers are to be obtained from these agencies (e.g., roads, parcel, and watercourse crossing layers), as well as information regarding flooding, landsliding, and other concerns that have occurred in the general area prior to the fire. The GIS team member will screen the complied data to ensure that only the most complete, up-to-date, and accurate data are used.

4. The Team Lead and/or Liaison should coordinate with the CAL FIRE Unit Chief or other appropriate CAL FIRE Chief Officer to arrange for a helicopter flight(s) to view the fire area to (1) obtain an overview of soil burn severity, and (2) locate Values-at-Risk in areas with moderate to high soil burn severity. The WERT team should take the flight(s) as soon as it is available.

5. The Team Lead must arrange for a safety briefing, identifying particular hazards in the fire area (e.g., mine shafts). The Team Lead must coordinate team logistics, organize communication methods, and set meeting times. The Team Lead must ensure that all field personnel arrive safely to a designated location each night from the field. The Team Lead and/or Liaison will gather and distribute

required safety equipment (e.g., Nomex clothing, hard hats, radios, phone/contact list, etc.), as well as return borrowed equipment to the incident or CAL FIRE Unit after completion of the assignment.

6. WERT members must identify areas on the large paper map to systematically field check the BARC map, focusing on high and moderate soil burn severity areas, but including spot checks of low burn severity areas to determine that soil burn severity is not underestimated. Depending on the burn area size, the area is to be divided into two logical sections for two sub-teams to evaluate in the field. If federal agencies have been mobilized (e.g., BAER Team), the Team Lead will coordinate with the federal agencies (e.g., USFS, BLM, NPS) to ensure that BARC map field verification is efficient and non-repetitive.

7. After field training from staff with experience evaluating soil burn severity to ensure that the group is calibrated using the same procedure, verify (ground truth) the BARC map burn severity categories using the form in Appendix B of Parsons et al. 2010 (Appendix E, Table E-4). Field data and site locations are recorded digitally using the Arc Collector app on a tablet. Key field indicators include post-fire ground cover, soil structure, ash color and depth, fine root condition, and soil char depth. Soil water repellency is also tested, but it is generally not a reliable indicator due to high variability. Attempt to evaluate both burned and unburned areas for comparison. The field check should be limited to two days for large fires, using a minimum of 30 field sites. The procedures outlined in the safety briefing are to be strictly followed. Following field verification, the final soil burn severity map is developed. If necessary, BARC thresholds for one or more of the soil burn severity categories are adjusted to produce the final soil burn severity map. It is important to field verify the BARC data even if the USGS has already completed the debris flow modeling.

8. If the USGS Post-Fire Debris flow model has not yet been produced, the corrected BARC map shapefiles, along with field verification data and possible data available from federal agencies, is to be sent to USGS research scientists in Golden, CO who conduct modeling for emergency assessment of post-fire debris-flow hazards. The USGS Landslide Hazards Program will generate debris flow model outputs and corresponding maps showing hazard probability, volumetric yield, and combined hazard at the watershed and segment scale for 15-minute rainfall intensities. USGS Post-Fire Debris Flow Hazard model information is posted at: http://landslides.usgs.gov/hazards/postfire_debrisflow/.

9. Once the USGS debris flow modeling is obtained in ArcGIS format, maps showing potential modeled debris flow hazard locations relative to previously obtained layers (e.g., roads, flood zone layers) are to be produced. The GIS team member will prepare geo-referenced pdf maps or other digital base maps for team members to use in the field. Also, The GIS team member will print maps on a plotter so that they can be used for discussion in the office prior to

and after field evaluation. Map results are to exported to KMZ for ease of use in Google Earth in order to accomplish Item 12, below.

10. The new ArcGIS map is to be loaded with the USGS debris flow segment model on iPads/tablets and smart phones with the ArcGIS Collector application.

11. The Team Lead and Co-Lead are to explain to team members and other appropriate personnel that (1) the USGS debris flow model is watershed-based and do not necessarily capture the smallest watersheds, individual areas within each watershed, or the areas downstream of the modeled watersheds; and (2) a test of reasonableness based on local conditions and geomorphic evidence should be applied to evaluate site specific and downstream concerns (e.g., even though a watercourse immediately downstream of a modeled watershed was not modeled, it may have a hazard similar to that of the upstream watershed). The Team Lead and Co-Lead should explain the criteria for the test of reasonableness and how to report the findings.

12. In the office using paper and digital maps, Google Earth, local information, etc., WERT members will identify high value areas potentially at risk that were affected by the fire and that correspond with moderate and/or high soil burn severity from the BARC map, high surface erosion potential, high potential of debris flows and/or rockfall, and/or high potential of flooding. These features can include: homes, businesses, power plants, bridges/culverts, domestic water supplies/high value reservoirs, highways, recreational areas, etc. **Initial investigation work in this step, as well as initial work on steps 13-16 and 20, may take place while the debris flow modeling is occurring if necessary**.

13. An office assessment of surface erosion potential may be conducted depending on the fire being evaluated. This can include using Batch ERMiT, WEPPcloud-PEP (Postfire Erosion Prediction Tool), BOF Technical Rule Addendum No. 1 (TRA#1) (procedure for estimating surface soil erosion hazard rating (EHR)), or other appropriate modeling approaches. Watershed-based surface erosion Batch ERMiT maps show relative erosion potential and erosion volumetric information (Robichaud et al. 2011). If Batch ERMiT values are generated, it is appropriate to provide a relative ranking (i.e., low, moderate, and high), rather than absolute values in tons per acre. WEPPcloud-PEP can be used for a specific pour point strategically located below a high risk VAR (e.g. a water supply reservoir). TRA#1 EHR pre- and post-fire maps can be rapidly generated, but they do not include soil burn severity information and only address post-fire conditions by adjustment of the vegetative cover factor. If generated, the digital EHR tool pre- and post-fire maps are to be only used as an internal screening tool.

14. Pre-fire and post-fire peak flow multipliers for 2 and 10-year recurrence interval flood events are to be estimated for the designated pour point watersheds using the corrected BARC soil burn severity map for high, moderate, low, and very

low/unburned soil burn severity data. Relative increase of peak flows from one pour point drainage basin to another is judged to be more important for these rapid assessments, rather than the estimated absolute values of the peak flows. The most appropriate methodology(s) for post-fire flow estimation for the fire location is to be utilized.[2]

15. Using the information from step 14, determine where the greatest flood risk areas are located in and downstream of the fire area. To assist in this determination, use FEMA 100-year floodplain maps if they are available and DWR floodplain awareness maps. Combine this information with the outputs from the surface erosion models to identify areas where flood flow may have high volumes of entrained (bulked) sediment from modeled high erosion hazard watersheds/ areas (thus resulting in a further elevated flood risk). Additionally, relate flood information to the areas identified as having high debris flow hazards as identified by the USGS debris flow hazard model.

16. Debris flow volume yields provided with the USGS debris flow model results are to be considered when evaluating potential VAR sites. Additionally, debris yield estimates for the pour point watersheds may be calculated, especially within the Transverse Ranges of southern California (e.g., Gatwood et al. 2000; Gartner et al., 2014), and compared to debris basin storage capacity.

17. Conduct field training with senior staff explaining to junior team members how to conduct rapid field evaluations of areas with potential significant threats to life and property, and how to record data in a consistent manner digitally on iPads or smart phones with Arc Collector (Table 3).

18. Depending on burn area size, the Team Lead will divide the WERT into two or more teams to conduct a comprehensive field investigation of potential high risk sites. One Engineering Geologist, or an Engineering Geologist and a Professional Engineer, must be included on each sub-group in order to make public safety evaluations, as well as a CAL FIRE safety-trained forester for areas within the fire perimeter that are not fully contained. Procedures outlined in the safety briefing must be strictly followed.

19. The WERT will field check locations that potentially present a significant risk to lives and property/infrastructure identified in the office (step 12). **<u>Only significant life-safety and property VARs are to be inventoried, as determined by an appropriately licensed team member (CEG or civil engineer), not low risk infrastructure (e.g,, culverts and other types of drainage structures). Low risk to life-safety and low risk to property infrastructure may be commented on in general recommendations, but shall not be considered as individual</u>**

[2] If determined to be necessary, considerably more detailed hydrologic and hydraulic (H&H) modeling can be undertaken by federal agencies in a second assessment phase.

<u>VARs nor specifically inventoried and included in the VAR list.</u> Pertinent information will be recorded digitally, including possible emergency protection measures (see Appendix A, Table A-2). Note that this is a rapid "first impression" of possible emergency measures to provide a general guide to subsequent more detailed evaluations. Map the locations digitally as points or polygons with the ArcGIS Collector application. Record data on field-verified sites digitally on iPads.

20. The Team Lead and/or Liaison will attend meetings as needed with county and other emergency management agency representatives to document their needs and concerns.

21. Additional local information will be obtained (see step 3) from county officials, CAL FIRE Unit staff (e.g., local Battalion Chief), internet research, and others regarding flooding and landsliding that occurred in the general area prior to the fire.

22. The life-safety and property risk information from the field work is to be summarized in a detailed Excel spreadsheet (using a standardized template) in the final report. VAR attributes and descriptions displayed in Appendix A, Table A-2 are to be included.

    Generate an ArcGIS file with the mapped locations of the significant hazards identified in the field (see Appendix C).

23. Compile all information in a brief draft report, following the report outline shown in Appendix A, Table A-4 (make modifications where appropriate). When necessary, the Team Lead and Co-Lead will assign a document team leader to oversee document preparation and formatting. Methods will not be described, only referenced to the WERT guidance document. Use standardized WERT report recommendations for specific VAR locations. Include general recommendations, such as use of early warning systems, culvert maintenance, storm patrol for watercourse crossings, as well as information on the high risk sites found in the field. Include brief general recommendations at the end of the VAR table. Include pertinent maps and links to pertinent data. Make it clear in the document what areas were not assessed (e.g., burned structures, areas that did not have access, etc.). Include as appendices contacts, VAR maps, VAR spreadsheet, VAR data driven information sheets (only include high risk sites, sites with recommended structure protection mitigation, representative examples of different types of VARs), and photos. **Make the final report concise and action-oriented.**

24. Conduct a closeout meeting with local emergency response agencies to present the WERT's findings, and answer questions regarding inventoried VARs and the recommended emergency protection measures. Distribute the following items at the closeout meeting: WERT report executive summary, VAR table, VAR

shapefiles, and an 11x17 inch poster/handout with photo(s) and VAR map (given that there is sufficient time for production).

25. Submit the draft report to the Home Office Coordinator for review. Develop a final report incorporating changes suggested by CAL FIRE Executive and CGS Supervising Geologist reviewers.

26. Release the final report in a timely manner to emergency management agencies including Cal OES, with the clear understanding that they are the leads for coordinating and implementing appropriate emergency actions (e.g., local and regional emergency response agencies that are responsible during winter storm events). Send the report to the contacts listed in the report.

27. Determine if emergency management agency coordination with NRCS is needed, since funding for post-fire recovery measures for exigent work may be available under NRCS's Emergency Watershed Protection (EWP) Program. CAL FIRE or the appropriate local agency (i.e., county) can serve as an EWP sponsor (see: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/ewpp/).

28. Arrange for posting the final ADA compliant WERT report on the CAL FIRE incident website.

29. Schedule an after-action meeting/conference call to debrief with team members after the completion of the WERT effort to discuss lessons learned, ideas for greater efficiencies, issues that arose, etc.

30. The Team Lead shall be responsible for retaining all GIS layers and maps used and generated in a centralized location for ease of access to data. Archive data and field information, and the final WERT report.

31. The CAL FIRE Home Office Coordinator will work with County/State OES when mission tasked to assist with project implementation.

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Appendix A. Supplemental Information for WERT Deployments

Table A-1. List of items to bring to the fire area.

Individuals

Laptop computer with appropriate software (Microsoft Office, ArcGIS (if available), Acrobat Pro, etc.), Google Earth, etc.
iPad and/or smart phone with Arc Collector and Avenza Maps application loaded
External hard drive, flash drives, and peripheral cables
Appropriate field gear, including hard hat, leather boots, sun glasses, rain gear, sun screen, multiple pairs of field pants and shirts, Nomex shirt and pants-if available
CAL FIRE uniforms and full PPE (CAL FIRE staff only)
Forestry equipment (vest with clinometer, compass, etc.)
GPS and digital camera (if smart phone or tablet are not available)
Personal items required

Team Leaders

Four-wheel drive vehicles for each sub-team (2 minimum)
Soil sampling equipment, including trowels, water droppers and bottles, etc.
CAL FIRE HT radios (at least two, can be obtained from the local CAL FIRE Unit)
Field books
Office materials (tape, paper, wall pins, etc.)
Appropriate manuals, reports, papers, etc.
Report template, spreadsheets, and previous reports (digital)

GIS

GIS desktop computer and appropriate software (ArcGIS, Collector App, Google Earth, ArcGIS Online account, Acrobat Pro, Word, Excel, etc.)
Color Printer and access to Plotter

Table A-2. VAR (Value-At-Risk) spreadsheet attributes and descriptions.

VAR (Value-At- Risk) Spreadsheet Attributes and Descriptions		
Attribute	**Description**	**Data Acquisition**
Site Number	Value-at-Risk (feature) site number.	Text entry by user.
Community/ local area	Name of community the feature is associated with as indicated on standard base map layers.	Text entry by user.
Street address	Street address of the at-risk feature (to be removed from final report).	Text entry by user when available.
Latitude	Global Navigation Satellite System (GNSS) Latitude in decimal degrees.	Auto filled by application.
Longitude	Global Navigation Satellite System (GNSS) Longitude in decimal degrees.	Auto filled by application.
Potential hazard/ Field Observation	Specific potential hazard based on field observation; a general description of the feature at risk and the observed potential hazard to that feature.	Text entry by user.
Hazard Category	General category of hazard.	Drop down menu: *Debris flow, Debris flow/flood, Flood, Rock Fall, Other.*
Specific at-risk feature	Description of feature that could be impacted by hazard.	Text entry by user.
Feature Category	General category of at-risk feature in drop down menu.	Drop down menu: *Business, Drainage structure, Home, Recreational, Utilities, Other, Multiple, State Park.*
Potential Hazard to life?	Impact to life in event of hazard occurrence.	Drop down menu: *High, Moderate, Low, No.*
Potential Hazard to property?	Impact to property in event of hazard occurrence.	Drop down menu: *High, Moderate, Low, No.*
USGS Basin ID	The number assigned to a sub-watershed by USGS debris flow modeling.	GISS: Intersected with VAR data points and polygons after completion of field work.
Basin Probability	The probability for debris flow within a sub-watershed basin per USGS debris flow modeling.	GISS: Intersected with VAR data points and polygons after completion of field work.
Segment Probability	The probability for debris flow along a segment of associated with a watercourse axis of a sub-watershed per USGS debris flow modeling.	GISS: Intersected with VAR data points and polygons after completion of field work.
100-Year Flood Plain	Indicates if the feature is located within a FEMA 100-year flood plain or other floodplain such as DWR awareness floodplains.	GISS: Intersected with VAR data points and polygons after completion of field work, entry is *Yes/No*.
Emergency Protective Measures (EMP)	Description of actions that could be implemented to protect life and property in the event of hazard occurrence.	Text entry by user.
General Observations and Recommendations	Descriptions of general or regional hazards not associated with specific geo-spatial locations, for example; *development of Early Warning Systems, Flood Zone awareness, Hazardous Mineral risks, possible impacts to campgrounds, trailer parks, temporary housing and municipal water supplies.*	Text included in Values-at-Risk spreadsheet, including description of actions intended to protect against impacts in the event of hazard occurrence.

Table A-3. Agency contact information (to be periodically updated).

US Forest Service 2020 Region 5 BAER Coordinators

National Forest	BAER Coordinator	Office	Mobile	Email
Region 5 BAER Coordinator	Dave Young	530-226-2545	530-768-4760	dave.young@usda.gov
Angeles	Kelsha Anderson	626-574-5257	626-632-1709	kelshaanderson@fs.fed.us
Cleveland	Emily Fudge	858-674-2993	619-430-3092	efudge@fs.fed.us
Cleveland alternate	Kirsten Winter	858-674-2956	858-673-6192	kwinter@fs.fed.us
Eldorado	Eric Nicita	530-621-5290	530-748-5827	enicita@fs.fed.us
Inyo	Todd Ellsworth	760-873-2457	760-937-2033	tellsworth@fs.fed.us
Inyo Alternate	Casey Shannon	760-873-2407	760-937-4245	casey.shannon@usda.gov
Klamath	Bill Wall	530-841-4521	530- 643-3058	wwall@fs.fed.us
Klamath alternate	Derek "Beal" Beal	530-841-4583	405-822-0955	derek.beal@usda.gov
Lassen	Doug Peters	(530) 252-6456	661-246-9723	dwpeters@fs.fed.us
Los Padres	Yonni Schwartz	805-646-4348 x311	805-698-9752	jonathanschwartz@fs.fed.us
Los Padres Alternate	Lloyd Simpson	805-646-4348 x316	805-901-2869	lloyd.simpson@usda.gov
Lake Tahoe Basin Management Unit	Stephanie Heller	530-543-2838	530-722-5891	sheller@fs.fed.us
Mendocino	Lauren Johnson	530-934-1153		lauren.johnson2@usda.gov
Modoc	Bill Goodman	(530) 233-8794		william.goodman@usda.gov
Modoc Alternate	Cathy A Carlock	(530) 279-8331	(530) 640-0390	ccarlock@fs.fed.us
Plumas	Joe Hoffman	(530) 283-7868		jahoffman@fs.fed.us
Plumas Alternate	Kurt Sable	530-283-7641	530-414-8137	kurt.sable@usda.gov

San Bernardino	Robert Taylor	(909) 382-2660	(909) 693-2875	rgtaylor@fs.fed.us
San Bernardino alternate	Kim Boss	(909) 382-2936	(909) 379-9330	kboss@fs.fed.us
Sequoia	Fletcher Linton	559-784-1500 x1185	(559) 719-0299	flinton@fs.fed.us
Shasta-Trinity	Brad Rust	530-226-2427	(530) 917-0434	brust@fs.fed.us
Shasta-Trinity Alternate	Dave Young	(530) 226-2545	(530) 227-9050	daveyoung@fs.fed.us
Sierra	Antonio Cabrera	559-297-0706 x4842	(559) 779-1590	acabrera02@fs.fed.us
Sierra alternate	Kellen Takenaka	559-297-0706 x4936	(406) 781-9612	ktakenaka@fs.fed.us
Six Rivers	Adam Dresser	707-441-3618		adresser@fs.fed.us
Stanislaus	Curtis Kvamme	209-288-6320	(208) 596-5369	curtiskvamme@fs.fed.us
Tahoe	Luke Rutten	209-965-3434 x5321	(218) 766-8662	lrutten@fs.fed.us

NRCS 2017 Contacts

Name	Location	Phone No.	email address
Julia Grim	Davis State Geologist	(530) 792-5623	Julia.Grim@ca.usda.gov
Chris Zimny	Davis State Forester	(530) 792-5655	Chris.Zimny@ca.usda.gov
Luis Laracuente	Davis State Conservation Engineer	(530) 792-5622	Luis.Laracuente@ca.usda.gov

NWS Contact Information[3]

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[3] On March 3, 2020, Lake County became the responsibility of the NWS Eureka Office.

Table A-4. WERT report outline (all sections to be brief and action-oriented). Methods to be referenced to this guidance document.

Cover Page
Table of Contents
List of Figures
List of Tables
List of Acronyms
Executive Summary
Introduction
WERT goals and objectives
Team members
Physical Setting (**very brief**)
Topography, climate, vegetation
Fire history
Hydrology/flood history
Soils and Geology
Hazardous minerals
Development and Key Infrastructure
Modeling Results (Brief)
Soil burn severity
Debris flow/debris yield
Surface erosion
VAR Observations and Recommendations
General Recommendations
Acknowledgments
References
Appendices
List of Contacts
VAR Table(s)
VAR Maps
VAR Site Information Sheets (higher risk VARs or those associated with structural mitigations only)
Photographs

Appendix B. WERT Post-Fire Debris Flow Screening Criteria

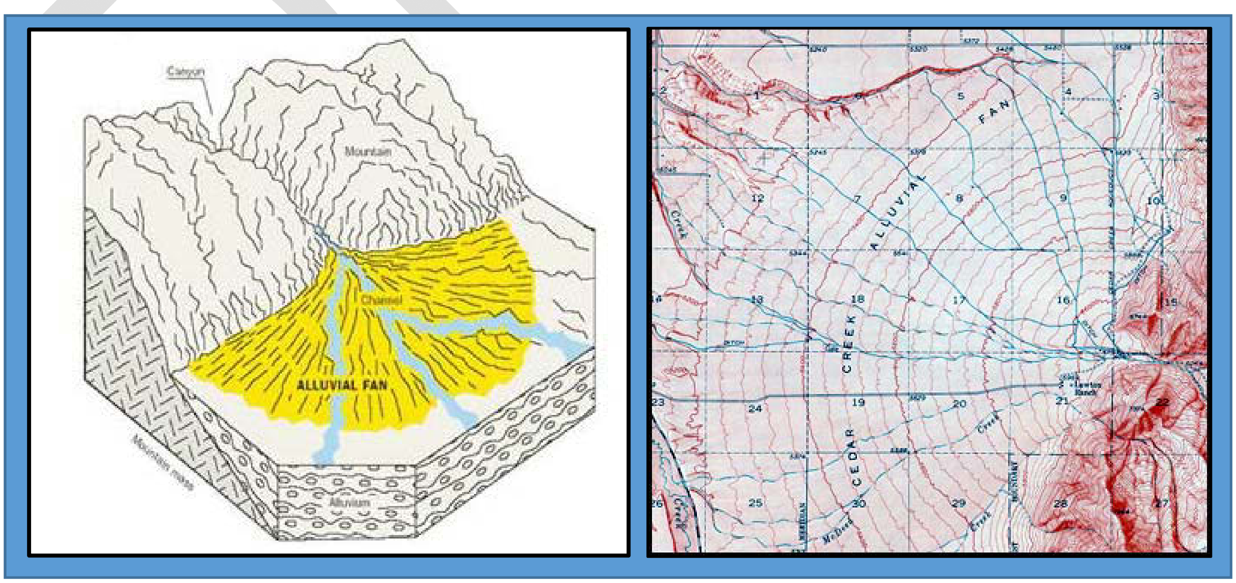
Goal: Provide CAL FIRE GIS Specialists and Unit Foresters with tools to use as part of the WERT screening criteria in order to better understand potential for debris flow hazards, and provide a threshold for decision support.

I. Evaluate Indictors of Potential Debris Flow Hazard

Identify the presence of alluvial fans and slope and burn percentage factors that indicate higher post-fire debris flow hazards in steps one and two; relating these data to threshold screening criteria in step three.

Step 1: Alluvial Fan Presence

a. Is the landform a sedimentary deposit composed of alluvium or debris flow deposits; lots of rounded boulders along roadsides. (Refer to surficial geologic and soils maps: https://maps.conservation.ca.gov/cgs/QSD/
    i. Review Geologic Map Unit names for confirmation. Deposit names that may indicate the presence of alluvial fans include:
        1. Qf, Qyf, Qof, Qhf
        2. Qw, Qyw
        3. Qa, Qoa
        4. Qls
    ii. Data can be downloaded via links on this web map site for direct use in GIS.
b. Does the landform have the shape of a fan? Think like a Japanese corrugated folding fan partially or fully extended. (Refer to topographic maps).
c. Is the landform located at a topographic break between a mountain front and valley? (Refer to topographic maps).



Step 2: Watershed Slope Criteria

a. Review topography in burn area
   i. Identify several of steepest watersheds above populated areas based on topographic characteristics.
   ii. Topography Source:
   USGS Topo View: https://ngmdb.usgs.gov/topoview/viewer/#4/39.98/-100.06
b. Access Streamstats online USGS program:
https://water.usgs.gov/osw/streamstats/
   i. In streamstats, zoom to watershed outlet (canyon mouth)
   ii. Place point at outlet mouth on stream's blue line to analyze watershed and click on delineate.
   iii. After delineation, select the basin characteristics report, calculate all values
   iv. Write down "mean basin slope" value
   v. Generally, compare fire perimeter to delineated watershed in order to define percent burned.
   vi. If fire perimeter and burn severity data are available, additional effort can be put forth in GIS to refine analysis.
   vii. Compare mean slope and burn percentage data to the following table.
   viii. Data can be downloaded and imported into GIS for analyses

Step 3: Watershed Slope and Burn Percentage Comparison

a. Review calculated watershed slope and burn percentage with threshold data in the following table

Percent of Watershed Burned by Fire	Average Slope from StreamStats (Percent)	Debris Flow Hazards	Notes
Category 1: Non-actionable debris flow potential			
0-25%	<40%	V. Low/Nil	Potential for localized debris flows in larger watersheds; less than significant for watersheds of 5 acres or less
	>40%	Low	
25-50%	<40%	Low	
Category 2: Actionable debris flow potential			
25-50%	>40%	Moderate	Potential for larger magnitude debris flows increases with burn percentage, severity and watershed slope
>50%	>40%	Moderate- V. High	

Summary of Steps 1- 3

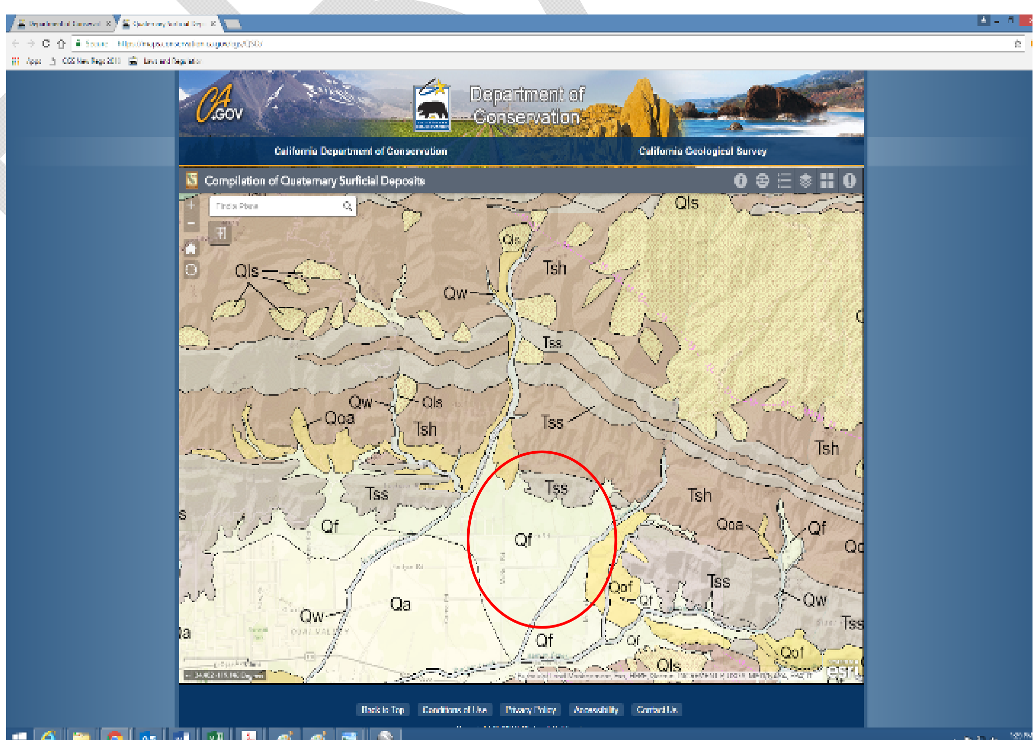
Review data collected at this point. If alluvial fan deposits are present emanating from a steep canyon at a topographic break, it is likely that significant debris-laden flooding and debris flows have occurred historically. In deep river canyons, such as those along the western slope of the Sierra Nevada, alluvial fans may occur at tributary junctions that are too small to be mapped or discerned from a standard 7.5-minute topographic map. In these cases, post-fire debris flow may occur as isolated events where the fan may be small in aerial extent with room for few homes or other improvements. Whereas on urbanized alluvial fans of larger aerial extent draining from large watersheds, both the magnitude of debris flow and presence of numerous improvements, dramatically increase the risk to public safety.

Significant judgment may be needed when evaluating the slope/fire percent categories against alluvial fan presence. In most cases, WERT deployment may not be necessary when Category 1 watershed characteristics occur above populated areas or infrastructure. There may also be many cases where Category 2 characteristic are present, but there are no Values-at-Risk within close proximity to the steep watershed. In any case, if an alluvial fan is present and there are significant Values-at-Risk, it may be best to refer the screening back to WERT management for additional consultation.

<u>Example</u>

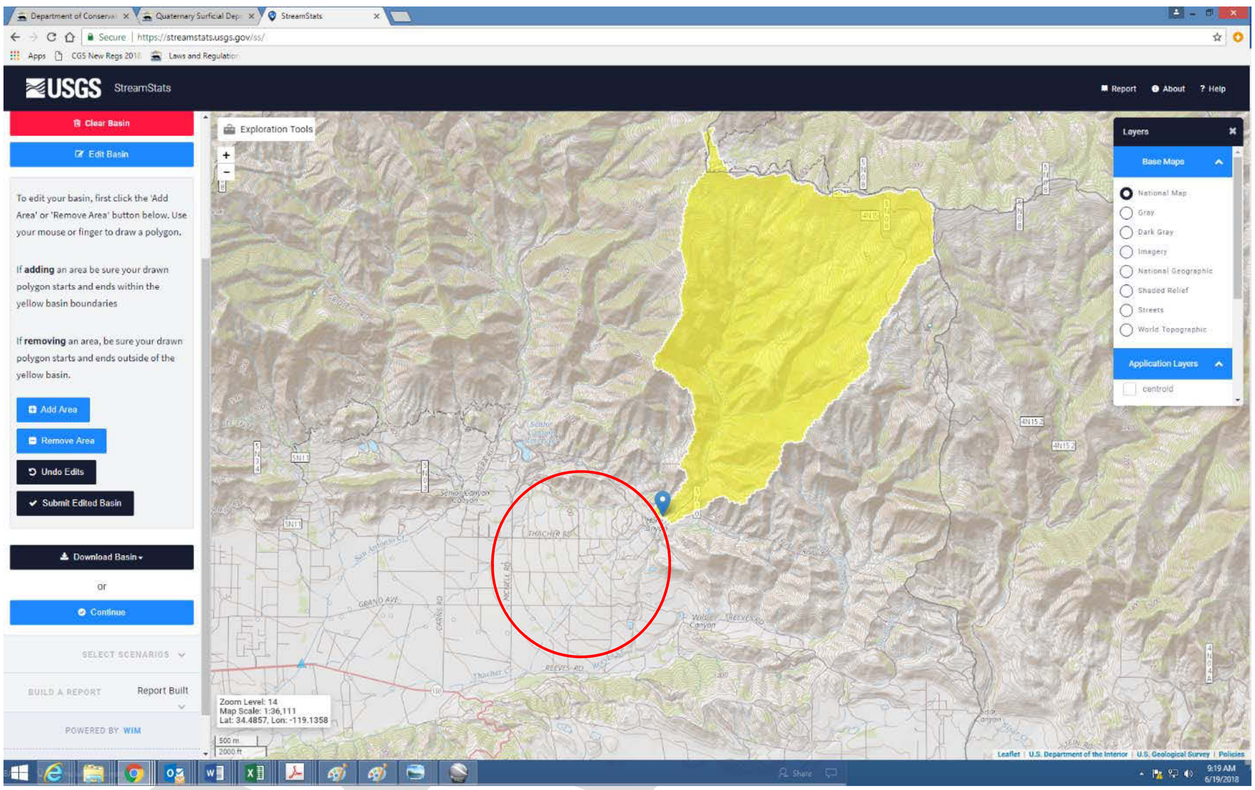
Step 1: Review of land use indicates populated area and presence of alluvial fans: Map unit Qf – Quaternary alluvial fan (red circle).

https://maps.conservation.ca.gov/cgs/QSD/

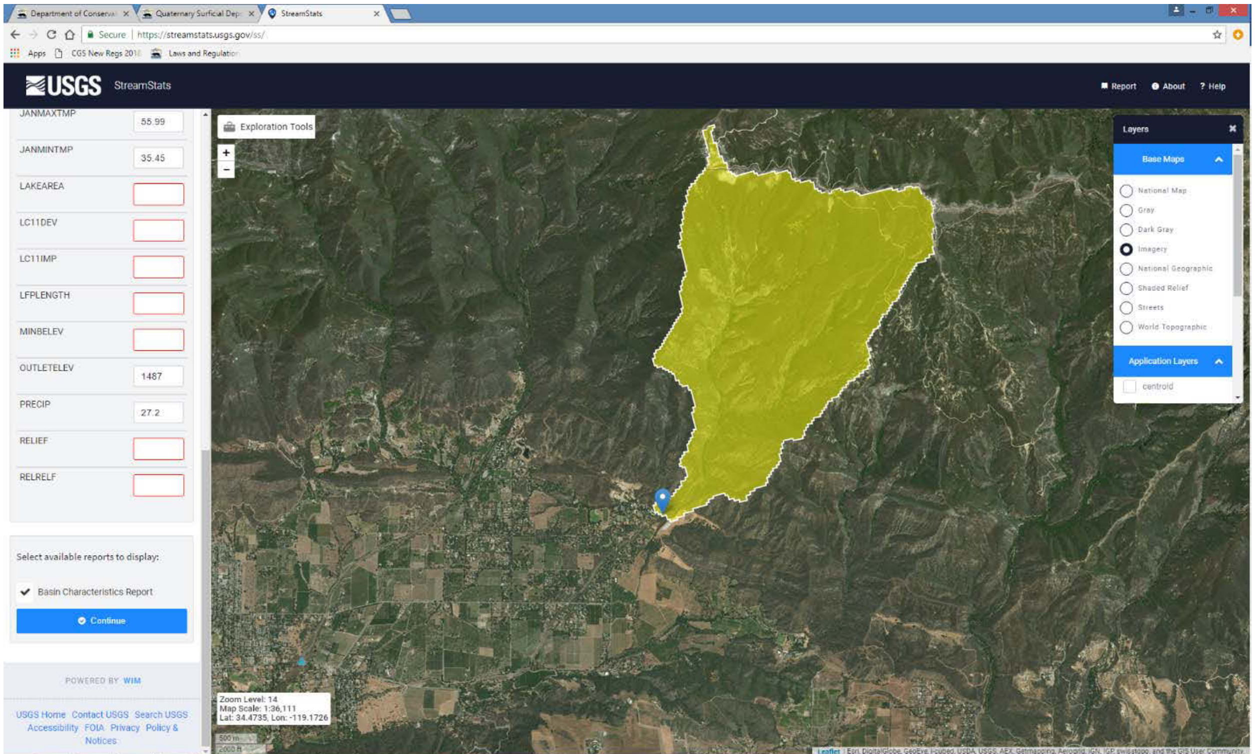


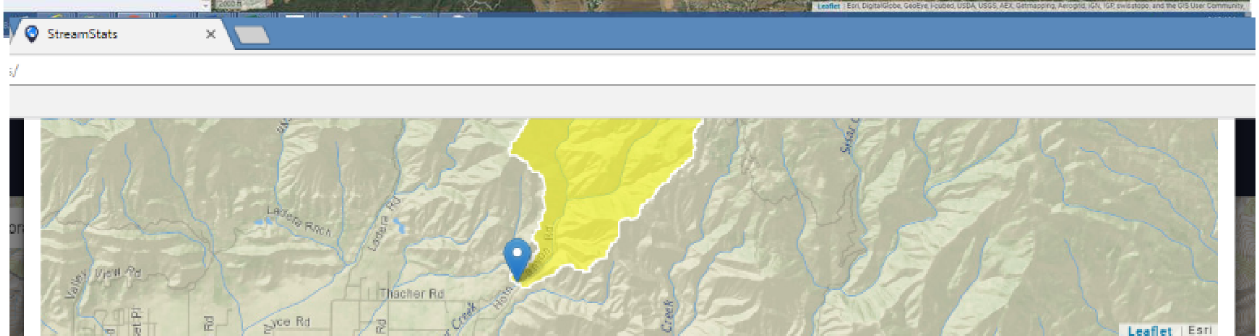
Step 2a and 2b: USGS Streamstats is used to draw watershed contributing area above fan at canyon mouth. Note that topographic contours are radial shaped indicating divergent flow paths and presence of fan-shaped landform (red circle).

https://streamstats.usgs.gov



Step 2b: USGS Streamstats is used to run a "Basin Characteristics Report." Report indicates that the average watershed slope based on a 30m DEM is 47.1%.

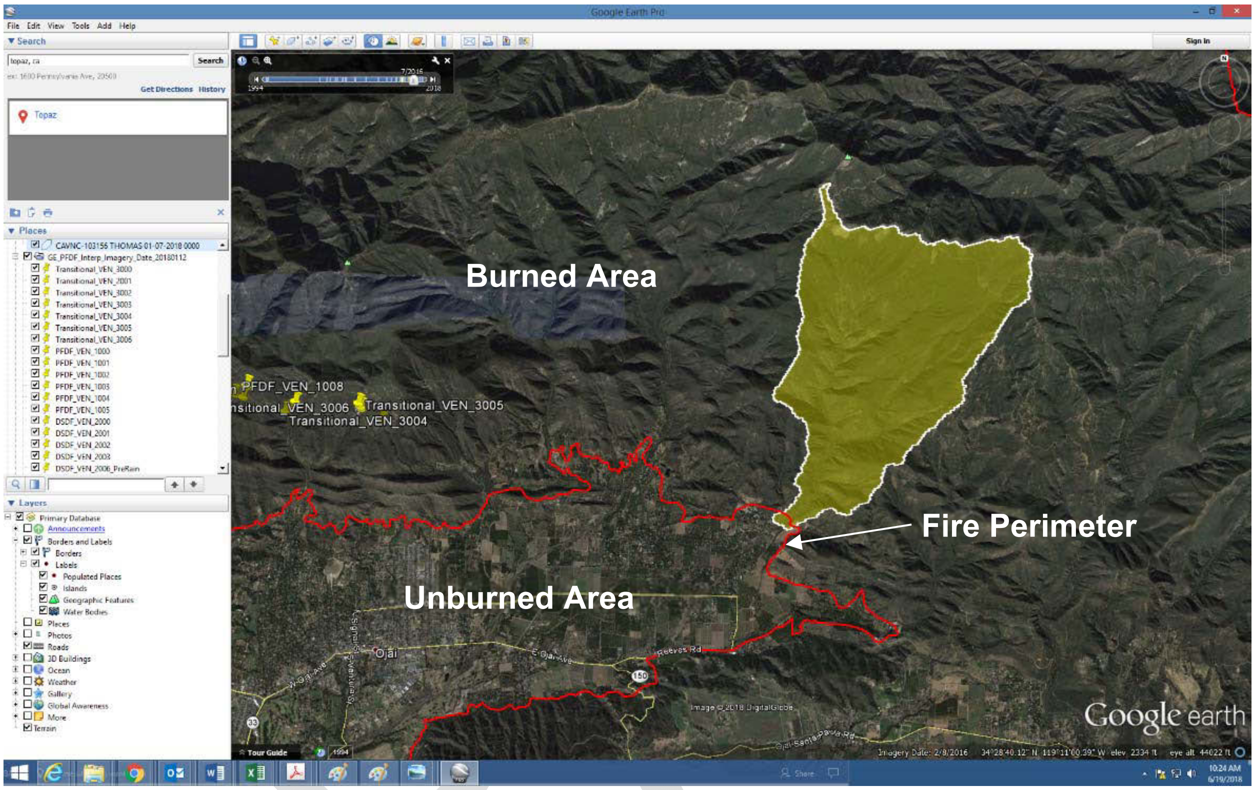




Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
BASINPERIM	Perimeter of the drainage basin as defined in SIR 2004-5262	11.8	thousand feet
BSLDEM30M	Mean basin slope computed from 30 m DEM	47.1	percent
CENTROIDX	Basin centroid horizontal (x) location in state plane coordinates	-2089717.3	feet
CENTROIDY	Basin centroid vertical (y) location in state plane units	1525364	feet
DRNAREA	Area that drains to a point on a stream	3.3	square miles
EL6000	Percent of area above 6000 ft	0	percent
ELEV	Mean Basin Elevation	3549	feet
ELEVMAX	Maximum basin elevation	5491	feet
FOREST	Percentage of area covered by forest	35.5	percent

Step 2B (Continued): Comparison of basin area with fire perimeter indicates the evaluated basin is >95% burned. The urbanized alluvial fan below remained generally unburned.



Appendix C. GIS Data and Resources**

Standard WERT GIS Data Layers and Maps			**DRAFT v2, 3/12/2020**
Data Layers			
Layer	Compiled by	Data Source	Notes
Fire perimeter	CAL FIRE (WERT GIS Lead)	Incident / NIFC	Most recent fire perimeters are uploaded by incident team to NIFC site.
Fire history *	CAL FIRE (WERT GIS Lead)	Incident	
Roads *	CAL FIRE (WERT GIS Lead)	Incident / County	
Structures*	CAL FIRE (WERT GIS Lead)	Incident / DINS / County / Microsoft layer	
DEM (for hillshade, slope) *	CAL FIRE Incident/DINS (NEXTMap 5m, used for most maps); CGS (compiles lidar data for Collector)	Lidar, NEXTMap One (1m) or NEXTMap (5m IfSAR), The National Map seamless elevation layer, or USGS 10 m or 30 m DEMs	US Interagency Elevation Inventory: https://www.coast.noaa.gov/inventory/#/app=b74d&b3b1-selectedIndex=0. Use standard WERT symbology for slope.
Geology	CGS	Best available, varies by area	
Landslides*	CGS	CGS Landslide Inventory, best available, varies by area	
Mineral hazards *	CGS	CGS mineral hazard reports for Caltrans Districts, USGS Mineral Resources Data System (MRDS)	
Wells (oil, gas, geothermal) *	CGS	GEMD web feature service, rescaled symbol size: https://https://gis.conservation.ca.gov/server/rest/services/WellSTAR/Wells/MapServer	
Soils *	CAL FIRE (WERT GIS Lead)	Esri SSURGO Downloader: http://www.arcgis.com/home/item.html?id=cdc49bd63ea54dd2977f3f2853e07fff	Soils data for use in erosion models may be clipped and downloaded from USFS WEPP web site listed under ERMiT below.
Ownership *	CAL FIRE (WERT GIS Lead)	Incident	

SRA *	CAL FIRE (WERT GIS Lead)	Incident	
Streams *	CAL FIRE (WERT GIS Lead)	Incident / USGS NHDH_CA.gdb (Hydrography > NHDFlowline)	If an NHD web feature svc becomes available (rather than a map service), could clip that.
Waterbodies *	CAL FIRE (WERT GIS Lead)	Incident / USGS NHDH_CA.gdb (Hydrography > NHDWaterbody)	If an NHD web feature svc becomes available (rather than a map service), could clip that.
Watershed boundaries *	CAL FIRE (WERT GIS Lead)	Incident / USGS NHDH_CA.gdb (WBD > WBD_HU12)	If an NHD web feature svc becomes available (rather than a map service), could clip that.
FEMA Flood Hazard Areas *	CGS	FEMA web feature service: https://hazards.fema.gov/gis/nfhl/rest/services, Public > NFHL > Flood Hazard Zones	Export FEMA web feature service to envelope. Update frequency: irregular. NFHL updated as studies go effective.
DWR Awareness Floodplains *	CGS	This layer no longer available from DWR web site. Their Best Available Maps (BAM) data is available to view in web map, but no download option.	
Post-fire imagery	CGS	USGS, Digital Globe, others	
BARC	CAL FIRE	USFS GTAC / USGS / CAL FIRE	
Soil Burn Severity	CAL FIRE	WERT Team (field-verified version of BARC)	
e-EHR	CAL FIRE (FPGIS)	CAL FIRE (FPGIS)	FPGIS developing an online platform?
ERMiT	CAL FIRE	Can download needed inputs from online USFS WEPP interfaces: https://forest.moscowfsl.wsu.edu/fswepp/	The online modeling tools only work for individual watersheds, and they may have a size limitation and course DEM resolution.
USGS debris flow estimates	CAL FIRE (WERT GIS Lead)	USGS	
VARs	CAL FIRE (WERT GIS Lead)	WERT Team	
Pour points	CAL FIRE	WERT Team	

* Data can be partially or fully pre-processed/staged before fire season, then clipped to envelope during incident.

** For individual fires, an inquiry for additional layers should be made to the local agencies (e.g., local flood control structures, parcel maps).

Maps

Map	Prepared by	Notes
For Planning only (page-sized)		
Slope	CGS	
For Field Team (large format)		
BARC/Soil Burn Severity	CAL FIRE	Plotted earlier (as soon as BARC data becomes available). Map includes stuctures (poly or poly centroids, depending on scale).
Debris flow estimates	CAL FIRE	Plotted later (after debris flow model data becomes available). Map includes stuctures (poly or poly centroids, depending on scale).
Post-fire imagery	CAL FIRE	Plotted after post-fire imagery becomes available (may be sooner or later, depending on timing of satellite passes and visibility conditions).
For Report (mostly page-sized)		
Overview	CAL FIRE (WERT GIS Lead)	
Fire history	CAL FIRE (WERT GIS Lead)	
Geology	CGS	
Landslides	CGS	If landslides not abundant, may be included on geology map instead of separate map.
Mineral hazards	CGS	
Wells (oil, gas, geothermal) *	CGS	If wells not abundant, may be included on mineral hazards map instead of separate map.
Soils	CAL FIRE (WERT GIS Lead)	
Soil Burn Severity	CAL FIRE (WERT GIS Lead)	
USGS debris flow estimates	CAL FIRE (WERT GIS Lead)	Whole fire (smaller scale, page-sized)
VARs	CAL FIRE (WERT GIS Lead)	Larger scale, multiple map book pages, subset of sites. Includes debris flow estimate data.
ERMiT	CAL FIRE (WERT GIS Lead)	
Pour points	CAL FIRE (WERT GIS Lead)	

Appendix D: WERT Methods

Values-at-Risk Inventory Methods

A fundamental step in the WERT process is the identification and characterization of significant Values-at-Risk (VARs). VARs are the values or resources at risk of damage or loss by post-wildfire geologic and/or hydrologic hazards (Calkin et al., 2007). Life, safety and property are the primary VARs. The WERT process utilizes a qualitative approach for assessing risk to these values, and relies on a combination of modeling and best professional judgement to guide risk determination.

Potential significant VARs may be identified during the initial phases of reconnaissance and/or through consultation with local agency personnel and stakeholders. However, these VARs may be found to have little risk associated with them following further assessment and analysis.

Field Observations of Values-at-Risk

The WERT conducts a site-specific evaluation of VARs within and immediately below fire areas. VAR and hazard determination relies on a combination of field observations, geomorphic interpretation, office review of available geologic and topographic data and aerial photography, post-fire debris flow modeling, flood flow modeling, and empirical information based on conversations with local agencies and residents.

Areas where there were concentrations of residential homes, schools, power stations, campgrounds, parks, access roads, and public infrastructure receive the greatest attention. Road-related features, such as culverts and bridges, are surveyed at major drainage crossings or where a potential risk to life may be present. Road-related features tend to fall into general observations and recommendations but may be documented as a VAR if they pose a substantial life safety hazard during a runoff or debris flow event where they may potentially clog, avulse and divert flow and debris towards nearby structures. **Some potential VARs may not be evaluated due to locked gates or general lack of access.**

The VARs assessed by the WERT include possible loss of life and property due to an elevated potential for increased streamflows, hyperconcentrated flows, debris torrents, debris flows, rock fall, and associated slope movement. VARs are assessed using the USGS post-fire debris flow modeling data for a threshold of a 15-minute rainfall intensity (probability hazard), FEMA 100-year flood plain mapping, soil burn severity data, topography, aerial imagery, hillshade, slope, watershed boundaries (HUC-12)[4], DWR awareness floodplains, and roads. Team members confirm hazards based on site-specific observations and interpretation of active geomorphic processes and landforms.

[4] A HUC-12 subwatershed is typically 15,000 to 40,000 acres in size.

When appropriate, team members note preliminary or possible emergency protection measures.

Potential hazards to life-safety and property are qualitatively ranked either as low, moderate or high as part of the WERT process, as shown in the VAR summary table. Rankings consider a combination of the probability of potential post-fire impacts as well as the severity of the consequences. High value sites, such as housing tracks, schools, hospitals, and critical infrastructure are ranked conservatively where larger events with lower probability may result in substantial consequences. **Only significant life-safety and property VARs are to be inventoried, not low risk infrastructure (e.g., culverts and other types of drainage structures).** **Low risk to life-safety and low risk to property infrastructure may be commented on in General Recommendations but shall not be considered as individual VARs nor included in the VARs inventory.**

It should be noted that the observations included in WERT reports are not intended to be fully comprehensive and/or conclusive, but rather to serve as a preliminary tool to assist emergency responding agencies (e.g., CAL FIRE, Caltrans, Office of Emergency Services, Natural Resource Conservation Service, utility companies, and other responsible agencies) in the development of more detailed post-fire emergency response plans. **It is intended that the emergency responding agencies will use the WERT VAR information as a preliminary guide to complete their own more detailed evaluations and develop detailed emergency response plans and mitigations.**

Field Observation Data

To validate the Burn Area Reflectance Classification (BARC) map for soil burn severity and to collect VAR points and polygons, as well as associated information, a mobile mapping application is used called “Collector for ArcGIS” to allow field observers to use mobile devices (tablets and smart phones) to view and use for reference several different information layers (http://doc.arcgis.com/en/collector/). Layers produced in the office and loaded on these devices prior to field work typically include:

- Fire perimeter
- Ownership
- BARC (Burned Area Reflectance Classification) layer
- Soil burn severity layer
- United States Geological Survey (USGS) debris flow model segments Watershed boundaries (HUC-12)
- Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas
- California Department of Water Resources (DWR) Awareness Floodplains
- Best available elevation data, preferable lidar hillshade
- Local flood control data (such as natural drainages, debris basins, culverts)
- Hydrography
- Structures, building footprints
- Roads
- Soils

- Hazardous minerals
- Geology (lithology and faults)
- Landslides
- Slope gradient
- Topographic hillshade

The Collector mobile application is useful for navigation and it provides drop-down menus that allows field observers to capture locations (as points or polygons), attributes, and georeferenced photos of the following features:

- Soil burn severity (for field verification of the BARC map)
- Values-at-Risk
- General observations

The data recorded in Collector is uploaded daily to a secure cloud service (ArcGIS Online), allowing it to be quickly viewed by team members in different locations or downloaded into desktop GIS software for preparation of custom maps. The positional accuracy of GPS points in Collector can be variable in confined canyon and heavy canopy settings. However, in areas of open sky and multiple satellite connections, positional accuracy generally ranges from 10 to 20 feet.

Post-Fire Debris Flow Prediction Method

The WERT uses the USGS post-fire debris flow hazard suite of models (Staley et al., 2017; Gartner et al., 2014) as a screening tool for field evaluation and as a decision support tool for geologic hazard determination. The dataset used to develop the USGS models contains data specific to the Transverse and Peninsular Ranges of southern California. See https://landslides.usgs.gov/hazards/postfire_debrisflow/ for more information on these models.

The USGS model assessment uses the soil burn severity map as a primary input to estimate the likelihood and potential volume of debris flows for selected basins and streams in response to a design storm. The empirical models are based upon historical debris flow occurrence and magnitude data, storm rainfall conditions, topographic and soils information, and soil burn severity data from recently burned areas (Staley et al., 2017). The models have become the standard for post-fire emergency response as they use readily acquirable input parameters.

Post-fire debris flow likelihood (Staley et al., 2017), volume (Gartner et al., 2014), and combined hazards are estimated at both the drainage basin scale and in a spatially distributed manner along the drainage network within each basin. These are described as basin and segment, respectively. The characteristics of basins and segments affected by the fire are generally calculated using a geographic information system (GIS) with a minimum area of 0.02 km^2 (approximately 5 ac) and a maximum area of 8.0 km^2 (1977 ac). Basins and segments with drainage areas greater than 8.0 km^2 are not explicitly modeled for debris flow probability, and may be designated as “watch streams”, which may consist of a combination of flood and debris flow hazards. Debris-flow likelihood and volume are normally estimated for each basin outlet, as well as along the upstream drainage networks. The US Geological Survey (USGS) preliminary hazard assessments can be accessed online at: https://landslides.usgs.gov/hazards/postfire_debrisflow/

The debris flow probability M-1 regression model (Staley et al., 2016, 2017) below may also be re-arranged to estimate the rainfall necessary to generate a targeted probability of debris flow at the watershed or fire-wide scale:

$$P = e^{x} / (1 + e^{x})$$

$$x\ (15\text{-minutes}) = -3.63 + (0.41 * bsl * R) + (0.67 * (dNBR/1000) * R) + (0.7 * SoilKF * R)$$

$$x\ (30\text{-minutes}) = -3.61 + (0.26 * bsl * R) + (0.39 * (dNBR/1000) * R) + (0.50 * SoilKF * R)$$

$$x\ (60\text{-minutes}) = -3.21 + (0.17 * bsl * R) + (0.20 * (dNBR/1000) * R) + (0.220 * SoilKF * R)$$

where:

bsl = Proportion of upslope area burned at high or moderate severity with gradients greater than or equal to 23 degrees
dNBR = Average difference normalized burn ratio for all upslope pixels

SoilKF = Soil erodibility index of the fine fraction of the soil, from Schwartz and Alexander 1995
R = Accumulated rainfall depth (in mm)

For reporting purposes, we frequently compare model outputs to threshold storms chosen by the National Weather Service to initiate flash flood watches and warnings, and to storm recurrence intervals based on point precipitation frequency (PF) estimates defined on the NOAA Atlas 14 website (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html).

The “emergency assessment” debris flow volume model (Gartner et al., 2014, Equation 3) predicts the volume of debris flows occurring within two years after a fire. This model offers advantages over other methods in that it explicitly factors soil burn severity into the calculation of debris yield:

$$V = e^{4.22 + 0.39(\sqrt{i15}) + 0.36(\ln Bmh) + 0.13(\sqrt{R})}$$

where:

V = Volume of sediment (m^3)
i15 = Peak rainfall intensity measured over a 15-minute period (mm hr^{-1})
Bmh = Watershed area burned at moderate and high soil burn severity (km^2)
R = Watershed relief (m)

Reports generally describe debris flow hazard in terms of an ordinally ranked “combined hazard” following the methods of Cannon et al. (2010). Figure D-1 (below) illustrates modeling results using the results of the Staley et al. (2016) probability model equation, and the Gartner et al. (2014) emergency assessment debris flow volume model Equation 3, where:

Combined Debris Flow Hazard = Predicted Debris Flow Likelihood + Predicted Debris Flow Volume

According to the USGS:[5]

> *Debris-flow hazards from a given basin can be considered as the combination of both probability and volume. For example, in a given setting, the most hazardous basins will show both a high probability of occurrence and a large estimated volume of material. Slightly less hazardous would be basins that show a combination of either relatively low probabilities and larger volume estimates or high probabilities and smaller volume estimates. The lowest relative hazard would be for basins that show both low probabilities and the smallest volumes.*

[5] https://www.usgs.gov/natural-hazards/landslide-hazards/science/scientific-background?qt-science_center_objects=0#qt-science_center_objects

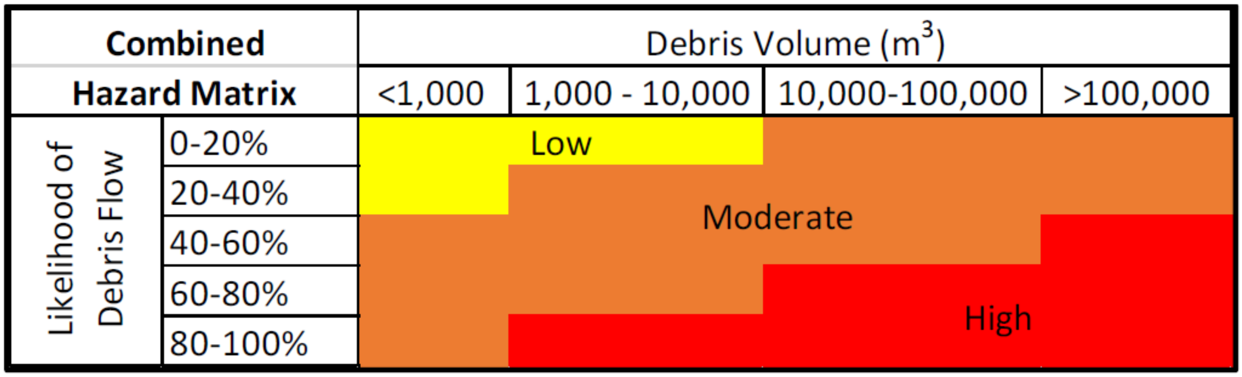


Figure D-1. The combined debris flow hazard classification as a function of predicted debris flow probability and debris volume production. Colors in yellow, orange, and red represent a combined debris flow hazard of low, moderate, and high, respectively.

Debris Flow Threshold Communication

A draft flowchart (Figure D-2) outlines the WERT's best practices to characterize rainfall thresholds that may trigger debris flows following wildfire with a focus on forecast meteorology and emergency management decision support. Consulting historic wildfires with debris flow monitoring data plays a large role in modifying debris-flow triggering thresholds. While debris flows create the most dangerous consequences to life-safety after wildfire, isolated flash floods, debris laden floods, rock falls and other types of landslides may occur at thresholds below those developed by this approach.

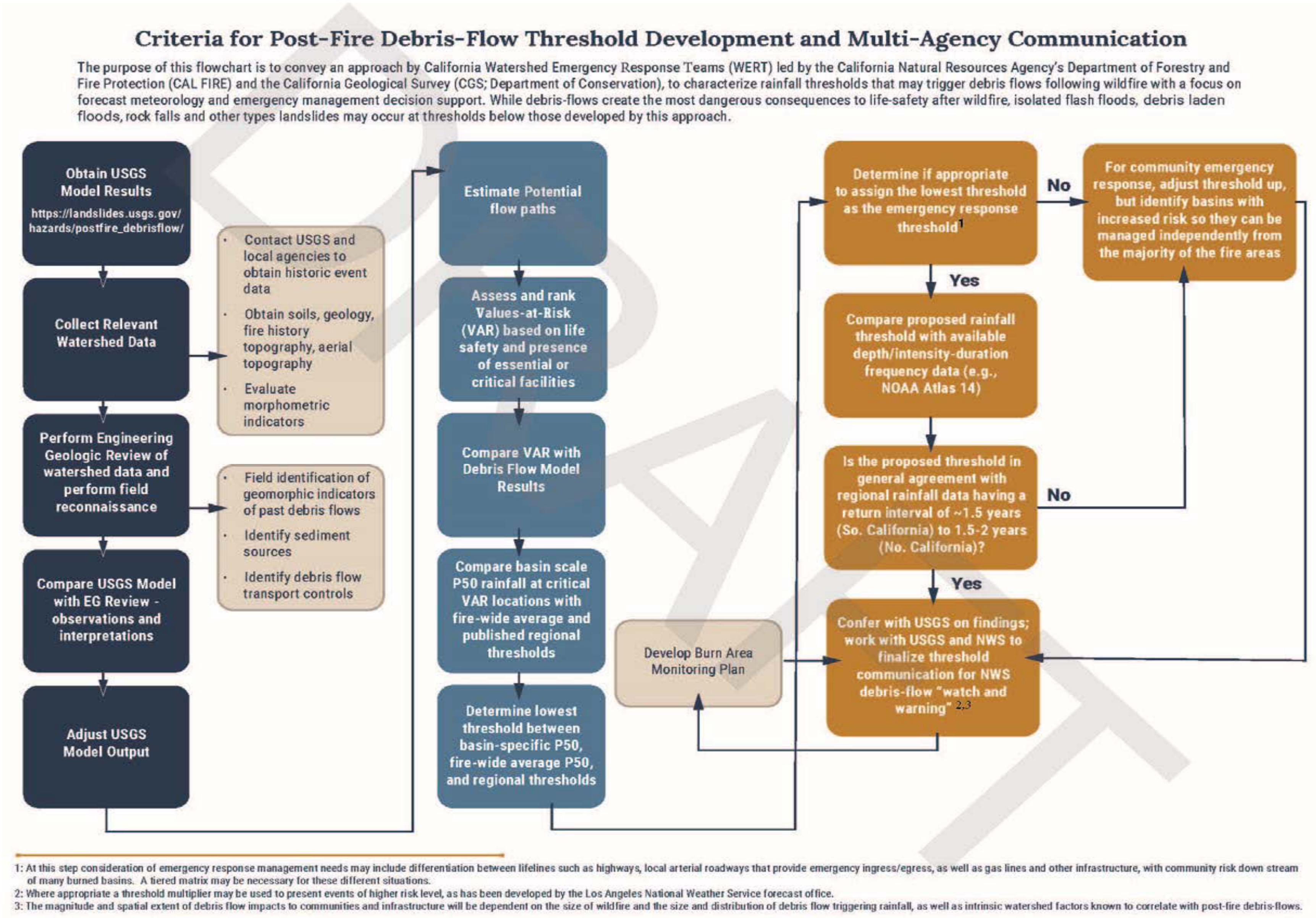


Figure D-2. Debris flow threshold communication matrix.

Peak Flow Prediction Methods

Peak flows increase following wildfire as a result of reduced surface cover and the formation of water repellent soils. The largest peaks occur during intense, short duration rainfall events on watersheds with steep slopes (Neary et al., 2005). Research conducted in southern California indicates that post-fire peak flows can increase as much as 10- to 30-fold for low magnitude storms and approximately 2- to 3-fold for larger magnitude storms (Rowe et al., 1949; Moody and Martin, 2001, Wohlgemuth 2016). Kinoshita et al. (2014) reported that commonly used flood flow prediction methods have lower confidence with larger recurrence interval events (25- and 50-year); therefore, pre- and post-fire flows using 2- and 10-year storm events are generally used for WERT evaluations.

Peak flow/flood response can be determined by first estimating pre-fire flood flows for these selected recurrence intervals associated with designated "pour point" watersheds. **If changes in flow recurrence intervals are not going to be evaluated, this step may be omitted and flow modifiers can be directly calculated**. Pour points for watersheds are established to obtain a better understanding of hydrologic response for areas potentially at risk from flooding, especially those that are related to VARs from flooding and/or debris flows. They are selected at locations in basins with VARs, upstream of existing debris basins, and upstream of alluvial fan formations. Pour points are watershed units used for both flood flow and debris yield analyses. Pour points represent a sampling of the fire and are not inclusive of all the VARs (i.e., not all VARs have an assigned pour point). Pour points that are closer to the burn area will yield greater post-fire flow increases than those further below the burn area events.

Pre-Fire Flood Flow Prediction Methods

Pre-fire flow estimates can be obtained with two primary methods. The most common approach is to rapidly use the USGS StreamStats online tool (https://streamstats.usgs.gov/ss/; Figure D-3).

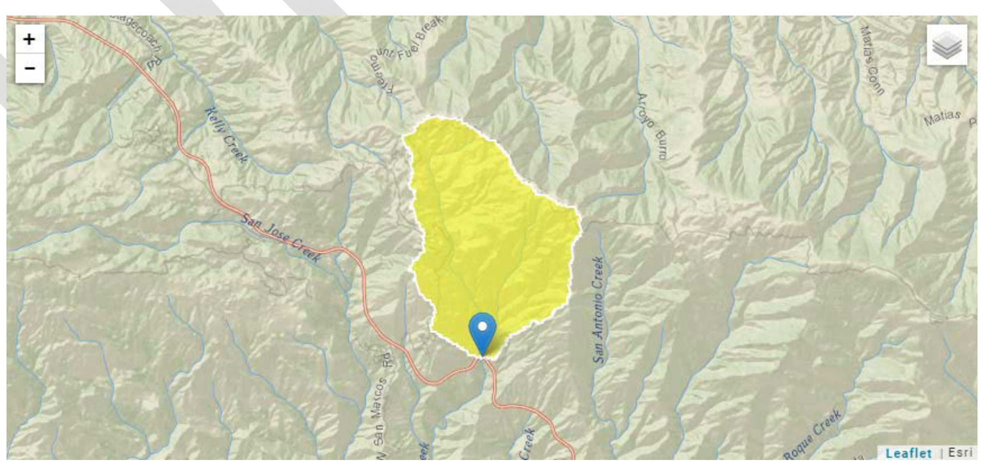


Figure D-3. StreamStats delineation for Maria Ygnacio Creek at Highway 154, a pour point watershed partially burned in the 2019 Cave Fire in Santa Barbara County.

StreamStats is a Web application that provides access to GIS analytical tools, and can be used to rapidly delineate pour point drainage areas, obtain basin characteristics, and peak flow statistics using the California USGS regional regression equations (Gotvald et al. 2012). It does have drainage area delineation accuracy issues for small watersheds, and ArcGIS analysis may be more appropriate for pour points associated with small watersheds.[6] In that case, pre-fire flood flows can be estimated using the Gotvald et al. (2012) regional regression equations available in an Excel spreadsheet.

For example, using Maria Ygnacio Creek at Highway 154 in Santa Barbara County, a pour point watershed with a drainage area of 2.1 mi^2 established for the 2019 Cave Fire has a 10-year pre-fire flow estimated to be 424 cfs (Figure D-4).

Peak-Flow Statistics Parameters[2012 5113 Region 5 South Coast]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	2.1	square miles	0.04	850
PRECIP	Mean Annual Precipitation	28.6	inches	10	45

Peak-Flow Statistics Flow Report[2012 5113 Region 5 South Coast]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PII	Plu	SEp
2 Year Peak Flood	74	ft^3/s	13.7	399	134
5 Year Peak Flood	239	ft^3/s	72.4	792	83.1
10 Year Peak Flood	424	ft^3/s	161	1110	64
25 Year Peak Flood	730	ft^3/s	329	1620	51.5
50 Year Peak Flood	1010	ft^3/s	484	2100	47.6
100 Year Peak Flood	1310	ft^3/s	631	2740	47.2
200 Year Peak Flood	1670	ft^3/s	795	3530	47.7
500 Year Peak Flood	2150	ft^3/s	974	4750	52

Figure D-4. StreamStats printout for Maria Ygnacio Creek at Highway 154.

Alternatively, if a stream gaging station with a sufficiently long flow record (e.g., ≥ 20 years) is located within the fire perimeter or a hydrologically similar gaging station is located near the fire (e.g., Figure D-5), a flood frequency analysis can be performed (e.g., use USGS PeakFQ program; https://water.usgs.gov/software/PeakFQ/), and the flow transference method (Waananen and Crippen 1977) method can be used to estimate pre-fire discharges for the pour point watersheds in an Excel spreadsheet.

[6] Generally, StreamStats is able to delineate basins with reasonable accuracy down to around 0.05 square miles (32 acres) in terrain with moderate relief. Delineations for flat areas will have lower accuracy (USGS StreamStats Support). Greater accuracy for drainage area will be obtained for basins >500 acres. Esri ArcMap software may be used for delineation of small pour point watersheds.

To adjust the 10-year discharge estimate for the gaged station to account for the difference in drainage area between the ungaged pour point basins and the gaged basin, use the following flow transference equation (Waananen and Crippen 1977):
$Q_{10u} = Q_{10g} (A_u/A_g)^b$

where:

Q_{10u} = 10-year flow at the ungaged pour point watershed in cfs

Q_{10g} = 10-year flow at the gaged site in cfs

A_u = drainage area of ungaged pour point watershed in mi^2

A_g = drainage area of gaged site in mi^2

b = exponent for drainage area from the appropriate Waananen and Crippen (1977) USGS Magnitude and Frequency regional regression equation (e.g., 0.79 for the 10-year equation for the South Coast Region, 0.90 for the Central Coast Region, 0.88 for the North Coast Region, and 0.80 for the Sierra Region)

Using Maria Ygnacio Creek as an example, a stream gaging station record exists with 25 years of valid annual flow data (Figure D-5). Utilizing the USGS PeakFQ online program, the estimated 10-year recurrence interval flow is 1,947 cfs for the gaging station with a drainage area of 6.33 mi^2 (Figure D-6).

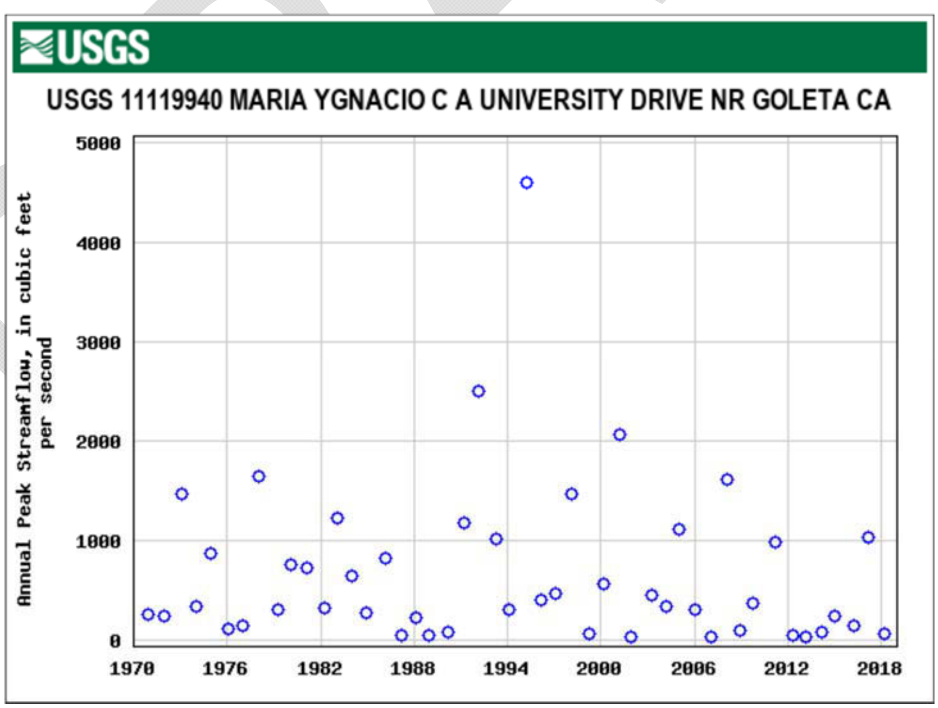


Figure D-5. Annual peak flow discharges for Maria Ygnacio Creek at University Drive near Goleta, California.

Using the flow transference equation, we have:

$Q_{10u} = Q_{10g}\ (A_u/A_g)^b$

Q_{10u} = 1947 cfs x $(2.1/6.33)^{0.79}$

Q_{10u} = 814 cfs

Waananen and Crippen (1977) state that the flow transference method is superior to the more general USGS Magnitude and Frequency Method regional regression equations if the stream gaging station is nearby and the available stream gaging annual peak discharge records are adequate. **Under these conditions, the flow transference method is preferable to the updated USGS regional regression equations because local data are likely to better represent the drainage-basin characteristics in terms of slope, geology, soils, and climate, when compared to the more general regional equations.** The highest level of confidence in this method occurs when the drainage area of the ungaged site is between 50 and 150 percent of the drainage area of the gaged site (Sumioka et al. 1998).

Station - 11119940 MARIA YGNACIO C A UNIVERSITY DRIVE NR GOLETA CA

TABLE 3 - ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	2.6455	0.5123	-0.162
BULL.17B ESTIMATE	0.0	1.0000	2.6455	0.5123	-0.213

BULL.17B ESTIMATE OF MSE OF AT-SITE SKEW 0.2116

TABLE 4 - ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

			<-- FOR BULLETIN 17B ESTIMATES -->		
ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	LOG VARIANCE OF EST.	CONFIDENCE INTERVALS 5% LOWER	95% UPPER
0.9950	16.7	17.7	----	5.5	34.4
0.9900	23.7	24.7	----	8.6	45.9
0.9500	59.3	60.2	----	27.6	100.2
0.9000	95.1	95.7	----	49.8	151.3
0.8000	166.1	165.5	----	98.0	250.6
0.6667	275.5	273.1	----	176.5	406.3
0.5000	461.0	456.3	----	309.9	689.2
0.4292	567.9	562.5	----	384.7	863.9
0.2000	1205.	1203.	----	797.8	2053.0
0.1000	1947.	1961.	----	1231.0	3674.0
0.0400	3190.	3261.	----	1897.0	6793.0
0.0200	4348.	4496.	----	2474.0	10040.0
0.0100	5709.	5973.	----	3118.0	14190.0
0.0050	7288.	7716.	----	3831.0	19380.0
0.0020	9734.	10470.	----	4883.0	28080.0

Figure D-6. USGS PeakFQ printout for Maria Ygnacio Creek gaging station flood frequency analysis.

Post-Fire Flood Flow Prediction Methods

To estimate changes in post-fire peak flows, the percent area burned at unburned/very low, low, moderate, and high soil burn severity (SBS) within each pour point watershed is determined by GIS analysis. Data for each pour point drainage area; area burned; area unburned (or burned at very low soil burn severity); area for low, moderate, and high soil burn severity; percent of the pour point watershed drainage area burned at low, moderate, and high soil burn severity; and the pre-fire 2-year and 10-year recurrence interval flow estimates, are entered or calculated in an Excel spreadsheet.

Post-fire WERT peak flow estimates are rapidly generated using different methods, depending on the fire location and data available. There is no one correct method for predicting the magnitude of post-fire flow change. Standard approaches include using Rowe, Countryman, and Storey (RCS) (1949, 1954) for southern California, and the USGS regional regression equations with a flow modifier method (Foltz et al., 2009) for other parts of California. Numerous other approaches exist as well, but have not been used by WERTs (e.g., 30-Minute Rainfall Intensity Method (Moody, 2012); Wildcat5 (Hawkins and Barreto-Munoz 2016), and AGWA (Sheppard 2016)). Brief summaries of the two main WERT methods are provided below and in Table D-1.

Table D-1. Selected WERT rapid post-fire flow estimation methods (see Kinoshita et al., 2013)

Post-Fire Peak Flow Estimation Approach	Applicable Location in CA	Applicable Drainage Area	Advantages	Disadvantages
Rowe, Countryman, and Storey (RCS) (1949, 1954)	Southern California	N/A	Empirical method easy to use	Large inaccuracy for small watersheds; data not updated
USGS Regression Equations with Flow Modifier (Foltz et al. 2009)	No limitation	Better for large basins (>3200 acres)	Easy to use; well understood	Must determine appropriate flow modifier (subjective)

Rowe, Countryman, and Storey (RCS 1949, 1954)

RCS developed relations for size of peak flow events and erosion rates associated with normal (unburned) conditions for 256 watersheds within five climatic zones in southern California. Changes in post-fire flows were also determined for these watersheds in each specific storm zone. Rowe et al. (1949) provided look up tables (LUTs) to calculate post-fire peak flows for the 256 watersheds throughout southern California. Each table includes post-fire streamflow predictions for 1, 2, 3, 7, 15, 30, and 70 years (normal) after burn, but WERTs only calculate flow changes for the first year. Additionally, Rowe et al. (1954) provide generalized curves to predict the ratio, or multiplier, of post-fire peak flow to pre-fire peak flow based on data for the Angeles storm zone in southern California.

To use this method, locate applicable watersheds included in the Rowe et al. 1949 tables for the fire being assessed. For each LUT being used, calculate the factor indicating the number of times flows will be increased for 2- and 10-year events. Once these factors are obtained, it is possible to use them to predict post-fire flood flows in an Excel spreadsheet. If it is determined to be appropriate, a fire intensity factor can be used to adjust for low, moderate, and high soil burn severity. For example, peak runoff from the low soil burn severity can be assumed to increase by a factor of 1.15 relative to unburned areas. Peak runoff from moderate and high soil burn severity areas can be assumed to increase by the calculated RCS factors relative to unburned areas, for the 2-year and 10-year recurrence intervals. In this case, the equation to use in the Excel spreadsheet is:

$$Q_{post} = (\%HighSBS \; x \; RCS \; x \; Q_n) + (\%ModerateSBS \; x \; RCS \; x \; Q_n) + (1.15 \; x \; \%Low \; SBS \; x \; Q_n) + (Q_{pre}(1 - \%Area \; Burned))$$

where:

Q_{post} = post-fire flow
%HighSBS = the percent of the pour point watershed with high SBS
%Moderate SBS = the percent of the pour point watershed with moderate SBS
%LowSBS = the percent of the pour point watershed with low SBS
RCS = Rowe et al. (1949) calculated first year flow increase factor
Q_{pre} = pre-fire flow

Rowe et al. (1949, 1954), do not make this distinction because their results are based on empirical data and assume fire as a lumped effect. Soil burn severity maps were not available when Rowe et al. (1949, 1954) conducted their research.

Rowe et al. (1954) may be able to be used for WERT reports where the earlier version (Rowe et al., 1949) does not include look up tables for the fire area in southern California (for example see 2018 Woolsey and Hill Fire WERT). Based on tables from a comparable watershed and storm zone within Rowe et al. (1954), the peak runoff from high, moderate, and low soil burn severity areas are assumed to increase by inferred factors (generally ranging from approximately 2-4) for the 2-year and 10-year recurrence intervals for the first year after the fire, compared to unburned areas. Unburned areas are given a multiplier of 1.0 because runoff characteristics are unchanged from pre-fire conditions.

USGS Regression Equations with Flow Modifier

The USGS Regression method is a commonly used post-fire runoff estimation method by WERT and BAER team members (Foltz et al. 2009). First, estimate pre-fire runoff for each pour point watershed using StreamStats. Then, determine the flow modifier that is defined as a ratio of post-fire to pre-fire runoff and calculated as follows:

$$modifier = 1 + \frac{percent \; runoff \; increase}{100\%} \cdot \frac{(A_h + A_m)}{A_T}$$

where:

A_m = area burned at moderate severity (acres)
A_h = area burned at high severity (acres)
A_T = total area burned (acres)

Finally, estimate post-fire clear water flow by multiplying the modifier and pre-fire runoff:

$$Q_{post} = modifier \cdot Q_{pre}$$

Since there are very limited studies and guidelines to determine the modifier or the percent runoff increase for high and moderate soil burn severity, WERT members usually rely on a simple rule: a 100% runoff increase (double the runoff amount) for high/moderate soil burn severity areas in the first year of the fire. This is the typical flow increase used by U.S. Forest Service BAER teams (Foltz et al. 2009).

Post-Fire Flood Flow Reporting

Due to modeling uncertainties, absolute changes in flow volumes or peak magnitude for post-fire flows are not provided in the WERT report; rather an estimate of peak flow response is displayed to make a more informed determination on flood hazard. Relative increase of peak flows from one pour point drainage basin to another is judged to be more important for these rapid assessments, rather than the estimated absolute values of the peak flows (i.e., percent change in flows rather than flow rates in cfs). If determined to be necessary, considerably more detailed hydrologic and hydraulic (H&H) modeling can be undertaken by federal agencies (e.g., USACE) in a second assessment phase.

In the Excel spreadsheet, columns are established for post-fire 2-year and 10-year flow estimates, and flow modifiers for both the 2-year and 10-year flow events.

The flow modifier (Q_m) for each pour point watershed is calculated by dividing the post-fire flow (Q_{post}) by the pre-fire flow (Q_{pre}):

$$Q_m = \frac{Q_{post}}{Q_{pre}}$$

The curves from Rowe et al. (1949; 1954), and the flow modifier from Foltz et al. (2009), do not reflect changes in clear water flow only, and there is some unspecified level of sediment bulking included in the post-fire flow predictions. Bulking by sediment can be extremely important during the first few post-winter periods (LACDPW, 2006). It is likely that bulking will increase flood flows another 30 to 70 percent during very infrequent, severe winter storm events.

As a conservative approach, a bulking factor is often applied to the post-fire flow estimates generated from the methods listed above. The bulking factor is calculated with this equation (Gusman, 2011):

$$BF = 1 + \%HighSBS\ x\ 0.7 + \%Moderate\ SBS\ x\ 0.5 + \%Low\ SBS\ x\ 0.2$$

Finally, a combined post-fire flow and bulking factor modifier (M) is calculated by multiplying the flow modifier by the bulking factor:

$$M = Q_m \, x \, BF$$

In addition to reporting the flow modifier for each pour point watershed, changes in flow recurrence intervals may also be reported for critical watersheds if the pre- and post-fire flow values are calculated. For example, a 10-year recurrence interval flood event may be modeled to increase to approximately a 50-year return period event the first year after the fire.

Although post-fire flood flow models utilized may show relatively low to moderate levels of flooding risk, uncertainties within these models don't preclude the threat of increased debris-laden floods and hyperconcentrated flows from impacting the built environment. This condition is pronounced during periods of high-intensity, short-duration (30 to 60 minute) storms that are not included in many of the post-fire hydrology models applied, such as the RCS method.[7] This information should be included in the WERT final report.

[7] Recent research conducted by Kinoshita and Wilder at San Diego State University has shown that the RCS methodology has large inaccuracy for post-fire flow estimation for small watersheds (~750 to 8,650 acres) in southern California. Predictors with the highest importance include peak hourly rainfall intensity, soil burn severity, highest point in the basin, and basin shape (perimeter, circulatory ratio) (Wilder and Kinoshita, 2019). An improved post-fire flow prediction method is under development.

Pre- and Post-Fire Surface Erosion Modeling Methods

Pre- and post-fire erosion rates for fire areas are most often modeled by CAL FIRE or USFS hydrologists and soil scientists using the Batch ERMiT (Erosion Risk Management Tool). ERMiT is a Water Erosion Prediction Project (WEPP) driven and web-based interface tool developed to predict surface erosion from pre- and post-fire hillslopes, and to evaluate the potential effectiveness of various erosion mitigation practices (Robichaud et al. 2011). ERMiT requires input for climate parameters based on location (PRISM interface), vegetation type (forest, range, chaparral), soil type (clay loam, silt loam, sandy loam, loam textures and rock content), topography (slope length, gradient, and profile), and soil burn severity class (unburned, low, moderate, high). This model provides probabilistic estimates of post-fire hillslope erosion from single recurrence interval "runoff events" by incorporating variability in rainfall characteristics, soil burn severity, and soil characteristics into each prediction (Robichaud et al. 2011). ERMiT only predicts rill and interrill erosion due to runoff events generated by precipitation. Watershed-based surface erosion Batch ERMiT maps show relative erosion potential and erosion volumetric information (Robichaud et al. 2011). **If Batch ERMiT values are generated, it is appropriate to include a relative ranking (i.e., low, moderate, and high), rather than absolute values in tons per acre.**

A newly developed cloud-based WEPP Post-Fire Erosion Prediction (WEPP-PEP) tool is available for use, which interfaces with ERMiT in the background (Robichaud et al. 2019). This tool allows users to upload a soil burn severity map and predict both flow increases and surface erosion at the same time. However, this tool is scale-limited, in general limited to drainage areas <2 square miles (1280 acres), so it is often only used for smaller pour point watersheds. WEPP-PEP can be used for a specific pour point strategically located below a high risk VAR (e.g. a water supply reservoir).

While these models provide an indication of pre- and post-fire surface erosion, they do not always produce consistent or feasible results, so conclusions on surface erosion should emphasize field conditions and observations.

ERMiT: http://forest.moscowfsl.wsu.edu/fswepp/batch/bERMiT.htmlWEPP: https://forest.moscowfsl.wsu.edu/fswepp/

WEPP-PEP: https://wepp1.nkn.uidaho.edu/weppcloud/

Debris Yield Prediction Methods

Debris yields may be calculated for pour point watersheds using two different empirical methods. The first method, the Gartner et al. (2014) “long-term model”, represented by Equation 2 in the paper, was developed for predicting volumes of sediment deposited by debris flows and sediment-laden floods with no time limit after a fire for watersheds draining the Transverse Ranges of southern California.

Gartner et al. (2014), Equation 2 is of the form:

$$V = e^{6.07 + 0.71(\ln i60) + 0.22(\ln Bt) - 0.24(\ln T) + 0.49(\ln A) + 0.13(\sqrt{R})}$$

where:

V = Volume of sediment (m^3)
I60 = Peak rainfall intensity measured over a 60-minute period (mm hr^{-1})
Bt = Watershed area burned since the most recent fire
T = Time since the most recent fire (years)
A = Watershed area (km^2)
R = Watershed relief (m)

The 2-year and 10-year recurrence interval 15-minute rainfall intensity is estimated using the NOAA Atlas 14-point precipitation frequency estimates website. Rainfall rates are selected at the top of watersheds (i.e., distal end of the channel network) using annual maximum time series. Watershed relief and the watershed area burned are extracted using GIS.

The second method regularly used is the USACE Los Angeles District Method Equations 1 through 5 for calculating total debris yield (Gatwood et al., 2000). The USACE equations predict unit area debris yield, which includes a combination of hillslope and fluvial erosion. The specific equation varies by watershed size where:

USACE Equation 1 (0.1 to 3.0 mi^2) is of the form:

(1) Dy =100.65(Log10 P) + 0.62(Log10 RR) + 0.18(Log10 A) + 0.12(FF)

USACE Equation 2 (3.0 to 10.0 mi^2) is of the form:

(2) Dy = 100.85(Log10 Q) + 0.53(Log10 RR) + 0.04(Log10 A) + 0.22(FF)

USACE Equation 3 (10.0 to 25.0 mi^2) is of the form:

(3) Dy = 100.88(Log10 Q) + 0.48(Log10 RR) + 0.06(Log10 A) + 0.20(FF)

USACE Equation 4 (25.0 to 50.0 mi^2) is of the form:

(4) Dy = 100.94(Log10 Q) + 0.32(Log10 RR) + 0.14(Log10 A) + 0.17(FF)

USACE Equation 5 (50.0 to 200.0 mi^2) is of the form:

$$(5)\ Dy = 101.02(Log10\ Q) + 0.0.23(Log10\ RR) + 0.16(Log10\ A) + 0.13(FF)$$

where:

Dy = Unit Debris Yield ($yd^3\ mi^{-2}$)
P = Maximum 1-Hour Precipitation (inches; taken two places after the decimal point and multiplied by 100)
RR = Relief Ratio ($ft\ mi^{-1}$)
A = Drainage Area (acres)
FF = Fire Factor
Q = Unit Peak Runoff ($ft^3\ s^{-1}\ mi^{-2}$)

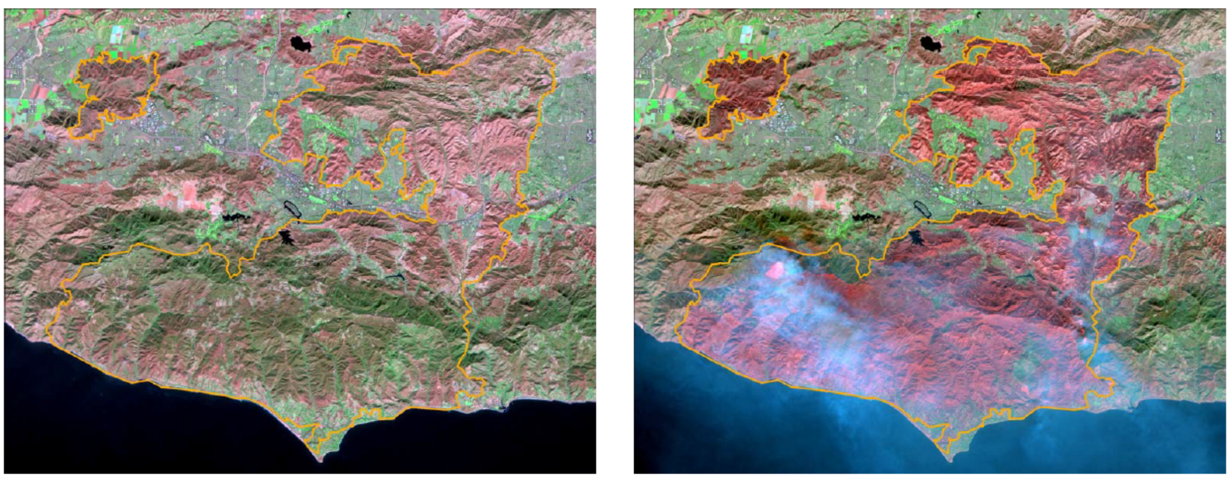
Precipitation (P) is selected by using the 2-year and 10-year, 1-hour rainfall magnitude (i.e., annual maximum time series) from the NOAA Atlas 14-point precipitation frequency estimates website for each selected pour point watershed at the distal end of the channel network. The USACE method is intended to estimate debris yield from runoff or precipitation events of greater than 5-year recurrence interval. Estimates below this generally display large errors (Gatwood et al., 2000). The 2-year and 10-year recurrence interval are chosen for this analysis to remain consistent with the flood modeling recurrence intervals; however, it should be noted that the 2-year recurrence debris yield could display larger errors than the 10-year recurrence debris yields. Unit Peak Runoff (Q), may be obtained from USGS StreamStats. Relief Ratio (RR) is calculated by taking the difference in elevation between the highest point in the watershed and the lowest point in the watershed and dividing the difference by the stream length using a combination of the NOAA Atlas 14 web browser interface and ArcGIS Collector. A weighted fire factor is calculated based on the percentage of burned and unburned area within the pour point watershed.

The USACE debris method indicates the need to apply an adjustment-transposition (A-T) factor to watersheds that are not included in the empirical data. The A-T factor is computed by assessing debris basin cleanout records and developing an average annual sediment yield (AASY) for each watershed and dividing by the average annual precipitation (AAP). This ratio is then compared to AASY/AAP ratios for watersheds within the USACE empirical dataset. The resulting unitless A-T factor represents the anticipated increase or decrease for erosion characteristics of each watershed and is applied to the results of the regression equations. Due to the rapid nature and time constraints of the WERT assessment, A-T factors are typically not included in the debris method analysis. If time permits and applying an A-T factor is necessary for accurate debris yield predictions, existing uniform and non-uniform debris basin cleanout data may be used (Lancaster et al., 2014).

Appendix E. Soil Burn Severity Information

The degree to which fire affects soil properties, along with other controlling factors, is important for predicting the potential for increased runoff and sedimentation (Keeley, 2009). Soil burn severity (SBS) mapping reflects the spatial distribution of the fire's effects on the ground surface and soil conditions. The SBS mapping is necessary to allow for the rapid evaluation of potential post-fire effects including identification of potential Values-at-Risk, and prioritization of field evaluations (Parsons et al., 2010). The soil burn severity map is a field-validated Burned Area Reflectance Classification (BARC) map which is derived from differencing pre-fire and post-fire Landsat 8 or Sentinel-2 satellite imagery (for example see Figures E-1 and E-2) using an image transformation algorithm known as the Normalized Burn Ratio (NBR)). A BARC map is field verified by the WERT team, or by a USFS/DOI BAER team tasked to the same fire (https://www.fs.fed.us/eng/rsac/baer/barc.html).

2018 Woolsey-Hill Fires Pre and Post-Fire Images
Sentinel-2 Imagery



Pre-Fire Image
5 Nov 2018

Post-Fire Image
15 Nov 2018

Figure E-1. Example of pre- and post-fire Landsat imagery (a and b). Here the change in wave lengths from green (pre-fire) to red (post-fire) represent areas where vegetation was most likely consumed during the fire.

The initial BARC maps are generally created by either the USGS EROS, USFS GTAC, or by CAL FIRE FRAP (Fire and Resource Assessment Program). The USGS EROS supports the Department of Interior (DOI) BAER teams responding to fires on DOI lands (BLM, FWS, NPS, etc.). USFS GTAC typically support USFS BAER teams responding to fires that burn on Forest Service lands. BARC maps have four burn severity classes: high, moderate, low, and unburned/very low. The BARC map is field-verified using methodology developed by Parsons et al. (2010). These methods include assessing key field indicators such as: post-fire ground cover, soil structure, fine-root condition, depth of burned mineral soil, and ash color and depth (Tables E-1 and E-2). Soil water repellency is also tested, however is generally not considered a reliable indicator due to inconsistent results (Doerr et al., 2000; Parsons et al. 2010). These factors are described in greater detail in Table E-3.

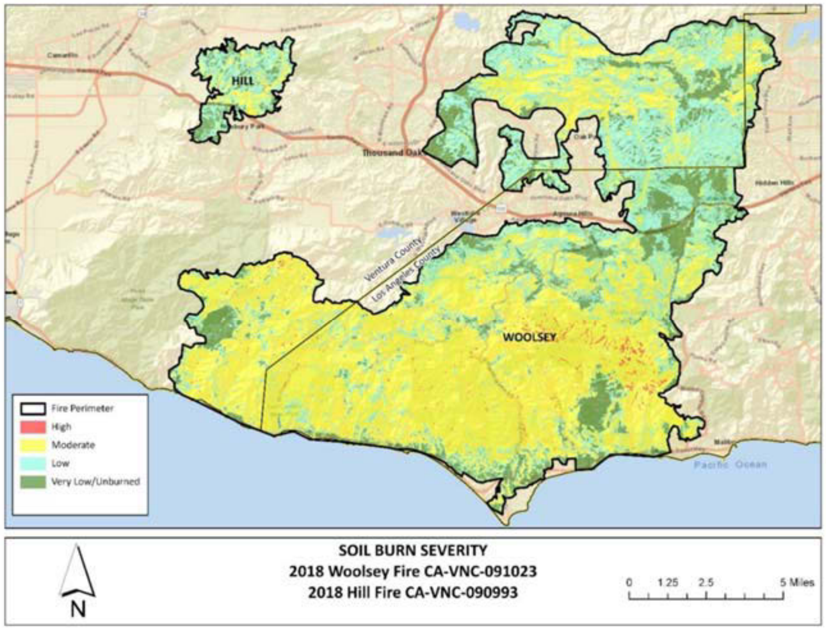


Figure E-2. BARC map of the 2018 Woolsey and Hill Fires. Note areas of higher burn severity (mostly yellow and red) correspond to changes in vegetation wave lengths when comparing between pre- and post-fire images shown in Figure E-1.

Table E-1. Soil burn severity classification (from Parsons et al., 2010).

SBS Class	Low	Moderate	High
Ground Cover	<50% litter consumed	Up to 80% litter/duff consumed	>80% litter/duff consumed
Soil Structure	Unchanged	Slightly altered	Destroyed, loose and powdery
Fine-Root Condition	Intact/unchanged	Maybe charred or scorched	Most fine roots gone or charred
Burned Mineral Soil Depth	<1 cm (1-2 mm)	1-2 cm	>2.5 cm
Ash Color/Depth	Black with fine fuels remaining	Black or gray; layer may be patchy	Gray or white (2.5-8 cm deep)
Soil Water Repellency	*No fire induced repellency*	*Weak to medium repellency*	*Strong repellency at surface or at depth*

Table E-2. Vegetation type and soil burn severity (from Parsons et al. 2010).

Table 1. Matrix of soil burn severity and vegetation type and density models.

Vegetation type	Density model[a]	Soil burn severity classes: Low	Moderate	High
Chaparral	Sparse	C[b]	U	
	Medium	C	C	U
	High	C	C	U
Forest	Sparse	C	U	
	Medium	C	C	U
	High	C	C	C
Sagebrush	Sparse	C	U	
	Medium	C	C	U
	High	C	C	U
Grass	Sparse	C		
	Medium	C	U	
	High	C	C	

[a] Percent canopy cover for sparse, medium, and high density are approximately defined as: Sparse ≤ 20%; Medium = 20–60%; and High ≥ 60%.
[b] Key: C = common; U = unlikely (but can occur in some circumstances); Gray cells = not applicable/does not occur.

Field verification of the BARC map includes comparison of BARC burn severity with visual observations of burned vegetation, ground cover, fine root condition, soil char depth (burned mineral soil depth), ash thickness and color, soil structure, and limited soil hydrophobicity testing, both at the soil surface and at depth. Based on these results, the team estimates soil burn severity in selected areas. All members of the WERT may initially work together to help calibrate visual interpretation of burn severity indicators before splitting into smaller teams (see Table E-4 for data collection template).

Based on the field evaluation work, the assessing team (WERT and/or BAER) may recommend changes to the BARC data. BARC thresholds for one or more of the soil burn severity categories are then adjusted using ArcGIS to produce the final soil burn severity map.

Three hazard maps can be produced with the final field verified soil burn severity map:

- Debris flow hazard map
- Peak flow/flood response map
- Surface soil erosion map

Table E-3. Indicators of soil burn severity (from Parsons et al. 2010).

Appendix E—Summary of Soil Burn Severity Class Factors

Adapted from the BAER Handbook (USDA 1995) by Alex Janicki.

Factor considered	Soil burn severity class		
	Low	**Moderate**	**High**
Aerial view of canopy	Tree canopy largely unaltered. Shrub canopy intact and patches of scorched leaves not dominant. Ash is spotty.	Tree canopy is scorched over 50% of area. Shrubs mostly charred but difficult to assess fuels from air. Black ash is visually dominant. Gray or white ash may be spotty.	Tree canopy is largely consumed over > 50% of area. Shrubs completely charred but difficult to assess fuels from air. Gray and white ash is visually dominant.
Vegetation Trees	Nearly all of crown remains "green." Some scorching in understory trees.	High scorch height. Generally, > 50% of crown is scorched. Mostly "brown" crowns with intact needles.	No needles or leaves remaining. Some or many branches may be consumed. Mostly "black" remaining vegetation.
Shrubs	Scorching in canopy but leaves remain mostly green. Limited fire runs with higher scorch. 5 to 30% charred canopy.	30 to 100% charred canopy. Smaller branches < 0.5 inch (1 cm) remain. Shrub density was moderate or high.	90 to 100% charred canopy. Most branches consumed, including fuels < 1 inch (2.5 cm). Skeletons or root crowns remain. Shrub density was moderate or high. Often old growth in character.
Fine fuels (Grassland)	Scorched or partially consumed.	Mostly consumed. Appears black from the air. Small roots and seed bank remain intact and viable.	Not rated as high unless loss of seed bank is suspected or soil structure strongly altered.
Ground cover	Generally, > 50% litter cover remains under trees—less under shrub community or where pre-fire cover is sparse.	Generally, 20 to 50% cover remains or will be contributed by scorched leaf fall from trees. Shrub litter will be mostly consumed.	0 to 20% cover remains as burned litter and woody debris under trees. Shrub litter is consumed.
Water repellency	Soils may be naturally water repellent under unburned chaparral. Other soils will infiltrate water drops in less than 10 sec; greater than 8 mL min^{-1} with the MDI.	The surface of the mineral soil below the ash layer may be moderately water repellent but water will infiltrate within 10 to 40 sec; 3 to 8 mL min^{-1} with the MDI.	Strongly water repellent soils (repels water drops for > 40 seconds; less than 3 mL min^{-1} with the MDI) may be present at surface or deeper.
Soil	Original soil structure—fine roots and pores are unaltered.	Original soil structure—roots and pores slightly altered or unaltered. Soil color darkened or charred at surface or just below surface only.	Soil structure to 1 inch is degraded to powdery, single-grained, or loose. Fine roots are charred. Pores are destroyed. Black charred soil color common below thick ash layer. Compare with unburned.

Table E-4. BARC Data Collection Template, modified from Appendix B from Parsons et al., 2010.

ArcGIS BARC map verification data layer fields and descriptions

Site Number	*Preliminary BARC classification (1)*	*Ground Cover % (2)*	*Surface Color (3)*	*Ash Depth (mm) (4)*	*Soil Structure (5)*	*Roots (6)*	*Test Type (7)*	*Surface Repellency Time (sec) (8)*	*Surface Repellency (9)*	*Sub-surface Repellenc y (10)*	*Slope % (11)*	*Surface Rock % (12)*	*Vegetation Type (13)*	*Observed Soil Burn Severity Class (14)*

1 Burn area reflectance classification provided by USFS or USGS. (ArcGIS drop-down menu: unburned/very low, low, moderate, high).

2 Record an estimated percentage of ground cover (greater than 50%, 20 to 50%, or less than 20%). Ground cover means effective organic cover as it pertains to mitigation of runoff and erosion and includes litter, duff, and woody debris.

3 Include a brief note on color.

4 Record depth of ash (mm) if any.

5 Has it changed from pre-fire structure? The most common change is from a granular structure in the surface horizon to a loose- or single-grained soil in areas where heat residence time was long and organic matter was consumed. (ArcGIS drop-down menu: changed (loose), no change).

6 Have they been altered from pre-fire condition? (ArcGIS drop-down menu: no change, moderately consumed, fully consumed).

7 Was the soil water repellency test conducted using infiltrometer (I) or the water drop penetration time method (W)? (ArcGIS drop-down menu: I, W).

8 How long does the water take to infiltrate the surface (in seconds)?

9 What is the percent of positive repellency?

10 Include depth of test, the percent of positive repellency, and time to infiltrate (in seconds).

11 Record percent slope of site.

12 Record an estimate of percentage of rock cover.

13 Record the general vegetation type of site (for example: chaparral, forest, sagebrush, grass).

14 Record the soil burn severity class at the observation point.

Appendix F. WERT Office Screening Form

Incident Name: Click or tap here to enter text.

Incident Number: Click or tap here to enter text.

Date: Click or tap to enter a date.

Evaluator's Name: Click or tap here to enter text.

Email: Click or tap here to enter text. **Phone Number:** Click or tap here to enter text.

Affiliation: Click or tap here to enter text.

EVALUATION DETERMINATION:		
☐ **WERT Needed**	☐**Field Reconnaissance**	☐**Pre-WERT Reconnaissance**
☐ **No WERT Needed**	☐ **Reevaluate at Later Date (too early to tell)**	

Evaluation Criteria (adapted from WERT Procedural Guide – Appendix B):

Mapped Perimeter Used: ☐Yes ☐No Date of Burn Perimeter: Click or tap to enter a date.

Predominant Vegetation Type: ☐Grass ☐Shrub/Chaparral ☐Forest

Values-at-Risk Present Downslope/Downstream:

☐No ☐Single Residential Structures ☐Subdivisions ☐School/Hospital

☐Critical Infrastructure (Explain: Click or tap here to enter text.)

☐Other (Explain: Click or tap here to enter text.)

Debris Flow Hazards Present: ☐No ☐Yes

Alluvial fans/ Debris fans Present (see Appendix B): ☐No ☐Yes

Burned Slopes >40% Above Populated Areas: ☐No ☐Yes

Explain (if necessary): Click or tap here to enter text.

Flood Hazard Present: ☐No ☐Yes

Explain (if necessary): Click or tap here to enter text.

Rockfall Present: ☐No ☐ Yes

Explain (if necessary): Click or tap here to enter text.

Comments/Observations: Click or tap here to enter text.

Notes: