USDA
United States Department of Agriculture

Rocky Mountain Research Station

Science You Can Use Bulletin

May / June 2017 | Issue 25

SPECIAL EDITION

Learn from the Burn: The High Park Fire 5 Years Later

The 2012 High Park Fire was particularly severe and resulted in nearly half of the total burn area being classified as high and moderate burn severity. Pictured above: aftermath of high severity fire within the High Park Burn (photo by B. Piehl).

SUMMARY

It has been 5 years since the High Park Fire burned over 85,000 acres in Northern Colorado, causing extensive property damage, loss of life, and severe impacts to the water quality of the Poudre River. In the fall of 2016, a conference was organized by the USFS Rocky Mountain Research Station and the Coalition for the Poudre River Watershed to discuss what has been learned about our response to the fire. Topics covered (and discussed in this article) included how treatment areas were prioritized; the main effects of the High Park fire; the effectiveness of postfire treatments, and where to find the most recent postfire treatment planning tools online.

Most natural catastrophes provide a learning opportunity that sharpens our ability to better respond to future problems, and Colorado's High Park Fire is no exception. Ignited by a lightning strike on June 9, 2012 in the foothills just west of Fort Collins, the High Park Fire burned for almost a month consuming 87,415 acres of forested landscape in the Poudre River watershed and the adjacent Rist Canyon and Buckhorn Creek drainages. When the smoke cleared, the losses were enormous: one resident killed, 259 homes destroyed (with insured losses totaling $113 million), and $38 million spent on suppression. Nearly half of the total burn area was classified as high- and moderate-burn severity

With the Poudre River serving as the main water source for the cities of Fort Collins and Greeley as well as several surrounding communities, erosion control and preservation of water quality were high priorities following the fire. After a fire on Forest Service (FS) land, treatments are usually planned by a Burned Area Emergency

Response (BAER) team, which conducts rapid assessments of the altered watershed condition to estimate risk and recommend the appropriate emergency response. Because the High Park Fire covered an area of mixed ownership, a BAER interagency team including the USFS, Natural Resource Conservation Service (NRCS), Colorado Department of Transportation (CDOT) and Larimer County was put together to develop treatment strategies. In addition, the cities of Fort Collins and Greeley and Larimer County were the primary financial sponsors for the NRCS-Emergency Watershed Protection program which focused on postfire emergency stabilization treatments on private lands. Between the two combined programs, the main erosion-control treatments deployed were aerial mulching (consisting of mostly agricultural straw, but also wood mulch and wood shreds) over roughly 10,000 acres. Other measures taken included seeding (to stabilize soil and prevent weeds from establishing) and road and trail work such as temporary closures, stabilization, and removal of hazard trees.

The very first rain events that followed the 2012 fire caused rapid and frequent spikes in turbidity as ash and sediments were washed from the hillslopes into the river. The watershed was so sensitive after the fire that even low intensity storms would result in significant erosion and debris flows. When the storms cleared, the sediment in the river water would drop out of suspension, settling out on the banks of the river. This provided a source of sediment ready to be re-suspended from the river banks when there was even the slightest change in water levels. At the same time, upstream reservoir releases—which are very common on this river—would produce storm-magnitude spikes in turbidity.

In the fall of 2013, a little more than a year after the fire, northern Colorado experienced an intense storm—the product of a clash between a slow-moving cold front and warm, humid, monsoonal air coming up from the south and stalling over the Colorado Front Range. Although the storm caused catastrophic flooding and loss of life in many areas along the Front Range, the net result for the Poudre

Trends in the Use of Postfire Erosion Control Measures over Time

Conference attendees were especially interested in the effectiveness of mulching and seeding in controlling postfire erosion. Pete Robichaud, Research Engineer with the Rocky Mountain Research Station, the keynote speaker, discussed longer-term trends in the popularity of certain mulch types to provide some context.

- **Agricultural Straw Mulch:** The use of agricultural straw has gone up dramatically as deployment methods have become more efficient, bringing the costs from $1500–1800 per acre to as low as $500. The main issues with this material are wind displacement and the presence of unwanted weed seeds.
- **Wood Straw and Shred Mulch:** Wood shreds are heavier and less liable to blow around, and are therefore good for windy areas and exposed ridges. This material is expensive to apply ($1500–$3500 per acre), but according to Robichaud, "Wood shred application will probably come down in price as well, as we are figuring out how to be more efficient and ways to make it less heavy for the helicopters, like using material with a lower moisture content."
- **Hydromulch:** Hydromulch use has dramatically declined since the 2000s because its short strands are not as persistent as the straw and wood mulches. It is also expensive to deploy at $3000/acre.
- **Contour-felled Logs:** Use of these has gone down over time too, as they are only effective for small rain events. In one paired watershed study, Robichaud explained, "Only 25% were operational, the rest were undercut, overtopped, off-contour, or full of sediment." The cost of this treatment is approximately $600–1000/acre depending on the number of logs installed.

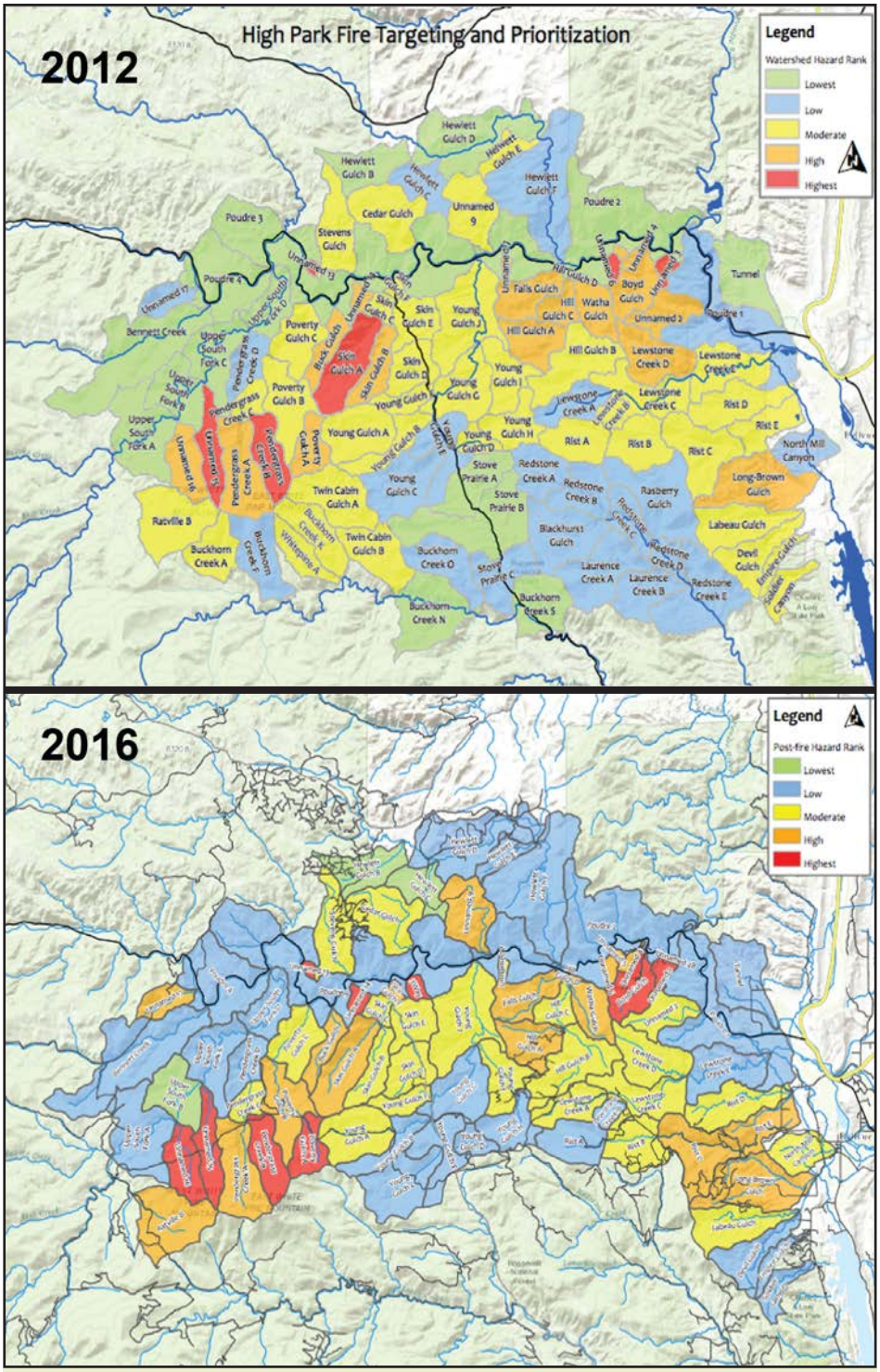
	Treatment	~Cost/acre
1	Aerial seeding	$20-50
2	Contour-felled logs	$600-1,000
3	Agricultural straw	$500-1,100
4	Wood shreds	$1,700-2,300
5	Wood strands	$2,500-3,500
6	Hydromulch	$3,000

Average cost per acre for various post-fire treatments (figure by P. Robichaud).

- **Aerial Seeding:** Rainfall amount and intensity are important for seeding success. Native species should be used if available and seed lots should be tested for presence of noxious weeds. The cost is about $20–50 per acre

River was actually an improvement in water quality—the high volumes of water scoured many of the problematic sediment deposits from the river channel and ultimately moved them downstream. This flood also shortened the watershed recovery timeline by elevating groundwater tables and accelerating postfire regrowth.

Now, 5 years after the fire, we are asking: What were the effects of the fire? Did the postfire BAER treatments help to prevent erosion and provide soil cover? What is the trajectory of recovery at the High Park Fire burn site? To this end, the Coalition for the Poudre River Watershed, along with the USFS Rocky Mountain Research Station, convened a group of researchers and managers on November 15, 2016, in Fort Collins, Colorado, with the goal of continuing a discussion about what we had learned from the response to the High Park Fire. What were results of ongoing research and monitoring? Are their implications for management going forward? Do we need additional information? The major findings of the High Park Conference are discussed in this article (the presentations can be viewed here), along with links to some recent developments in USFS postfire erosion modelling. Research results are described on Prioritizing Treatment, Effects of the Fire, Effectiveness of Treatments and Tools for Post-fire Planning.



After the High Park Fire in 2012, "watershed target factors"—including stream gradient, ruggedness, burn severity, peakflow increase, and distance to water supply—were used to create a watershed hazard ranking map for prioritization of treatment. The area was revisited in 2016 to assess the burn recovery and to determine which areas, if any, should receive further treatments (figure by B.Piehl).

PRIORITIZING WHERE TO TREAT

Prioritizing treatment in areas of mixed land ownership

After the burn, Forest Service members of the BAER interagency team developed recommendations for treating USFS land, while the NRCS and Larimer County team members made recommendations for non-Federal land. About 5,600 acres of Federal land was aerially mulched. On the non-federal land, treatment costs were paid for jointly by the NRCS Emergency Watershed Protection (EWP) program, along with the City of Greeley, City of Fort Collins, and Larimer County. As part of the non-federal implementation effort, Brad Piehl, a consultant with JW Associates, was hired to undertake risk analysis to further guide treatments. Piehl's approach used "watershed target factors" to create a watershed hazard ranking map. These factors included stream gradient, ruggedness, burn severity, peakflow increase, and distance to water supply. Mulch was then applied to those watersheds (an additional 5,400 acres of non-USFS land) at highest risk of delivering larger amounts of sediment to the Poudre River.

In 2016, Piehl revisited the High Park burned area to assess the effectiveness of the watershed target factors approach by looking at subsequent erosion patterns. He was also hoping that an assessment of the current conditions would help to determine which areas, if any, should receive further treatments. Overall, Piehl reflects, "The watershed targeting approach worked well. The majority of the top 25 watersheds identified as needing treatment were continuing to display substantial erosion issues, indicating that the targeting was effective and the erosion control efforts probably prevented bigger issues." There were some problem areas, however. In one area (known as Pendergrass), the application of straw mulch had not been successful at limiting hillslope erosion, as evidenced by a large sediment fan in the South Fork of the Poudre River. Possible reasons were high numbers of trees, which blocked the mulch from reaching the ground, or that the watershed was too exposed in areas, and the mulch blew away. Exposed areas like this might be good candidates for the more expensive, yet more persistent, wood mulch.

One area that Piehl and colleagues found needed revising in the targeted watershed approach was the "distance-to-water supply" factor. According to Piehl, "We thought the South Fork was too far away from the main stem of the Poudre to cause problems, but it wasn't—it was very connected to the main stem and able to transfer that turbidity and sediment." Also, he found that the presence of roads in a watershed was a factor that needed to be added, because roads can be a major conduit of sediment. The watershed target factors were revised based on the current watershed conditions. "We revised the watershed target factors because we could see that some areas recovered more than others, and also several roads became priorities for follow-up treatments" said Piehl.

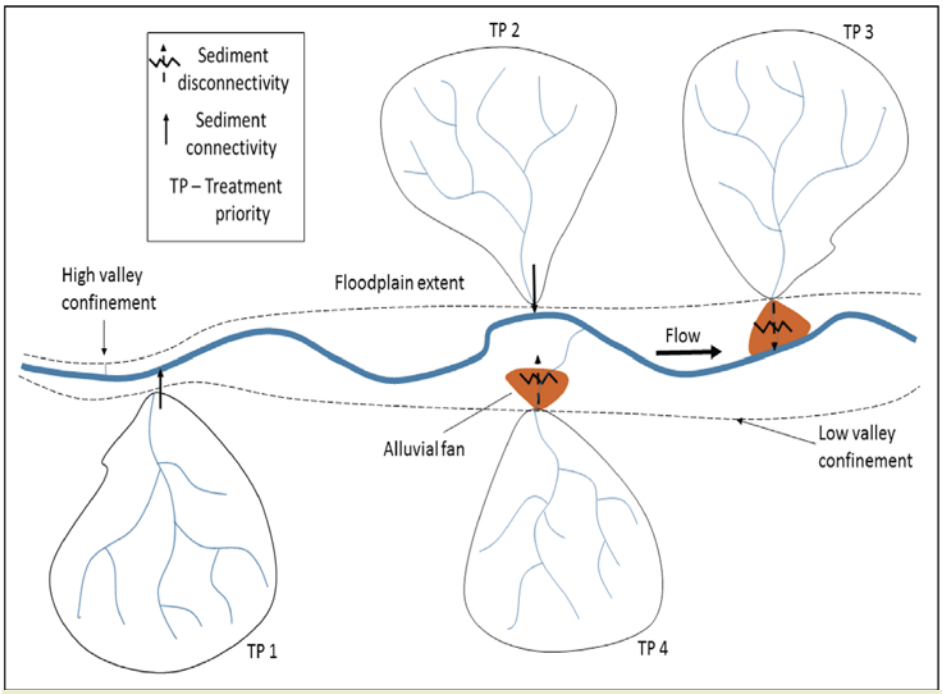
Coalition for the Poudre River Watershed

Within days of the ignition of the High Park Fire, it became clear that it was going to be a large wildfire, with significant impacts. Experiences from other large wildfires in Colorado made it clear that the High Park Fire may cause long lasting impacts to our watershed, water supplies, and communities. Knowing this, a group of local government agencies (USFS, CSFS, NRCS, CDOT to name just a few), nonprofits, representatives from the cities of Greeley, Fort Collins, and Larimer County, local businesses, and individuals, gathered to discuss how they could work together to rehabilitate the lands affected by the burn. Initially formed as an informal network known as the High Park Restoration Coalition, the group worked with JW Associates to identify the top priorities for restoration efforts, finding funding to implement the plans, and training volunteers to help with implementation.

Based on the success of these early efforts, in May 2013, the High Park Restoration Coalition evolved into a formal nonprofit—the Coalition for the Poudre River Watershed—whose mission is to improve and maintain the ecological health of the Poudre River watershed through community collaboration."

The importance of considering "connectivity" in future postfire treatment prioritization

According to Sara Rathburn, Associate Professor in the Department of Geosciences at Colorado State University, "Sediment transport and storage responses are hard to predict in both space and time. As such, it is hard to measure what is going on in a watershed at a small scale." Her research following the High Park fire suggests that when prioritizing



Watersheds connected to the river in areas of high valley confinement (TP1 and TP2) should be given higher treatment priority than those with low valley confinement due to lack of alluvial fans and a wide floodplain for sediment to settle out before the water enters the river (figure provided by Rathburn from Shahverdian 2015).

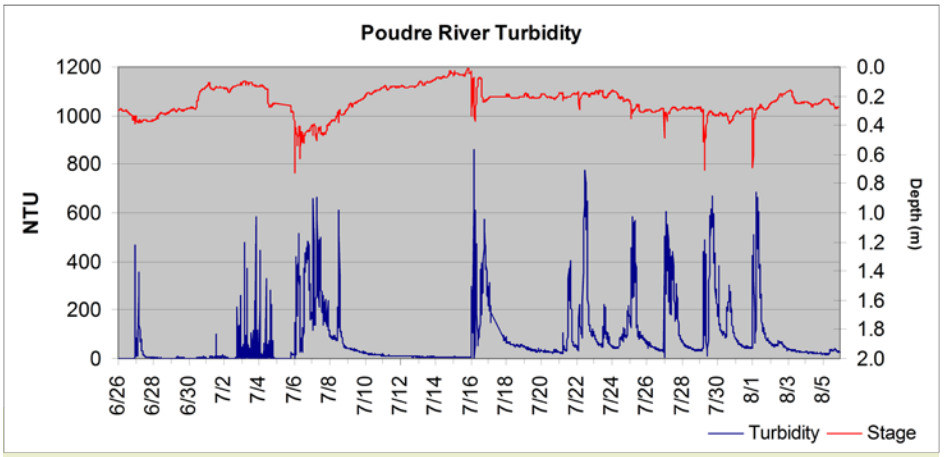
treatments, it could be useful to take a larger-scale approach by looking at the degree of main stem river valley confinement at the catchment outlets. If the river valley is narrow and more confined, then there is more connectivity between the watershed outlet and river in terms of sediment transport—in other words, the sediment has nowhere to settle out prior to entering the river and so becomes a concern for downstream users. When the river valleys are wider and less confined, the catchments draining into the river at those points may develop alluvial fans where eroded sediments can settle out before reaching the river. Rathburn's research suggests that over a large watershed, remote imagery and "connectivity indices" based on the degree of valley confinement can be used to evaluate an entire network of smaller catchments feeding into the main river stem to prioritize treatment after a burn.

EFFECTS OF THE HIGH PARK FIRE

Water quality impacts of the fire

Treatments can reduce but will not eliminate the problem of postfire erosion. According to Pete Robichaud, a Research Engineer with the Rocky Mountain Research Station, the conference keynote speaker, "When the big storm comes, our treatments—no matter what they are—will not stop everything." Rainfall intensity and amount are very important driving factors in postfire erosion. The frequency of summer monsoonal storms and the record rainfalls that came to northern Colorado within the year after the High Park Fire and the erosion had a significant impact of the quality of the Fort Collins water supply.

The first rain events following the fire produced severe runoff, and turbidity levels in the Poudre River frequently exceeded 500 NTU (turbidity units) and on occasion exceeded 1,000 NTU. Prior to this, maximum turbidity values on the Poudre River were observed during



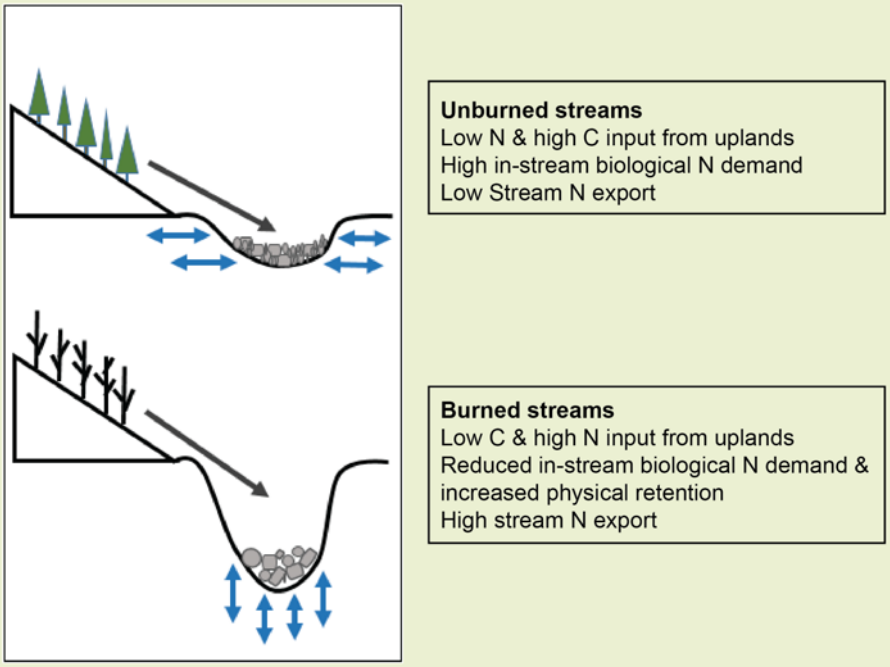
Turbidity frequently exceeded 500 NTU and on occasion exceeded 1,000 NTU during the rain events that followed the fire (figure by J. Oropeza).

The longer-term impact of the fire and flood is large amounts of sediment have been transported to lower stream reaches and the river acts as a potential turbidity source during future rains (photo by J. Oropeza).

snowmelt runoff when turbidity ranged between 50–70 NTU. Unable to treat the water at this turbidity level, the City of Fort Collins implemented a strict shut-down threshold of 100 NTU at the Poudre intake and Pleasant Valley Pipelines. These intake remained shut off from the Poudre River water for 98 days during which time they relied solely on water from Horsetooth Reservoir.

Water quality of the Poudre River is still affected by the High Park Fire, even 5 years later. The acute problems have subsided, but the longer-term impact of these events is that large amounts of sediment have been transported to lower stream reaches where it is temporarily stored in backwater areas and the river can act as a potential sediment source during future rains. Jarod Heath, Watershed Specialist for the City of Fort Collins, explained, "The City's ability to shut down the Poudre River pipeline during storm events has provided an important tool to mitigate impacts, but questions still remain on the treatability of wildfire-impacted water quality." The questions around treatability of water, impacted by fire, become especially important in the event that an alternate water supply is not available.

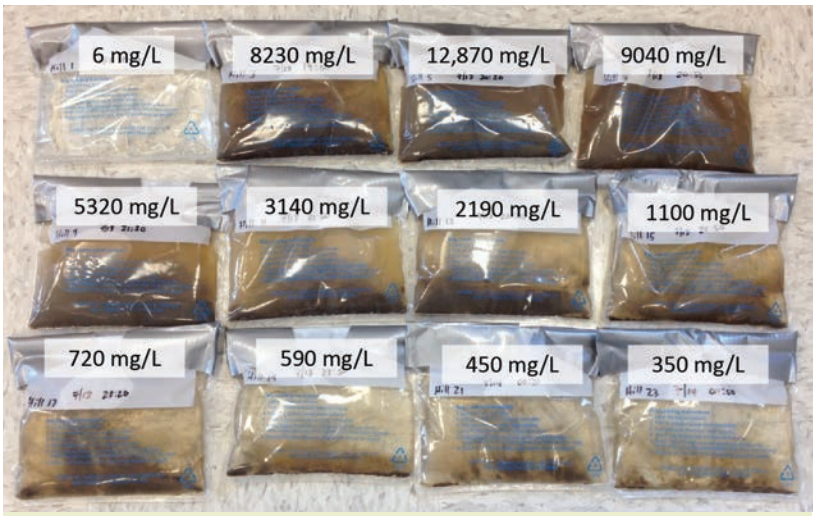
Wildfire alters both the biological and physical processes that have long-lasting effects on stream nutrient concentrations. Working on the High Park and other Front Range fires, Chuck Rhoades, Research Biogeochemist with the Rocky Mountain Research Station, and colleagues have found elevated stream nitrogen (N) levels in watersheds where high-severity wildfires burned vegetation and surface organic matter, and that increased stream flows have restructured the channel. In unburned watersheds, high demand by plants and soil microbes limits export of nitrogen in stream water. But in burned watersheds, combustion of vegetation reduces the demand for



In an unburned watershed there is high biological demand and little export of N. After an event like the High Park Fire, nitrogen inputs to the stream are higher. Physical scouring of the channel from increased runoff affects the stream biological community, lowering in-stream biological N demand and increasing the export of nitrogen from the watershed (figure by A. Rhea and C. Rhoades).

nutrients on burned hillslopes and riparian areas and results in elevated nutrient export to streams. Physical scouring of the stream channel that often accompanies increased postfire runoff may also affect the stream biological activity and lowers instream nitrogen demand, further elevating stream nitrogen levels.

How long would the increased N export be expected to continue after the High Park Fire? A long-term water quality record Rhoades has compiled from the Hayman Fire (which burned in Colorado in 2002) provides insight. Although stream water nitrogen is commonly elevated after a fire, it is generally expected to return to background levels within 5–10 years. This recovery has not been seen in the streams affected by the Hayman Fire. "We have found that stream nitrate and total dissolved nitrogen remains elevated 15 years later, particularly in the most severely burned areas," he explains. In High Park, he has also found that the stream water N remained elevated after 5 years; ongoing USFS and CSU research aims to better understand how wildfires disrupt nutrient retention by watersheds, forests, and streams and to better predict how long it will take to return to prefire levels.



A series of water samples from the Poudre River starting right before a storm, when the turbidity is low. In the first year or two after the High Park Fire, the rainfall intensity needed to produce turbidity spikes was only on the order of an annual or semi-annual storm. Over time, there is an increase in intensity of rainfall required to generate high turbidity This sequence of suspended sediment samples was collected by an automated water quality sampler at Hill Gulch between 7/13/14 19:00 and 7/14/14 00:50. This was after 0.3 inch of rain fell over 30 and 60 minutes, based on USGS data from Rist Canyon and Stove Prairie gages. (photo by S. Ryan).

Erosion patterns across larger spatial scales

Postfire treatment decisions are made at the watershed scale, so the effectiveness of these treatments at the watershed scale is most relevant to land managers. Several studies following the High Park fire attempted to look at erosion patterns at this scale.

Fire causes degradation of water quality from fine ash and sediment. Looking at turbidity as a measure of suspended solids concentrations in water, Sandra Ryan, Research Geomorphologist at the Rocky Mountain Research Station, found that in the first year or two after the High Park Fire, the rainfall needed to produce turbidity spikes was only on the order of an annual or semi-annual storm. The measured levels reached a maximum of 7,000 mg/l in 2013, and were still high following rains in 2014 (for reference, suspended sediment concentrations are typically far less than 100 mg/L in these watersheds). By 2015 though, the turbidity levels had dropped and increasingly higher intensity storms were needed to generate spikes in turbidity. In general, by 4–7 years postfire, the sediment concentrations usually return to background values.

If mulching is effective at controlling erosion at a hillslope scale, it was a lot harder for the researchers to discern this effect at a watershed scale. Ryan (and others) actually measured slightly more sediment from the mulched watershed vs. the partially mulched watershed after the High Park Fire (although this pattern was muted over time). Some of the contributing factors could be the watersheds that were mulched were also that ones that burned at higher severity, and they also could have had lower levels of plant cover. But, as she sees it, "The jury is still out on whether mulching reduces

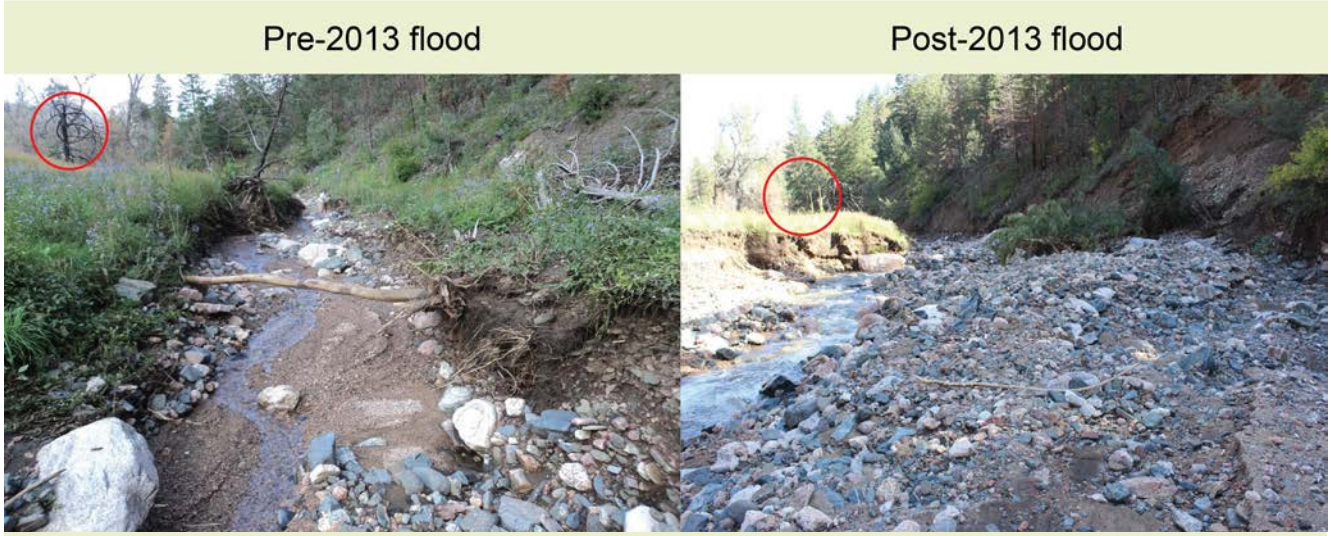
Photos taken at the same spot in Hill Gulch before and after a rain event in 2015 show the deposition of sediment in this channel as a result of erosion from the High Park Fire (photos by C. Wilson).

instream sedimentation over a larger watershed scale."

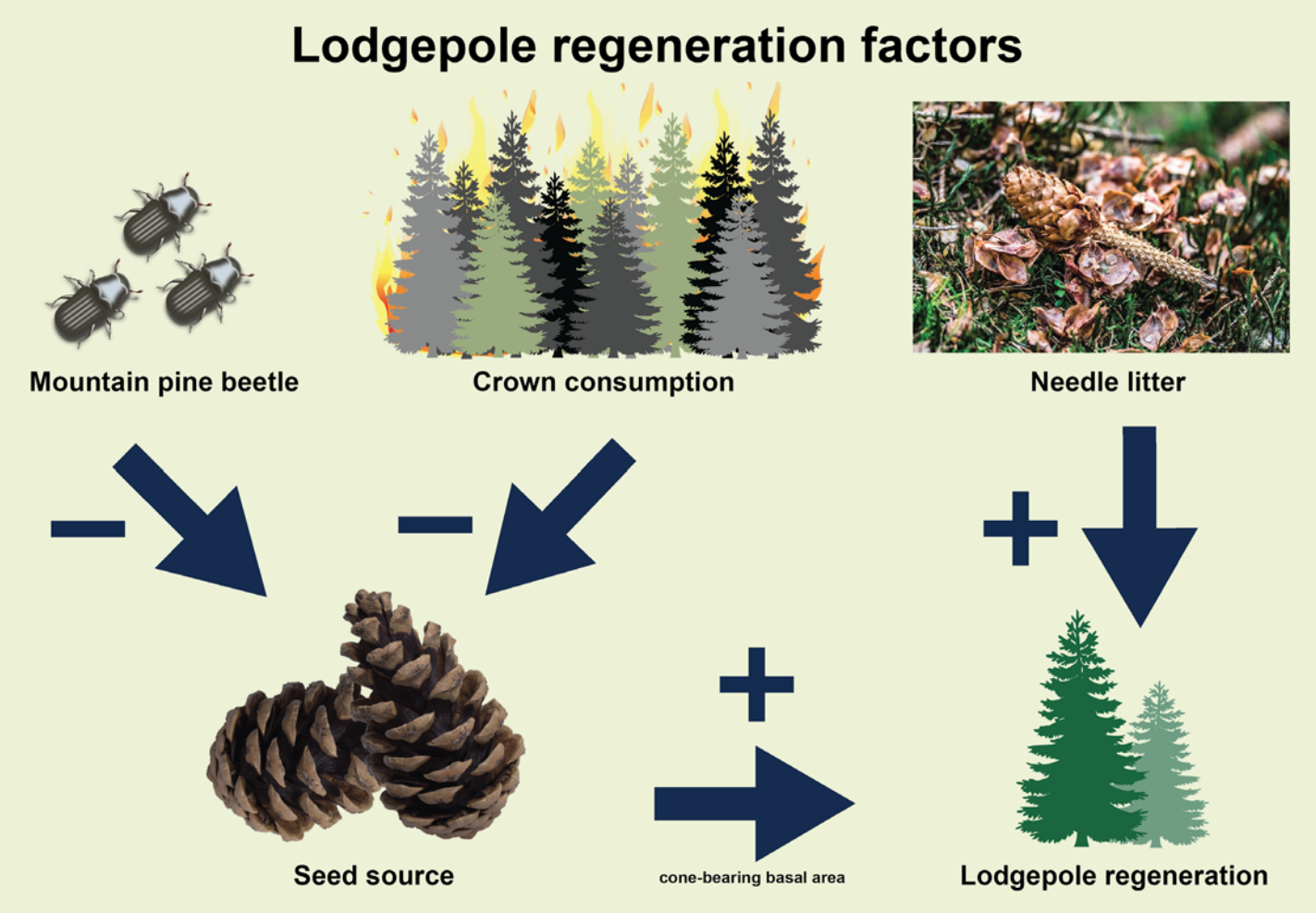
Mulching may be effective for keeping sediment in place on hillslopes, but was not shown to have a larger scale effect on in-channel processes. Codie Wilson, Ph.D. student at CSU's Watershed Studies Department, and colleagues looked at connectivity between hillslope-scale and watershed-scale runoff and sediment for a large rain storm in Hill Gulch 3 years after the High Park Fire. Sediment transport was still occurring, with the highest runoff and erosion being produced on the hillslope and headwater catchments. They found the runoff and erosion from this storm were stored on the hillslopes and channel network before reaching the watershed outlet. The channels both stored and transported sediment during storms. She observed, "The streambeds and banks are still very unstable, so we expect sediment to continue to move through the watershed, especially during snowmelt runoff and rain events."

Repeat ground surveys and LiDAR were used by Dan Brogan, Ph.D. student at Colorado State University in the Hydraulic Engineering, Stream Restoration and River Mechanics program, to look at changes in channel and valley topography over time in two watersheds (Skin and Hill Gulches, both feeding directly into the Poudre River). The aim of his research is to determine which watershed parameters are most related to erosional patterns. Although the work is still ongoing, his data suggests that the overall trend in the valley bottoms of both watersheds is that sediment is deposited. The exception was the 2013 floods when large quantities of water flushed sediments downstream.

Lodgepole pine regeneration



Postfire, the valleys in the High Park fire area accumulated sediment. The 2013 floods flushed large quantities of sediments downstream, widening the channels as can be seen in these two photos taken from the same spot less than 30 days apart (photos by D. Brogan).



Natural regeneration of lodgepole pine after the High Park Fire was high overall and was influenced by various factors. If the area had experienced both crown fire and high mortality due to mountain pine beetle, the seedling densities were the lowest, presumably due to lower amounts of seed available. Higher amounts of needle litter enhanced the number of seedlings recruited, while the application of straw mulch had a negligible effect (Figure provided by M. Rocca/M. Wright).

A portion of the High Park Fire burned area was dominated by lodgepole pine stands which had experienced significant mountain pine beetle (MPB) die off before the fire. Monique Rocca, an Associate Professor of Wildland Fire Science at Colorado State University, explains, "We wanted to know how the beetle kill, along with fire patterns (e.g., crown fire vs. surface fire), and topography and surface conditions (like mulch) combined to affect how well lodgepole regenerated."

Lodgepole pine is a fire-adapted species with serotinous cones that release seeds after a fire. However, if cones are burned during a crown fire, or absent due to tree death from beetle kill, this could limit the regeneration potential. And in fact, these factors did influence seedling numbers. Areas that experienced only surface fire had higher seedling numbers than those where the tree crowns had burned. If the area had experienced both crown fire and high mortality due to mountain pine beetle, the seedling densities were lower yet. However, seedling numbers were high overall regardless of beetle kill or crown fire. Over the 52 study areas, the median density was 17,000 seedlings/ha, and only one area had seedling densities below the "minimum stocking rate" of 350 stems/ha.

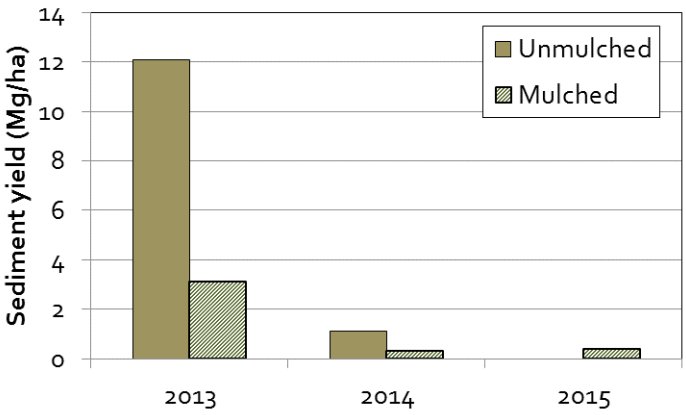
Soil surface conditions also affected regeneration. Higher levels of postfire needle cover enhanced seedling numbers, but this was also related to whether a site experienced crown or surface fire, since areas with crown fire lacked needle cast. Straw mulch did not appear to hinder seedling establishment, and may enhance it, but was not as important as the other factors (litter cover, and crown versus surface fire).

THE EFFECTIVENESS OF POSTFIRE TREATMENTS

Forty-eight percent of the High Park Fire burned area was classified as high to moderate severity. According to Carl Chambers, Hydrologist with the Arapaho Roosevelt National Forest and Pawnee National Grassland, "High and moderate severity burns often produce responses that can be damaging in terms of erosion." To prevent damage to drinking water supplies and other values, it is important to deploy effective erosion control measures. When surveyed as part of this conference, attendees rated the straw and wood mulches as the erosion control measures that they placed the most confidence in. They had lower confidence in straw wattles, log erosion barriers, in-channel tree felling, and sediment basins. However, the aerial application of mulch is expensive due to the costs of operating aircraft, so managers are particularly interested in how well it works. Some of the research following the High Park Fire considered mulch effectiveness at the hillslope and watershed scales.

Mulching reduces hillslope erosion

Measuring the amount of sediment yield collected from sediment traps, Stephanie Kampf, Associate Professor in the Department of Ecosystem Science and Sustainability at Colorado State University, and colleagues found that mulch was effective at reducing hillslope erosion—unmulched sites produced much more sediment in 2013 continuing into 2014. This effect disappeared overtime, which could have been due in part to low levels of rain in 2014 and 2015. They observed that for the mulch to stay in place, it needs to be distributed smoothly over the surface; if it is applied in a clumpy fashion, it is more easily moved around by wind and water. At the watershed scale, mulch was found to reduce sediment delivery by 2–8% in Skin Gulch and 13–26% in Hill Gulch, with the differences attributable to the geology of each watershed.



Mulch was effective at reducing hillslope erosion, with unmulched sites producing much more sediment in 2013 in sediment-trapping fences. This effect disappeared over time as vegetation recovered on the hillslopes (figure by S. Kampf).

Seeding provides high cover, reduces weeds, and potentially reduces erosion

Seeding an area after a fire can help to reduce erosion as vegetation grows and roots hold the soil in place. After the High Park Fire, John Giordanengo, founder and owner of AloTerra Restoration, looked at the effectiveness of seeding at providing ground cover. Although not practical for large expanses, it has been long thought that raking the seed into the ground after application—which effectively buries it slightly—may increase the seed germination rates, which will enhance the plant cover and reduce soil erosion. Using a perennial grass seed mix (*Bromus marginatus, Elymus trachycaulus, Pascopyrum smithii,* and *Poa secunda* Triticale at a prescribed rate of 27 pounds per acre), his study compared raked and unraked seeded areas to untreated controls, all mulched with certified weed-free agricultural straw at a rate of 1 ton/acre. The unseeded controls only had 4% cover in 2013, and required 2 more years before reaching 40% cover; a model run for 2014 predicted much higher erosion in the these unmulched areas due to the low plant cover. He found that contrary to expectation, raking did not increase the vegetation cover in 2013 or 2014, where there was greater than 50% vegetation cover for both years in

MANAGEMENT IMPLICATIONS

What can we say about mulching and seeding after the High Park Fire?

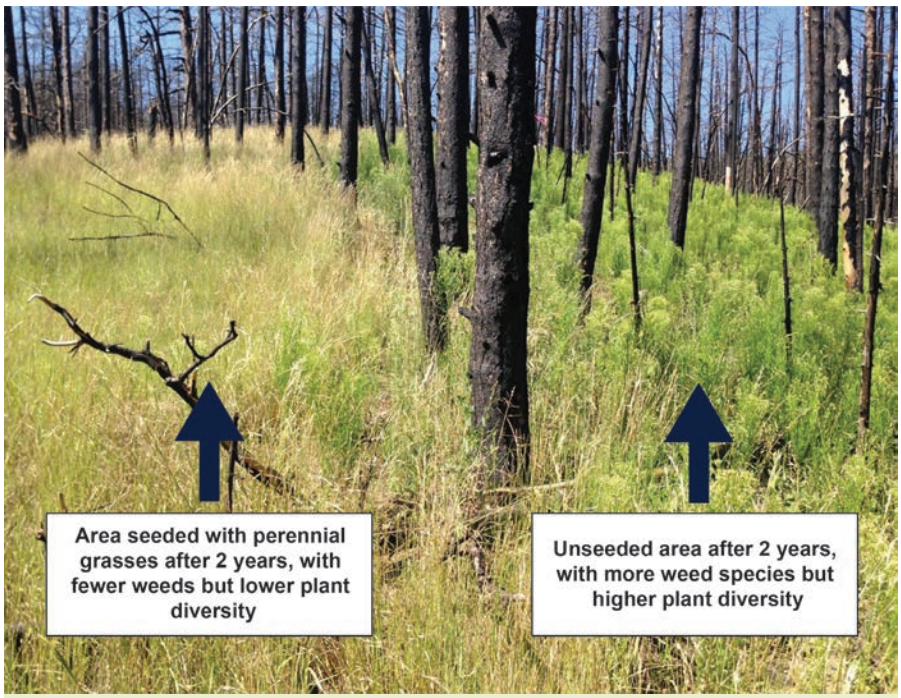
- Mulching reduces soil movement on hillslopes, depending on the application and whether or not the mulch stays in place. Over time the mulch moves off the site and the areas become vegetated. Straw mulch did not work as well when applied to exposed areas (where it could easily blow away); these areas are good candidates for wood mulch. Straw mulch only worked well to control erosion when applied in a smooth rather than clumped fashion.
- At the larger watershed scale, the effects of mulching on water quality are difficult to quantify because of variable rainfall across the burn area and challenges of quantifying how much of the sediment eroded from hillslopes reaches the outlets of watersheds.
- Mulching does not negatively affect lodgepole pine regeneration and may enhance it, although other factors such as seed sources and elevation may be more important.
- Seeding helped to control weeds and created a high level of perennial grass cover. However, over 3 years the trend was that the seeded mixture dominated the site, which suppressed weeds but also slightly reduced overall plant diversity.

seeded areas, and less than 41% cover in control plots in 2014. The study suggested that there were not enough benefits from raking to justify doing it over large areas after a burn, although he cautioned that additional studies are needed to determine how widely this can be applied.

This study also asked whether postfire slope stability treatments (like seeding/mulching) have a significant impact on native species diversity and weed cover. For example, some native plants have seeds with a very long dormancy period (e.g., *Geranium bicknellii, Corydalis aurea*) and can be stimulated to germinate after a fire. Ideally, erosion control treatments like seeding and mulching don't negatively impact these plants, nor the native mosses, fungi, and resprouting shrubs. His study found that seeding helped to control weeds and created a high level of perennial grass cover; seeded areas had only 1% weeds while unseeded controls had 36% weed cover (including *Conyza canadensis* and cheatgrass) in 2015. However, over 3 years the trend was that the seeded mixture dominated the relative cover where it is placed, suppressing weeds but also slightly reducing overall plant diversity. The main trade-off with seeding may be between plant diversity vs. erosion control, as seeded areas showed much less predicted erosion during model runs but the perennial grasses that get established may suppress the native vegetation. Keeping this trade-off in mind can help managers to prioritize areas for seeding based on erosion risk and plant ecology goals.

Mulch effects on soil and ecosystem processes

Straw mulch is effective at holding soil in place and retaining moisture for seedlings, but does it influence soil and ecosystem processes for better or



Giordanengo's study found that seeding helped to control weeds and created a high level of perennial grass cover. However, over 3 years the trend was that the seeded mixture dominated the site which suppressed weeds but also reduced overall plant diversity (photo by J. Giordanengo).

Mulch and Ecosystem Process				
Mulch type	Enhanced soil moisture	Plant establishment	Tree seedling establishment	Nitrogen availability
Wheat straw	✓✓✓	✓✓✓	✓	✓
Wood strands	✓✓	✓✓	✓✓	✓✓
Wood shreds	✓✓✓	✓	✓✓	✓

✓ = Fair ✓✓ = Good ✓✓✓ = Best

In a controlled experiment following the High Park Fire, all of the mulches were effective in enhancing soil water content (SWC), but the wheat straw was associated with higher plant (grass/forb) cover, while the wood mulches were associated with higher tree seedling numbers. None of the mulches appeared to tie up soil nitrogen over the longer term (figure by E. Berryman).

worse? One issue, according to Erin Berryman, Research Ecologist with the U.S. Geological Survey, is that putting down a carbon-rich food source for soil microbes can cause a lot of nitrogen to be tied up that could otherwise be available to plants. At the High Park Fire burn site, she compared plant and soil properties under four kinds of mulch—wheat straw, wood strands, wood shred, and rubber (as a moisture-retaining but non-biologically active control)—along with unmulched areas. Comparing data from 2012 and 2015, she found that over that time period wood mulch (both shreds and straws) stayed around the longest, with no real effect of application rate. The mulch treatments increased soil moisture and promoted seedling establishment in the first 3 years following application after wildfire. Wheat straw yielded high plant cover 3 months after application compared to other mulches and unmulched areas, declining in the second year. She explains, "If the goal is to get something growing fast, wheat straw works for that, if you don't care what is growing. However, it may inhibit tree seedling establishment compared to the wood mulches." She also found that while wheat and wood shreds may be tying up soil N, this effect subsided by year 3 and so these mulches are unlikely to have long-term effects on soil plant-nutrient availability.

TOOL	DESCRIPTION	USE
WEPP-PEP: Water Erosion Prediction Project, Post-Fire Erosion Predictor	Google Earth-like interface in which users upload soil burn severity and select watersheds of interest	Estimates soil erosion following an actual or simulated wildfire
RRED: Rapid Response Erosion Database	Online database that uses data from LandFire existing vegetation type maps, USGS National Elevation Datasets, and NRCS soils data	Rapidly formats soils, topography and land cover data to be used in modeling postfire erosion and run-off
BAERDAT: Burned Area Report Database	Public database searchable by fire/region/state/treatment	BAER teams can determine if a treatment is appropriate for an area (results are available in either a table or a map view)
BAERCAT: Burned Area Emergency Response Treatments Catalog	Catalogue list of tools available for BAER teams	Awareness of available tools to inform postfire stabilization treatment decisions
VAR Calculator: Values At Risk Calculator Tool	Spreadsheet-based calculation tool	Assess risk to human life and safety, cultural and ecological resources, land use, and existing infrastructure from the secondary effects of fire

There are a number of tools available for post-fire planning, including erosion models and values at risk calculators.

TOOLS FOR POSTFIRE PLANNING AND WHERE TO FIND THEM

BAER teams must identify and plan treatments within 7 days of fire containment, and to do this they need the very best information possible. There are important values at risk such as public drinking water supply. "Modeling really helps to determine which areas should be priorities for treatment after a fire," according to Pete Robichaud, RMRS Research Engineer. Typically, the BAER Team develops a burn severity map reflecting fire-induced changes in vegetative cover and soil properties using satellite (Landsat) data. Then, slope, climate, soils, vegetation and location can be factored in using a physically based model such as the Water Erosion Prediction Project (WEPP).

KEY FINDINGS

- Mulching is effective, especially at the hillslope scale, but work still needs to be done to understand how sediment continues to move through the system to receiving waters.
- After a catastrophic fire, the most dramatic impacts to water supply will taper off in a few years, but longer-term water quality impacts may persist.
- In addition to controlling erosion, mulch may be modestly helpful in promoting tree seedling establishment, particularly the wood mulches.
- Researchers at RMRS and other institutions are rapidly developing and creating tools to make postfire treatment decisions easier and more robust.

WEPP-PEP, a Google Earth-like erosion prediction tool

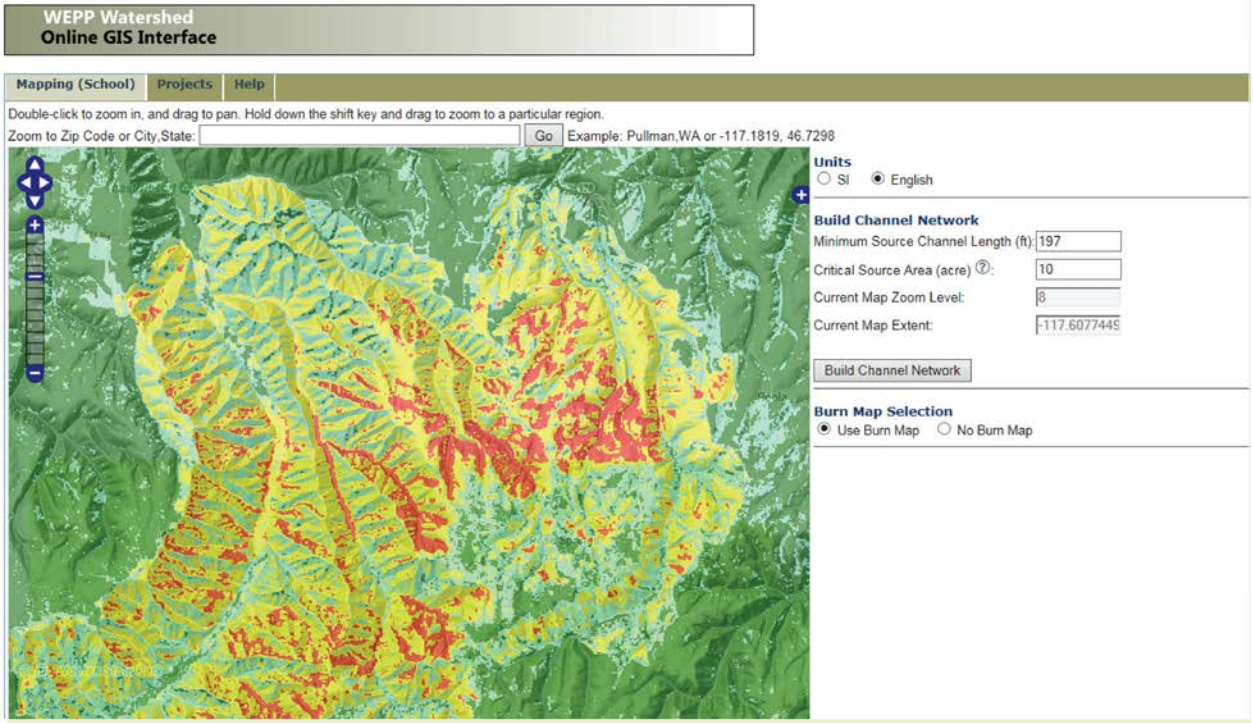
One of the watershed-level modeling tools recently developed by the USFS and collaborators is the Water Erosion Potential Project—Post-fire Erosion Predictor, or WEPP–PEP. A unique feature of WEPP-PEP is that it is a Google-like interface using open source GIS software. A user can upload a soil burn severity map for any fire in the United States, and interactively select watersheds of interest. "With WEPP-PEP, very little GIS expertise is required so a land manager, hydrologist, soil scientist can access this WEPP technology for erosion predictions. If you can find your house in Google Earth, you can define a watershed to run the model—we're making it that easy for people to use," explains Robichaud. This computer simulation tool estimates soil erosion following an actual or simulated wildfire from soil burn severity maps. It identifies priority areas, provides hillslope and small catchment results, and makes it easy to determine where the erosion risk is the highest.

RRED, an online database to model postfire erosion and run-off

The second tool for supporting watershed-level erosion modeling is the Rapid Response Erosion Database (RRED), developed by Mary Ellen Miller, Research Engineer at Michigan Tech Research Institute, in collaboration with NASA and USFS colleagues Pete Robichaud, RMRS Research Engineer, and Bill Elliot, RMRS Research Civil Engineer. The database was created to eliminate hours of data preparation required for using process based hydrological models for forestry applications. RRED relies on data from LandFire existing vegetation type maps, USGS National Elevation Datasets, and NRCS soils data. "When I create inputs for postfire erosion modelling," Miller explains, "everything has changed, the vegetation and soils data need to be modified using a soil burn severity map." Users of the database can select an "area of interest," upload a new burn severity map or select a historical map of burn severity; the database then rapidly formats soils, topography and land cover data to be used in modeling postfire erosion and run-off. Prior to the database it could take modelers up to a week to prepare modeling inputs; with the new database, inputs are created in seconds.

A new modeling interface, QWEPP, is currently being developed to work seamlessly with the RRED. QWEPP is a spatial interface to the Water Erosion Prediction Project (WEPP) developed in QGIS, an open source GIS package. With these new tools, BAER teams can focus their efforts on modelling the effects of multiple storm or treatment scenarios and determine which locations in the burn scar are most vulnerable to erosion and flooding. Miller also has some advice for BAER team users who plan to use these tools: "Prepare ahead of time! Practice the models you have selected, have them installed and ready to go!"

Other USFS postfire tools



WEPP-PEPP uses a Google-like interface to identify priority areas, and provide hillslope and small catchment results; it is easy to determine where the erosion risk is the highest (Burn severity map of School Fire in Umatilla Forest, Pomeroy, WA).

Other useful USFS postfire planning tools catalog past BAER reports and available tools for postfire treatment or can help to calculate the risks posed by erosion.

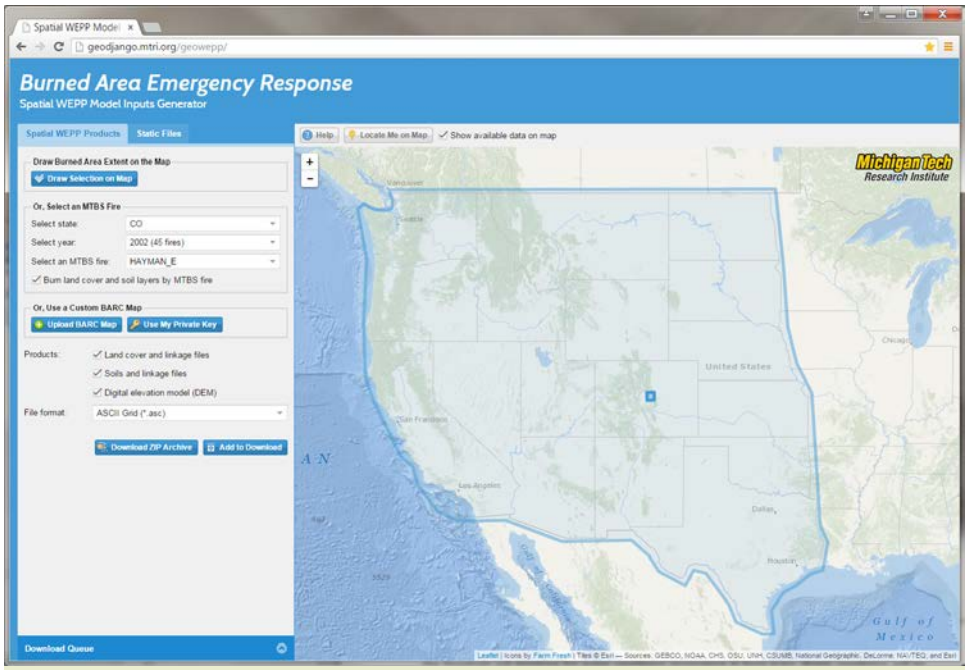
- The Burned Area Reports Database (BAERDAT) is a public database searchable by fire/region/state/treatment. Users can determine, for example, what people did postfire in the Colorado Front Range over the past 25 years. Using the database, BAER teams determine if a treatment is appropriate for an area, and the results are available in either a table or a map view.
- The Burned Area Emergency Response Treatments Catalog (BAERCAT) is a 266-page PDF that includes most of the tools at a BAER teams disposal, including treatment descriptions, installation instructions, monitoring tools, and references that BAER assessment and implementation teams may use to inform postfire stabilization treatment decisions.
- The Values At Risk Calculator assesses risk to human life and safety, cultural and ecological resources, land use, and existing infrastructure from the secondary effects of fire.

LOOKING AHEAD

Fire season is upon us again. Fires are an integral landscape process, and for much of the Front Range, it is not a matter of "if" but "when" those areas that have not experienced wildfire in the recent past will burn. One way that we as a community can learn to better live with wildfire is to be more prepared by learning from our past experiences.

Five years after the High Park Fire, the recovery of the burn area is well underway. Several of the scientists featured in this article have ongoing investigations on its long-term impacts or other topics related to the fire. For example, Monique Rocca, Associate Professor of Wildland Fire Science at Colorado State University, is still following lodgepole pine regeneration, while Sara Rathburn, Associate Professor in the Department

of Geosciences at Colorado State University, is using carbon-14 dating to estimate the return-fire interval for this area. The Coalition for the Poudre River Watershed will continue its efforts in watershed through community collaboration, including Larimer County stakeholders, to plan and implement watershed activities to reduce the risk of future large fires. The managers and researchers at the Arapaho Roosevelt National Forest are developing a proactive fire management strategy focused on identifying the right types of fire in the right places at the right time to lessen the opportunities for catastrophic fires such as High Park in other parts of the National Forest.



RRED is an online interface that creates postfire erosion modelling inputs by merging spatial soils and land cover with satellite-derived burn severity maps and formats data for hydrological modeling.

FURTHER READING

- Morgan, Penelope; Moy, Marshell; Droske, Christine A.; Lentile, Leigh B.; Lewis, Sarah A.; Robichaud, Peter R.; Hudak, Andrew T. 2014. Vegetation response after post-fire mulching and native grass seeding. Fire Ecology. 10(3): 49-62.
- Miller, M. E.; Elliot, William J.; Billmire, M.; Robichaud, Pete R.; Endsley, K. A., 2016. Rapid-response tools and datasets for post-fire remediation: Linking remote sensing and process-based hydrological models. International Journal of Wildland Fire. 25: 1061-1073.
- Rhoades, Charles C.; Minatre, Kerri L.; Pierson, Derek N.; Fegel, Timothy S.; Cotrufo, M. Francesca; Kelly, Eugene F. 2017. Examining the potential of forest residue-based amendments for post-wildfire rehabilitation in Colorado, USA. Scientifica: Article ID 4758316.
- Rhoades, Charles C.; Entwistle, Deborah; Butler, Dana. 2011. The influence of wildfire extent and severity on streamwater chemistry, sediment and temperature following the Hayman Fire, Colorado. International Journal of Wildfire Science. 20: 430-442.
- Robichaud, Peter R.; Ashmun, Louise E.; Foltz, Randy B.; Showers, Charles G.; Groenier, J. Scott; Kesler, Jennifer; DeLeo, Claire; Moore, Mary. 2013. Production and aerial application of wood shreds as a post-fire hillslope erosion mitigation treatment. Gen. Tech. Rep. RMRS-GTR-307. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 31 p.
- Robichaud, Peter R.; Ashmun, Louise E. 2013. Tools to aid post-wildfire assessment and erosion-mitigation treatment decisions. International Journal of Wildland Fire. 22: 95-105.
- Ryan, Sandra; Dwire, Kathleen. 2012. Wildfire impacts on stream sedimentation: re-visiting the Boulder Creek Burn in Little Granite Creek, Wyoming, USA. In: Stone, Mike; Collins, Adrian; Thoms, Martin, eds. Wildfire and Water Quality: Processes, Impacts and Challenges (Proceedings of a conference held in Banff, Canada, 11¬14 June 2012). IAHS Publ. 354. International Association of Hydrological Sciences. p. 75-80.

CONTRIBUTOR PROFILES

The following contributors were instrumental in the creation of this Bulletin.

RMRS Scientist Profiles

CHARLES RHOADES is a Research Biogeochemist with the U.S. Forest Service, Rocky Mountain Research Station. His research focuses on the biogeochemical processes that sustain productive soils and forests and regulate delivery of clean water. Current projects examine the biogeochemical and watershed responses to hazardous fuel reduction, biomass harvesting, post-wildfire rehabilitation, bark beetle infestations and wild and prescribed fires.

PETE ROBICHAUD is a Research Engineer with the U.S. Forest Service, Rocky Mountain Research Station. He investigates and develops new knowledge on infiltration, overland flow, erosion and erosion mitigation techniques in disturbed forest and rangeland conditions and develops predictive models and decision support tools for use by land managers. And you can find him playing in the dirt.

SANDRA RYAN is a Research Geomorphologist in the Air, Water, and Aquatic Environments Program at the U.S. Forest Service, Rocky Mountain Research Station. Her research focus is on channel form and instream sedimentation processes following large-scale forest disturbances. In addition to her current research in the High Park burn area, she also studies the impacts of the 2013 flood on streams on the Arapaho & Roosevelt National Forest.

Other Contributor Profiles

JEN KOVECSES is the Executive Director of the Coalition for the Poudre River Watershed and coordinated this conference.

CARL CHAMBERS is a Forest Hydrologist with U.S. Forest Service, Rocky Mountain Region,Arapaho & Roosevelt National Forest.

SARA RATHBURN is an Associate Professor in the Department of Geosciences at CSU. Her current research interest is drainage response to disturbances, especially post-disturbance sediment dynamics, recovery trajectories, landscape resilience, and the influence of a changing climate. Sara currently has students working in drainage basins in Montana, Alaska, Colorado, and Italy.

JARED HEATH is the Watershed Specialist for the City of Fort Collins Utilities' Water Resources and Production Division. Jared is responsible for watershed monitoring and assessment activities that support the protection and management of the City's drinking water sources.

STEPHANIE KAMPF is an Associate Professor in the Department of Ecosystem Science and Sustainability. Her research focuses on physical hydrology across spatial scales from plots to basins. Some of her current research examines controls on postfire runoff, erosion, and channel change from hillslope to watershed scale.

Chuck, Pete and Sandra can be reached at:

USDA Forest Service

Rocky Mountain Research Station

240 W. Prospect Ave.

Fort Collins, CO 80526

CONTRIBUTOR PROFILES *continued.*

CODIE WILSON is a Ph.D. candidate in CSU's Watershed Science program and is a fellow with the National Science Foundation's Interdisciplinary Graduate Education and Research Traineeship program. She has been monitoring precipitation, runoff and sediment production at nested sites over a range of spatial scales within the High Park Fire since 2014.

DAN BROGAN is a Ph.D. student at Colorado State University in the Hydraulic Engineering, Stream Restoration and River Mechanics program. He is interested in the impacts of land disturbance on riverine environments and is currently researching the spatial and temporal changes in sediment storage following the 2012 High Park Fire.

BRAD PIEHL is a principal owner of JW Associates and is a forest hydrologist with 30 years of experience working in Colorado's watersheds. For the last 18 years he has focused on watershed hazard assessments and pre- and post-wildfire planning for water agencies and collaborative groups. He has lead the technical and stakeholder process for more than 15 Wildfire/Watershed assessments in Colorado and Wyoming.

MARY ELLEN MILLER, currently a Research Engineer at Michigan Tech Research Institute. Research interests include developing practical methods of supporting land management with remote sensing and environmental modeling, large scale mapping of vegetation, land cover and land use change, and developing and improving environmental models. Her current research focus is on improving modeling tools for postfire risk assessment and remediation.

JOHN GIORDANENGO, founder and owner of AloTerra Restoration has been engaged in ecological restoration and natural resource management for over 19 years in Colorado and Wyoming.

ERIN BERRYMAN, Research Ecologist at U.S. Geological Society is interested in how natural disturbances and human management actions alter carbon and nutrient cycling, mainly in western North America montane and subalpine forests. She investigates lingering effects of the massive bark beetle outbreaks in the Rocky Mountains on soil respiration and its physical and biological controls.

MONIQUE ROCCA is an Associate Professor of Wildland Fire Science at Colorado State University. She studies wildland fire science, forest restoration, plant community ecology, and landscape ecology.

WRITER'S PROFILE

Sue Miller is a science writer living in Fort Collins, Colorado. She received her PhD in ecology from the University of Georgia. Sue can be reached at millroad@comcast.net.

Purpose of the Science You Can Use Bulletin

To provide scientific information to people who make and influence decisions about managing land. The US Forest Service RMRS Science You Can Use Bulletin is published regularly by:

Rocky Mountain Research Station (RMRS)

US Forest Service

240 W Prospect Rd

Fort Collins, CO 80526

Forest Service researchers work at the forefront of science to improve the health and use of our Nation's forests and grasslands. More information about Forest Service research in the Rocky Mountain Region can be found here: http://www.fs.fed.us/rmrs

To receive this bulletin via email, scan the QR code below or use this link: http://tinyurl.com/RMRSsciencebulletin

Nehalem Clark, Bulletin editor, ncclark@fs.fed.us

Jan Engert, Assistant Station Director,

Science Application & Integration;

jengert@fs.fed.us

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at http://www.ascr.usda.gov/complaint_filing_cust.html and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.