Multi-year evaluation of the hydrologic, geomorphic, and biogeochemical impacts of post-fire mulching

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Introduction

Wildfires consume vegetation and alter soil physical and chemical characteristics (Parsons et al., 2010), causing hydrologic changes that lead to increased likelihood of flash flooding, erosion, and debris flows (Shakesby and Doerr, 2006; Moody and Martin, 2001, 2009). To mitigate these risks to human safety, infrastructure, and water supply, management agencies may apply post-fire treatments aimed at reducing runoff and erosion. Mulching – application of material such as straw or wood directly on the burned surface – is a commonly used post-fire treatment and has been shown to reduce erosion from rainfall impacts and surface runoff (e.g., Robichaud et al., 2010, 2013; Schmeer et al., 2018).

Drought conditions in the summer and fall of 2020 in Colorado led to a very active fire season. The Cameron Peak Fire was the largest wildfire in Colorado history, burning over 830 km^2 in the upper Cache la Poudre basin, which is a primary water supply source for the cities of Fort Collins and Greeley. Active monsoonal precipitation in July 2021 has produced numerous debris flows and flash floods, leading to road closures, destruction of property, and at least three fatalities (Swanson, 2021). With financial support from the Colorado state government, aerial application of wood mulch over high-priority burned areas took place in the summer and fall of 2021.

This project will investigate how water quality, hydrologic response, and hillslope and channel geomorphology are affected by these mulching practices. Most prior research evaluating the effects of post-fire mulching on runoff, erosion, and water quality has been conducted at the hillslope or plot scale, and the effects of mulching at larger scales are generally unknown (Zema, 2021; Prosdocimi et al., 2016). Therefore, we propose to monitor paired (mulched/unmulched) at a small watersheds (0.5-1.5 km^2) and examine the effects of mulching on hydrology, geomorphology, and water quality.

Research objectives

The proposed research has the following objectives:

Objective 1: Characterize the hydrologic response at the watershed scale for mulched and unmulched burned watersheds.

Hypothesis 1: mulched watersheds will produce less runoff, smaller flood peaks, and longer lag times between peak precipitation and peak discharge than unmulched watersheds.

Rationale: Mulching increases the surface roughness of the hillslopes, leading to more opportunities for breaking up and slowing down overland flow paths compared to an unmulched surface. Ultimately, slower and more diffuse overland flow could have more opportunities to infiltrate, leading to slower and lower water delivery to streams during rain storms.

Objective 2: Measure geomorphic changes in mulched and unmulched burned watersheds at the watershed and hillslope scale.

Hypothesis 2: Hillslope erosion, rilling, and channel changes will be more pronounced in unmulched watersheds than in mulched watersheds.

Rationale: Mulching increases ground cover, which provides a layer of protection to hillslope sediment from raindrop impacts. Additionally, increased surface roughness due to mulch may decrease the erosive capability of overland flow. So, for a given precipitation intensity, hillslope erosion is less likely to occur on a mulched hillslope. Lower peak flows in streams (H1) would also lead to less channel change compared to unmulched watersheds.

Objective 3: Measure biogeochemical characteristics (carbon, nutrients, metals) of mulch, soil, and stream water, and evaluate the impact of mulching on water quality.

Hypothesis 3: Mulching will alter water chemistry compared to unmulched watersheds, with lower nitrogen, but higher C concentrations and export from mulched watersheds.

Rationale: Post-fire stream water chemistry reflects contributions from ash, eroded sediment and subsurface leachate. Elevated nutrient losses are typical in burned watersheds, and the magnitude of this response scales with burn severity (Riggan et al., 1994; Rhoades et al., 2011). The duration of elevated nutrients relates to the extent of a catchment burned and the rate of vegetation recovery (Rhoades et al., 2019; Rust et al., 2019). Mulch has the potential to alter water chemistry in the short term by reducing soil erosion (Pierson et al. 2019), and the carbon contained in fresh wood mulch can also stimulate soil microbes to immobilize nitrogen and reduce nitrogen leaching losses (Homyak et al., 2008; Rhoades et al., 2015). Mulch layers can also increase soil moisture and stimulate plant recovery (Rhoades et al., 2012 & 2017) and nutrient demand, thus limiting nutrient export to stream water.

Proposed work

Field sites

Research will primarily be conducted in six watersheds that drain to Bennett Creek (Figure 1). The watersheds range in size from 0.57 – 1.49 km^2, have similar distributions of burn severity (Table 1), and are all draining to the northeast. Three of these watersheds have been mulched (prefix “M” in Figure 1) and three were not mulched (prefix “U” in Figure 1a).

Table 1. Study watershed areas and burn severities.

Watershed name	Area (km^2)	% Unburned	% Low	% Moderate	% High
U_W	1.03	0	11	81	8
U_M	0.57	0	11	74	14
U_E	0.62	0	5	80	15
M_W	1.49	0	15	74	12
M_M	0.71	0	20	74	6
M_E	1.37	0	18	71	11

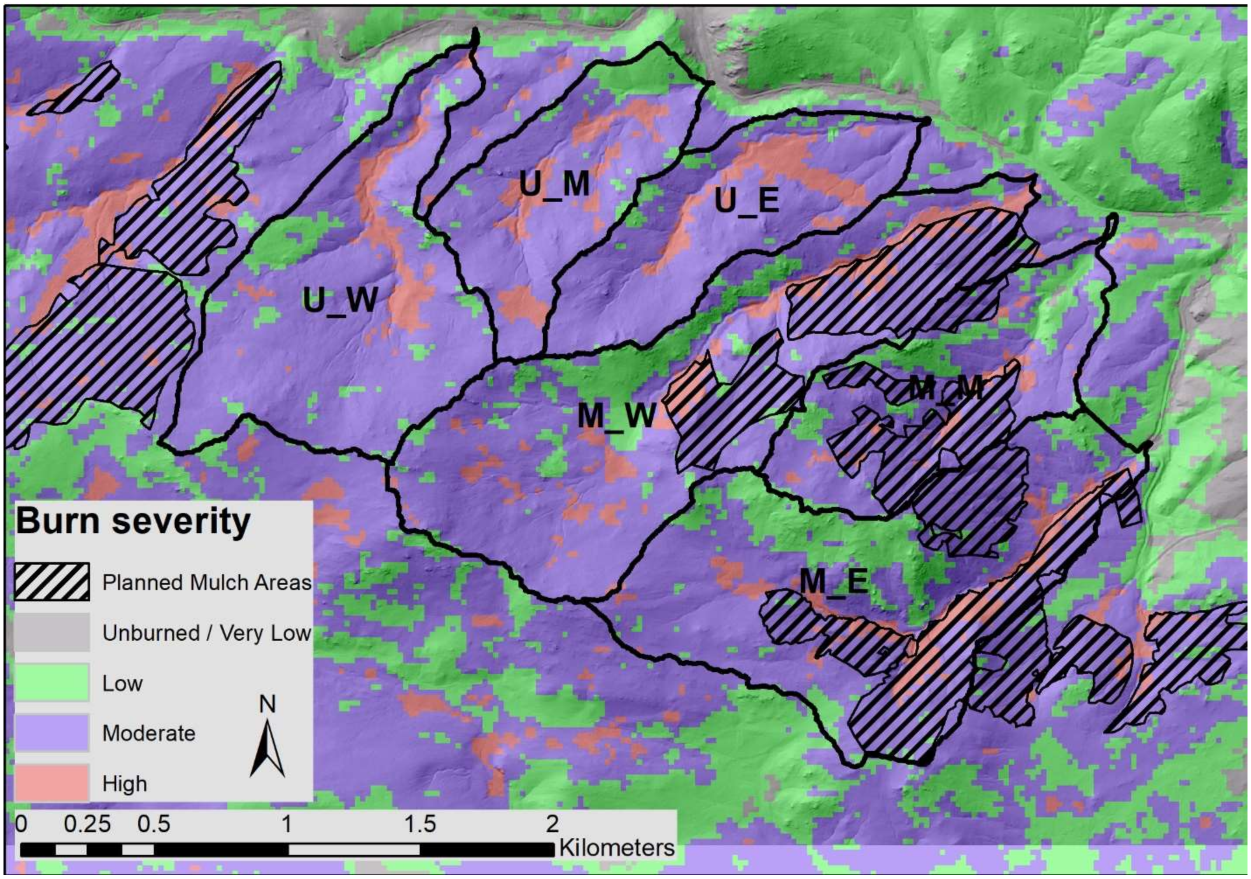

Figure 1. Proposed study watersheds. Prefixes "M" and "U" indicate "mulched" and "unmulched", respectively, and suffixes “W”, “M” and “E” indicate “west”, “middle”, and “east”.

Shredded wood mulch was applied via helicopter to the three mulched watersheds in August 2021. The targeted areas for mulching are shown in Figure 1.

Hydrologic monitoring

The hydrologic response of each watershed will be monitored throughout the study. Capacitance rods have been installed near the outlet of each watershed, and will record water stage at 5-minute intervals during the summer; recording intervals will be reduced to 30 min during the fall-spring. Periodically throughout the study, salt dilution discharge measurements will be collected so that stage-discharge rating curves may be developed; however, these channels are rapidly changing in their morphology, so we may not be able to derive a consistent stage-discharge relationship. Staff plates with game cameras pointed at them have also been installed near the watershed outlets to provide additional data on water stage and general vegetation and mulch conditions. Six tipping-bucket rain gauges have been installed across the study area to characterize rainfall intensity and patterns.

Geomorphic monitoring

Geomorphic changes will be characterized at the watershed and hillslope/channel scale primarily using remote-sensing methods. Pre-fire high-resolution LiDAR topography was collected in summer 2020, and these data provide a baseline condition for the study watersheds. Twice yearly, high-resolution watershed-scale topographic datasets will be collected using drone imagery processed with structure-from-motion (SfM) software to generate very high-resolution point clouds, scaled and registered using ground-control targets surveyed with real-time kinematic (RTK) geographic navigation satellite systems (GNSS). Watershed-scale topographic datasets will be differenced to quantify volumes and patterns of erosion and deposition. Additionally, we will scan individual hillslopes in each watershed with a terrestrial laser scanner (TLS). Five of the six watersheds have had hillslopes scanned already, and two of the mulched watersheds had the same hillslope scanned before and after mulch application. These hillslope scans will be repeated twice per year to document hillslope-scale topographic changes that may not be resolvable with the LiDAR or SfM watershed-scale data. Both the hillslope and watershed-scale topographic changes will be related to the hydrologic measurements, burn severity, and presence or absence of mulch.

Biogeochemical sampling

Streamwater samples will be collected near the outlet of each study watershed. Pre- and post-mulch longitudinal streamwater sampling will also occur throughout each watershed to assess inputs from individual sub-watersheds. Mulch mass and bulk density will be collected from quadrats (0.1 m^2) located along transects distributed throughout mulched polygons each study watershed (see sampling below). Surface organic soil horizons and mineral horizons will be sampled in each plot. Chemical analysis of mulch will quantitate concentrations of water-extractable and acid-digestible elemental forms.

Table 2. Stream, soil and mulch biogeochemical constituents.

Nutrients	PO_4, NH_4, NO_3, total N, total P
Carbon	TOC, DOC, fluorescence
Sediment	Total suspended sediment, turbidity
Chemistry	ANC (alkalinity), pH, EC
Major Ions	Ca, Mg, K, Na, SO4, Cl, F
Metals	Ti, V, Cr, Mn, Al, Fe, Co, Ni, Cu, Zn, Cd, Pb

All samples will be analyzed at the US Forest Service Rocky Mountain Research Station biogeochemistry lab using standard protocols and QA/QC procedures (https://www.fs.usda.gov/rmrs/research-labs/fort-collins-biogeochemistry-laboratory) (Table 2). Metal and total P analysis will be conducted by ICP on a subset of samples at the Analytical Resources Core - Bioanalysis and Omics (ARC-BIO) on the CSU campus. Analyses of constituent concentrations will be coupled with streamflow estimates to generate downstream loads likely to influence receiving waters that are of concern to water providers, aquatic ecosystems and other users.

<u>Mulch and vegetation cover monitoring</u>

Mulch cover will be characterized through a combination of ground observations and drone imagery. Ground cover of mulch, bare soil, rock, residual litter/duff (O-horizon) and vegetation will be measured within 25 x 25 cm quadrats along a systematic grid within the mulched areas. These plots will be identified in the drone imagery collected closest to the sampling date and used to establish a relationship between ground cover and image characteristics (e.g., RGB values). That relationship will then be used to map mulch across the entire study area. Repeat measurements will allow us to document how persistent mulch coverage is, possible transport of mulch by wind or overland flow, and changes in vegetation during the study.

Budget and Justification

		Sponsor contribution			Cost Share			Total Project Costs
		Year 1	Year 2	Total CoG	Year 1	Year 2	Total Cost Share	
PERSONNEL SALARIES								
Peter Nelson, 0.12 month/yr	*match: 1.6 mo/yr*	*$ 1,586*	*$ 1,634*	*$ 3,220*	*$ 21,681*	*$ 22,332*	*$ 44,013*	*$ 47,233*
Fringe	*26.70%*	*$ 423*	*$ 436*	*$ 860*	*$ 5,789*	*$ 5,963*	*$ 11,751*	*$ 12,611*
Stephanie Kampf, 0.12 month/yr	*match: 1.6 mo/yr*	*$ 1,334*	*$ 1,374*	*$ 2,708*	*$ 18,233*	*$ 18,780*	*$ 37,013*	*$ 39,720*
Fringe	*26.70%*	*$ 356*	*$ 367*	*$ 723*	*$ 4,868*	*$ 5,014*	*$ 9,882*	*$ 10,605*
GRA1 (CEE), 50% for 12 mo/yr1; 6 mo/yr2 at 2100/month		*$ 25,200*	*$ 12,600*	*$ 37,800*	*$ -*	*$ -*	*$ -*	*$ 37,800*
Fringe	*10.00%*	*$ 2,520*	*$ 1,260*	*$ 3,780*	*$ -*	*$ -*	*$ -*	*$ 3,780*
GRA2 (CEE), 50% for 12 months/yr at 2100/month		*$ 25,200*	*$ 25,200*	*$ 50,400*	*$ -*	*$ -*	*$ -*	*$ 50,400*
Fringe	*10.00%*	*$ 2,520*	*$ 2,520*	*$ 5,040*	*$ -*	*$ -*	*$ -*	*$ 5,040*
Undergrad hourlies,		*$ 9,600*	*$ 9,600*	*$ 19,200*	*$ -*	*$ -*	*$ -*	*$ 19,200*
Fringe	*0.20%*	*$ 19*	*$ 19*	*$ 38*	*$ -*	*$ -*	*$ -*	*$ 38*
TOTAL SALARY:		$ 62,920	$ 50,408	$ 113,327	$ 39,914	$ 41,112	$ 81,026	$ 194,353
TOTAL FRINGE:		$ 5,839	$ 4,602	$ 10,441	$ 10,657	$ 10,977	$ 21,634	$ 32,075
TOTAL PERSONNEL:		**$ 68,759**	**$ 55,010**	**$ 123,769**	**$ 50,571**	**$ 52,088**	**$ 102,659**	**$ 226,428**
DOMESTIC TRAVEL:		**$ 624**	**$ 624**	**$ 1,248**	**$ -**	**$ -**	**$ -**	**$ 1,248**
MATERIALS AND SUPPLIES		**$ 270**	**$ 200**	**$ 470**	**$ -**	**$ -**	**$ -**	**$ 470**
OTHER DIRECT COSTS								
In-State Tuition:		*$ 23,453*	*$ 11,659*	*$ 35,112*	*$ -*	*$ -*	*$ -*	*$ 35,112*
Equipment Use Fees:	*CSU Drone Center; analysis costs*	*$ 1,000*	*$ 1,000*	*$ 2,000*	*$ -*	*$ -*	*$ -*	*$ 2,000*
Other:	*RMRS water analysis costs*	*$ 7,025*	*$ 7,025*	*$ 14,050*	*$ -*	*$ -*	*$ -*	*$ 14,050*
TOTAL OTHER DIRECT:		**$ 31,478**	**$ 19,684**	**$ 51,162**	**$ -**	**$ -**	**$ -**	**$ 51,162**
TOTAL DIRECT COSTS:		**$ 101,131**	**$ 75,517**	**$ 176,648**	**$ 50,571**	**$ 52,088**	**$ 102,659**	**$ 279,308**
Facilities & Administrative:		**$ 15,170**	**$ 11,328**	**$ 26,497**	**$ 26,297**	**$ 27,086**	**$ 53,383**	**$ 79,880**
Unrecovered F&A	52% MTDC - requested 15% TDC	**$ -**	**$ -**	**$ -**	**$ 25,223**	**$ 21,879**	**$ 47,102**	**$ 47,102**
TOTAL:		**$ 116,300**	**$ 86,845**	**$ 203,145**	**$ 102,091**	**$ 101,053**	**$ 203,145**	**$ 406,290**
	Cost share:	53.3%	46.2%	**50.0%**	46.7%	53.8%	**50.0%**	**100.00%**

	Year 1	Year 2	Total CoG	Year 1	Year 2	Total Cost Share	Total Project Costs
F&A Rate:	15.0%	15.0%		52.0%	52.0%		
F&A Base:	$ 101,131	$ 75,517	$ 176,648	$ 50,571	$ 52,088	$ 102,659	$ 279,308
	$ 15,170	**$ 11,328**	**$ 26,497**	**$ 26,297**	**$ 27,086**	**$ 53,383**	**$ 79,880**

Personnel:

- Minimal salary (0.12 month per year) is requested for Nelson and Kampf to oversee the project.
- Graduate students: Funds are requested for salary for two graduate research assistants (GRAs) at $2100/month, distributed as 12 months GRA effort (at 50%) for each student in year 1; 6 months effort (at 50%) for GRA1 in year 2, and 12 months effort (at 50%) for GRA2. ($50,400 year 1; $37,800 year 2). One GRA will be responsible for the hydrologic and water quality analysis, and the other will be responsible for the geomorphic analysis.
- Undergrad hourlies: Funds for undergraduate student hourly labor, primarily for field data collection support, are requested for both years ($16/hr, 40 hours/week, 15 weeks/year). ($9600/year).
- Fringe benefits are calculated following Colorado State University's federally negotiated rates: Administrative Professional at 26.7%, Graduate Students at 10.0%, student hourly at 0.2%.

Other Direct Costs:

- Drone Center: costs requested to cover aircraft rental, pilot time, and training for graduate students to become certified pilots (10 days/year @ $50/day drone rental + 16.5 hrs of pilot time/year @ $30/hr).
- Biogeochemical analyses will be conducted at CSU and at the USFS Rocky Mountain Research Station (RMRS). The RMRS 'suite' of analyses (Table 2) cost $20/sample. Metals will be measured at CSU's ARC-BIO at a cost of $25/sample. Funds are requested to analyze 290 'suite' samples per year, and 49 metals samples per year ($7,025/year).
- Tuition: GRA1: One 9-credit semester and one 5-credit semester year 1, one 5-credit semester year 2 ($14,007). GRA2: two 9-credit semesters year 1, two 5-credit semesters year 2 ($21,105).
- Travel: $624/year for mileage to field sites (12 trips/year, 100 miles/trip, $0.52/mile).
- Materials and supplies: $470 requested for supplies (e.g., sample bottles and bags, drone targets, flagging, and other consumables).

Facilities and Administrative:

- Indirect costs are charged at the 15% rate authorized by the Colorado Water Conservation Board (CWCB) for contracts between CSU and CWCB.

Cost share

- 1:1 cost share achieved through salary match for Kampf and Nelson (1.6 months/year for each), as well as the unrecovered indirect cost difference between CSU's regular 52% rate on modified total direct costs and the requested 15% rate on total direct costs.

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