Evaluating Post-Fire Geomorphic Change on Paired Mulched and Unmulched Watersheds using Repeat Drone Surveys

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Introduction

Sediment redistribution post wildfire can dramatically alter a watershed and pose risks to local infrastructure and water quality. Mulch application is increasingly being used to mitigate post-fire hillslope runoff and erosion, although relatively little is known about its effects on the watershed scale (Zema, 2021; Prosdocimi et al., 2016). In this study we use repeat drone surveys to measure erosion and deposition across 6 small (0.5-1.5 km^2) watersheds, 3 mulched and 3 unmulched, in the 2020 Colorado Cameron Peak Fire (CPF) burn scar. Initial drone surveys were gathered in the spring of 2022 shortly after mulching and were differenced to surveys done in fall of 2022, capturing the erosional effects of a Colorado monsoon season. The objectives are to (1) quantify sediment volumes and spatial patterns of erosion and deposition on a watershed scale, (2) compare geomorphic change to mulch coverage, precipitation patterns, burn severity, and morphologic metrics, and (3) identify conditions in which mulch may be most appropriate based on findings.

Study Site

Six adjoining watersheds, three mulched and three unmulched, were selected to investigate the impacts of mulch on post-fire geomorphic response (Figure 1).

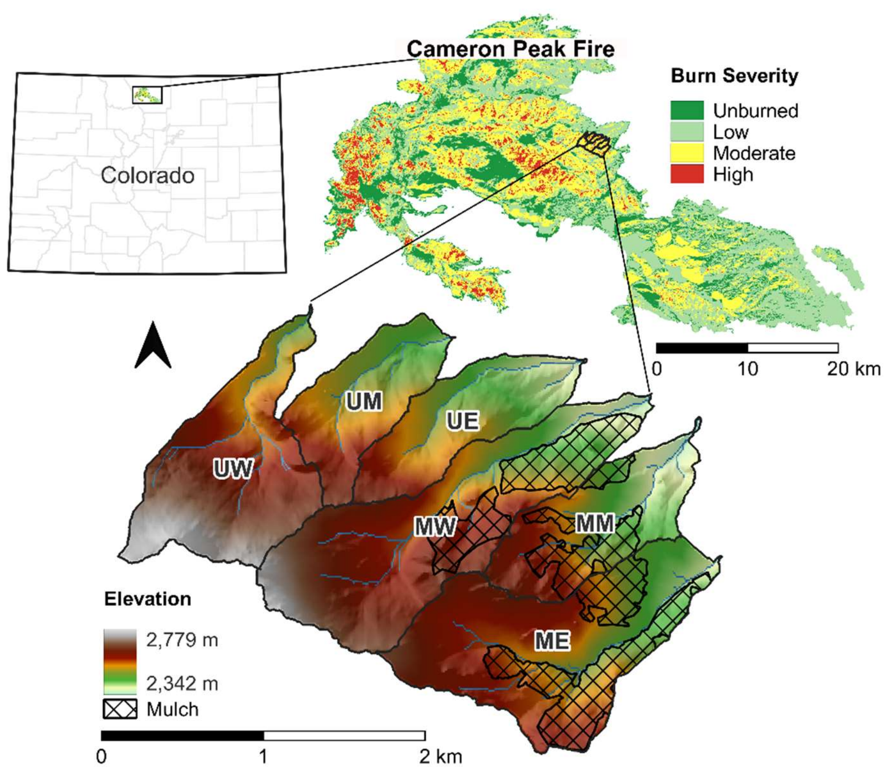

Figure 1. Mulched and unmulched Bennett Creek catchments in the Colorado CPF burn scar

The watersheds burned in the Cameron Peak Fire, drain into Bennett Creek to the northeast, and range in size from 0.57-1.49 km^2. Wood mulch was applied aerially to portions of the three easternmost watersheds during late summer of 2021. Approximately 23%, 31%, and 33% of the hillslopes in the MW, MM, and ME watersheds were mulched respectively at a coverage of about 22%, although the coverage was found to be inconsistent across the study area.

UAV-SfM Methods

Drone imagery across the catchments was collected using a DJI Phantom 4 RTK drone during May and October of 2022. The 2 surveys were coregistered in Agisoft Metashape and processed to build DEMs of 6.4 cm resolution. DEMs were differenced to produce a DEM of Difference (DoD) for each catchment where negative change represents erosion and positive change represents deposition.

Errors between the surveys were propagated and thresholded to a 95% confidence level. Vertical errors included precision estimates which were extracted from Metashape (James et al., 2020) and systematic error which was assessed visually and by calculating GCP errors. Our analysis yielded spatially distributed levels of detection with maximum levels of detection of 12-16 cm and mean levels of detection of 5 cm.

Results

Calculated sediment volumes show the mulched watersheds had a greater erosional response compared to the unmulched. Hillslope yields dominated the sediment budget with hillslope erosion accounting for 94-96% of erosion for all watersheds except UE where hillslope erosion accounted for 78%. Even after normalizing the volumes by area (Figure 2), the mulched watersheds eroded about 2 times more than the unmulched. Channels were overall net depositional and acted as sinks for the hillslope sediments. Despite our effort to filter out low vegetation growth, we could not quantify depositional volumes on the watershed scale accurately. Channel delineations were relatively free from vegetative effects, so we focus analysis on volumes in the channels.

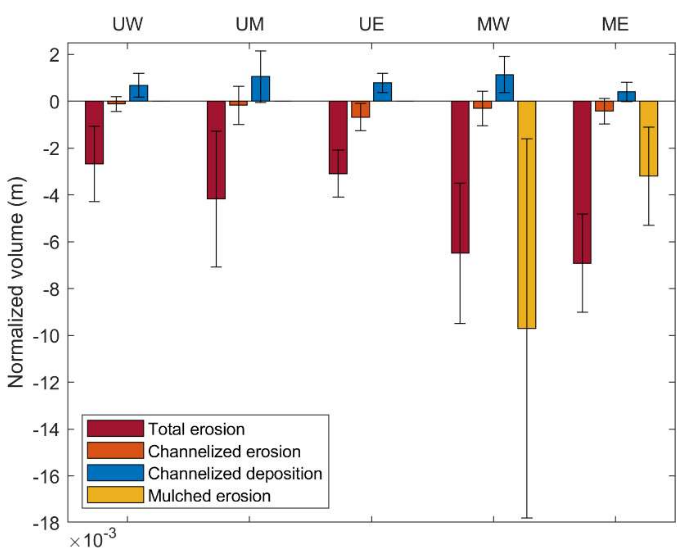

Figure 2. Sediment volumes divided by catchment area with mulched erosion divided by area mulched. Positive values indicate deposition; negative values, erosion; and verticals bars, uncertainty

Sediment yields varied between the watersheds and exhibit complex behavior with respect to mulch, slope, contributing drainage area, precipitation, NDVI, burn severity, and shape. A multi-linear regression analysis found erosion volumes to be weakly but significantly related to, in order of decreasing significance, NDVI, slope, contributing area, topographic wetness index, elevation range, burn severity, and accumulated precipitation. No obvious effects of mulch were found visually, although the regression model indicated mulch to have slight significance in the ME watershed. Channel response followed watershed response in that the mulched watersheds' in-channel incision and aggradation were magnified. Substantial channel erosion occurred where the steep hillsides constricted the valley width. A multi-linear regression model run on channel change ranked slope, change in slope, and change in stream power in order of significance in producing erosion or deposition. Visually, longitudinal profiles show change in slope or stream power to indicate a change in sediment transport resulting in an alternating erosion and deposition pattern upstream.

Given that each watershed is unique, it is a challenge to comparatively quantify post-fire erosion and mulch impacts. Mulch cover at our study site was sparse and not evenly distributed, making it a challenge to measure mulch effectiveness. Our on-ground cover measurements of 22% pale in comparison to the suggested coverage of 60% needed to reduce post-fire hillslope erosion rates (Robichaud et al., 2000). Additionally, due to our UAV-SfM level of detection, we are not able to detect small-scale erosion processes such as rainsplash, sheetwash, and shallow rilling, which mulch may mitigate. Our data show that ME and MW experienced the most erosion, but they also have higher slopes and greater relief than the unmulched watersheds. The outlets of the unmulched channels were depositional while the upper portions of the mulched watersheds were depositional. Our results suggest these spatial variances primarily control post-fire erosion and deposition, more so than whether the hillslopes were mulched or unmulched.

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