Large-scale remote sensing of geomorphic change in mulched and unmulched watersheds burned in the 2020 East Troublesome Fire, Colorado

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Introduction

Wildfires often lead to elevated levels of surface runoff and transport of surface sediment and debris (Swanson 1981). The resulting erosion and deposition pose a threat to downstream structures and can degrade water quality in downstream channels and riparian zones. 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 at the hillslope scale to reduce erosion from rainfall impacts and surface runoff (Girona-Garcia 2021). However, the effects of mulching at the watershed scale are generally unknown. This gap in knowledge provides a valuable opportunity for our research to have a profound impact on the implementation of mulching in the future.

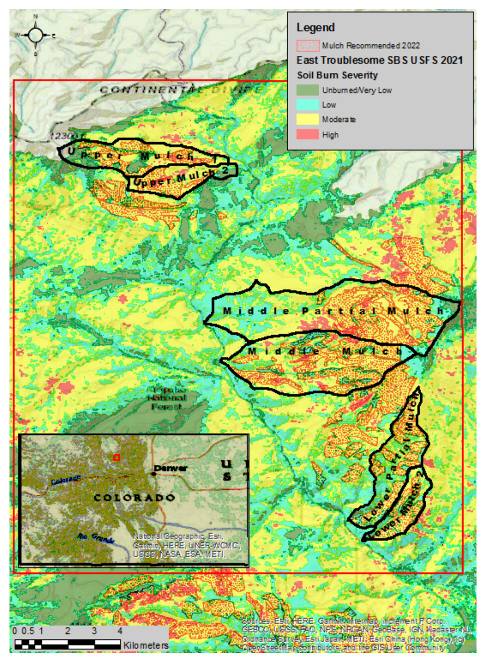

Figure 1: Location of study watersheds within East Troublesome Burn area, including burn severity and proposed mulching layers

We have been monitoring three pairs of partially mulched watersheds burned in the 2020 East Troublesome Fire, the second-largest wildfire in Colorado's recorded history. Six watersheds were selected for data collection (Figure 1), ranging from elevations of 2,575 m to 3,619 m. The lower and middle watersheds drain directly into Willow Creek, while the upper watersheds drain into Pass Creek, a tributary of Willow Creek. Each pair of watersheds share comparable geomorphic characteristics, as well as similar vegetative regrowth, precipitation patterns, burn severity, and size. However, these characteristics differ between the upper, middle, and lower portions of the study area. Additionally, eleven roughly 1 km portions of the Willow Creek channel and riparian zone were monitored to identify areas of significant sediment flux out of the study watersheds, and any resulting channel morphological changes. The proposed areas for the application of mulch are shown in Figure 1 as the red shaded areas. Our objectives are to determine how mulch applications affect the distribution and magnitude of net erosion and deposition volumes across the watershed, and to relate these findings to geomorphic and fire characteristics to inform future post-fire mulching operations.

Methods

Understanding the spatial distribution and variability of erosion and deposition within these watersheds is of critical importance to the goals of this study. Data collection is difficult due to the extreme and unstable geology of these watersheds, and the high threat levels of dangerous flash flooding in the area. Therefore, we have collected aerial imagery from locations close to the watershed outlets along Willow Creek and HWY 125. Spatial patterns of erosion and deposition were quantified by differencing high-resolution digital elevation models (DEMs). DEMs were generated using structure-from-motion (SfM) processing on repeat aerial surveys of the study areas. Alignment and differencing of drone-based imagery was performed in Agisoft Metashape Professional (Over 2021), using a co-registration workflow during SfM processing (Cook and Dietze 2019). After co-registration and optimization of the point clouds, uncertainty of the elevation values was estimated using a point precision mapping script (James 2017). This technique indicated vertical uncertainties of <1 to 3 cm for the Lower Partial Mulch (LPM) datasets. An example histogram of point precisions, derived from this script, for the October flight of LPM can be seen below in Figure 2.

We began collecting high resolution (~3 cm/pixel) aerial imagery in late July 2022 of the 6 watersheds draining into Willow Creek, and portions of the Willow Creek channel and riparian zone. Aerial imagery was collected using a WingtraOne Gen II fixed wing mapping drone, operating a 42-megapixel Sony RX1R II camera payload. Due to the data collection limitations mentioned, it was logistically infeasible to collect aerial imagery over the entire extent of the watersheds. Therefore, we collected aerial imagery for areas near the watershed outlets, ranging from 0.5 to 1 km^2. During this time each watershed area was flown 3 times and each channel section was flown at least twice (with two sections flown three times) to allow for identification of sediment transport occurring from July to October 2022. The aerial images collected were processed using SfM to generate DEMs and orthomosaic images. The DEMs and orthoimages were exported to ESRI ArcMap 10.8.1 where DEMs of difference (DoD) were calculated using the Raster Calculator tool. The vertical uncertainties for each flight were combined using equation 1 (Anderson 2018) to determine a detection threshold for erosion and deposition identified in the DoDs at a 95% confidence interval, where σ_x and σ_y are the maximum vertical uncertainty for flight one and two, respectively, and t is the constant for a given confidence interval (in this case 95%). As an example, for the Lower Partial Mulch (LPM) watershed this detection threshold was calculated to be roughly 8 cm.

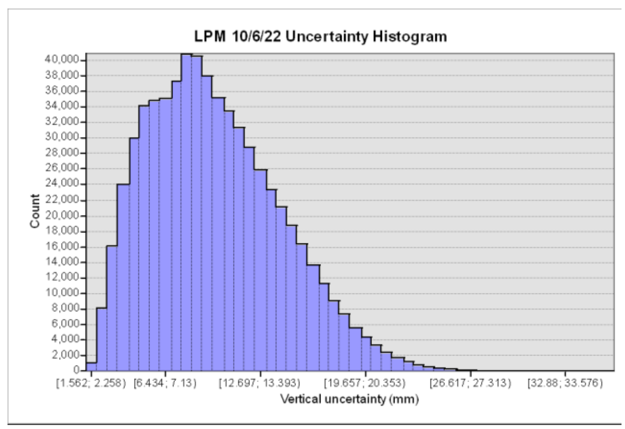

Figure 2: Histogram of point precision uncertainty for October LPM flight

$$\sigma_{x+y} = t\sqrt{\sigma_x^2 + \sigma_y^2} \qquad (1)$$

The DoDs were then filtered using the detection threshold and multiplied by the area of each raster pixel to calculate the volumetric topographic change. A regression model will be developed for each watershed to relate the net volume of erosion and deposition in specific subbasins, with watershed specific parameters, such as burn severity, total rainfall, rainfall intensity, presence of mulch, and slope. This analysis will help to identify the driving forces behind topographic change in a post-fire landscape and help to inform future mulching operations.

Results and Discussion

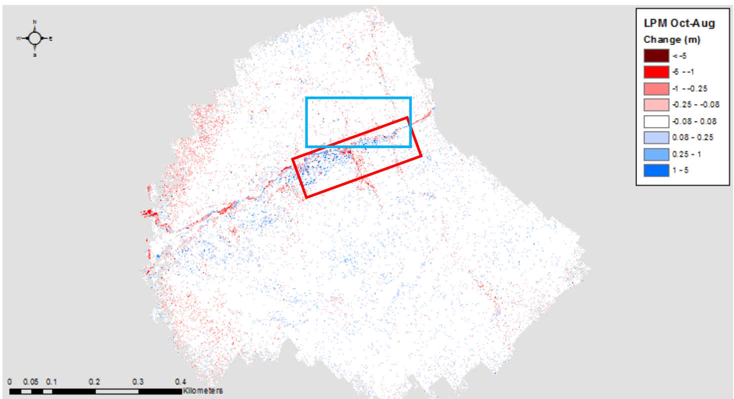

Figure 3: LPM DoD showing elevation change from August 12th to October 6th. Red and blue boxes indicate locations shown in Figures 3 and 4.

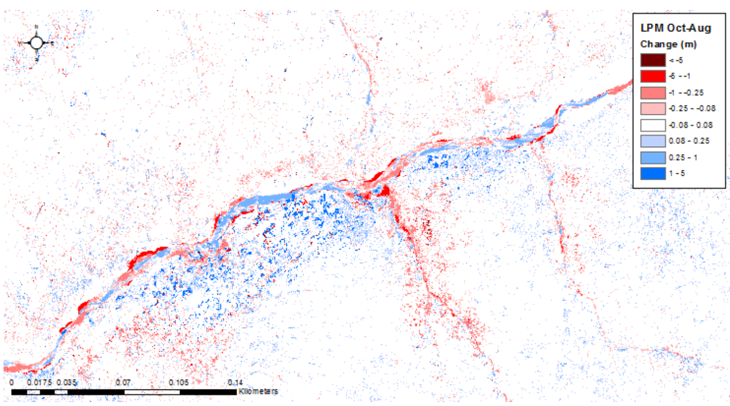

Figure 4: LPM in-channel elevation change, showing incision, channel migration, and deposition (red box Figure 2)

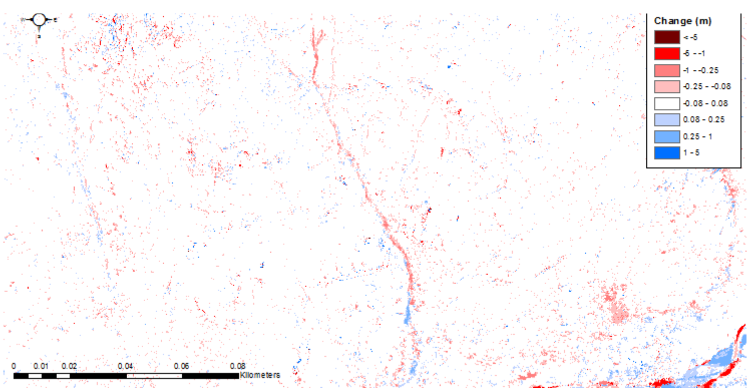

Figure 5: LPM hillslope elevation change, showing formation of rills and gullies (blue box Figure 2)

Figures 3 to 5 present preliminary results of topographic differencing of LPM for the period of August through October 2022. Roughly half of the area flown in LPM was mulched in early July 2022. Despite mulching, this area was extremely dynamic during the observation period, with vertical changes upwards of three meters being observed near the channel (Figure 4), and upwards of 50 cm on the hillslopes (Figure 5). Evidence of significant rilling on hillslopes, formation of gullies, debris flows, channel incision, and channel degradation are evident in both mulched and unmulched areas in LPM. Preliminary estimates of volume flux from LPM show net erosion volumes upwards of 1200 m^3, indicating significant sediment influx from the affected watersheds to Willow Creek. These results agree with observations from Lower Mulch 2 and both middle-elevation watersheds, while the two higher-elevation watersheds appear to be relatively less dynamic. Further investigation into the changes in these watersheds is necessary before any conclusions on the impacts of mulching on post-fire erosion can be drawn due to their levels of vegetation regrowth, differing geomorphic characteristics, and mulching coverage. Vegetation growth and die-off between aerial surveys makes identification of erosion and deposition in areas with significant vegetation change difficult. We are in the process of testing several vegetation filtering techniques which show promise in identifying and removing ground cover and downed trees from the DoDs, but presently we are limited to analyzing the portions of the DoDs absent of vegetation.

Conclusions

Geomorphological, meteorological, and burn characteristics are all likely to influence where, and how much, post-fire erosion and sediment transport occurs. Even though the areas of LPM shown in Figure 3 to 5 were mulched, the channel and hillslopes experienced substantial erosion and deposition. Whether the mulch had an effect on the amount of sediment redistribution is unclear, but continued analysis of data from all six study watersheds will help tease out the impacts of mulching as well as geographic and hydrologic factors.

Ongoing work will aim to improve volume flux estimates by filtering vegetation and normalizing volumes based on slope and area characteristics of the watersheds. Once the sediment volume data has been filtered and normalized it will be used as the dependent variable in our regression model, where we hope to identify and develop relationships with independent variables including, total rainfall, rainfall intensity, burn severity, presence of vegetation, slope, aspect, and presence of mulch. Once identified, any correlations between these variables and sediment transport can be used to inform mitigation efforts for future wildfires.

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