Wildfire in the West: Characterizing Drivers of Post-Disturbance Hydrologic and Water Quality Response through Laboratory Analysis

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1 Motivation

Wildfires are a perennial problem across the western U.S. and internationally. These fires affect water quality and supply by:

- Increasing watershed sedimentation rates to 25 times or more above base levels, potentially **overwhelming water treatment plants** and driving reservoir filling[1].
- Raising levels of dissolved organic matter (DOM), which can form **carcinogenic disinfection byproducts** during the water treatment process[2].
- Generating increased nutrient concentrations in streamflow, leading to **eutrophication** in freshwater systems[3].

Accurate predictions of water quality and supply responses to wildfires will aid in the planning and mitigation of these effects.

The overarching goal of this research effort is to evaluate the effect of wildfires on runoff and constituents loads using laboratory simulation techniques.

2 Context of study

Numerous studies have used *in situ* data and simulation techniques to analyze the physical and chemical effects of burning on soil and runoff. This study is unique in that it will enable a simultaneous evaluation of **precipitation intensity, terrain slope, and burn severity** on runoff, sedimentation, and water quality response. Other studies have observed the individual effects of these factors and have been key references in the design of this study:

Study Factors and Subjects	Authors
Burn effects on dissolved organic matter	Hohner et al. (2019)
Burn effects on increased runoff and erosion	Larsen et al. (2009)
Burn and rainfall intensity effects on water repellency and sedimentation	Keestra et al. (2014)
Rainfall intensity effects on sedimentation and water quality	Kibet et al. (2014)

3 Site Description

Study areas are the **Cache la Poudre (CLP) Basin** near Fort Collins, CO, and the **Fraser Experimental Forest (FEF)** near Fraser, CO

- The CLP basin was affected by the High Park wildfire in 2012, which burned 85,000 ac (34,498 ha) at a moderate-high severity[4,5]
- Burn pile wildfire simulations were conducted by Dr. Charles Rhoades at the FEF[6]
- Water quality and supply data collected from the burn piles in the FEF and following the High Park Fire in the CLP will provide **benchmark numbers** to validate the results of this study[5,7]

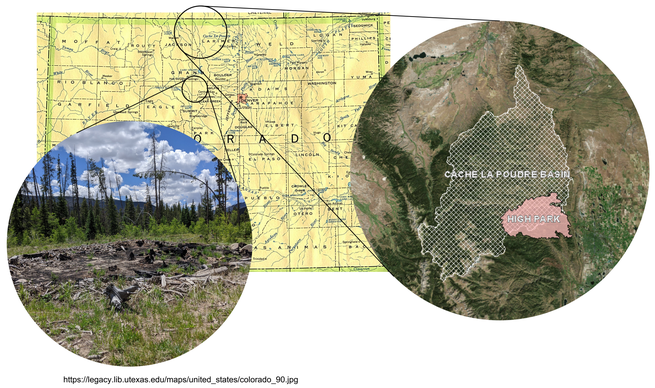

Figure 1: A burn pile at the FEF (left) and the Cache la Poudre Basin overlain with the outline of the High Park fire (right.

Key scientific question:

- **How do the factors of burn severity, rainfall intensity, and terrain slope effect runoff response, as well as sedimentation, turbidity, total organic carbon (TOC), and total dissolved nitrogen (TDN)?**

4 Experimental Design

This experiment is designed to analyze sedimentation response in a 3D matrix of controls

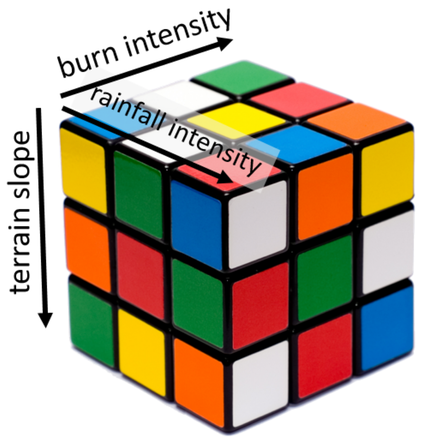

Figure 2: The experiment can be thought of as a Rubix cube, where each axis represents a different variable and each block corresponds to a certain sedimentation response.

Terrain Slope Simulation

- Tilting mechanism holds samples at specified terrain slopes
- Custom-designed funnels for holding samples and separating infiltration from runoff

Figure 4 (above): Tilting mechanism and funnel setup in the rainfall simulator

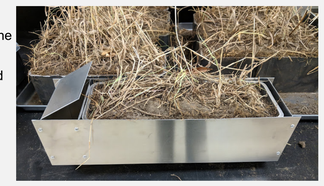

Figure 5 (right): Custom-designed funnels for holding samples, which separate infiltration from runoff in the rainfall simulator

Burn Simulation

- Using a temperature-based burn severity scale to simulate a range of wildfire intensities, based on previous wildfire simulation studies[8]
- 375 W heat lamps raise the temperature of the surface of the soil samples
- Thermocouples and a datalogger track surface and subsurface temperatures

Figure 3: Wildfire simulator using heat lamps to burn the surface of the soil samples

Rainfall Simulation

- Variable-intensity rainfall simulator closely approximates natural rainfall kinetic energy, droplet size, and distribution
- Created by carefully selecting components of the rainfall simulator, including the *FullJet*® nozzles

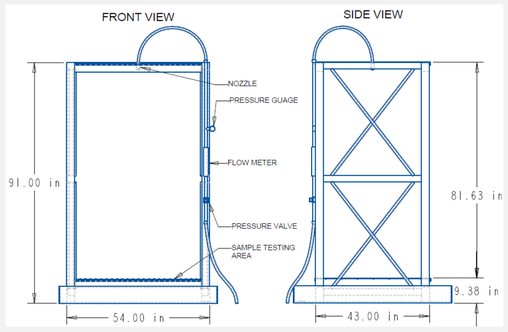

Figure 6: Schematic of rainfall simulator with front view and side view

5 Experimental Procedure

1. **12 x 4 x 4 in (30.4 x 10.1 x 10.1 cm) soil samples are collected from the sampling sites and inserted into steel containers, carefully maintaining soil structural integrity**
2. **Wildfire simulator burns samples, raising the soil surface to specific temperatures**
3. **Samples are then placed into the tilting mechanism set at specific terrain slopes**
4. **Rainfall simulator is run for 2-hour storm event at specific rainfall intensities**
5. **Runoff and infiltration collected from each sample are analyzed for sediment amount, turbidity, TOC, and TDN**

Table 1: Variables tested and range of values

Variable	Testing Values
Burn Temperature	100°C, 300°C, and 550°C
Precipitation Intensity	0.76 in/hr, 1.69 in/hr, 2.50 in/hr
Terrain Slope	10°, 20°, 30°

6 Simulation Calibration

Calibration of the wildfire and rainfall simulators was completed after construction to ensure accurate simulation of the natural processes.

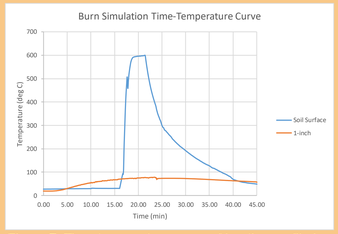

Figure 7: Time-temperature curve of heating profile in soil sample in burn simulator

The wildfire simulator creates a heating profile on the soil similar to a naturally occurring wildfire. It simulates low, moderate, and high severity fires up to > 550° C.

Distribution and intensity of the rainfall in the simulator were tested to ensure the required minimum and maximum rainfall intensities can be achieved, and that all samples in the simulator receive an even distribution of rainfall.

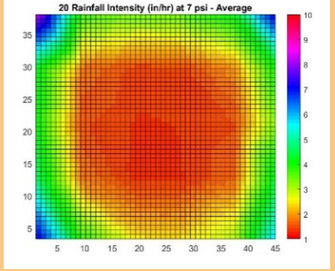

Figure 8: Rainfall distribution testing in rainfall simulator

7 Initial Results

Total organic carbon seemed to increase with increasing burn severity, indicating that water extractable organic carbon is released at higher burn severities and dissolved in subsequent streamflow.

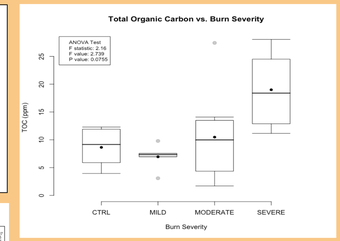

Figure 9: TOC levels at increasing burn severities.

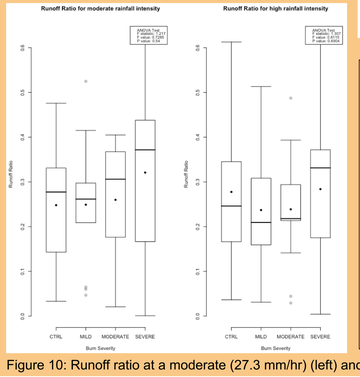

Figure 10: Runoff ratio at a moderate (27.3 mm/hr) (left) and high (58.1 mm/hr) (right) rainfall intensity.

A slight increase in runoff ratio with increasing burn severity for a moderate rainfall intensity vs. no clear trend for high rainfall intensity may indicate that burn severity is a stronger driver of runoff at lower rainfall intensities, whereas burn effects are overwhelmed at higher rainfall intensities.

8 Major Conclusions and Next Steps

The calibration of the wildfire and rainfall simulators indicate a time-temperature curve similar to a natural wildfire, and an even distribution of a wide range of rainfall intensities, respectively. While initial results are presented here, work remains to complete the full dataset:

- Complete **water quality testing** for all runoff samples, including weighing sediment amounts and testing for TOC, turbidity, and TDN
- Perform **statistical analyses** on datasets, comparing all variables against each other assessing where trends exist

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References: 1. Benavides-Solorio and MacDonald (2001), 2. Richardson et al. (2007), 3. Bladon et al. (2014), 4. City of Fort Collins (n.d.), 5. Kampf et al. (2016), 6. Rhoades et al. (2015), 7. Contrufo et al. (2016), 8. Cancelo-González et al. (2012)