Finding balance between fire hazard reduction and erosion control in the Lake Tahoe Basin, California-Nevada

Nicolas M. Harrison

Lead Hydrologist
Humboldt Redwood Company

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Collaborators:

Dr. Andrew Stubblefield (HSU)
Dr. Eric Knapp (USFS)
Dr. Morgan Varner (USFS)

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- **Land management in the Tahoe Basin**
- **Study objectives and methodology**
- **Study results**
- **Implications for land management practices**

Reduce fuel loading in order to decrease the potential for catastrophic wildfires

Photo: healthyforests.org

South Lake Tahoe, 2007 post-Angora Fire

- **3,100 acres (12.5 km^2)**
- **\$141 million in damages**
- **\$10 million in fire fighting costs**

(USFS, InciWeb)

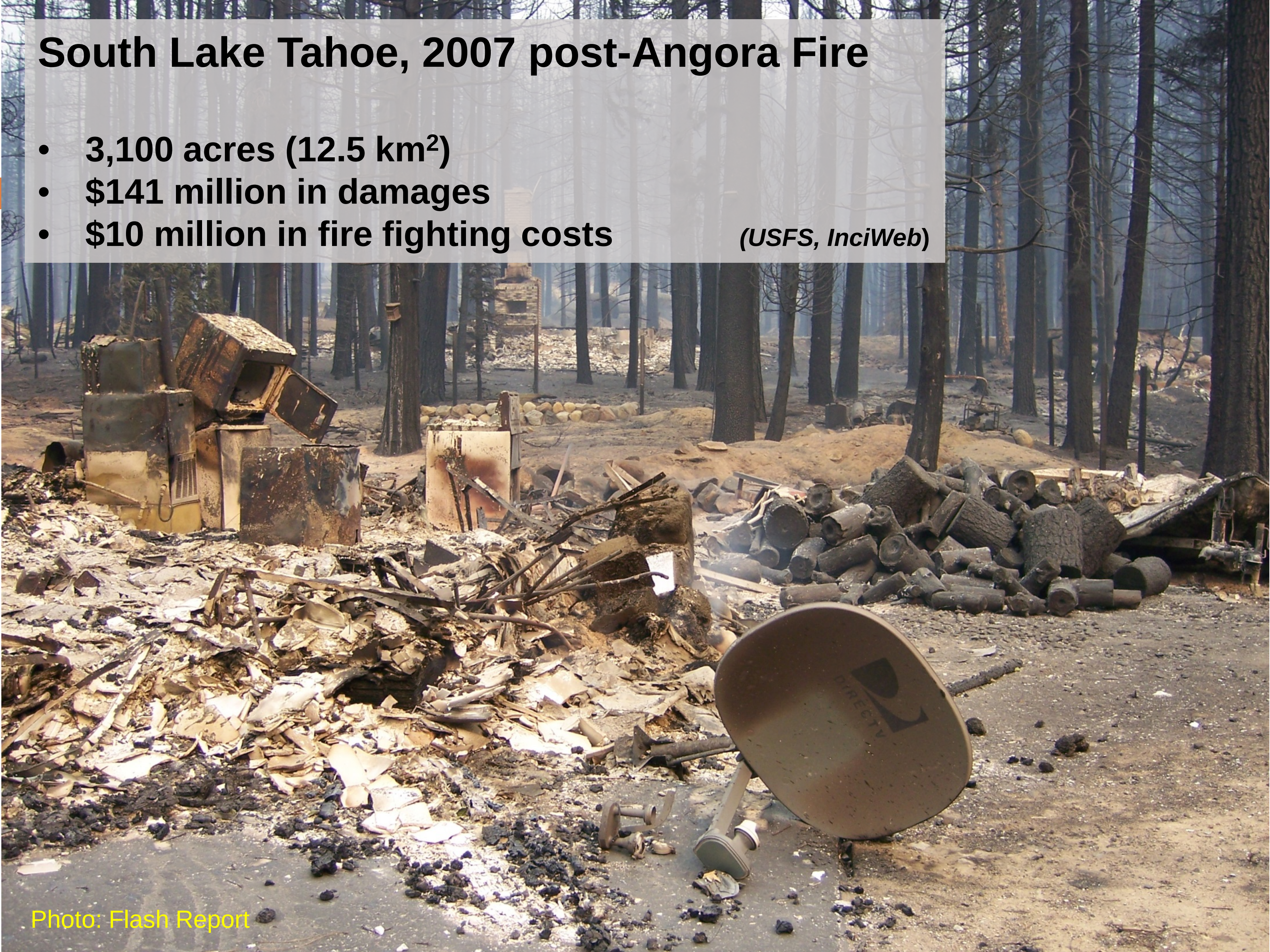


Photo: Flash Report

Mechanical mastication

Prescribed fire: broadcast burns

Prescribed fire: pile burns


Maintain sufficient groundcover
to mitigate erosion
Photo: USGS

Paradox:

Corresponding removal of forest floor fuels in Basin may increase erosion rates

Study Objective: Quantify tradeoffs between fuel reduction and erosion

Paradox:

Corresponding removal of forest floor fuels in Basin may increase erosion rates

Critical Question:

What are optimal levels of surface fuel retention for mechanical mastication and prescribed fire treatments?

30% loss of water clarity in Lake Tahoe over three decades

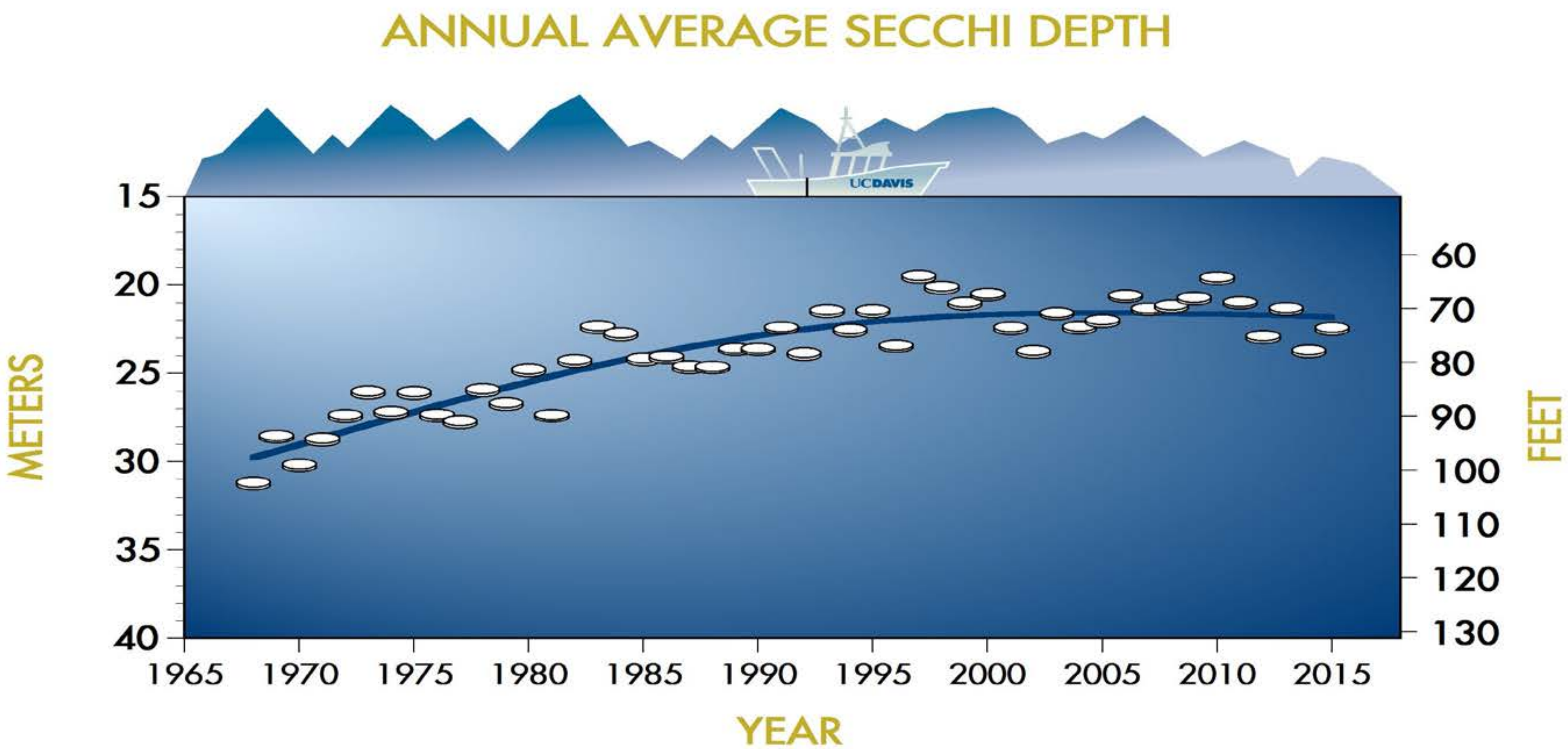
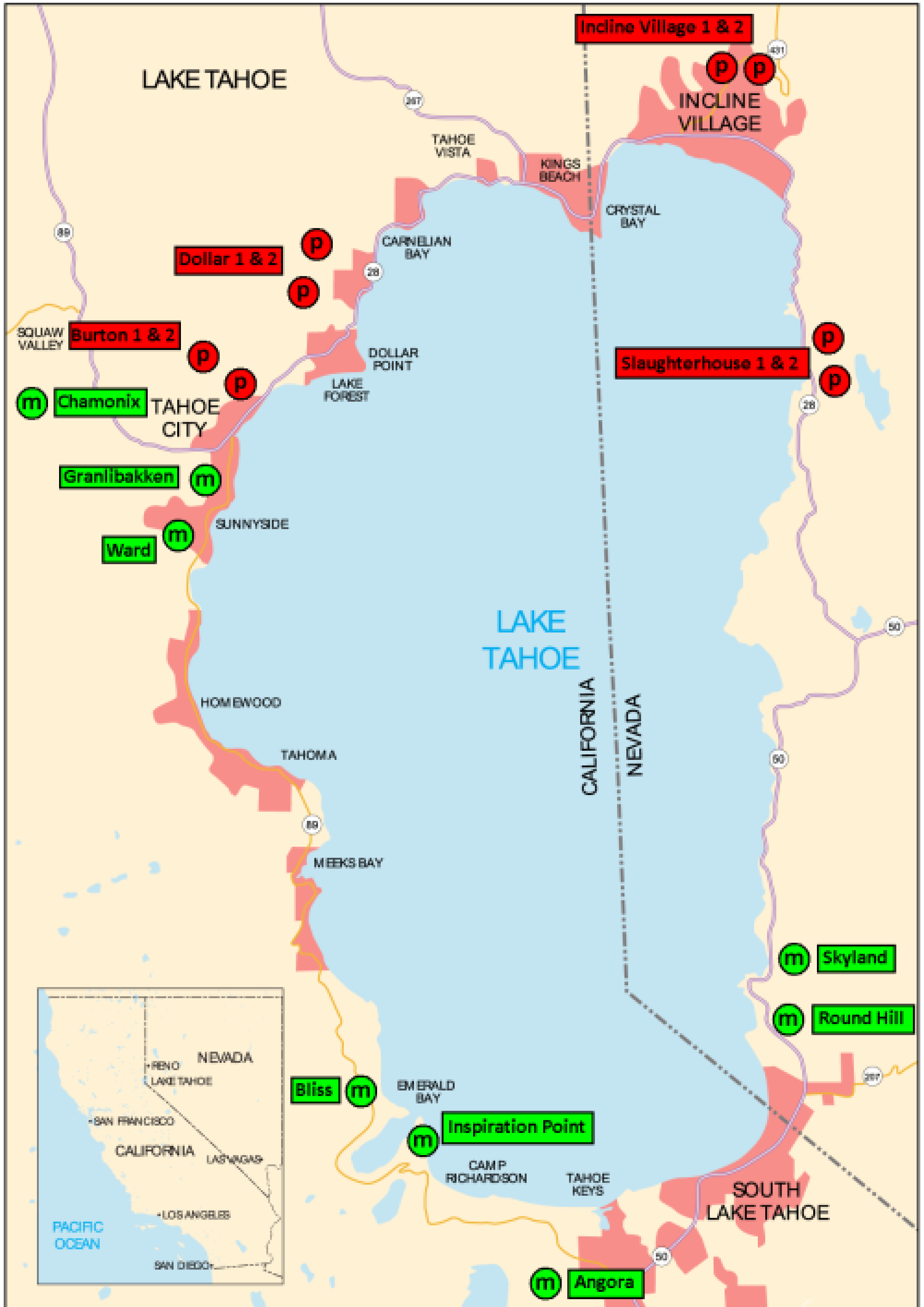


Figure: UC Davis Tahoe Environmental Research Center

How are sediment and nutrients reaching Lake Tahoe?

- 90% of precipitation within a normal water year is derived from snow (Leonard et al. 1979)

- Snowmelt recharge to shallow groundwater systems is the primary source of sustained streamflow in the Tahoe Basin (Kattelman 1989)



Experimental Design

Snowmelt runoff simulation

- 8 masticated sites (2009)
- 8 prescribed fire sites (2010)
- Slopes: 15-38%
- Soil types: Granitic (n = 7)
  Volcanic (n = 9)

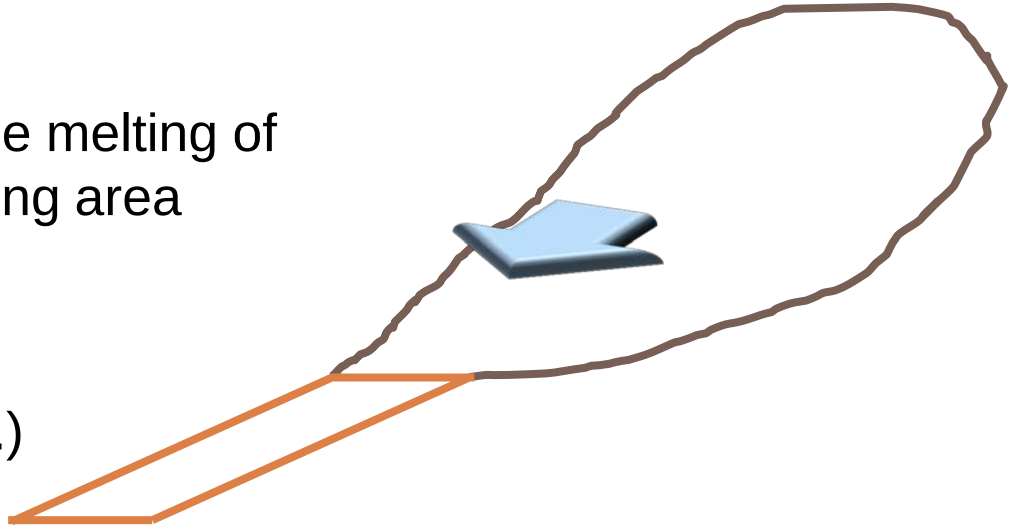
Snowmelt Runoff Simulation

- 15 L/m of water applied for 3 successive 12-minute runs on 5m x 2m plots

- Total of 540 L of water applied to each plot

- Equal to runoff produced by the melting of 5 cm of snow from a contributing area of 100 m^2

- Runoff collected in 20 L (5 gal.) buckets and in 500 mL and 175 mL Nalgene bottles



Water Bladder

Constant Level Container

Runoff Simulator

Collection Apron

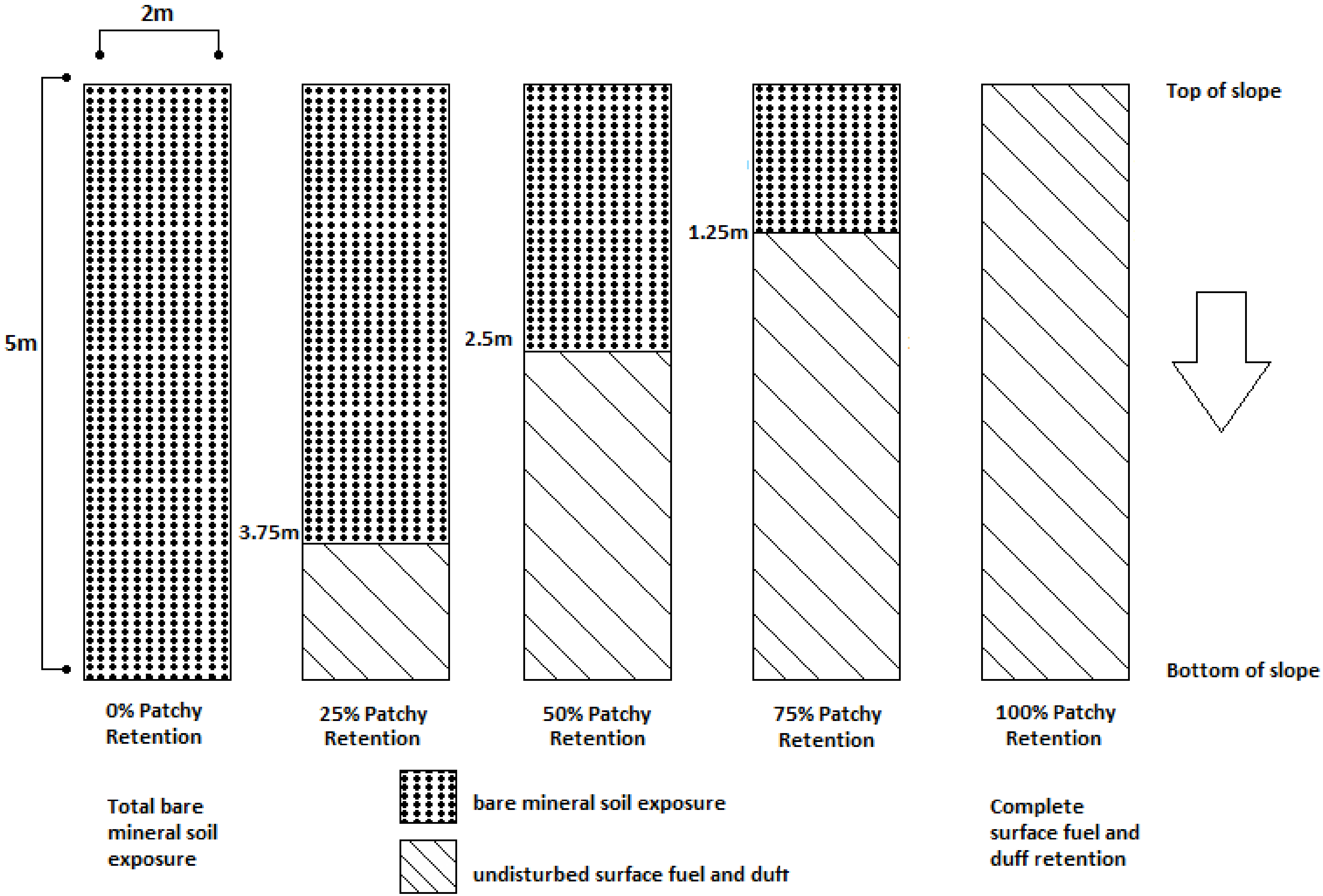
Complete plot setup

Masticated Sites

- 8 sites
- 9 plots per site (5m x 2m)
- 5 plots: Patchy retention treatments
- 4 plots: Even retention treatments
- 2 Control treatments

Masticated Sites: Patchy Retention Treatments

- Variable spatial distribution of masticated surface fuels
- What proportion of fully covered ground area is necessary to trap sediment contributed by the proportion of bare mineral soil area?
- 5 treatment types: 1 type assigned to 1 plot per site


2m
5m
3.75m
2.5m
1.25m
Top of slope
Bottom of slope
0% Patchy Retention
25% Patchy Retention
50% Patchy Retention
75% Patchy Retention
100% Patchy Retention
Total bare mineral soil exposure
bare mineral soil exposure
undisturbed surface fuel and duff
Complete surface fuel and duff retention

100% Patchy Retention (complete surface fuel and duff preservation; Control #1)

75% Patchy Retention

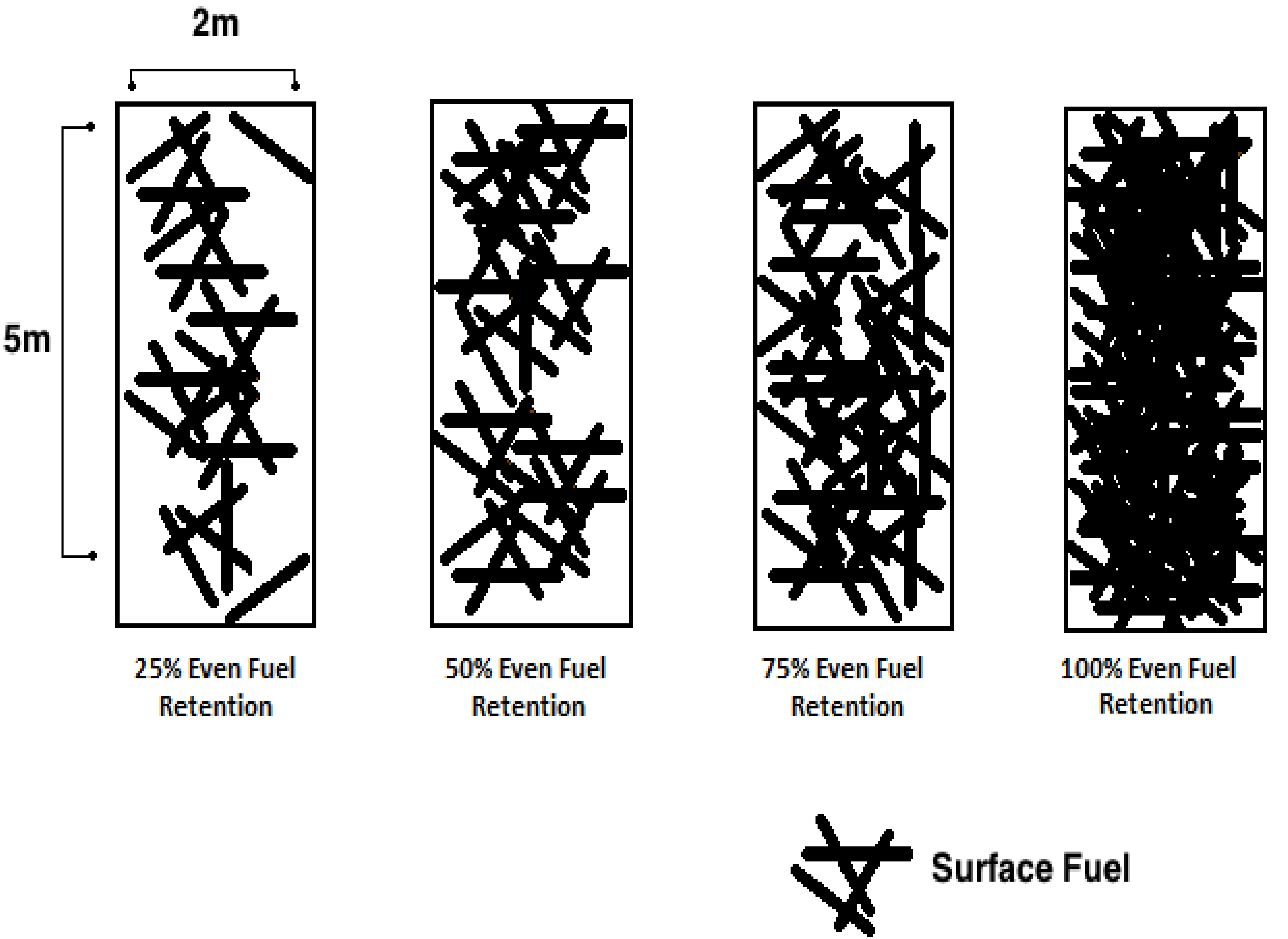

50% Patchy Retention

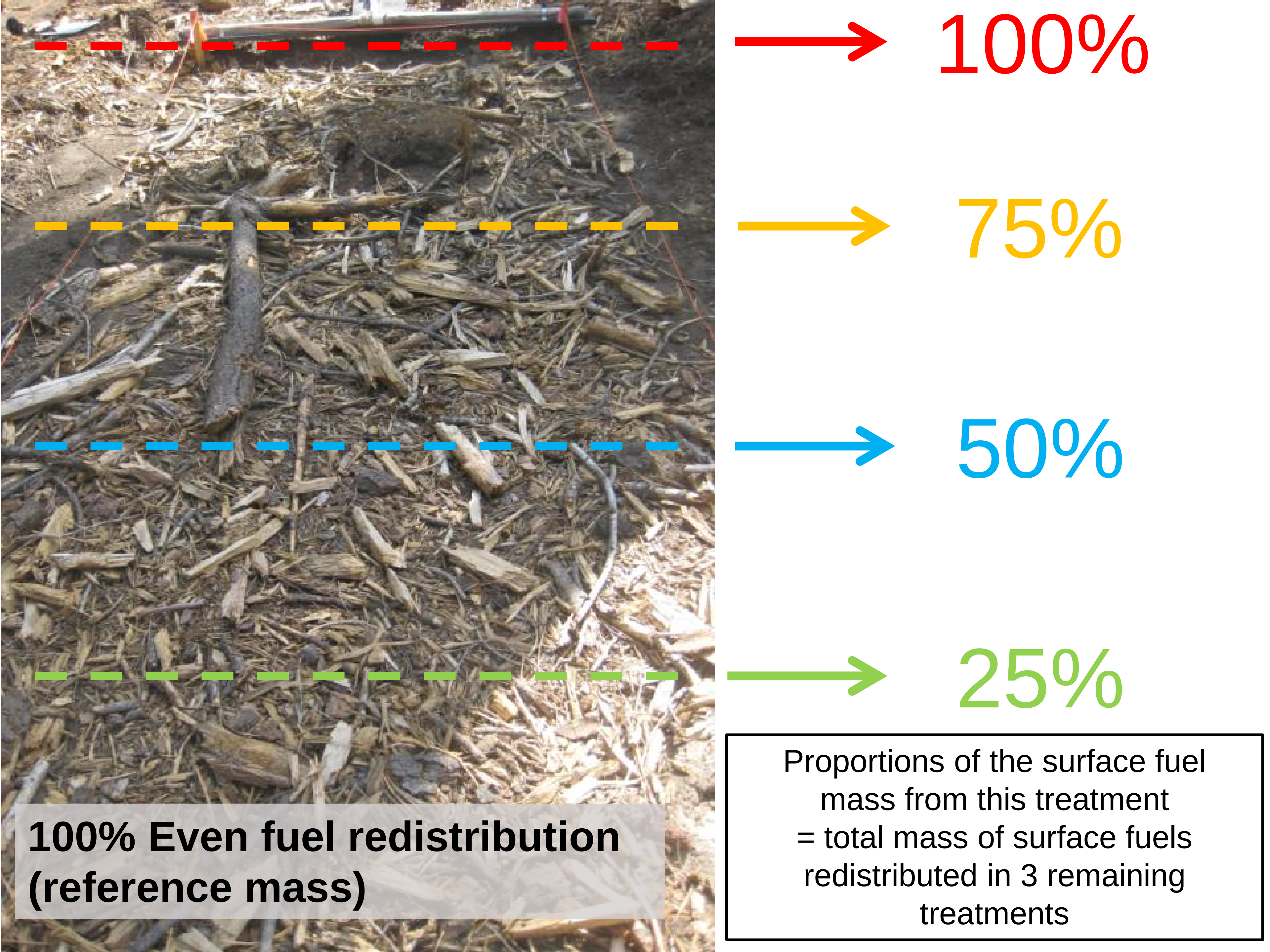

25% Patchy Retention

0% Patchy Retention (complete bare soil exposure; Control #2)

Masticated Sites: Even Fuel Retention Treatments

- Variable thickness (depth) of masticated surface fuels
- What amount of surface fuel is necessary to mitigate erosion without the aid of underlying litter and duff?
- 4 treatment types: 1 type assigned to 1 plot per site


2m
5m
25% Even Fuel Retention
50% Even Fuel Retention
75% Even Fuel Retention
100% Even Fuel Retention
Surface Fuel


100%
75%
50%
25%
100% Even fuel redistribution (reference mass)
Proportions of the surface fuel mass from this treatment = total mass of surface fuels redistributed in 3 remaining treatments


75% Even fuel
redistribution


50% Even fuel redistribution


25% Even fuel
redistribution

Prescribed Fire Sites

- Variable spatial distributions of fuel consumption and burn patchiness

- How do specific burn patterns affect measured erosion?

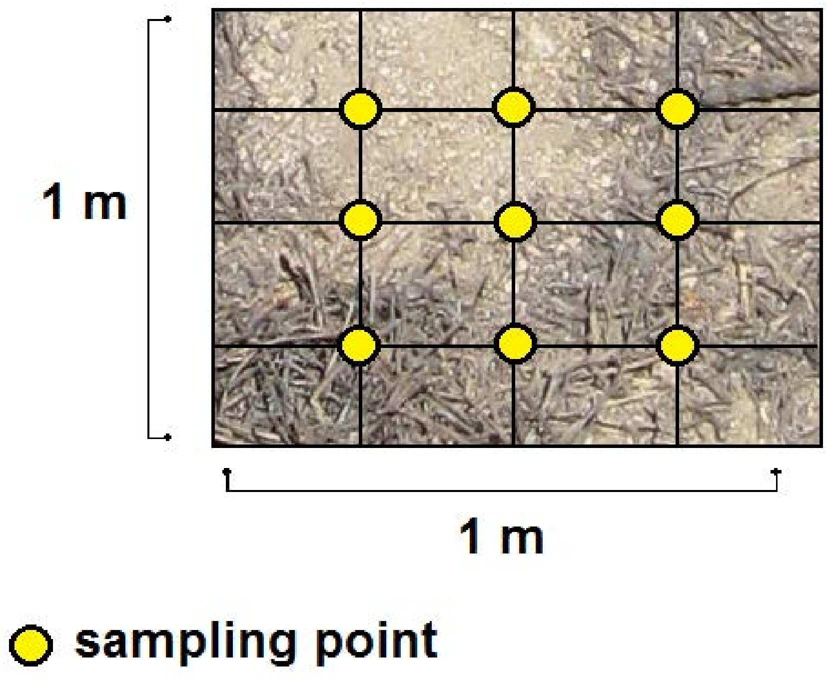
- Plots were not manipulated (no treatments)

Prescribed Fire Sites

- 8 sites, 6 plots per site (5m x 2m)
- 2 Control Plots:
  - 1 plot placed in a completely unburned area
  - 1 plot placed in an area where 100% of available fuel and duff were consumed by fire
- Depending on site-specific burn patterns, the remaining 4 plots were placed in areas where fire had consumed 0-25%, 25-50%, 50-75%, and 75-100% of surface fuels and duff

Prescribed Fire Sites: Estimating Burn Severity

- Point Quadrat Method (Levy and Madden, 1933)
- Cover type identified & depth measured at each sample point per plot
- N = 90



$$\text{Burn severity} = \frac{\sum \text{“bare”} + \sum \text{“ash”} + [0.5(\sum \text{“incomplete/ash”})]}{90}$$


0% burn severity
(Control #1)


13% burn severity


46% burn severity


90% burn severity


100% burn severity
(Control #2)
Pre-Run #1


100% burn severity
(Control #2)
Post-Run #1


100% burn severity
(Control #2)
Post-Run #2

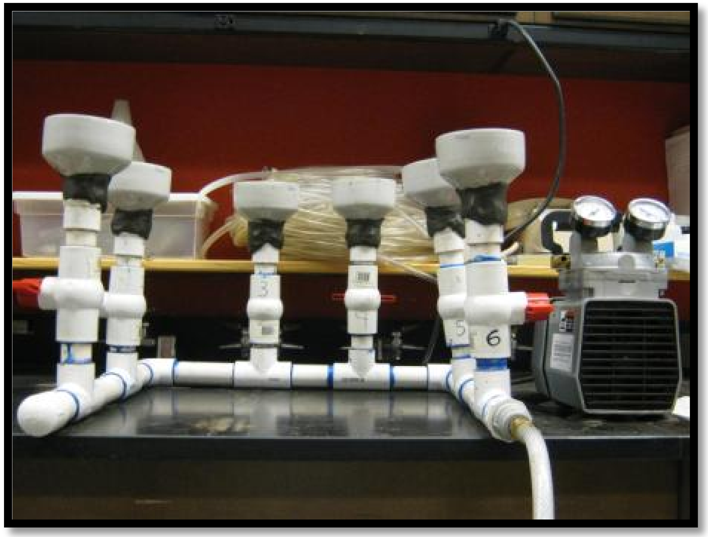

100% burn severity
(Control #2)
Post-Run #3

Soil Sampling

- 5 sampling points per site
- Estimated bulk density, hydraulic conductivity, and volumetric water content prior to runoff simulation

Processing runoff samples

- Vacuum filtration
- TSS (mg/L); total sediment yield (kg)
- Particle-size distribution analysis on samples collected at prescribed fire sites



Statistical Analysis: Masticated Sites

- 3-factor ANOVA (Zar, 1999)

- General Linear Model utilized to determine if site, slope, and treatment significantly influenced ($\propto < 0.05$) sediment yield

- Sequential Sum of Squares: removed the effects of site and slope to test for significant differences in sediment yield due to treatment

- A post-hoc Tukey test examined significant differences ($\propto < 0.05$) between masticated treatments (Tukey, Kramer HSD)

Statistical Analysis: Prescribed Fire Sites

- 3-factor ANOVA

- General Linear Model utilized to determine if site, slope, and percentage of plot area burned significantly influenced ($\propto < 0.05$) sediment yield

- Adjusted Sum of Squares tested the amount of variation explained by percentage of plot area burned when site and slope were treated as co-variates

- Tobit piecewise regression utilized to determine erosion thresholds – accounts for unequal variances across the gradient of area burned.

Results: Masticated Sites

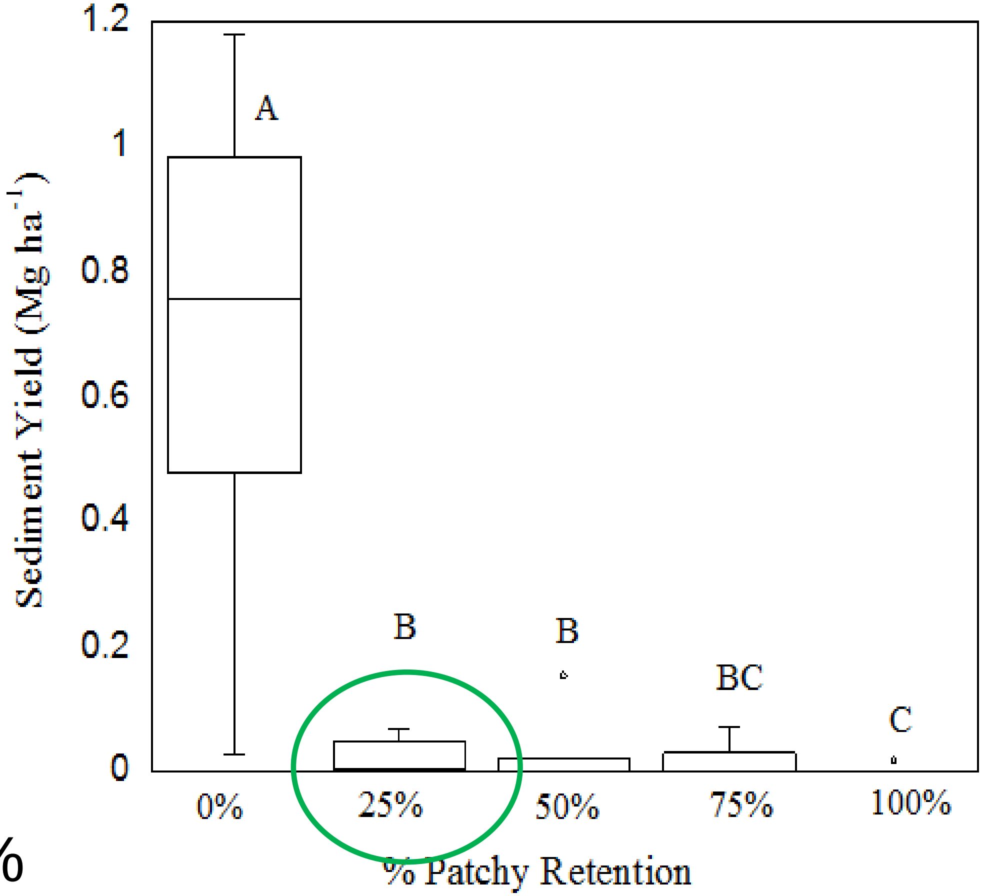
- Sediment yields were greatest in treatments characterized by complete soil exposure and lowest in treatments characterized by complete surface fuel retention
- Sites with patchy retention treatments had significantly lower sediment yields than those with even retention treatments (Tukey test, 95% confidence) – highlights importance of duff layers to mitigate erosion
- “Treatment” was a significant predictor of sediment yield ($P < 0.001$)
- Significant differences in sediment yield among sites ($P = 0.011$)
- Slope (range = 12-33%) was not a significant predictor of sediment yield ($P = 0.791$)

Results: Masticated Sites: Patchy Retention Treatments

- Bare soil exposure resulted in highest avg. sediment yields

- Similar sediment yields in 25% and 50% treatments but both were 97% lower relative to 0% treatments

- No significant difference between sediment yields measured in 75% and 100% treatments

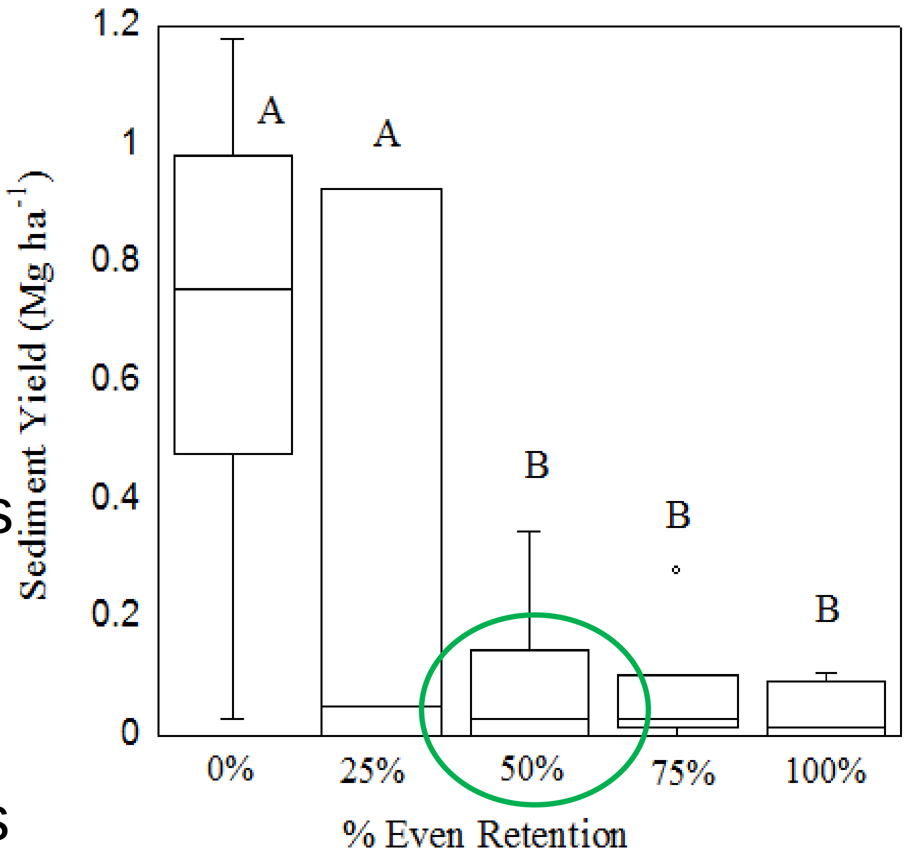


Results: Masticated Sites: Even Retention Treatments

- Avg. sediment yield in 25% treatments was 44% less than 0% treatments.

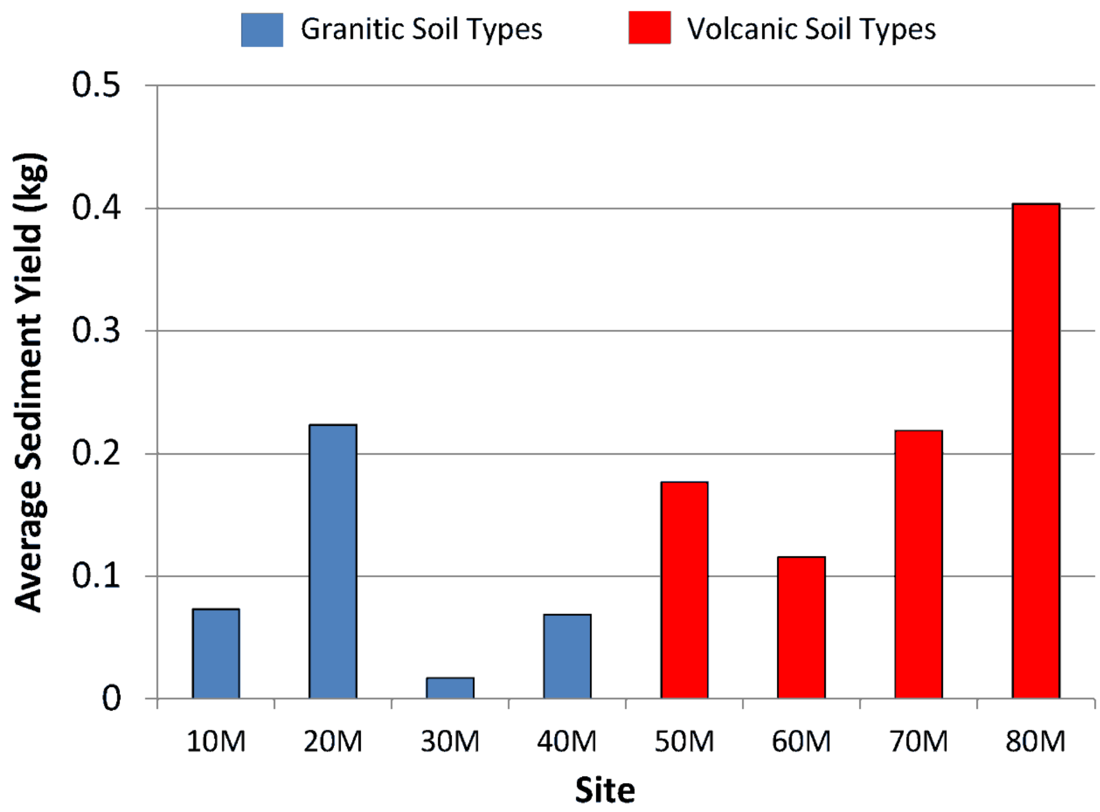
- 83% reduction in avg. yield from 25% to 50% treatments

- 50%, 75%, and 100% treatments contained means that were not significantly different.



Results: Masticated Sites, Soil types

- Bulk Density: 0.81 – 1.38 g/cm^3 (avg. = 1.2)
- Higher sediment yields on average in volcanic soil types across all treatments
- Volcanic soils: older, weathered, more prone to erosion

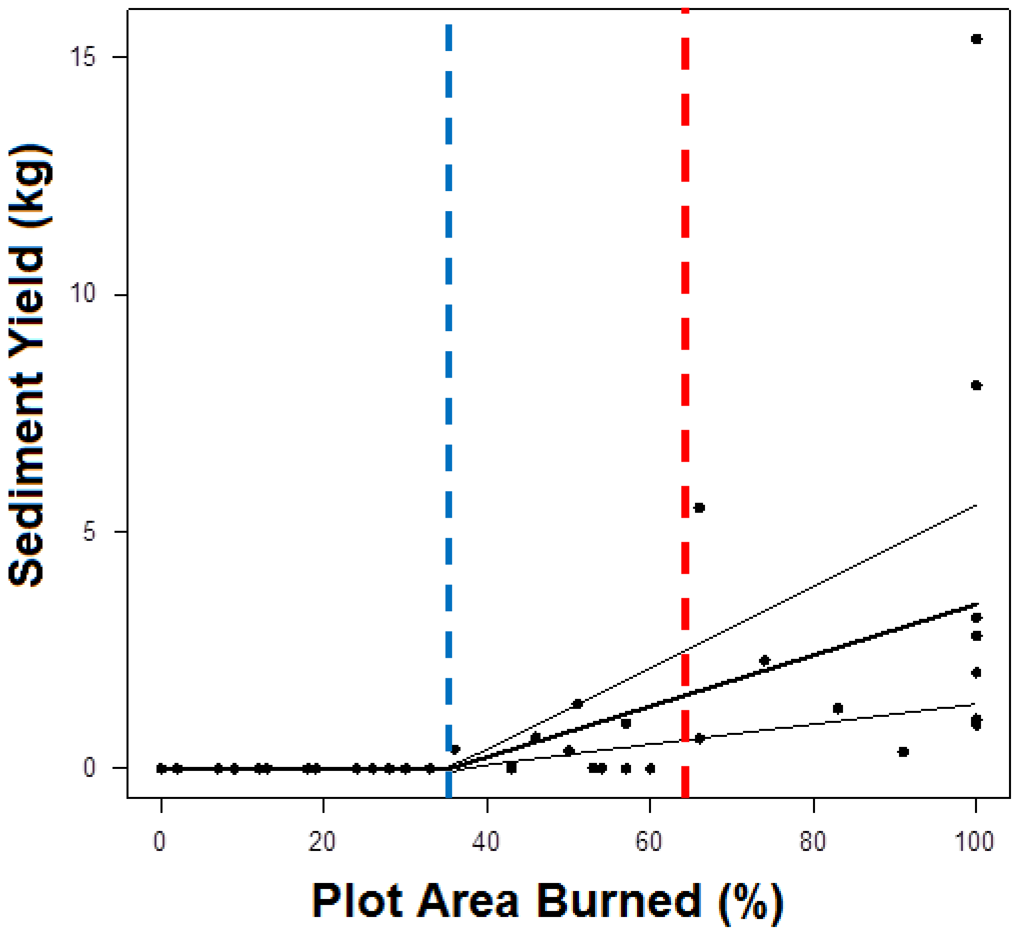


Results: Prescribed Fire Sites

- Sediment yield increased with increasing burn severity
- Strong increases in sediment yield observed at burn severity > 35%
- Highest sediment yield occurring in the 66% to 100% range
- Plot area burned was a significant predictor of sediment yield ($P < 0.001$)
- No significant differences in sediment yield among sites ($P = 0.086$)
- Slope (range = 20% - 40%) was not a significant predictor of sediment yield ($P = 0.693$)

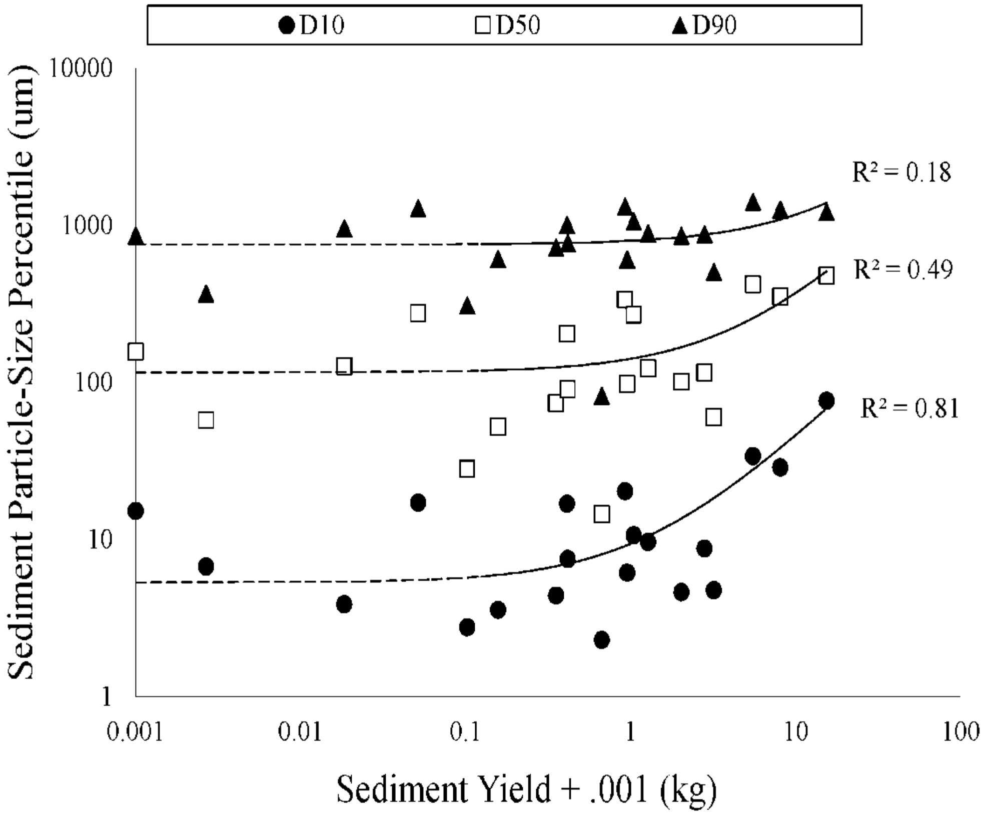
Results: Prescribed Fire Sites

- Minimal to no sediment yields at < 35% burn severity
- Variable sediment yields at 35% - 66% burn severity
- High sediment yields at >65% burn severity



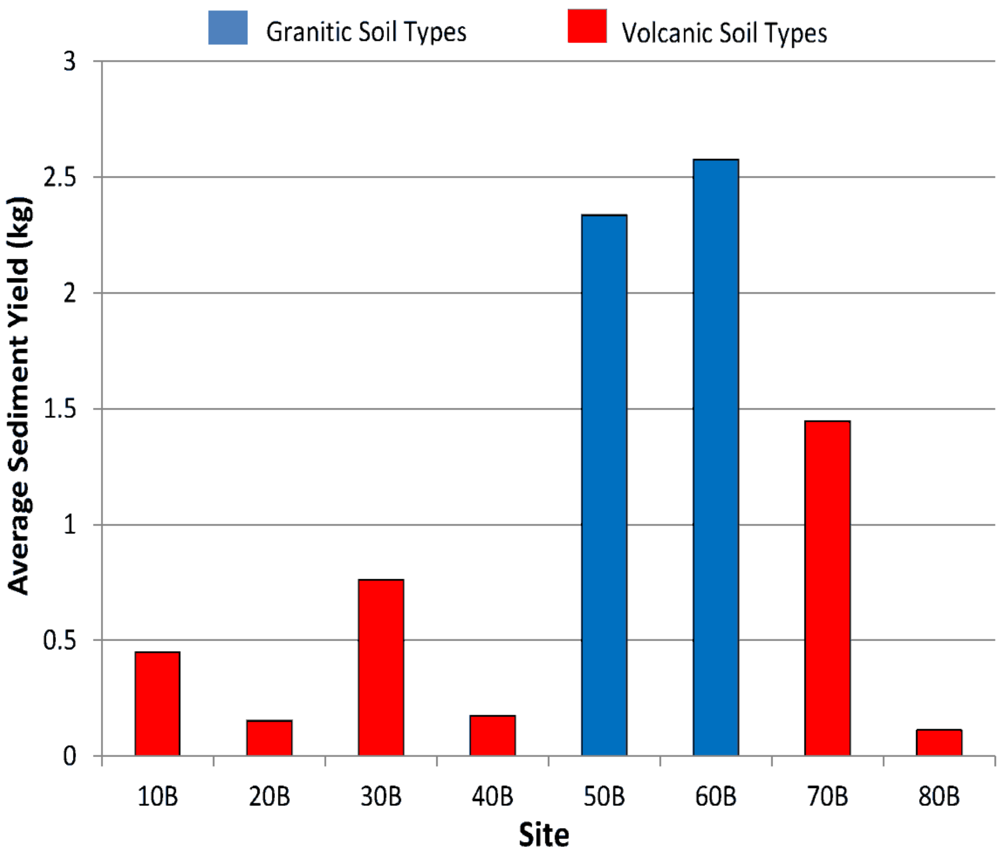
Results: Prescribed Fire Sites, Sediment Yield vs. Particle-size distribution

- Strongest positive relationship with finest particle-size classes (D_{10})
- Strongest negative relationship with coarsest particle-size classes (D_{90})
- Particles sizes were greatest in plots where burn severity was highest



Results: Prescribed Fire Sites – Soil Types

- Bulk Density: 0.84 - 1.26 g/cm^3 (avg. = 1.03)
- Two sites (50B, 60B) with decomposed granitic soil types; produced highest sediment yields
- DG soils: highly weathered, very prone to erosion

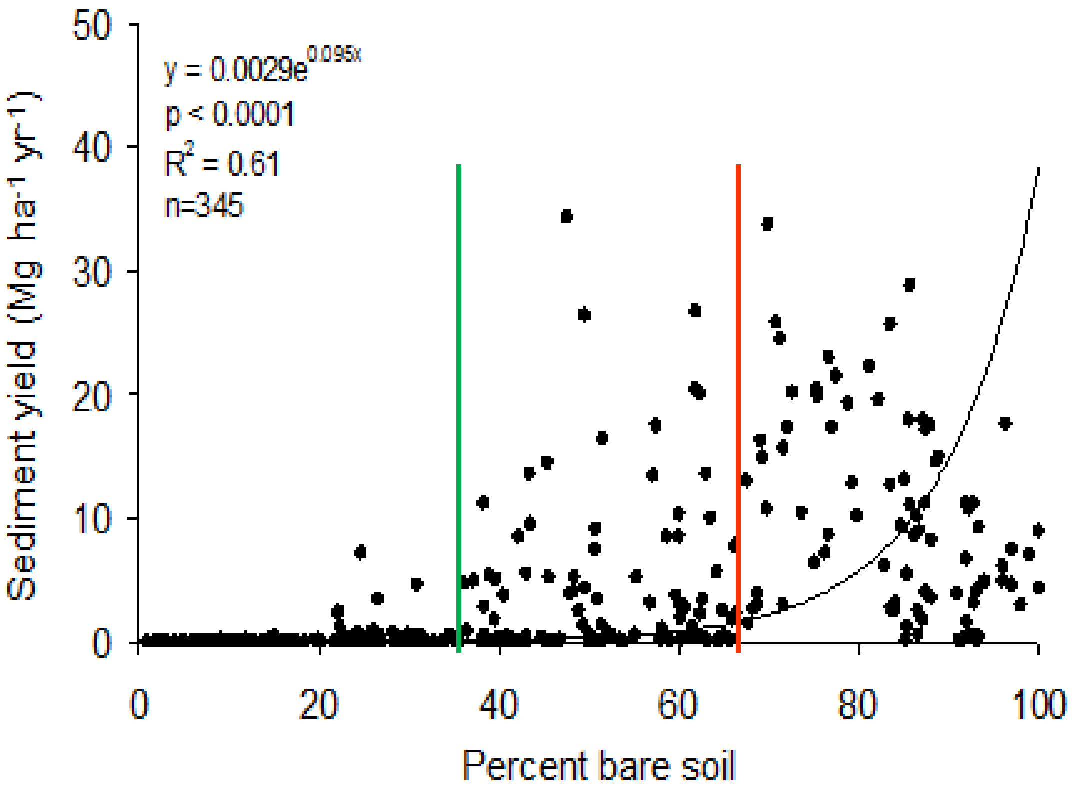


Complimentary Research

- Hatchett et al. (2006) (Plot scale)
  - Sediment yields greatest on bare mineral soils following rainfall simulation on masticated plots
  - Erosion and runoff rates in Lake Tahoe Basin are largely dependent on granitic or volcanic soil types
- Grismer et al. (2008) (Plot scale)
  - 3x higher sediment concentration and yield measured on bare volcanic soil types than on bare granitics during rainfall simulation in Tahoe Basin

Complimentary Research

- Larsen et al. (2009)
- Post-fire sediment yields primarily due to loss of surface cover
- Indices at 35% and 65%
- Ash temporarily prevents soil sealing and reduces post-fire runoff



Larsen et al., 2009. *SSSAJ*

Complimentary Research

- Johansen et al. (2001) (Plot scale)
  - When percent bare soils exceeded a threshold of ~60-70%, sharp increases in sediment yield occurred in burned plots within a ponderosa pine forest in New Mexico
- Campbell et al. (1978) (Watershed scale)
  - Little sediment yield from unburned and moderately burned ponderosa pine watersheds having 8% and 61% bare soil exposure, respectively, but high sediment yield from a severely burned watershed with 77% bare soil

How can masticated treatments and prescribed fires

meet wildland fuel reduction objectives that reduce the potential for catastrophic fires

while simultaneously

reducing hillslope runoff into Lake Tahoe by mitigating erosion?

Masticated Treatments	By minimally distributing masticated surface fuel and limiting patches of exposed soil
Prescribed Fires	By generating heterogeneous, rather than homogenous, patches of bare soil exposure

Mastication Treatments

Provide minimal groundcover, limit large areas of soil exposure

Reducing soil exposure from 100% to 75% per 10 m2
=
97% reduction of erosion

Duff layers are important, maintain a minimal amount of undisturbed ground cover

Prescribed Fire Treatments

Limit overall burn severity to ~ 65% in order to substantially reduce erosion potential

Limit prolonged exposures to fire that result in large patches of exposed soil, linked together through areas of thin, disturbed groundcover.

Attempt to expose only select areas of the landscape to moderate fire intensity while leaving surface fuels intact in other areas that will trap sediment and increase infiltration

Continued research

Replicate treatments within sites

Include a finer range of patchy gradations (e.g. 20%, 30%, 40%)

Randomly place surface fuel and duff patches rather than just at the bottom of the plot

Increase plot size in order to examine results at larger scales

Refine levels of retained fuels appropriate for different forest floor conditions and treatments that achieve target fuel levels

Continued research

Further explore the role of burn severity on particle-size distribution

Expand statistical analysis – take a closer look at the significance of soils data

Explore the role of ash

Examine changes in rill density and volume in response to different treatments

Expand evaluation of WEPP (and GeoWEPP) efficacy

Thank You!