Hillslope Runoff and Sediment Production After Wildfire and Post-Fire Forest Management on the Boggs Mountain Demonstration State Forest, Lake County

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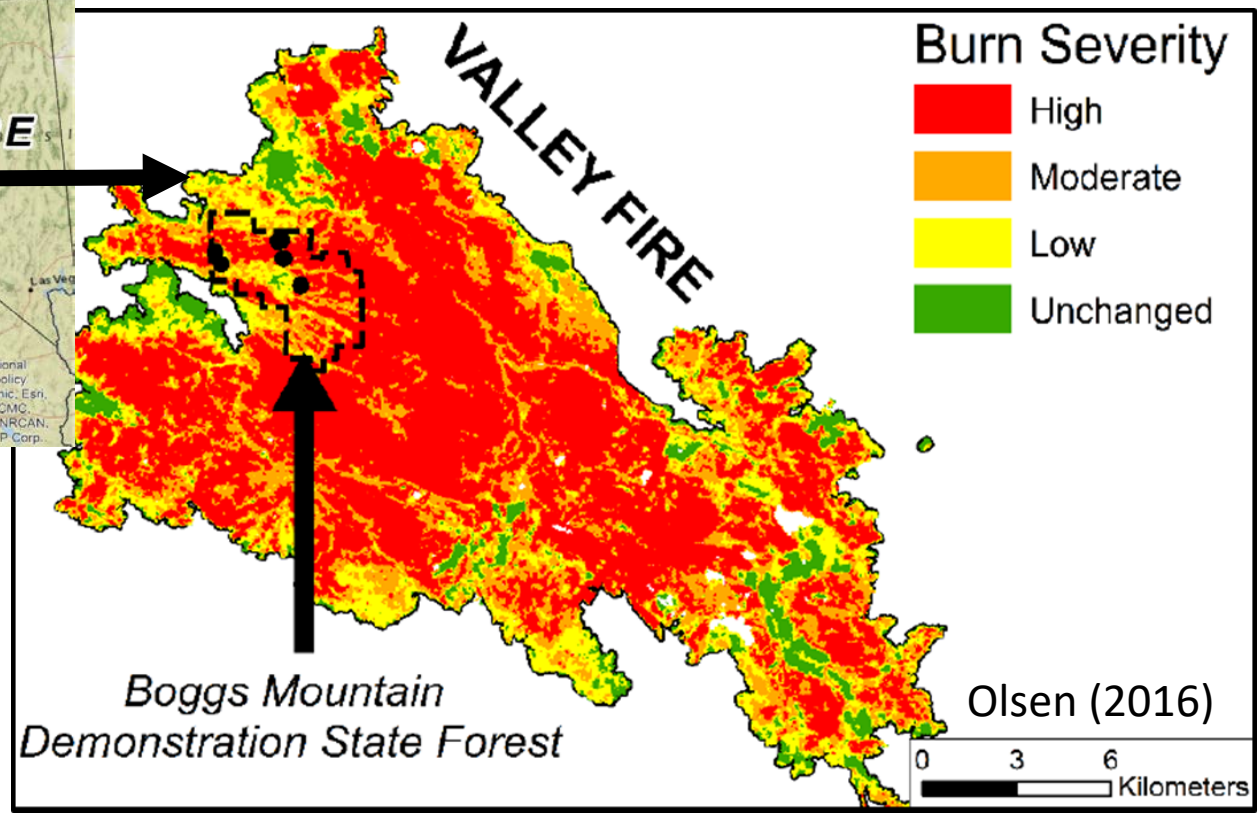
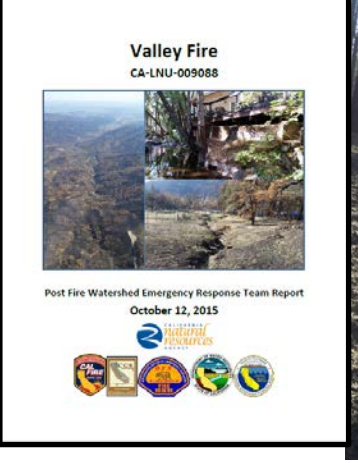
2015 Valley Fire, Lake County

- September 2015
- 76,067 acres burned
- 4 fatalities
- 1280 homes destroyed

- 67% of Valley Fire burned at moderate to high soil burn severity
- 98% of Boggs Mountain Demonstration State Forest burned





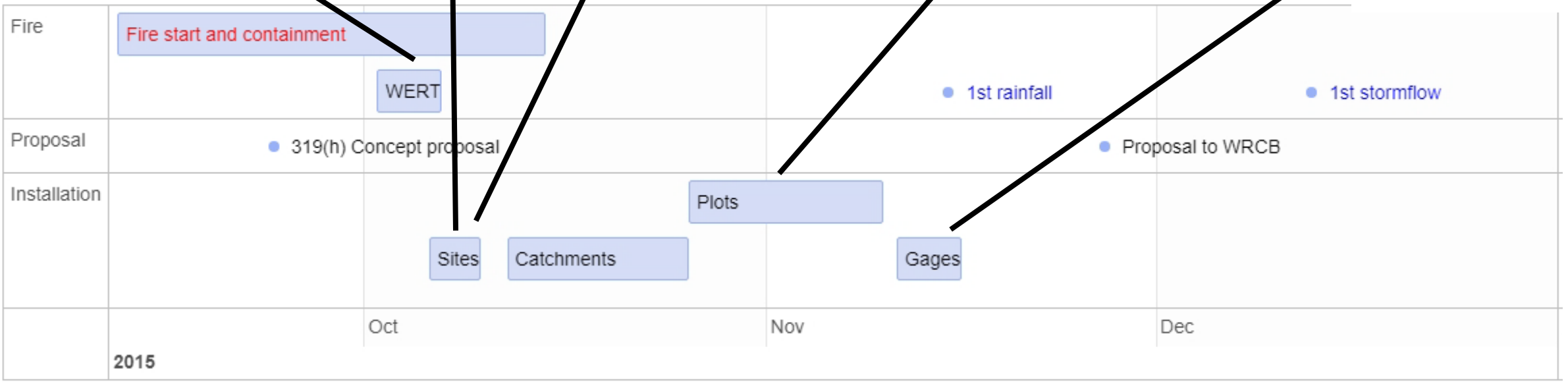
WERT Assessment, Oct 2015

Identifying catchments for runoff and sediment yield study, Oct 2015

Reconnaissance of salvage logging experimental blocks, Oct 2015

Establishing plots in the experimental blocks, Nov 2015

Installing e-tape for measuring runoff, Nov 2015



Initial Study Objectives

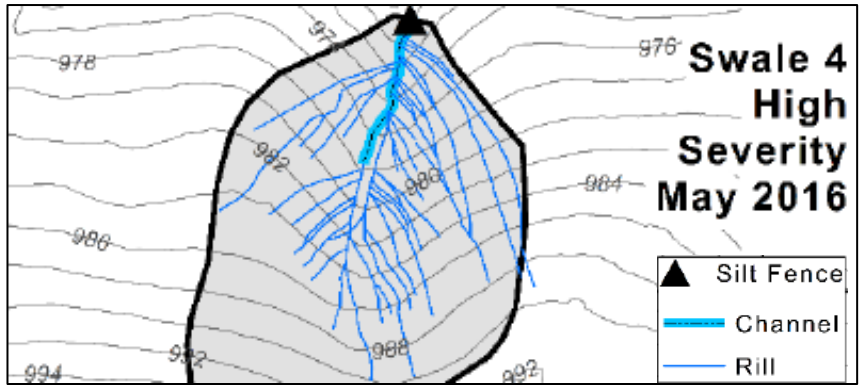
Drew Coe and Dr. Lee MacDonald (CSU) at Catchment 4

1. To quantify the effects of different soil burn severities on catchment scale runoff rates, sediment delivery, changes in channel and rill networks, and organic matter/soil carbon transport
2. Quantify the effects of post-fire logging and site preparation on runoff, erosion, soil carbon, and vegetation
3. Development and demonstration of alternative BMPs for post-fire salvage operations

Catchment Study

- Quantify catchment scale runoff and sediment yield across a gradient of soil burn severity
- 0.4 to 1.6 acre zero to first order catchments
- 1-minute runoff data
- Mapped rills in 2016

Rill mapping of catchment 4



(Olsen, 2016)

Swale Burn Severity

Swale 1: Low

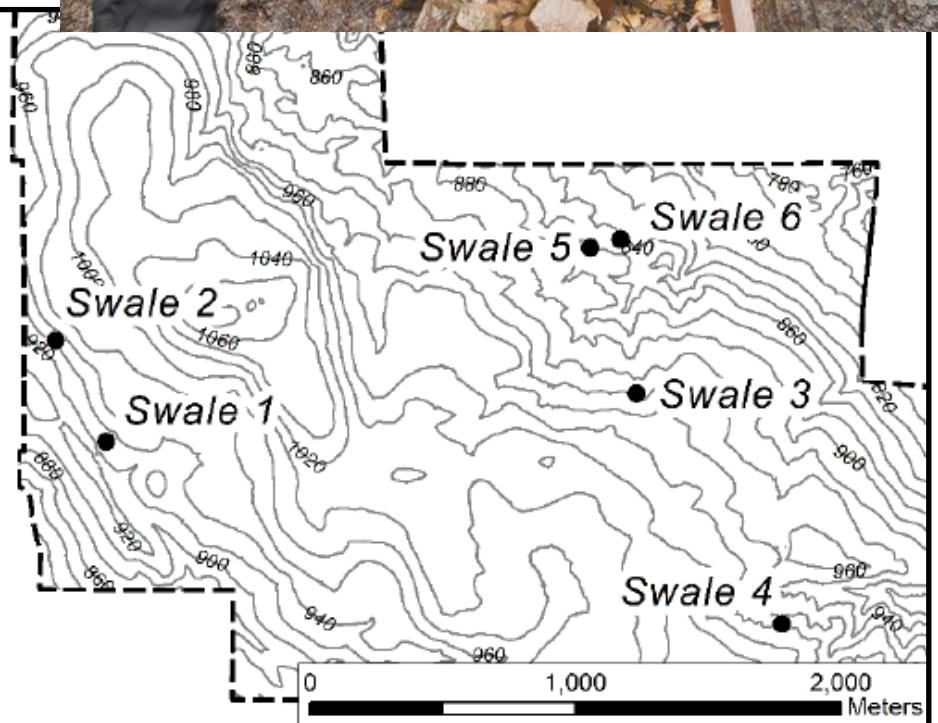
Swale 2: Low

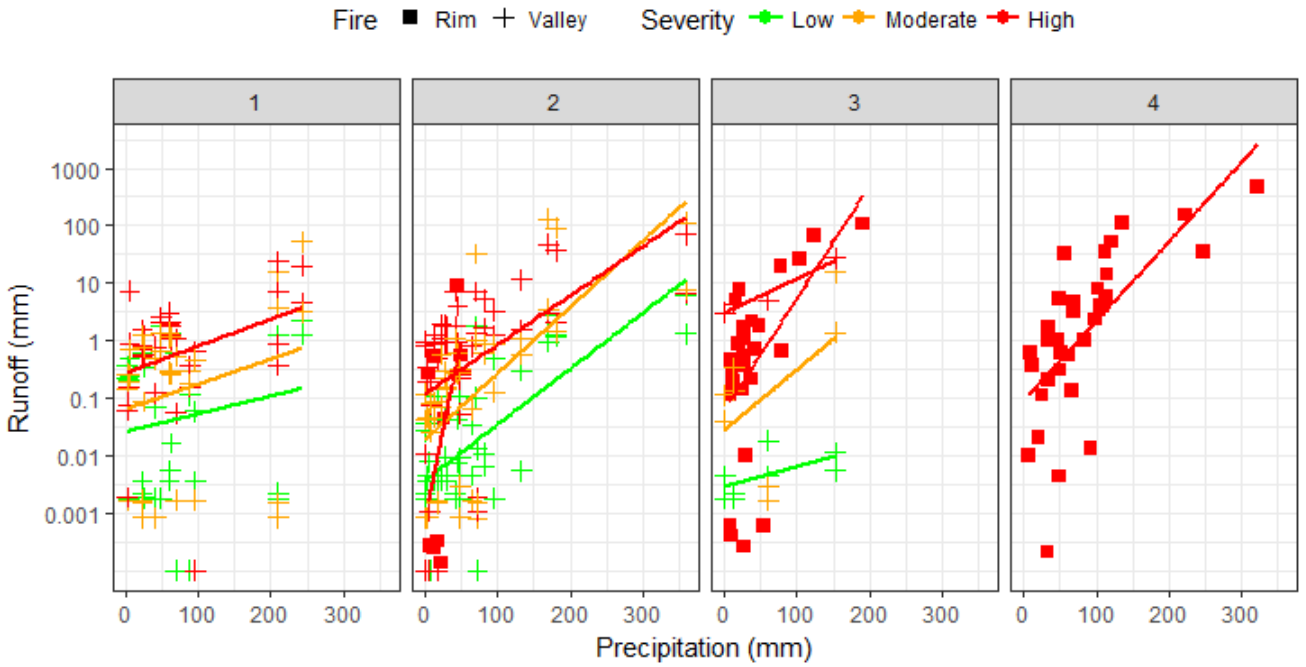
Swale 3: Moderate

Swale 4: High

Swale 5: High

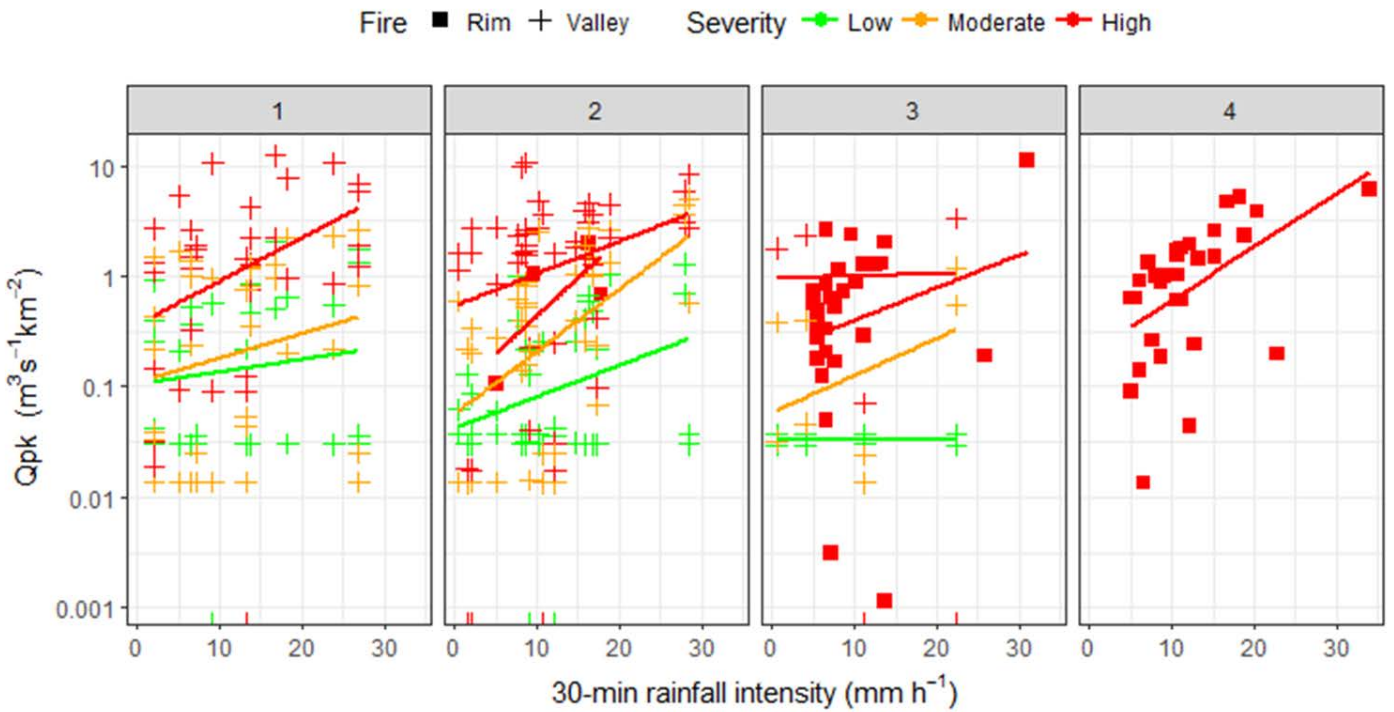
Swale 6: Moderate



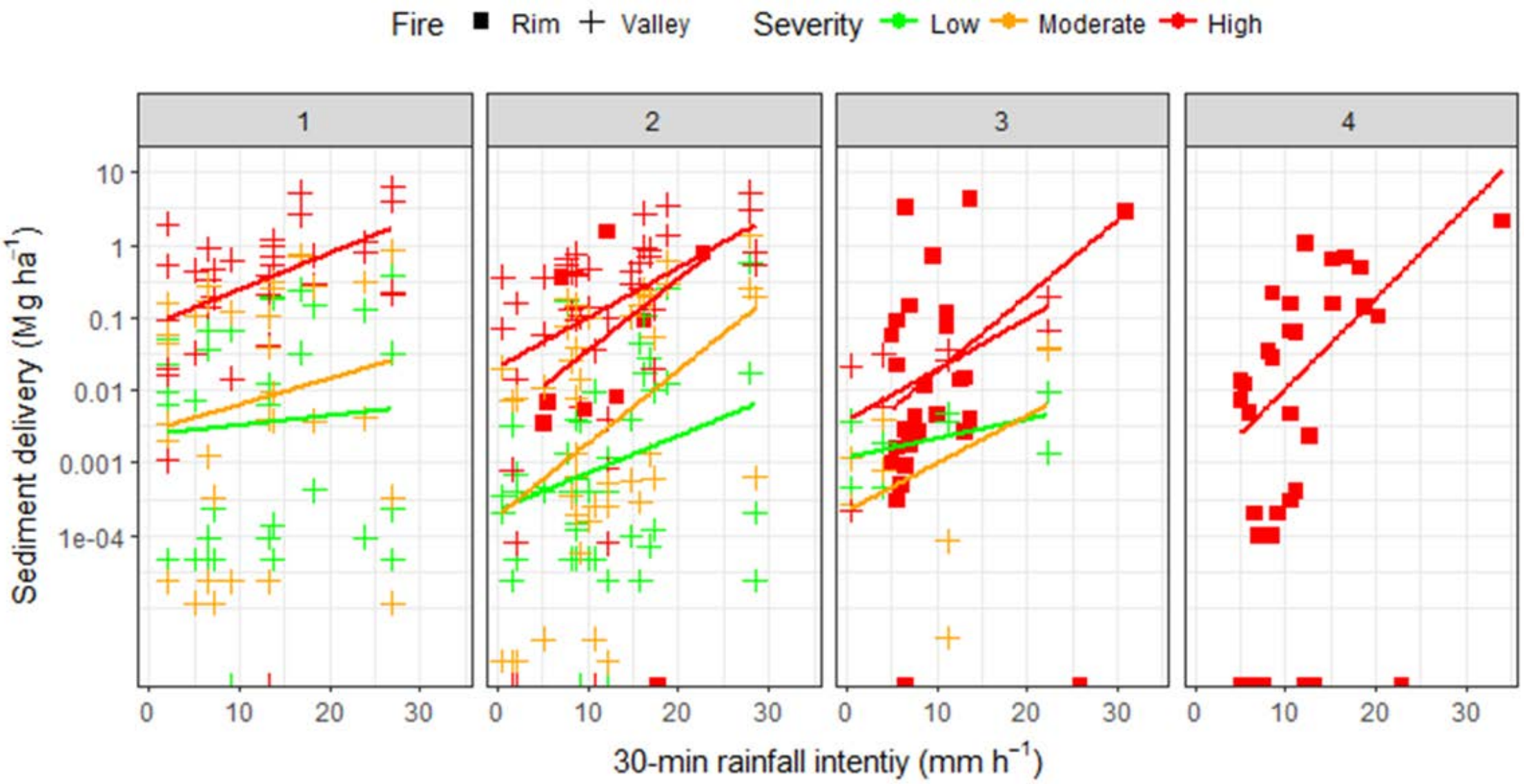


Runoff Production vs Precipitation By Burn Severity and Wet Season

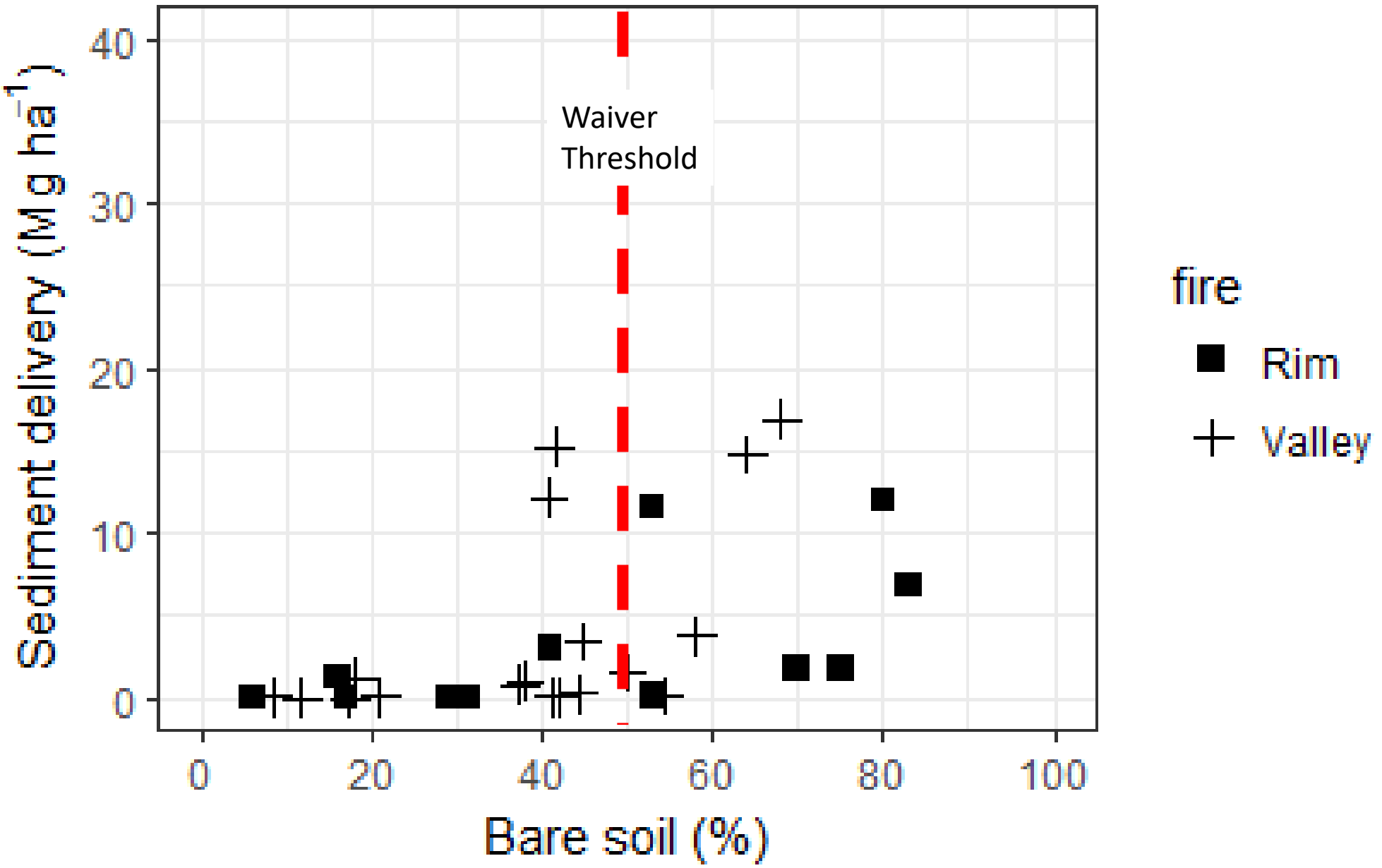
Unit Peak Flow vs 30-minute Rainfall Intensity By Burn Severity and Wet Season

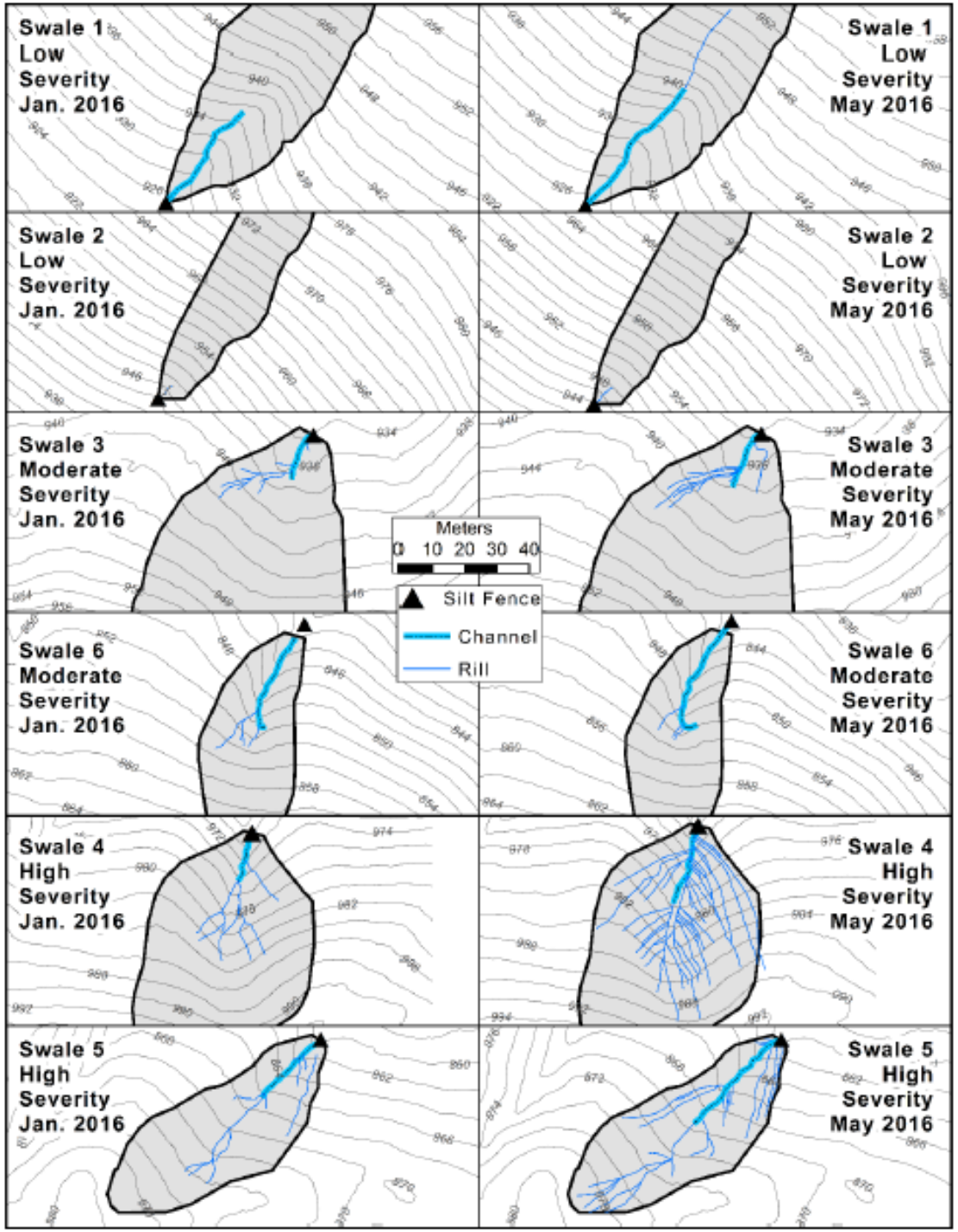


Sediment Delivery vs. Peak 30-minute Rainfall Intensity



Ground Cover Matters!



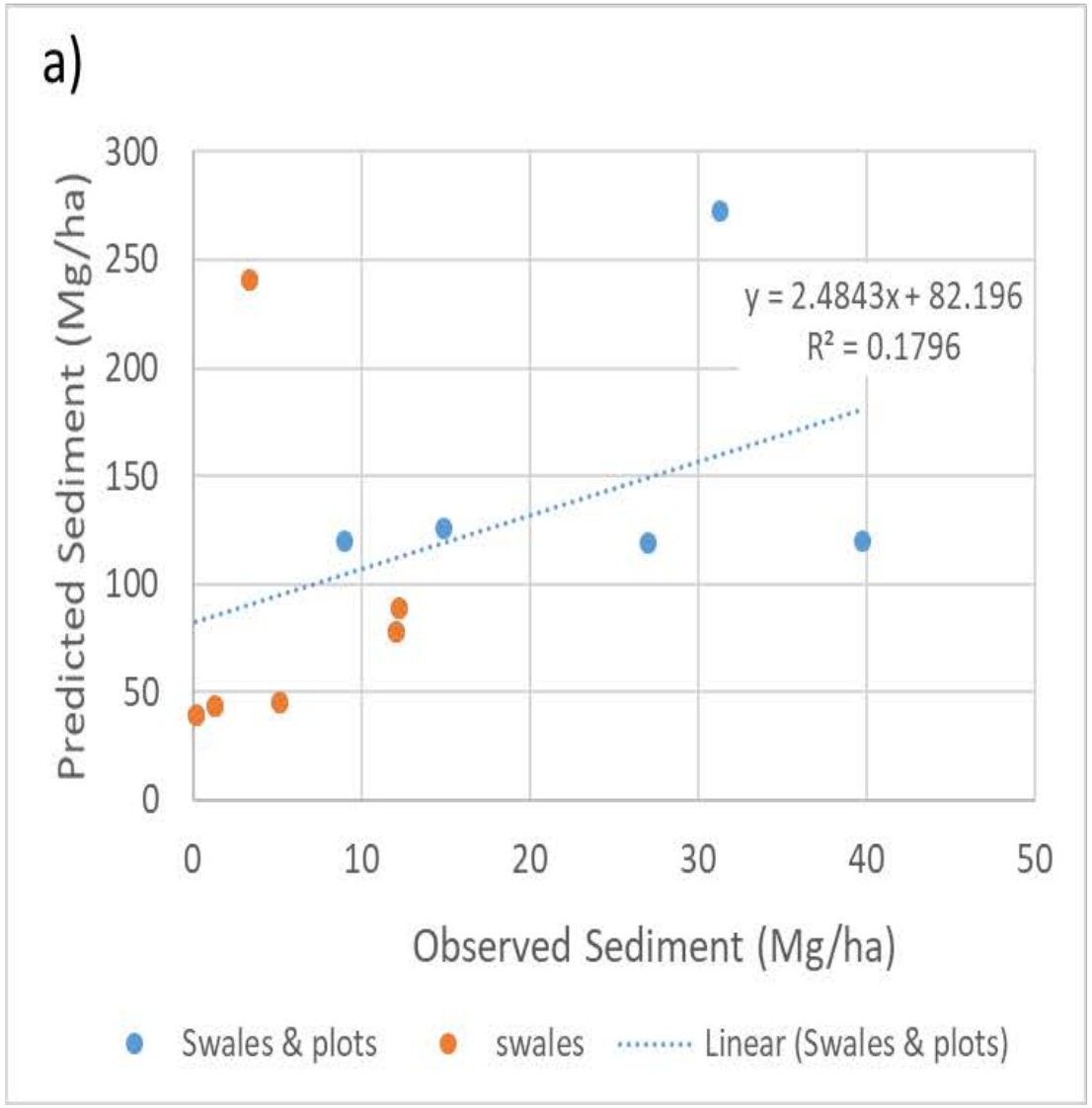


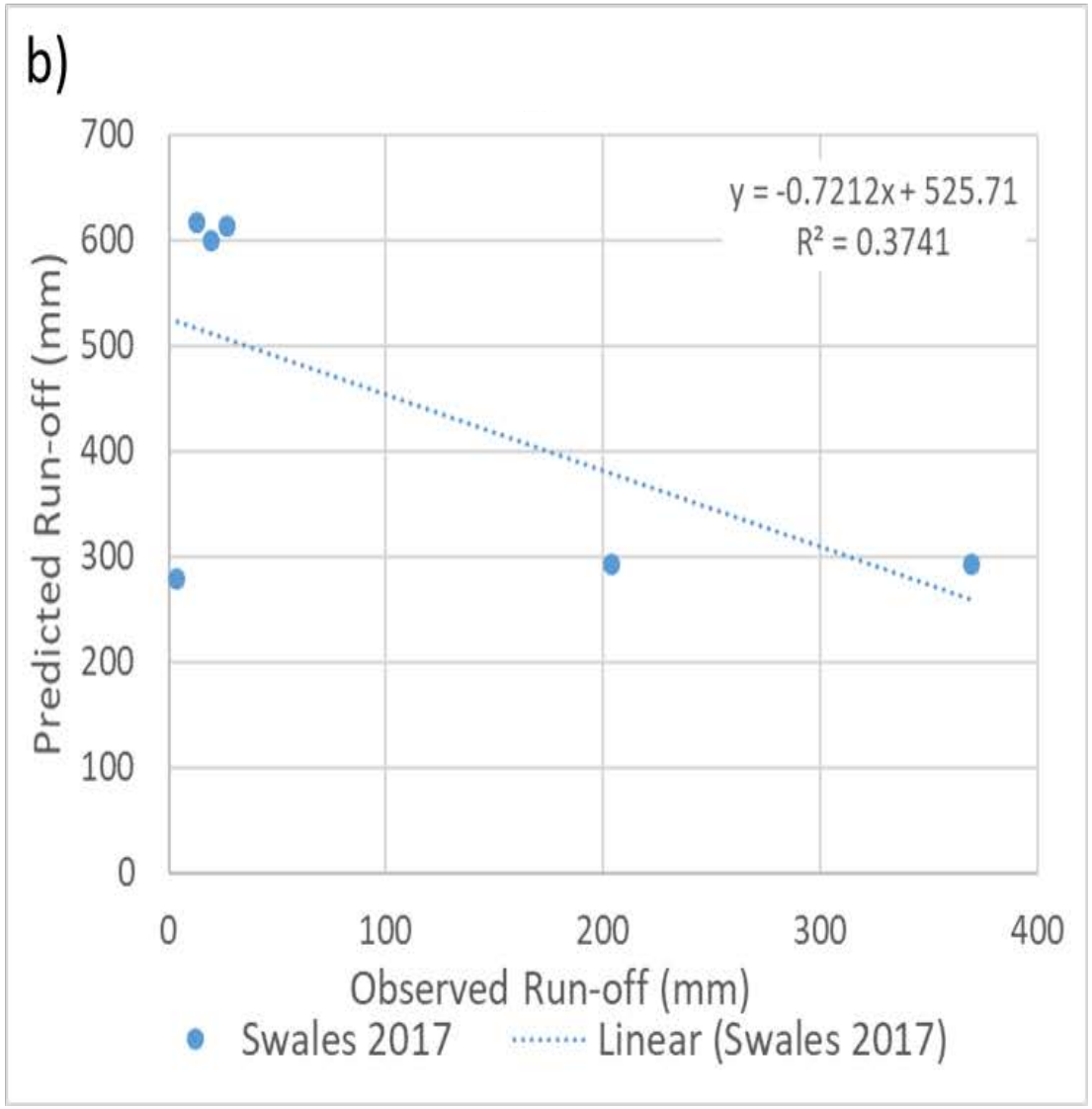
Cover controls rilling, and rilling controls sediment delivery

Variable	P value	Slope coefficient	r^2	Residual standard error
Rill Density (cm m^{-2}) (May)				
Bare ground (%)	0.02	0.57	0.8	5.2
Litter (%)	0.02	-0.63	0.76	5.6
Wood (%)	0.4	-4.1	0.18	10.4
Rock (%)	0.5	-0.9	0.12	10.8
Mean slope (%)	0.84	-0.22	0.01	11.5
Number of rills	0.003	0.66	0.91	3.41
Channel density (cm m^{-2})	0.70	2.3	0.04	11.4
Sediment Yield (Mg ha^{-1})				
Bare Ground (%)	0.003	0.41	0.92	2.2
Litter (%)	0.006	-0.45	0.88	2.66
Wood (%)	0.56	-1.94	0.09	7.23
Rock (%)	0.43	-0.67	0.16	6.95
Mean slope (%)	0.96	-0.04	0	7.59
Channel density (cm m^{-2})	0.61	2.0	0.07	7.31
Number of rills	0.008	0.42	0.85	2.90
Rill length (m)	0.01	0.02	0.84	3.07
Rill density (cm m^{-2})	0.0004	0.65	0.97	1.38

(Olsen, 2016)

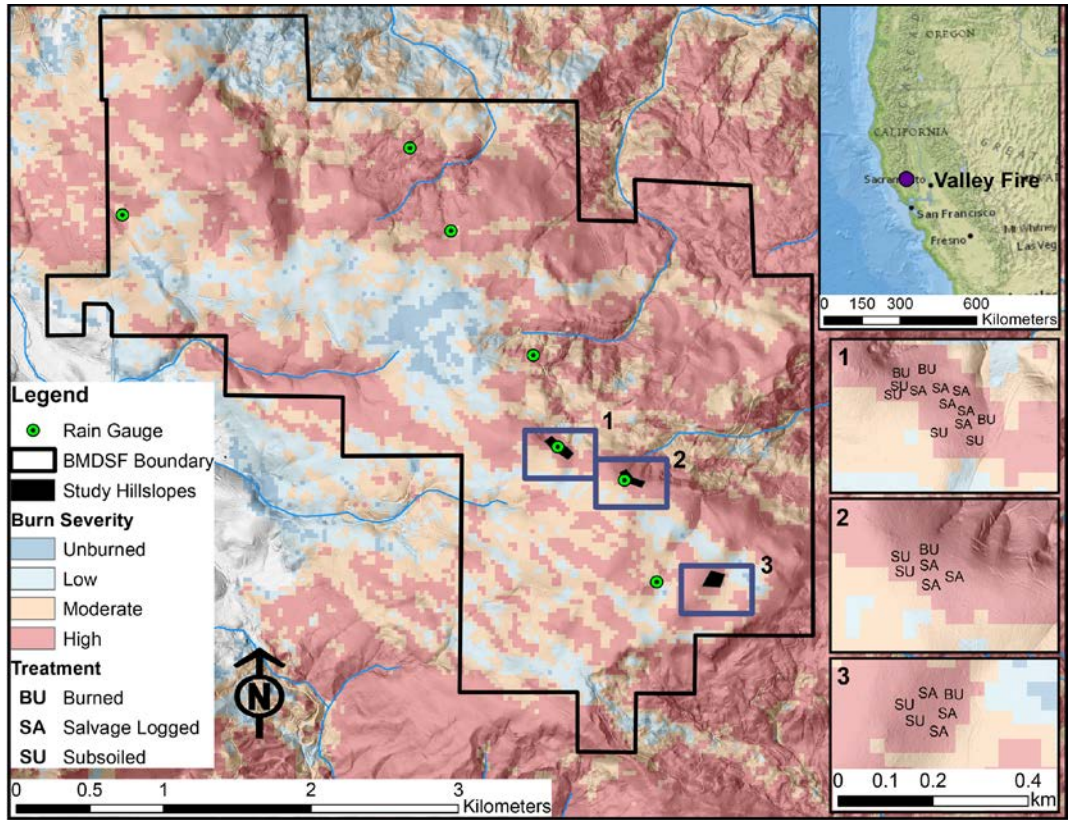
How Well do Models Do? - GeoWEPP Validation





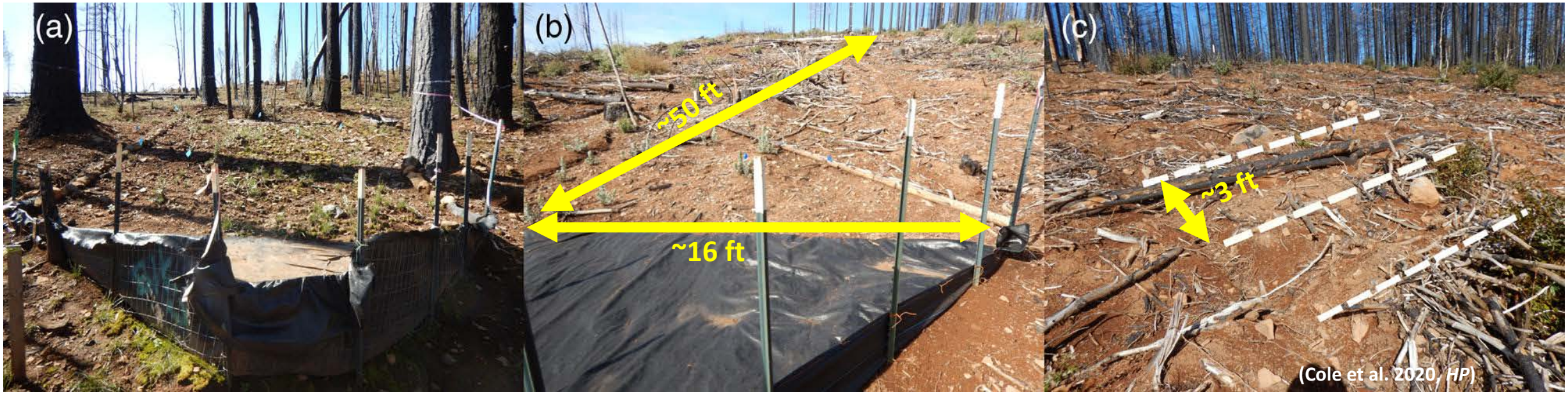
Hillslope plot study

- Compare sediment yields from plots with post-fire logging and subsoiling
- Management timeline
  - Nov 2015: Control plots installed within logging units
  - Jun-Sep 2016: Logging
    - Mostly hand-felling
    - Ground-based yarding
  - Sep-Oct 2016: Subsoiling completed
  - Sep 2017-Jun 2018: Herbicide treatments
  - Apr 2018: Planting

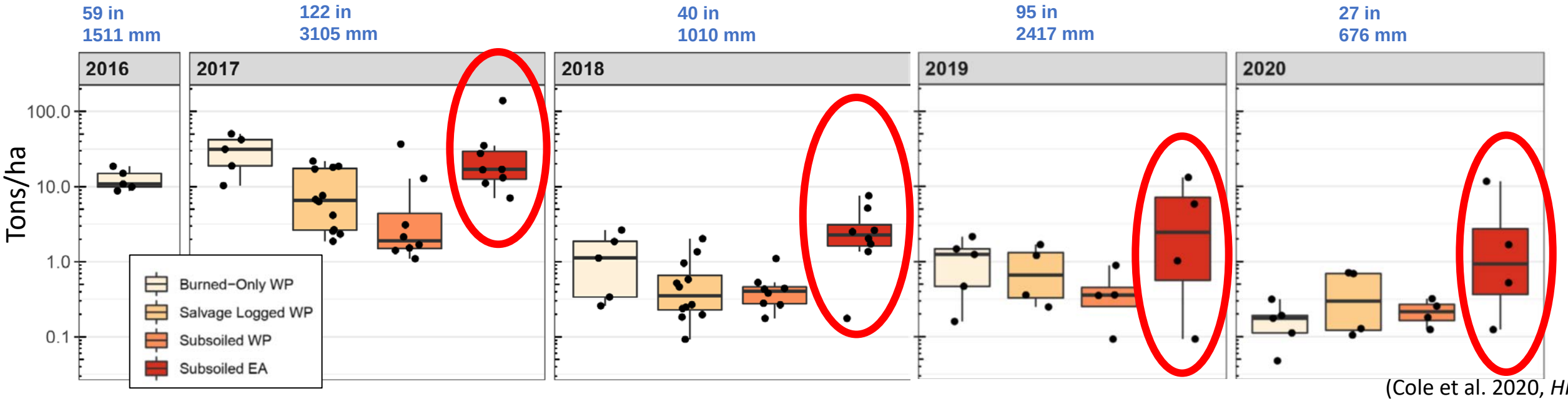


(Cole et al. 2020, *HP*)

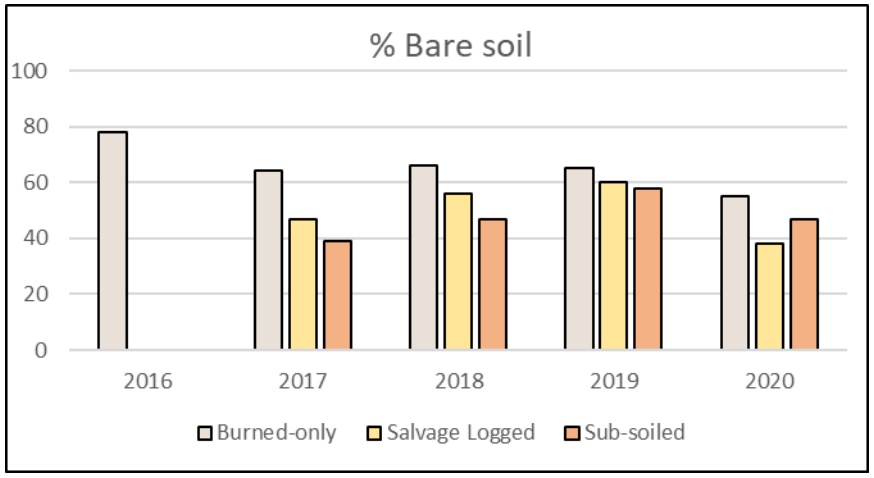
Hillslope plot study-methods

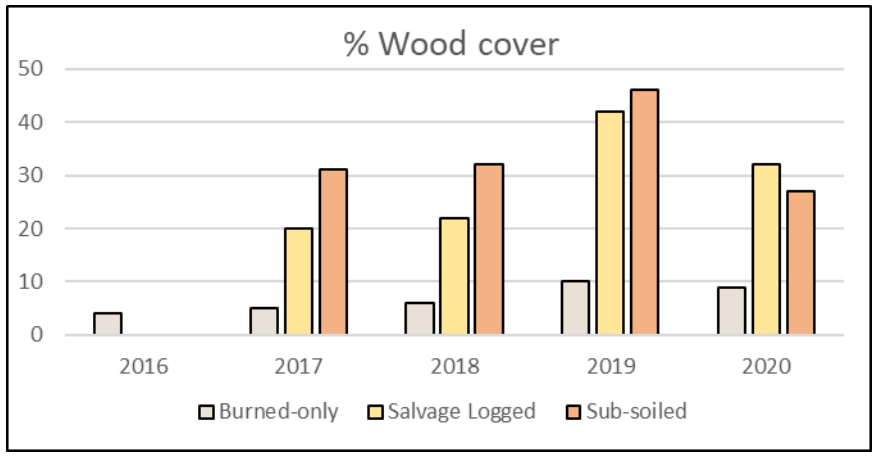


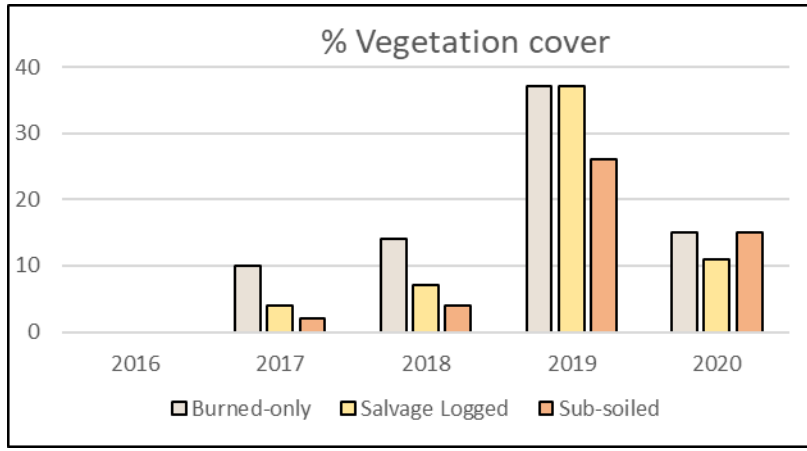
Hillslope plot study-results



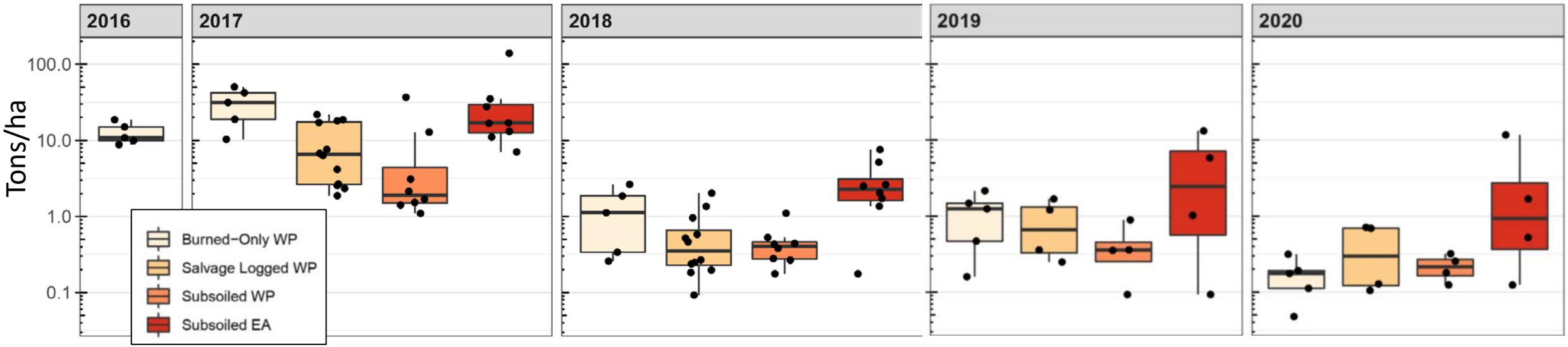
(Cole et al. 2020, *HP*)







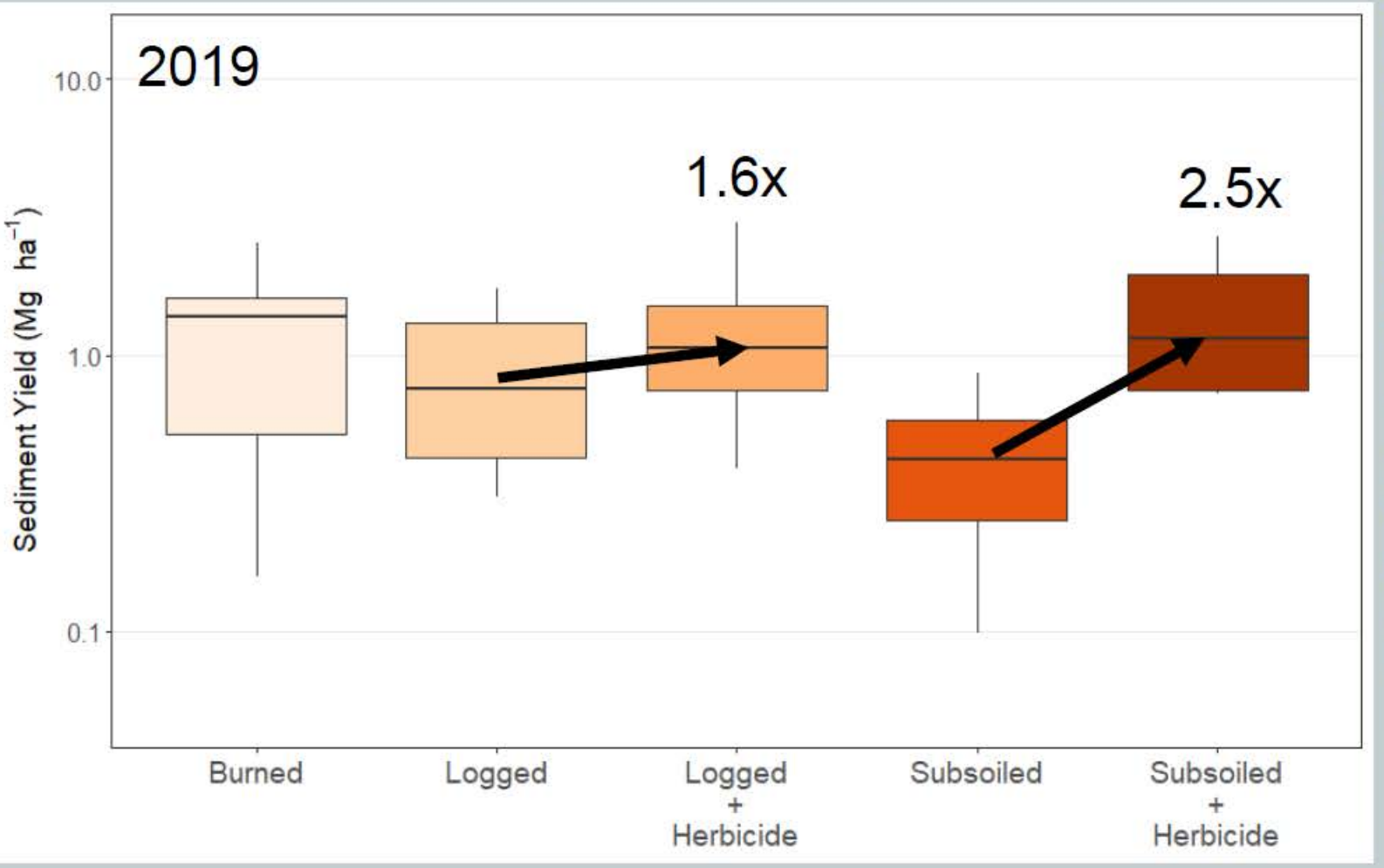
Hillslope plot study-discussion

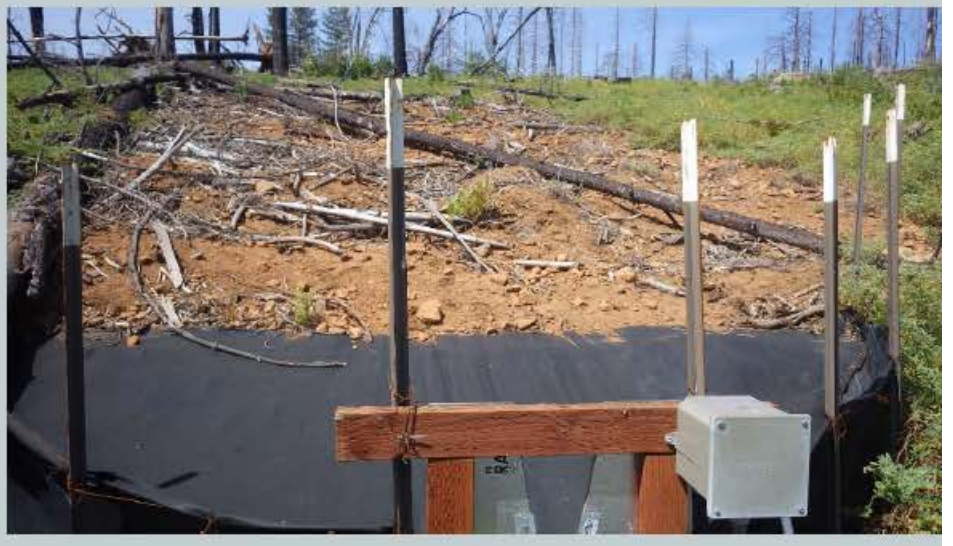


Burned-only Salvage logged Subsoiled

(Cole et al. 2020, *HP*)

Sediment Yields – Herbicide





Higher sediment yields from plots affected by herbicide

Rainfall simulation studies

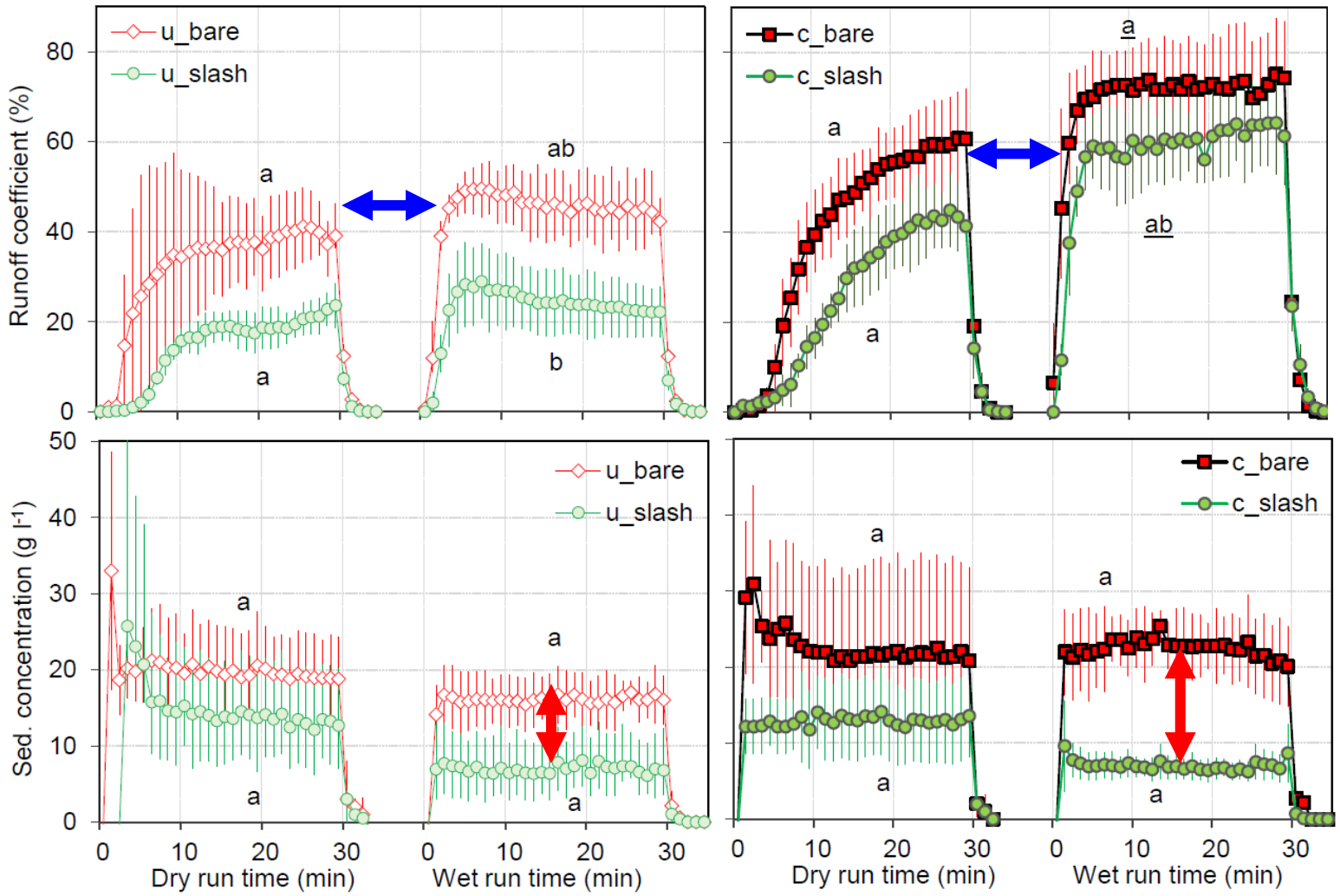
- Added in 2016 to address specific mechanisms
- Objectives
  - Compare soil compaction and slash cover runoff and erosion
- Methods
  - 2 treatments, 2 levels:
    - Uncompacted and compacted
    - Bare and 60% slash cover
  - 2 @ 30 min rain events on each 0.5 m^2 plot
  - Lots of measurements: runoff, splash, soil properties

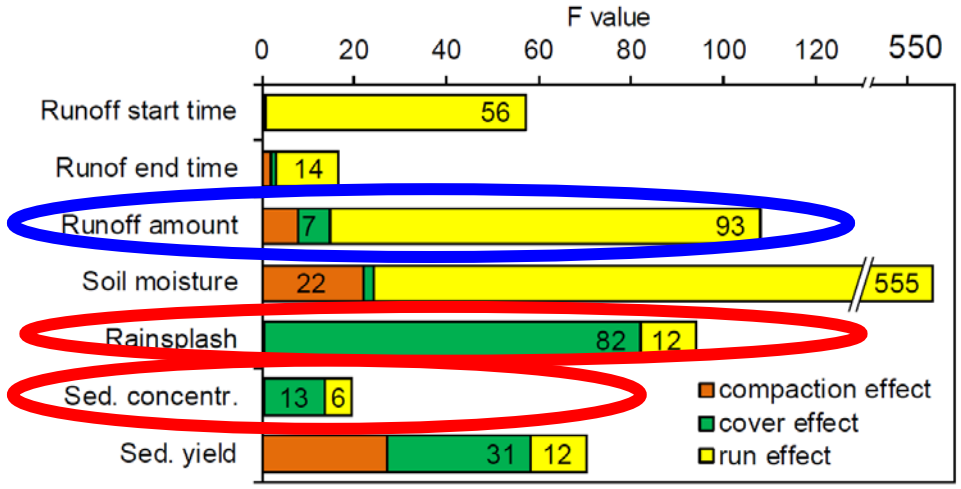
(Prats et al. 2020, *HP*)

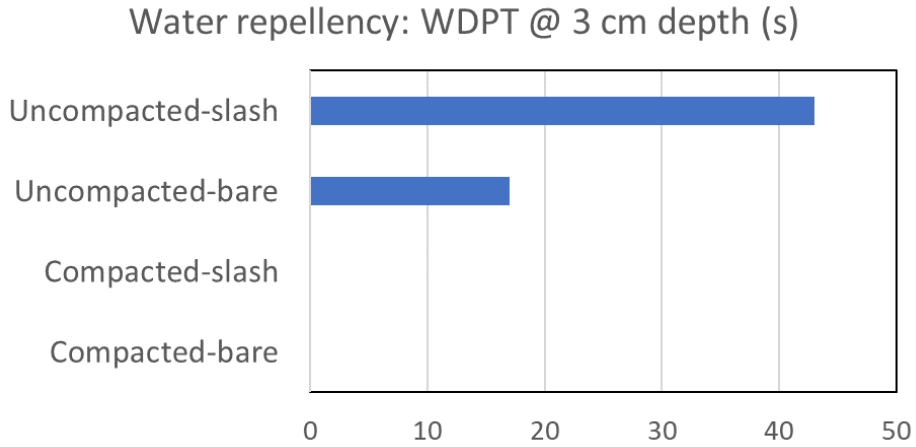
Rainfall simulation studies-results

Uncompacted

Compacted





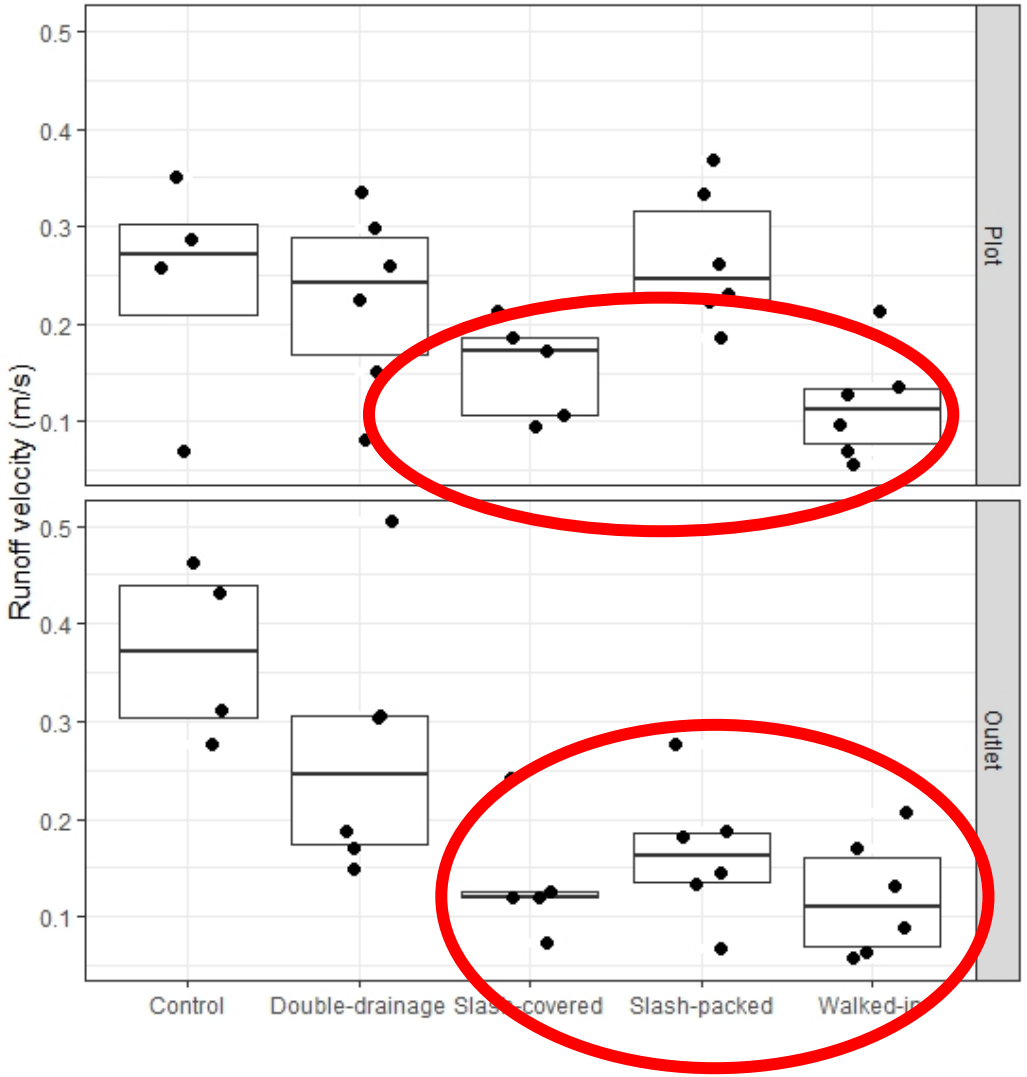


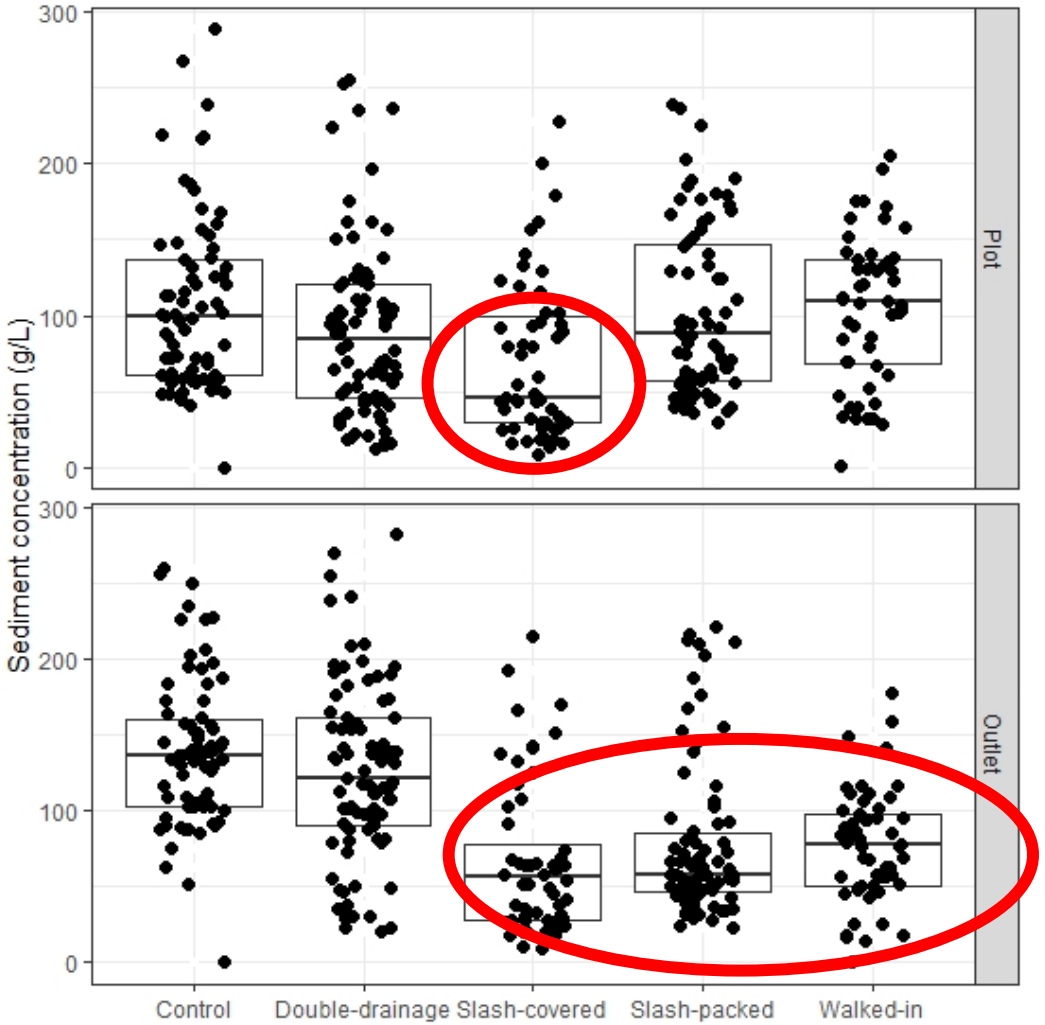
(Prats et al. 2021, *HP*)

Skid trail runoff simulations

- **Objectives:** Compare runoff and sediment among five skid trail erosion BMPs (6 replicates)
- Simulates >100 year 30-minute rainstorm

Skid trail runoff simulations





Summary of findings to date

- Burn severity affects runoff and sediment delivery
  - Relatively small storms can produce high flow rates in first 1-2 post-fire years at this scale
  - Rilling and sediment delivery increases with burn severity
- Heavy equipment compacts soil and reduces water repellency
  - Net result: Increases runoff
- Post-fire salvage operations affect surface cover
  - Can initially decrease vegetation cover
  - Can increase slash cover
  - With net increase in cover, can reduce splash erosion
- Skid trails can interact with rill networks to increase sediment delivery
  - Most interaction with high traffic skid trails
- Adding slash to skid trail and waterbar outlets slows runoff and reduces sediment delivery

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WILDFIRE AND HYDROLOGICAL PROCESSES

WILEY

Hillslope sediment production after wildfire and post-fire forest management in northern California

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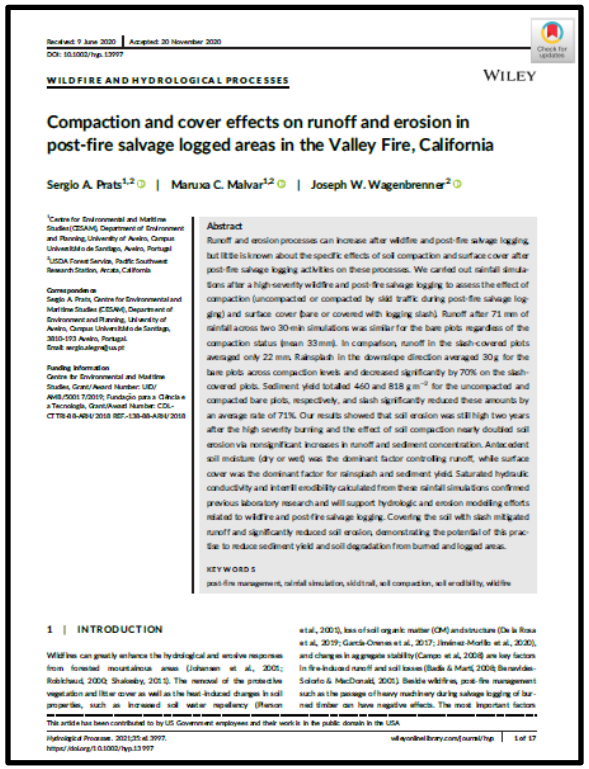
Abstract

High severity wildfires impact hillslope processes, including infiltration, runoff, erosion, and sediment delivery to streams. Wildfire effects on these processes can impair vegetation recovery, producing impacts on headwater and downstream water supplies. To promote forest regeneration and maintain forest and aquatic ecosystem functions, land managers often undertake active post-fire land management (e.g., salvage logging, sub-soiling, re-vegetation). The primary objective of our study was to quantify and compare sediment yields eroded from (a) burned, (b) burned and salvage logged, and (c) burned, salvage logged, and sub-soiled plots following the 2015 Valley Fire in the northern California Coast Range. We distributed 25 sediment fences (~75 m^2 contributing area) across four hillslopes burned at high severity and representative of the three management types. We collected eroded sediment from the fences after precipitation events for 5 years. We also quantified precipitation, canopy cover, ground cover, and soil properties to characterize the processes driving erosion across the three management types. Interestingly, during the second year after the fire, sediment yields were greater in the burned-only plots compared with both the salvage logged and sub-soiled plots. By the third year, there were no differences in sediment yields among the three management types. Sediment yields decreased over the 5 years of the study, which may have occurred due to site recovery or exhaustion of mobile sediment. As expected, sediment yields were positively related to precipitation depth, bulk density, and exposed bare soil, and negatively related to the presence of wood cover on the soil surface. Unexpectedly, we observed greater sediment yields on the burned-only plots with greater canopy closure, which we attributed to increased throughfall drop size and kinetic energy related to the residual canopy. While these results will aid post-fire management decisions in areas with Mediterranean climates prone to low intensity, long duration rainstorms, additional research is needed on the comparative effects of post-fire land management approaches to improve our understanding of the mechanisms driving post-fire erosion and sediment delivery.

KEYWORDS
erosion, forest fire, hillslope processes, runoff, salvage logging, sediment

(Cole et al., 2020)



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WILDFIRE AND HYDROLOGICAL PROCESSES

WILEY

Compaction and cover effects on runoff and erosion in post-fire salvage logged areas in the Valley Fire, California

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Abstract

Runoff and erosion processes can increase after wildfire and post-fire salvage logging, but little is known about the specific effects of soil compaction and surface cover after post-fire salvage logging activities on these processes. We carried out rainfall simulations after a high-severity wildfire and post-fire salvage logging to assess the effect of compaction (uncompacted or compacted by skid traffic during post-fire salvage logging) and surface cover (bare or covered with logging slash). Runoff after 71 mm of rainfall across two 30-min simulations was similar for the bare plots regardless of the compaction status (mean 33 mm). In comparison, runoff in the slash-covered plots averaged only 22 mm. Rainsplash in the downslope direction averaged 30 g for the bare plots across compaction levels and decreased significantly by 70% on the slash-covered plots. Sediment yield totaled 460 and 818 g m^{-2} for the uncompacted and compacted bare plots, respectively, and slash significantly reduced these amounts by an average rate of 71%. Our results showed that soil erosion was still high two years after the high severity burning and the effect of soil compaction nearly doubled soil erosion via nonsignificant increases in runoff and sediment concentration. Antecedent soil moisture (dry or wet) was the dominant factor controlling runoff, while surface cover was the dominant factor for rainsplash and sediment yield. Saturated hydraulic conductivity and interrill erodibility calculated from these rainfall simulations confirmed previous laboratory research and will support hydrologic and erosion modelling efforts related to wildfire and post-fire salvage logging. Covering the soil with slash mitigated runoff and significantly reduced soil erosion, demonstrating the potential of this practice to reduce sediment yield and soil degradation from burned and logged areas.

KEYWORDS
post-fire management, rainfall simulation, skid trail, soil compaction, soil erodibility, wildfire

1 | INTRODUCTION

Wildfires can greatly enhance the hydrological and erosive responses from forested mountainous areas (Johansen et al., 2005; Robichaud, 2000; Shakesby, 2011). The removal of the protective vegetation and litter cover as well as the heat-induced changes in soil properties, such as increased soil water repellency (Parson et al., 2010), loss of soil organic matter (OM) and structure (De la Rosa et al., 2019; García-Orenes et al., 2017; Jiménez-Morillo et al., 2020), and changes in aggregate stability (Campo et al., 2006) are key factors in fire-induced runoff and soil losses (Badía & Martí, 2000; Benavides-Solorio & MacDonald, 2001). Beside wildfires, post-fire management such as the passage of heavy machinery during salvage logging of burned timber can have negative effects. The most important factors

(Prats et al., 2020)

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Research papers

Hydrologic and erosion responses to compaction and added surface cover in post-fire logged areas: Isolating splash, interrill and rill erosion

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ARTICLE INFO

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Runoff
Sheetwash
Soil moisture
Salvage logging

ABSTRACT

Soil compaction during post-fire logging can increase runoff and erosion. Increasing surface cover is an effective way to reduce erosion, but this hasnot been tested on soils impacted by both fire and compaction. We measured the effects of compaction (bulk density of 0.9 or 1.1 g cm^{-3}) and surface cover (0% or 60%) using both mulch or logging slash (compacted only) on runoff, leaching and erosion. Four 0.5 m^2 plots per treatment were filled with burned soil and fertilized in 18°. Two 30-min simulated rainfall events with 72 $mm\,h^{-1}$ intensity and one concentrated flow event were applied to each plot.

The runoff from the dry and wet runs totaled 32 mm in the uncompacted bare plots and the value was not significantly different for the compacted bare plots, any of the mulch plots, or the compacted slash plots. Leaching was higher for the uncompacted bare plots (7 mm) than for the compacted bare plots (1 mm), and mulch or slash did not affect leaching. The uncompacted bare plots produced 3.8 g of rainsplash and 497 g m^{-2} of sheetwash, and these were about half the values for the compacted bare plots. Mulching strongly reduced the rainsplash and sheetwash for both the uncompacted (2.0 g and 184 g m^{-2}, respectively) and compacted conditions (1.9 g and 431 g m^{-2}, respectively), although the difference in sheetwash was only significant for the uncompacted plots. Slash also reduced rainsplash (1.9 g) relative to the compacted bare plots (7.4 g) but did not affect sheetwash. Concentrated flow produced 836 g m^{-2} of rilling from the uncompacted bare plots, which was greater than the compacted plots (237 g m^{-2}). Mulching reduced rilling by 95% in the uncompacted plots and 79% in the compacted plots, but slash did not reduce rilling.

The reductions in rainsplash erosion caused by the mulch and slash were attributed to the increase in surface cover, which reduced the energy imparted to the soil by the rainfall. The mulch, with its high degree of contact with the soil, also reduced particle detachment and transport by overland flow. In contrast, the slash did not have complete contact with the soil surface and did not affect sheetwash or rilling. Compaction and the type of material used to increase surface cover are important factors to consider when assessing potential impacts of logging on runoff and sediment delivery from burned soils.

1. Introduction

Runoff and soil erosion can increase substantially after wildfires, especially in severely burned areas (Benavides-Solorio and MacDonald, 2001, 2005; Moody et al., 2013). These increases have been associated with negative on-site and off-site effects such as soil fertility losses (Shakesby, 2011), stream water pollution (Smith et al., 2011; Lewis et al., 2016) and sedimentation (Shakesby, 2011; Robichaud et al., 2016). Soil compaction by machinery used during post-fire logging activities has been shown to affect soil roughness, bulk density and shear strength, and it can increase post-fire runoff and erosion (Cerdà et al., 1999a,b, 2001; McIver and McNeil, 2006; Sillins et al., 2009; Smith et al., 2011) which may greatly exacerbate the detrimental effects of the wildfire itself. Some post-fire field studies have shown that unlogged areas exhibited lower runoff and erosion volumes as compared to soils impacted by logging equipment (Wagenbrenner et al., 2015, 2016; McIver et al., 2017). In contrast, other experiments have shown that compaction or disturbance related to post-fire logging led to lower soil erosion rates (Arbelaiz et al., 2006; Silveira and Hartfield, 2015; James and Rowland, 2018).

Soil surface cover, such as litter, stones, char, ash and vegetation cover are known to inhibit surface runoff (Arnau-Rosalén et al., 2008;

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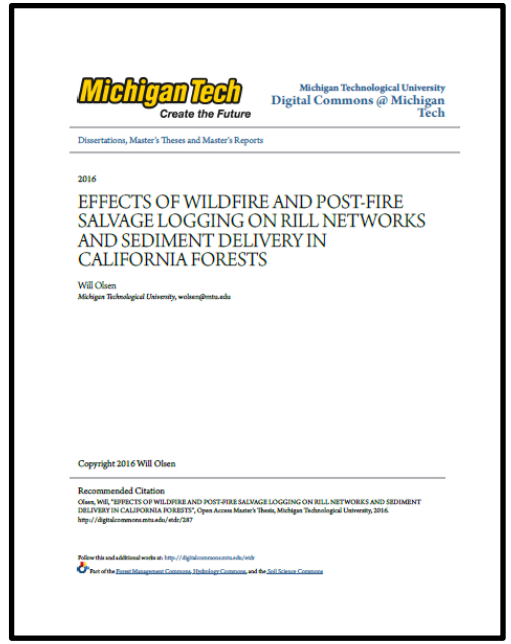
(Prats et al., 2019)



2016

EFFECTS OF WILDFIRE AND POST-FIRE SALVAGE LOGGING ON RILL NETWORKS AND SEDIMENT DELIVERY IN CALIFORNIA FORESTS

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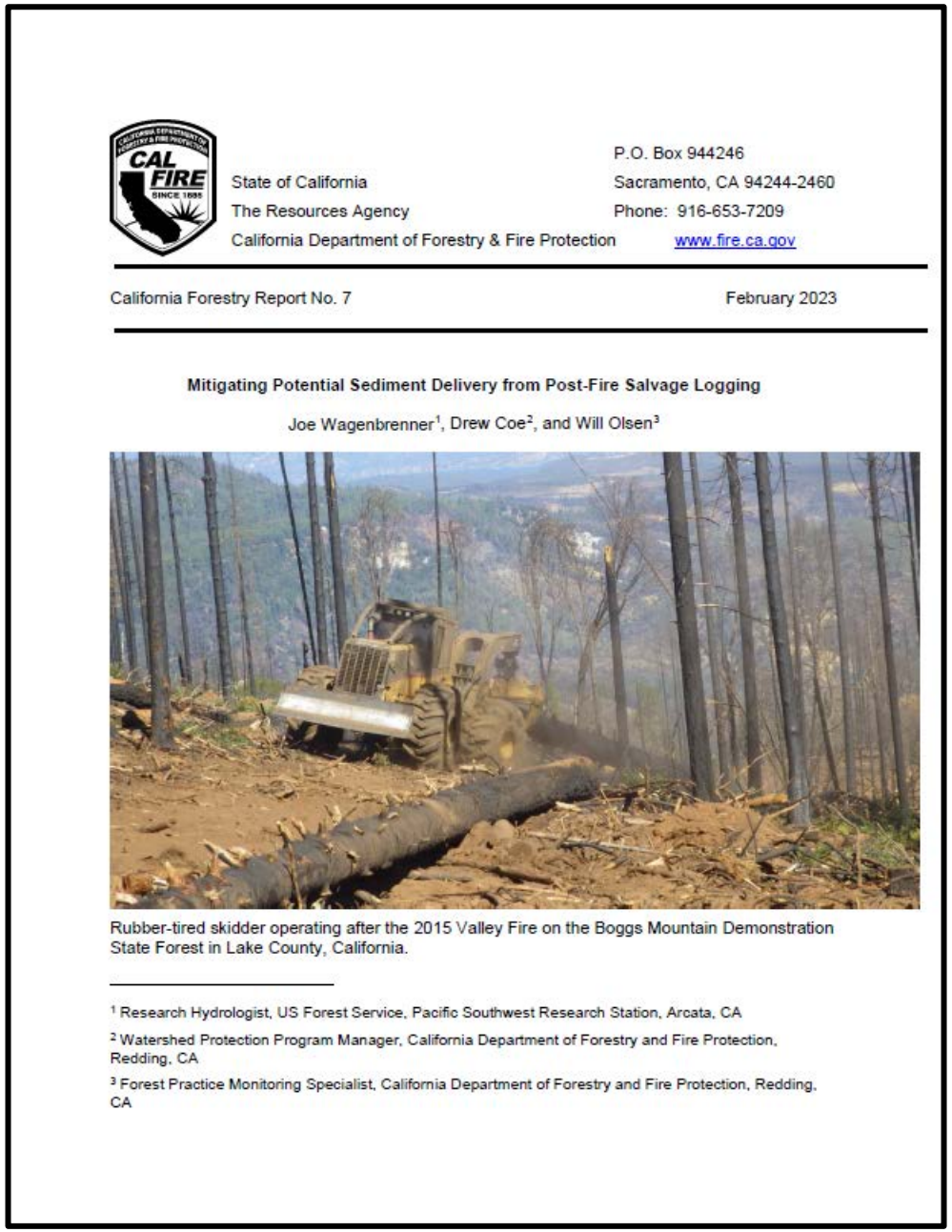
(Olsen, 2016)



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Mitigating Potential Sediment Delivery from Post-Fire Salvage Logging

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Rubber-tired skidder operating after the 2015 Valley Fire on the Boggs Mountain Demonstration State Forest in Lake County, California.

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(Wagenbrenner et al., 2023)

Products to Come:

- Salvage guidance document – California Forestry Report #7 (published 2023)
- Catchment scale runoff and sediment delivery paper
- Skid trail BMP paper
- Herbicide effects paper
- Post-fire soil nutrient/carbon paper
- Post-fire scaling (microplot to hillslope plot to catchment scale)

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