FINAL REPORT

Title: Prescribed Fire Effects on Soil Hydraulic Properties and Ecohydrological Function

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List of Abbreviations/Acronyms

WEPP – Water Erosion Prediction Project (USDA)
BAER – Burned Area Emergency Response
ERMiT – Erosion Risk Management Tool (USFS)
SSURGO - Soil Survey Geographic Database (NRCS)
dNBR – Difference Normalized Burn Ratio
TNC – The Nature Conservancy
MED – Molarity of Ethanol Droplet
MDI – Mini Disk Infiltrometer
CART – Classification and Regression Tree

Keywords

infiltration, soil erosion, soil hydraulics, hydrophobicity, prescribed fire, wildfire

Acknowledgments

We would like to thank and acknowledge the support of Katie Sauerbray and Craig Bienz of The Nature Conservancy for inviting us to conduct research at the Sycan Marsh Preserve along with their efforts in active prescribed fire management. Our work within the 2020 Labor Day fires areas of Mt. Hood, Willamette, and Umpqua National Forests would not have been possible without the support of numerous US Forest Service staff, but most especially Cheryl Friesen, Region 6 Science Liaison, and Alexandra Rozin, Region 6 BAER coordinator.

Abstract

Wildfire directly changes the physical properties of Earth's critical zone, which leads to catastrophic changes in ecological and hydrological processes (Shakesby & Doerr, 2006). Uncontrolled wildfire in forested headwater catchments often increases the risk to downstream communities and ecosystems from increased frequency and magnitude of runoff, erosion, landslides, and debris flows. Post-fire changes to soil properties also limit the total soil moisture storage and plant available water in recovering systems due to a combination of organic matter loss and direct changes to soil bulk properties, posing risk to long-term forest regrowth and landscape stability. To mitigate these risks we need improved understanding of the key mechanisms that control fire effects on soils and more capable predictions of post-fire ecohydrological responses across a broad range of ecoregions. With the expected increases in wildfire burned area and burn severity in the western U.S., land managers will require effective science-based decision support tools, based on robustly-tested theories, to efficiently direct mitigation efforts in highly sensitive landscapes.

Currently, many models exist to assist managers in targeted post-fire treatment and pre-fire planning for erosion and flood risk. There are a growing number of groups, including some Burned Area Emergency Response (BAER) teams in the U.S., and similar groups internationally, relying on physically-based models; e.g., the Water Erosion Prediction Project (WEPP) model is a commonly used example of such tools. Newer spatial interfaces for WEPP or other such models have proved valuable for rapid assessment, but the extensive and spatially-variable soil hydraulic parameterizations needed to make this type of model most effective have so far not moved past a static set of generalized soil parameters that, critically, also do not yet systematically account for fire alterations, e.g., by predicting likely post-fire changes and variations in soil hydraulic properties. While the general effects of wildfire on soils are well known, we lack a suite of robust functions to quantitatively transform the typical model inputs from general (pre-fire) soil survey data (e.g., SSURGO) to the likely post-fire altered-states needed for site-specific post-fire ecohydrological and geomorphological assessments. Without such ability to update soil hydraulic properties to account for burn effects, the potential value of such spatially-distributed risk and impact models to aid post-fire risk management and recovery planning remains substantially hampered.

This study expands our knowledge of how key soil hydraulic properties are affected by differing degrees of wildfire burn severity across the temperate rainforest regions of the western Cascade Mountains of the U.S. Pacific Northwest, as well as, in contrast, dry forest of the eastern Cascades foothills bordering on the northern Basin and Range in south-central Oregon. This study particularly attended to sampling across several distinct soil groups of differing soil textural properties, and to collecting many different types of measures of soil physical and hydraulic properties both in-field and lab-base. These efforts were aimed to help clarify the various contributions of forest ecosystem type, soil-series and texture, choice of measurement variable, and choice of measurement method on the degrees to which various soil hydraulic properties were changed by wildfire, toward being able to more systematically assess and predict how soil hydraulic properties' input parameter values in research and management models ought to numerically change upon fire-impact to more capably simulate post-fire soil physics and landscape hazards.

Objectives

The originally proposed work addressed the needs and priorities of the Joint Fire Science Program through the support of science-based management tools to assist in post-fire ecohydrological risk and assessment. It was further centered around two of the key topic areas: assessment of fire effects and post-fire recovery, and relative impacts of prescribed fire versus wildfire.

As written in the original research proposal, the overall objective of this project was to address two target research questions (RQs):

RQ1: *How do prescribed fire and wildfire alter soil hydraulic properties across differing ecological and soil-type settings?*

RQ2: *How can widely-used fire-impact models efficiently translate available pre-fire soil characteristics into applicable post-fire emergent hydraulic properties to improve modeled water, landscape change and hazard risk predictions?*

The specific technical objectives of this GRIN-extension project, as written in the original research proposal, were therefore the following.

- ❑ Obtain burned and paired unburned soil samples immediately after prescribed fire and, if available, wildfires in the US West from ecosystems and soil types contrasting with the sampling previously conducted in a prescribed-burn area for the student's dissertation in 2019 (Sycan Marsh site), including in nearby Cascades range National Forest land
- ❑ Conduct follow-up sampling at the prior 2019 sampling sites in 2020/2021 to extend the prior work into a change-over-time –after-fire perspective

These two objectives were Completed: Although the COVID-pandemic caused the cancellation of the planned prescribed fires and sampling in 2020-2021 at Sycan Marsh, other actions and events enabled completion of this objective, and more. The occurrence of the catastrophic Labor Day fires in September 2020 in the Oregon Cascades was leveraged to go deeply into the wildfire aspect of this objective, which at the time of the original proposal could only be hoped for, not ensured; these fires also intersected large areas of National Forest lands and resources. The sizable Bootleg Fire in 2021 then coincidentally over-burned the 2019 Sycan Marsh prescribed-burn plots that had been previously sampled, so unburned, wildfire-only, and prescribed-plus-wildfire-burned samples were collected following that event and also with the change-over-time perspective.

- ❑ Collect these new samples with an emphasis on assessing effects of differing soil textures on fire-induced changes in soil properties (vs. prior dissertation work focusing on effects of different intensities of heating but on one soil type)
- ❑ Analyze the field samples for bulk density, particle size distribution/texture, porosity, organic matter content, field infiltration, field hydrophobicity, lab infiltration, and lab soil water retention curves

These two objectives were Completed: The opportunity to dive deep into the wildfire aspect of the original proposal and the extensive burn area of the 2020 Labor Day fires, combined with the support of this grant, allowed highly distributed sampling across several distinct soil types/textures. This project work further kept and met the objectives for extended sampling work at the Sycan Marsh site, related to both prescribed fire and wildfire, which presents a strongly contrasting (dry forest vs temperate rainforest) ecosystem type. Methodological developments in lab measurement, data analysis, and cross-method intercomparison were additionally explored as added value to these objectives.

- ❑ Integrate results from these new measurements with literature and existing practice/parameters to begin to develop transfer functions predicting post-fire soil hydraulic properties from pre-fire soil database and parameter values and minimal fire data, for use to improve post-fire hydrology, erosion, and forest management modeling

This objective was not completed in the grant term but is still <u>In Progress</u>: The integration of results from these new measurements with literature and existing practice/parameters to begin to develop transfer functions predicting post-fire soil hydraulic properties from pre-fire soil database and parameter values and minimal fire data is still in progress. These relations are intended for use to improve post-fire hydrology, erosion, and forest management modeling, as noted in the original proposal, but at this time require further work. The exceptional, if somewhat catastrophic, opportunities afforded by the Labor Day and Bootleg fires pushed more of the research effort during this project into field, and then extensive laboratory, work such that modeling is still ongoing now. The hydraulic property changes found in this study are already being preliminarily implemented in an ongoing modeling study to explore wildfire impacts to surface hydrology in the Oregon Cascades, however. These improvements will bolster the applicability of such models for this region, which has historically been understudied with regard to wildfire effects on hydrology, perhaps because of the longer fire return intervals in the wetter forest systems. The relations aimed for in the objective are continuing to be assessed and are anticipated to be included in the future manuscript(s) submitted for peer-reviewed publication and otherwise disseminated to researchers and land managers following this work.

<u>Background</u>

Post-fire changes to soil properties also limit the total soil moisture storage and plant available water in recovering systems due to a combination of organic matter loss and direct changes to soil bulk properties (Stoof et al., 2010), posing risk to long-term forest regrowth and landscape stability. Wildfire has become increasingly recognized as a potent driver of hydrological and geomorphological systems (Moody et al., 2013; Shakesby & Doerr, 2006), and has been increasing in wildfire burned area and burn severity in the western U.S. (Miller & Safford, 2012). Many researchers have documented critical changes in the hydraulic properties of soil caused by the downward soil heating effects of fire. Through heat produced during combustion of surface fuels and soil organic matter smoldering, pre-existing hydrocarbon compounds can volatilize and condense across the heat gradient and form a concentrated hydrophobic layer in the soil profile (DeBano, 1966; Letey, 2001). Soil aggregates which exhibit this hydrophobicity will have a reduced wettability which reduces the effective capillary contribution of soils in the short-time scale infiltration. The hydrophobic effect has been shown to vary across differing soil textures (Doerr et al., 2000), pre-fire soil moisture (Doerr & Thomas, 2000), and burn severity (Debano, 2000). Other than water repellency, many researchers have suggested soil surface sealing and pore clogging as substantial mechanisms of infiltration reduction. In these cases, ash or fine sediment may be transported by rainsplash or through compaction will inhibit infiltration through reduction in micro-pore size within the first few centimeters of the soil surface (Larsen et al., 2009). Similarly, changes in bulk properties including density (Ebel et al., 2018), porosity (Giovannini & Lucchesi, 1997), particle sizes (Moody et al., 2005), and aggregate stability (Mataix-Solera et al., 2011) have been reported. The prevalence of pore-clogging is likely texture-dependent, as Stoof et al. (2016) found no evidence of hydraulic impedance by ash in a sandy soil, however Onda et al. (Onda et al., 2008) suggests that precipitation- and time-based evolution of the dominating hydraulic mechanism change may be important.

Research Motivation

Currently, many models exist to assist managers in targeted post-fire treatment and pre-fire planning for erosion and flood risk (Robichaud & Ashmun, 2013). There are a growing number of groups, including some Burned Area Emergency Response (BAER) teams in the U.S., and similar groups internationally (Robichaud et al., 2016), relying on physically-based models. The Water Erosion Prediction Project (WEPP) model is a commonly used example of such tools, which currently provides various targeted interfaces including the Erosion Risk Management Tool (ERMiT) (Robichaud et al., 2007), Disturbed WEPP (Elliot et al., 2001). Newer spatial interfaces for WEPP (Dobre et al., 2016; Miller et al., 2016) have proved valuable for rapid assessment, but the extensive and spatially-variable soil hydraulic parameterizations needed to make this type of model most effective have so far not moved past a static set of generalized soil parameters that, critically, also do not yet systematically account for fire alterations, e.g., by predicting likely post-fire changes and variations in soil hydraulic properties. Continuous, quantitative functions capturing the key changes to different types of soils that then cause post-fire response variations are lacking. In other words, while the general effects of wildfire on soils are well known, we lack a suite of robust functions to quantitatively transform the typical model inputs from general (pre-fire) soil survey data (e.g., SSURGO (NRCS, 2019)) to the likely post-fire altered-states needed for site-specific post-fire ecohydrological and geomorphological assessments. Without such ability to update soil hydraulic properties to account for burn effects, the potential value of such spatially-distributed risk and impact models to aid post-fire risk management and recovery planning remains substantially hampered.

Research Gap

We need a geographically transferrable relationship between soil heating severity, pre-fire soil properties, and the post-fire hydraulic properties including infiltration capacity and soil moisture retention characteristics. Current studies vary widely in the mode of soil heating (wildfire, prescribed fire, artificial heating) and are often limited to applying one (or few) methodology to a single geographic location or soil type. Studies which cover a broad set of textural classes and ecoregions is needed to determine the cross-regional impacts of fire on soil hydraulic properties. Moreover, cross-comparison of effects on several different soil and hydraulic properties, as measured with different methods, and implementation of studies which link differing heating intensities from prescribed fire treatment to severe wildfire are needed.

Methods

This report encompasses two study regions, one with study focused on wildfire effects on soil hydraulic properties across the seasonal temperate rainforests of the western Cascade Mountains Oregon burned extensively in the 2020 "Labor Day" fires, and the other addressing prescribed fire vs. wildfire impacts on soil hydraulic properties, and their combined effects when the Bootleg Fire burned over previous prescribed fire areas, in a dry pine forest of the eastern Cascades foothills bordering on the northern Basin and Range in south-central Oregon.

Site Description

Oregon 2020 "Labor Day" Fires

In early September 2020, the relatively minor fire season of the Western US was suddenly driven to historic levels during an extreme fire weather event, which lasted only a few days during the week of 07 September 2020. Along with a climate primed for fire, extreme dry easterly fohn winds provoked smaller ongoing wildfires to eventually overwhelm on-the-ground resources and consume over 760,000 ha of forested land in Washington and Oregon at the end of the season (Higuera & Abatzoglou, 2021), along with blow-ups in California and elsewhere.

In the Oregon Cascade Range, four of the five largest wildfires were included in this study (Figure 1): the Riverside fire located in Clackamas County with primary USFS jurisdiction in the Clackamas Ranger District, Mt. Hood National Forest; the Beachie Creek and Lionshead fires located primarily in Marion County with USFS jurisdiction in the Detroit Ranger District of the Willamette National Forest; and the Holiday Farm fire located in Lane County with USFS jurisdiction in the McKenzie River District of the Willamette National Forest. Each fire also impacted large portions of private land managed by multiple timber companies, and the Lionshead fire a large portion land on The Confederated Tribes of Warm Springs' reservation.

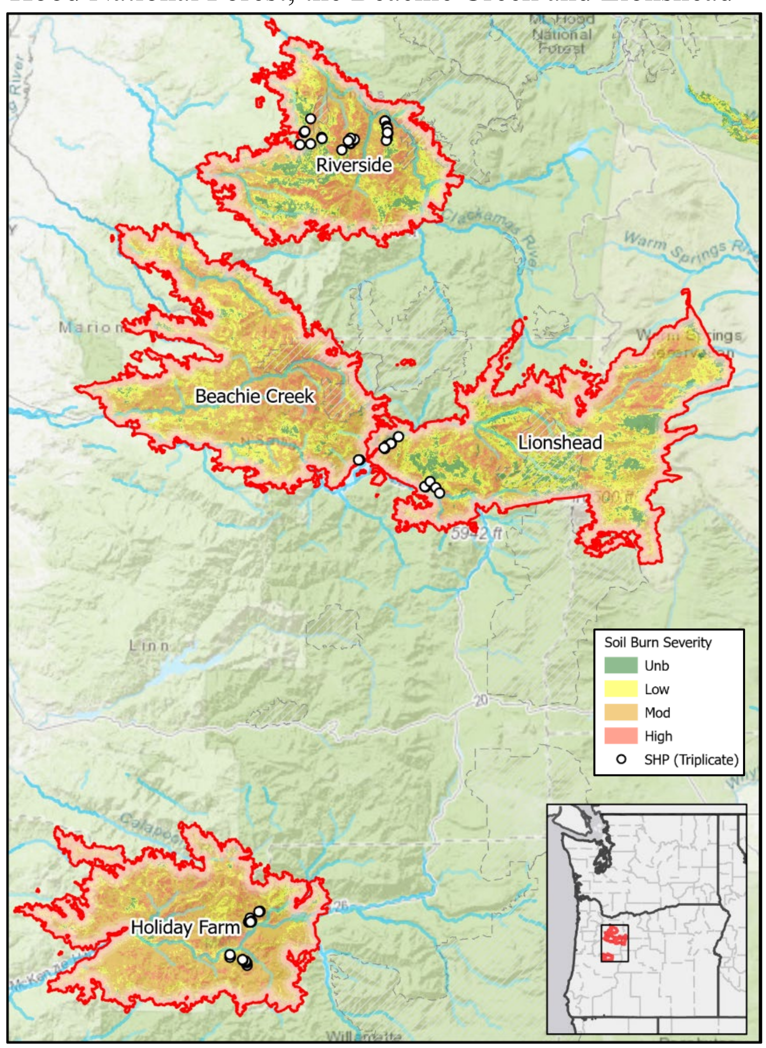


Figure 1 Location of the four selected fires in Oregon

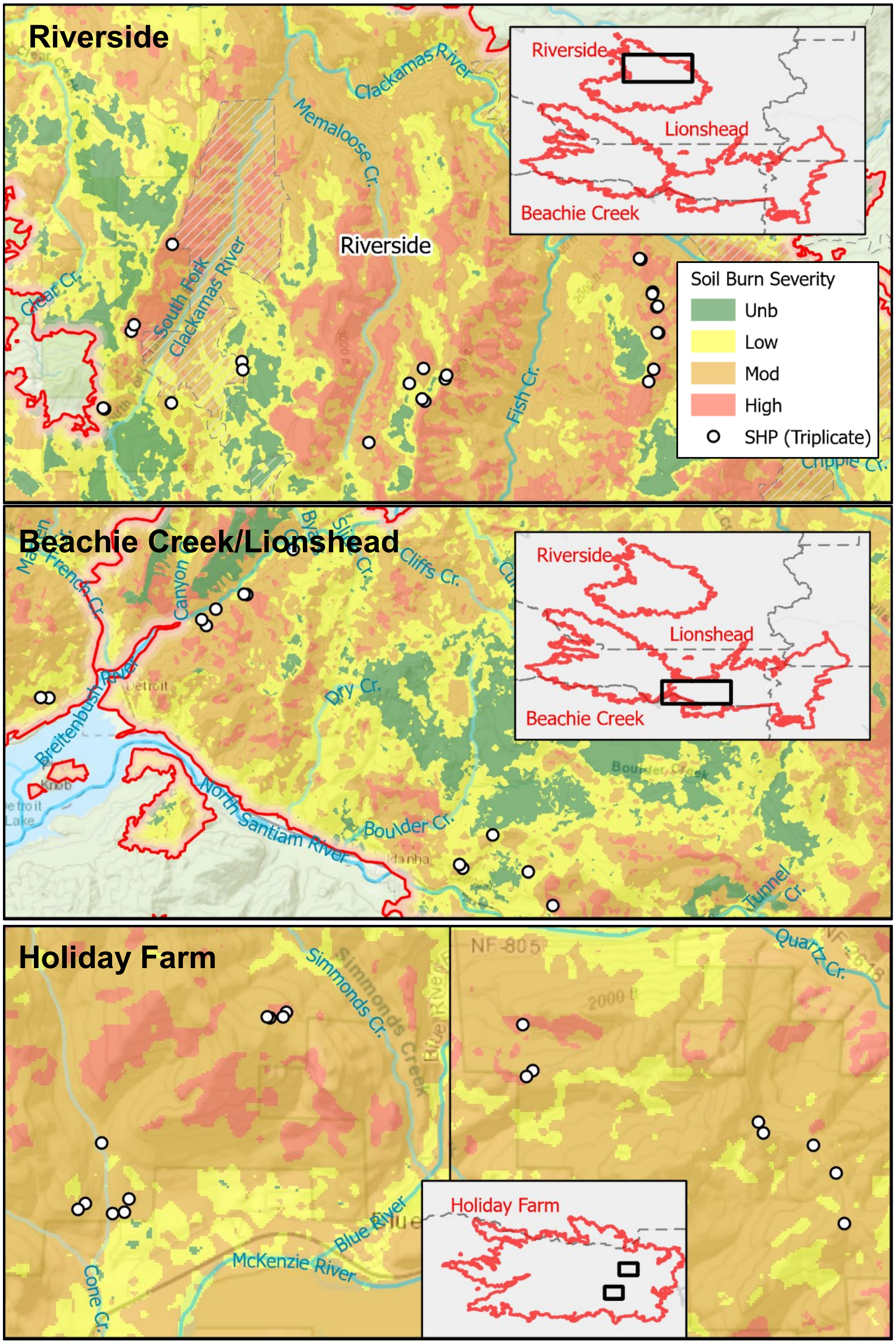


Figure 2 Soil sample triplicate locations on the Riverside, Lionshead, Beachie Creek, and Holiday Farm fires.

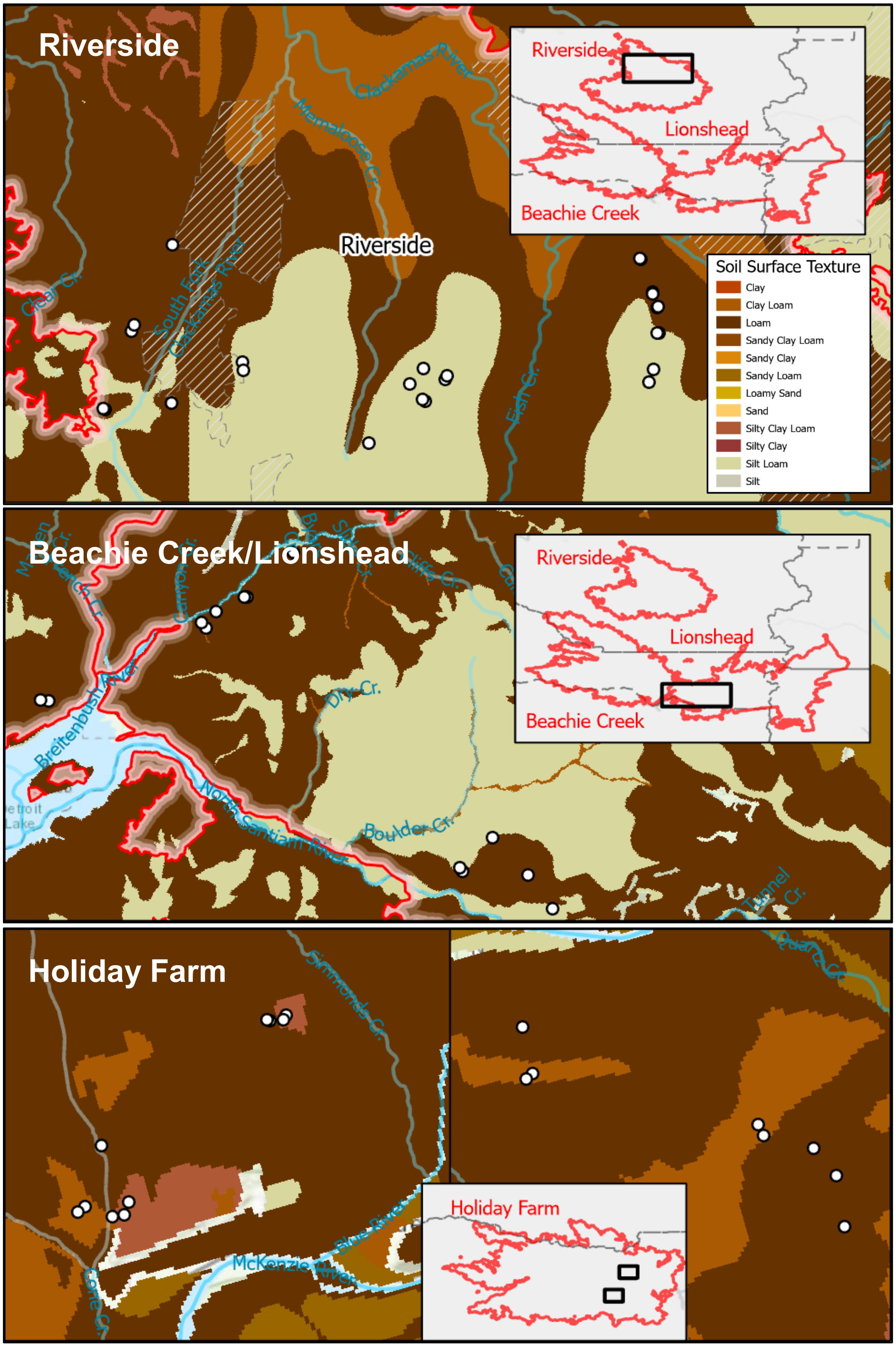


Figure 3 General surface soil characteristics defined in the gNATSGO database and locations of soil sample triplicate points

Sycan Marsh RxFire and Bootleg Fire

The Sycan Marsh preserve is located in Lake County, Oregon and managed by The Nature Conservancy (TNC) with permanent conservation easements in place. The surrounding upland forested areas within TNC boundaries are managed with cross-boundary agreements with the USFS Silver Lake Ranger District, Fremont-Winema National Forest along with interest from adjacent private landowners. Prescribed burns for management, fuel reduction, and research objectives have been conducted continuously over the past decade, and in 2019 the burn units included approximately 400 ha sparse to moderately dense ponderosa pine and lodgepole pine forest, which transitions into a scattered overstory with brush understory and grass prairie. The soils vary widely between upland and wetland areas, but have a predominant sandy loam texture with low organic content and are well drained.

In July 2021, the Bootleg Fire burned over 162,000 ha (400,000 acres) in South-Central Oregon, and nearly 9,000 ha (22,000 acres) of marsh and upland forest within the Sycan Marsh Preserve with mixed severity.

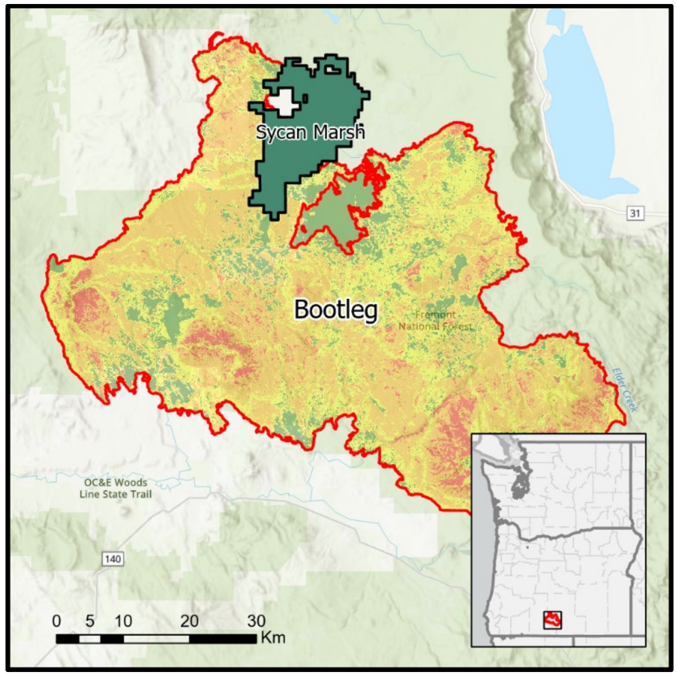


Figure 4. Bootleg Fire soil burn severity map and The Nature Conservancy's Sycan Marsh property boundaries.

Field and Lab Methods

For both studies, we conducted field tests and collected samples in the field for later analysis under laboratory conditions. These methods did not substantially vary between studies, and are further comparable with the pre-project work done for the student's dissertation, which this grant and work extended to new research directions.

Field Samples

At each plot, we collected two samples in triplicate: *Soil Hydraulic Cores* – Intact soil cores measuring 5.08 cm diameter by 7.62 cm (2 by 3 in) collected by hand using a mallet and trowel. Samples are collected in plastic sleeves lined with petroleum jelly before collection. *Bulk Density Samples* – Loose soil samples were collected using the 5.08 cm diameter by 5.08 cm (2 by 2 in) circular bulk density attachment of the soil corer and placed into a zip-lock plastic bag

Field Measurements

At sampling point, field-saturated infiltration was measured with a minidisk tension infiltrometer (MDI, Meter Group, Pullman, WA) with the tension set to -1 cm. Infiltration tests were recorded for every millimeter increment using a smartphone and standard timer app.

Water repellency of the field conditions was measured using molarity of ethanol droplet (MED) test with standard ethanol concentrations (Doerr et al., 2000; Letey, 2001) using a 10 ml syringe. These concentrations are: 0, 0.85, 1.46, 2.23, 3.08, 4.11, and 6.17 mol/L. For this test, values were recorded on the soil surface after removing any ash residue, and in 1 cm increments to 5 cm below the surface for a collection of 5 measurements at each point.

Table 1. Molarity of Ethanol Droplet test parameters following Doerr et al. (2000).

	Class						
	0	1	2	3	4	5	6
Ethanol Molarity (M)	0.00	0.86	1.46	2.23	3.08	4.11	6.17
Concentration (% v/v)	0	5	8.5	13	18	24	36
Hydrophobicity	None	Slight	↔	Strong	↔	Extreme	
Label Color	white	red	orange	yellow	green	blue	violet

Lab Measurements

Soil bulk and mineral properties were measured in the lab using the following several standard procedures. Dry bulk density was measured by drying the bulk density sample at 105 C for at least 48 hours and recording the dry mass. Particle size distribution was measured with a suspended particle analyzer (Pario, Meter Group, Pullman, WA). Pario samples were prepared from the bulk density sample and organic matter was removed using hydrogen peroxide destruction. Organic matter content was assessed generally from this change in mass during particle size analysis preparation, and specifically using the loss on ignition (LOI) method with a 3 gram sub-sample at 550 C (Schulte et al., 1991).

Saturated hydraulic conductivity was measured for each soil core using both a ponded constant-head method and the MDI tension-head method. Hydraulic cores were processed by securing 3-ply cheesecloth to the bottom, adding contact sand, and adding extra petroleum jelly with a small gauge needle if a gap had formed in between the core wall and soil. After the core was prepared, the MDI test was conducted, followed immediately by the ponded head test. The core was then allowed to saturate for two days, and another ponded head test was conducted. Porosity was calculated gravimetrically from the saturated cores (Nimmo, 2004). Water retention characteristics and *van Genuchten* parameters were measured with a T5 tensiometer (Meter Group, Pullman, WA) by allowing the core to dry down from saturation on a scale.

Hydraulic Property Analysis

MDI tests were analyzed using the cumulative infiltration (CI) method (Vandervaere et al., 2000) to produce estimates of field saturated hydraulic conductivity (K_{fs}) and sorptivity (S)

Sampling Design

Oregon 2020-2021 Fires

Across the four major wildfires, we identified 69 plots (Riverside: 25 , Lionshead: 13, Holiday Farm: 18, Bootleg: 13) sampled in triplicate for a total of 207 sampling points, mainly in November 2020, which was as soon as possible following fire-ends in September and October. These plots were stratified across soil textural properties estimated from the GNATSGO soils database, consistent with the project objectives, and selected based on logistical access to the wildfire sites. Logistical access was facilitated by collaboration with the USFS Region 6 BAER coordinator and USFS district staff, however continuing fire operations and contracting work limited some access to district approved areas. Notably, access to the majority of areas with a "High" burn severity designation was restricted due to safety so soon after the fires.

Sycan Marsh Prescribed Fire and Bootleg Fire

In Fall 2019, we selected two sites (S1, S2) in the upland pine forests of the Sycan Marsh preserve that were planned to be burned in the coming month. Both sites are dominated by ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*P. contorta*) with a bitterbrush (*Purshia tridentata*) and manzanita (*Arctostaphylos*). These plots coincided with existing research plots from external research groups. The sites consisted of seven sampling plots contained within a 100 meter square, with four plots on each corner and three plots within the center of the site within 10 meters of each other. All plots were sampled in triplicate using the methods described above before the prescribed fire (unburned) early October 2019, after the prescribed fire (rx fire) in late October 2019, and again within one month of the Bootleg fire (wildfire) in November 2021.

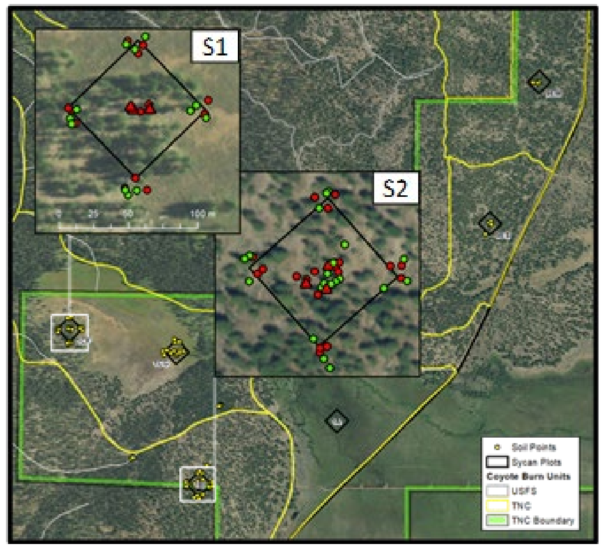


Figure 5 Site maps of Sycan Marsh sampling plots S1 and S2.

Results and Discussion

Oregon 2020-2021 Wildfires

Physical Characteristics

Within the four wildfire sites, plots were selected which encompassed 95 sandy loam, 25 silt loam, 23 clay loam, and 39 loam samples (Figure 5). Each of the 2020 'Labor Day' fires accounted for at least one sample in each major textural category, however the Bootleg fire samples all fell within the sandy loam classification. The mean elevation of the 'Labor Day' fire plots was 737 meters AMSL ranging between 337 – 1094 meters. Bootleg plots all fell within a narrow elevation range of 1520 meters.

General physical characteristics of the samples separated by soil textural class can be found in Table 2 and separated by wildfire can be found in Table 3.

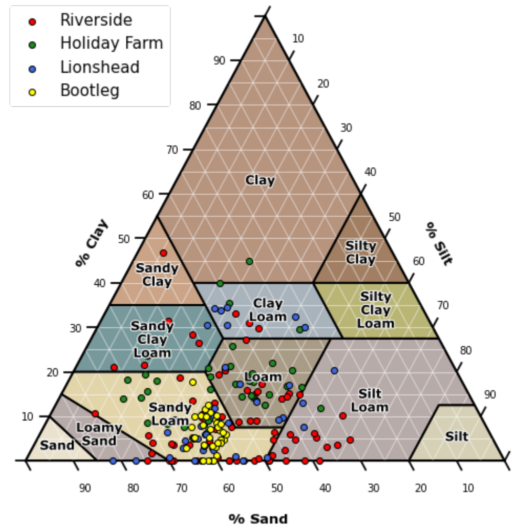


Figure 6 Soil texture triangle for all wildfire sampling points.

Table 2 Summary of textural properties from all sample locations. Organic content was measured using the loss-on-ignition method (LOI). Porosity was measured by complete saturation of intact cores.

Soil Texture	Bulk Density ($g\ cm^{-3}$)		Organic Content (%w/w)		Rock > 2 mm (%w/w)		Porosity (%v/v)	
	Mean	(Std.Dev)	Mean	(Std.Dev)	Mean	(Std.Dev)	Mean	(Std.Dev)
Clay Loam	0.65	(0.16)	18.3	(7.3)	63	(18)	47.0	(4.5)
Loam	0.71	(0.12)	13.8	(4.6)	55	(15)	48.6	(6.3)
Sandy Loam	0.68	(0.15)	16.9	(6.7)	53	(17)	48.4	(6.2)
Silt Loam	0.65	(0.18)	21.6	(7.3)	66	(14)	44.1	(6.9)
All	0.67	(0.14)	17.1	(6.8)	57	(17)	47.9	(6.1)

Table 3 Summary of textural properties from all sample locations. Organic content was measured using the loss-on-ignition method (LOI). Porosity was measured by complete saturation of intact cores.

Soil Texture	Bulk Density ($g\ cm^{-3}$)		Organic Content (%w/w)		Rock > 2 mm (%w/w)		Porosity (%v/v)	
	Mean	(Std.Dev)	Mean	(Std.Dev)	Mean	(Std.Dev)	Mean	(Std.Dev)
Holiday Farm	0.71	(0.11)	14.1	(5.0)	61.5	(13.3)	50.4	(3.8)
Lionshead	0.73	(0.18)	13.0	(4.4)	42.5	(15.2)	46.2	(5.1)
Riverside	0.64	(0.16)	21.1	(6.7)	61.3	(15.5)	44.9	(6.8)
Bootleg	0.62	(0.11)	-	-	-	-	54.4	(2.6)
Total	0.67	(0.14)	17.1	(6.8)	57	(17)	47.9	(6.1)

Water Repellency (MED)

Field measurements of water repellency were collected under varying ambient conditions including different antecedent precipitation and relative humidity across the field campaigns. Consistent with other findings, higher ambient moisture and soil moisture levels strongly decreased both surface (Figure 7A) and subsurface (Figure 7B) water repellency in the field compared to measurements collected in the lab (Figure 9). This relationship was significant for all collection sites, however shallow (1-3 cm) water repellency was more strongly related the soil moisture content than deeper (3-5 cm) repellency samples.

Soil texture significantly affected the relationships between soil water content and water repellency (Figure 8). Clay loam and silt loam samples were most affected by existing soil moisture within the shallow depths, while loam and sandy loam samples were generally less affected. Similar trends appeared for the deeper samples, however there was a much higher degree of variability.

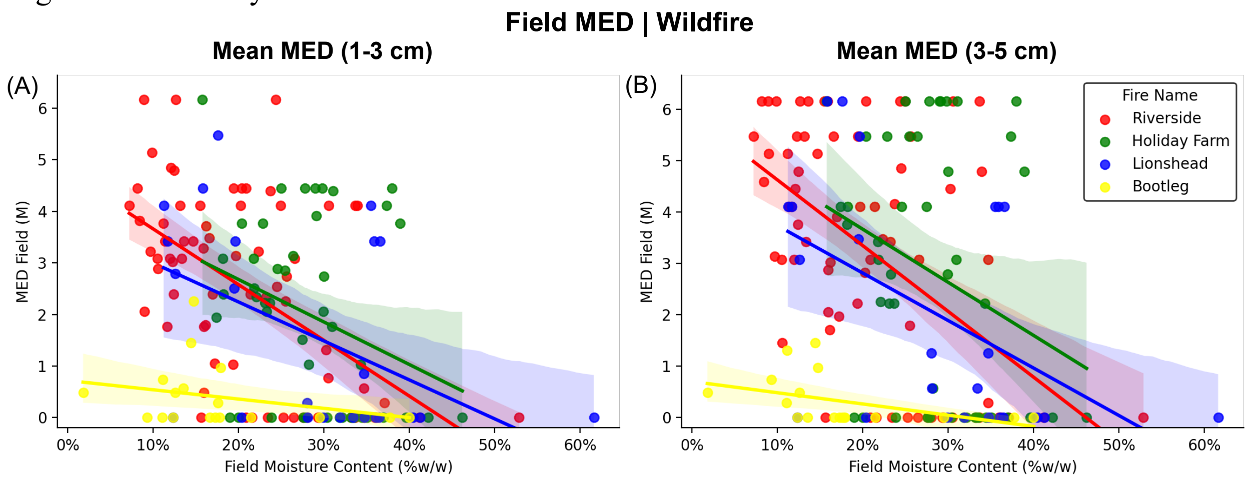


Figure 7 Mean shallow (1-3 cm) and deep (3-5 cm) field soil water repellency (MED) samples by wildfire site affected by soil moisture content.

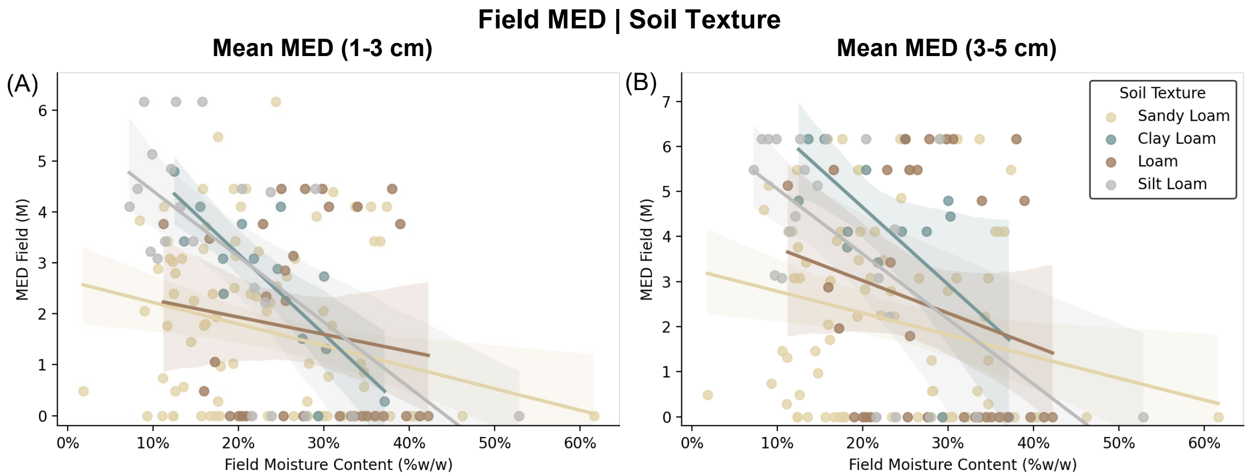


Figure 8 Mean shallow (1-3 cm) and deep (3-5 cm) field soil water repellency (MED) samples by major soil texture class affected by soil moisture content.

Despite a major effect due to the soil moisture content during sampling, field values of water repellency were generally well correlated to the lab-dried estimate when averaged over the surface 0-3 cm depths (Figure 9).

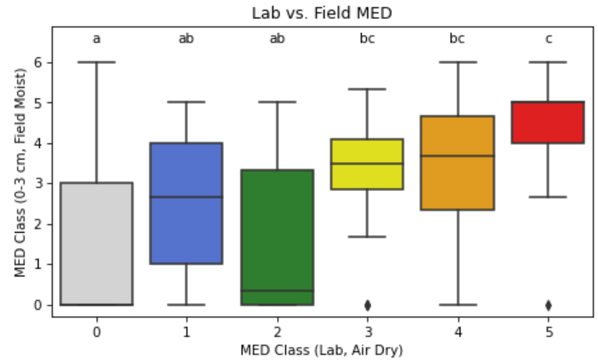


Figure 9 Range of field-based MED values that fall within the same grouping measured in the lab setting.

Water repellency was also significantly correlated to organic content (LOI) for sites in moderate to high soil burn severity (SBS) plots, however this was not the case for low SBS plots (Figure 9). Overall, water repellency was only correlated with dNBR (remotely-sensed) for the finer-grained silt loam and clay loam soils, but not for loam or sandy loam soils (Figure 10A). Organic content (LOI) was significantly correlated to water repellency for all soil textures (Figure 10B).

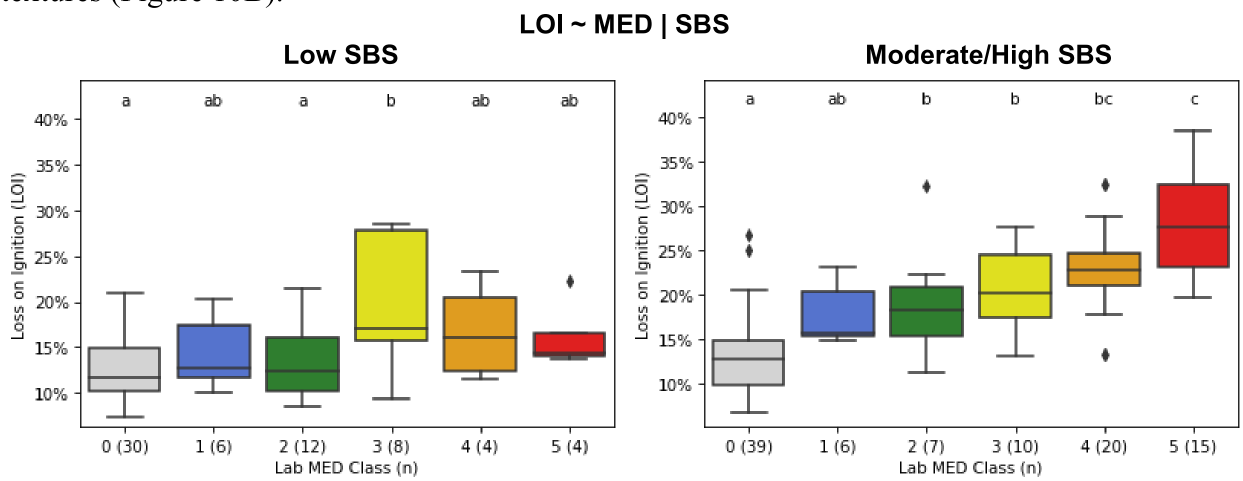


Figure 10 Loss on ignition (LOI) grouped by water repellency class (MED) for sites with low and moderate/high soil burn severity (SBS).

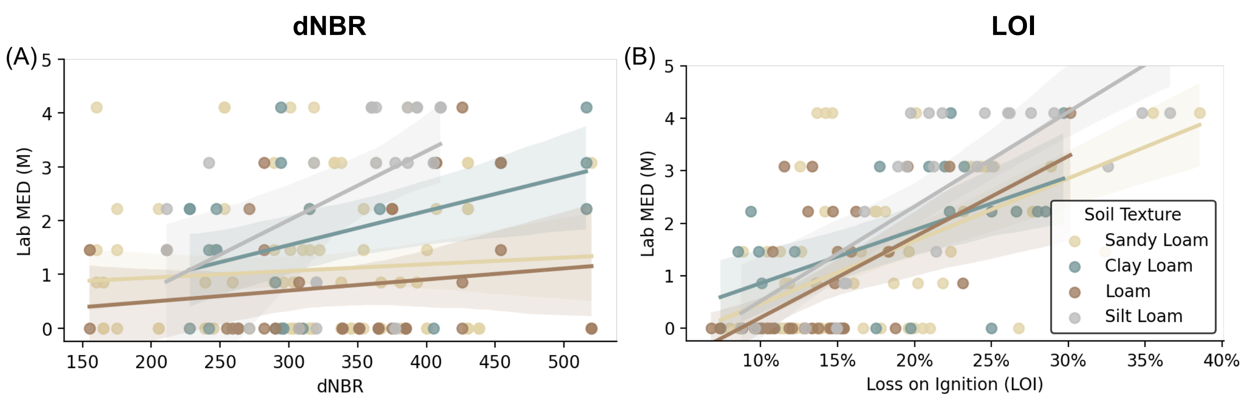


Figure 11 Water repellency (MED) under laboratory conditions grouped by major textural classes against dNBR (A) and organic matter content from loss on ignition (B)

Hydraulic Conductivity

Tension based hydraulic conductivity was significantly reduced for higher MED samples (Figure 13). These relationships also persisted under ponded conditions, while the variability in the relationships between hydraulic conductivity and water repellency across soil textural classes decreased (Figure 14).

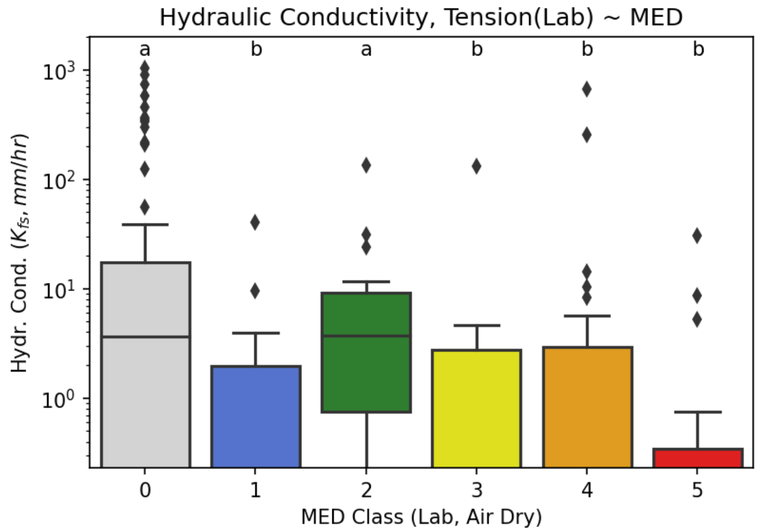


Figure 12. Lab Tension Hydraulic Conductivity for all cores against air dry MED class.

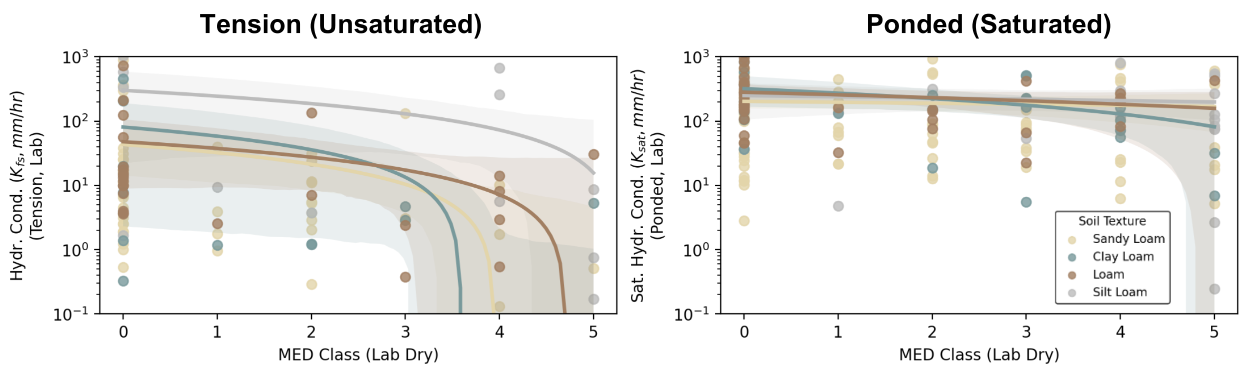
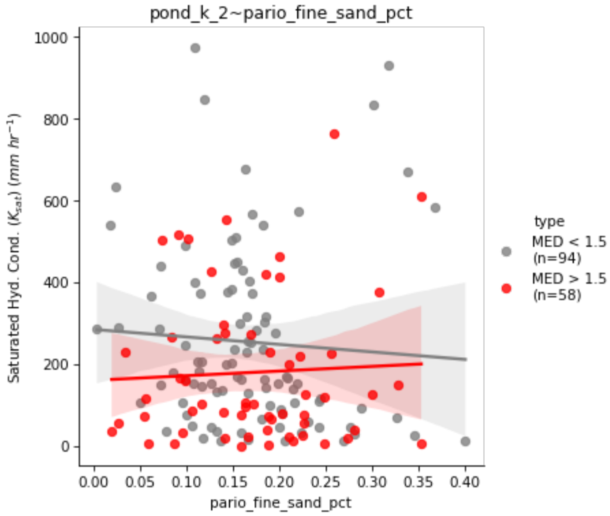
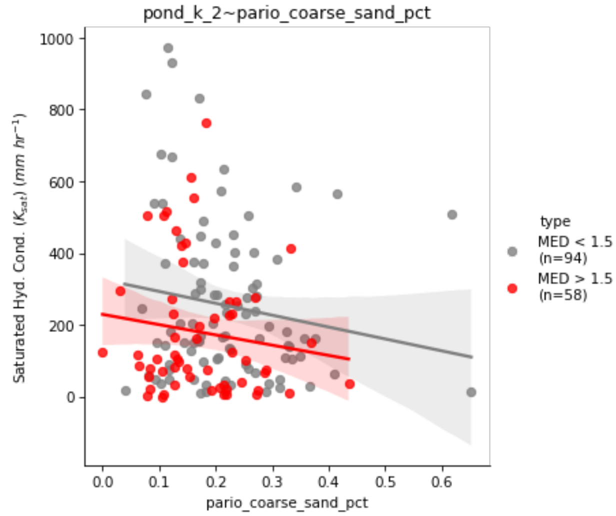


Figure 13 Tension (A) and Ponded Head (B) infiltration values using the cumulative infiltration method plotted against the sample MED value grouped by soil textural class. Note log scale on y-axis.

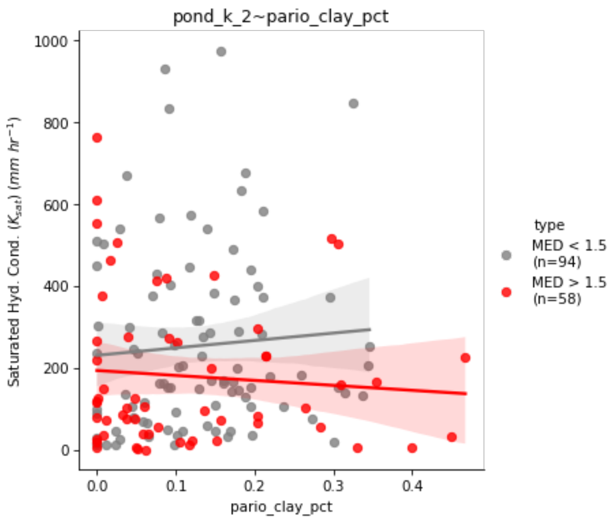
Lab Saturated Hydraulic Conductivity

Sand

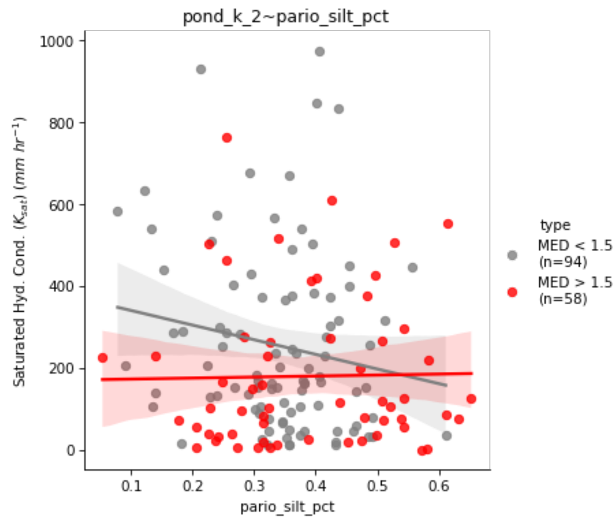




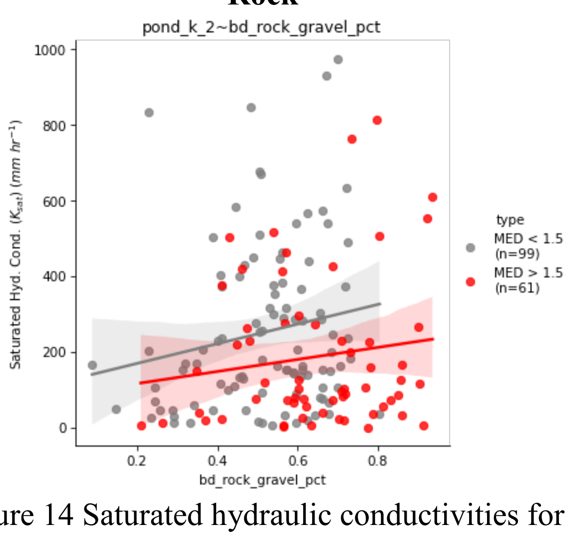
Clay



Silt



Rock



LOI

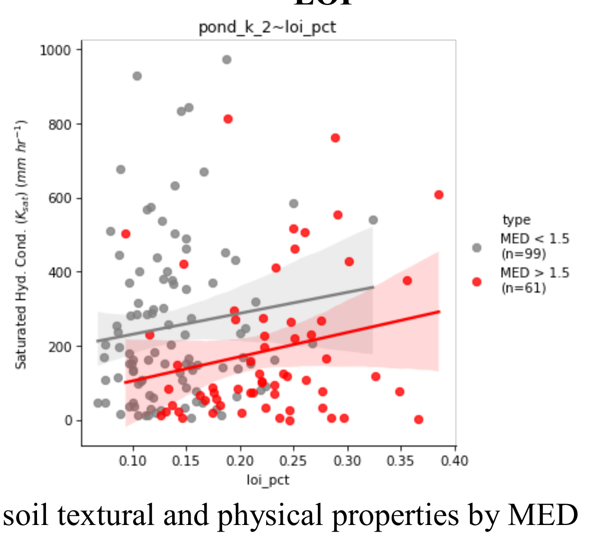


Figure 14 Saturated hydraulic conductivities for soil textural and physical properties by MED

Field Hydrauic Conductivity

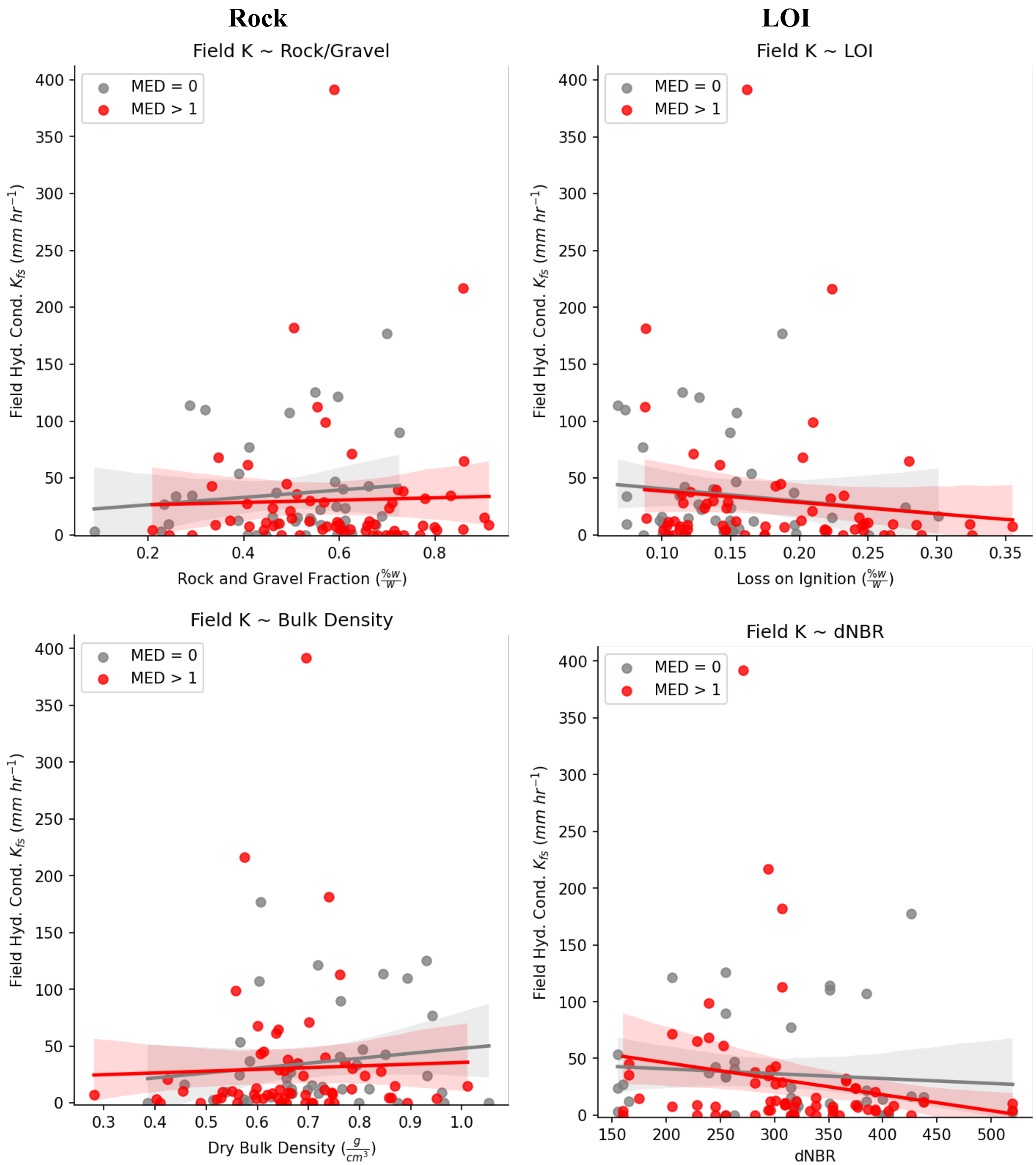


Figure 15. Field Hydraulic Conductivity against rock fraction, Loss on Ignition (LOI) organic matter fraction, bulk density, and dNBR, separated by field hydrophobicity

Sycan RxFire and Wildfire

Water Repellency (MED)

Similar to the Oregon 2020 wildfire samples, water repellency measurements collected across all burn statuses, unburned, prescribed burn, and wildfire, were heavily affected by the sampling soil moisture content (Figure 15). Lab measured MED showed to be most consistent compared to field measured values, however, for the prescribed fire samples, the MED values measured in the field were nearly double that of the lab measured values across the similar range of moisture contents.

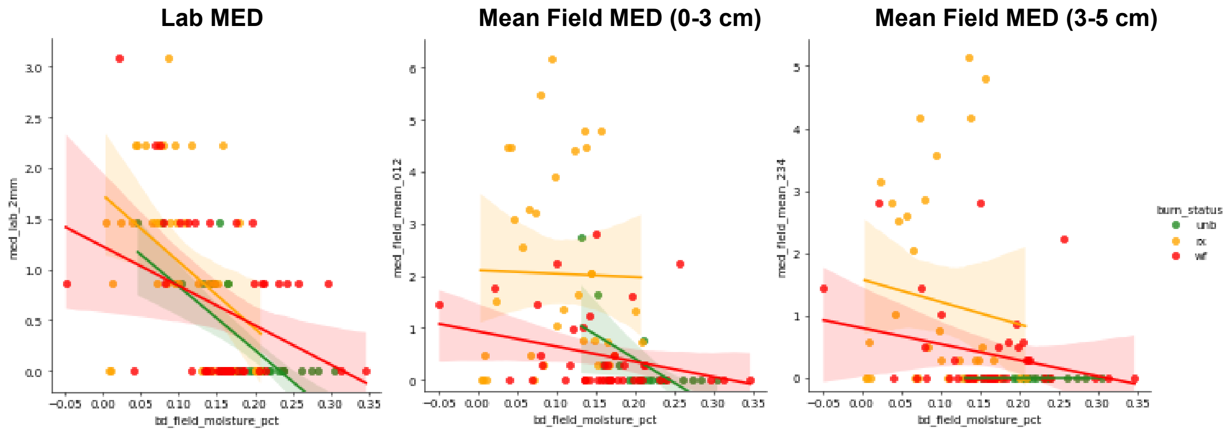


Figure 16 Water repellency against soil moisture during sampling for unburned, prescribed fire, and wildfire sampling periods.

Hydraulic Conductivity

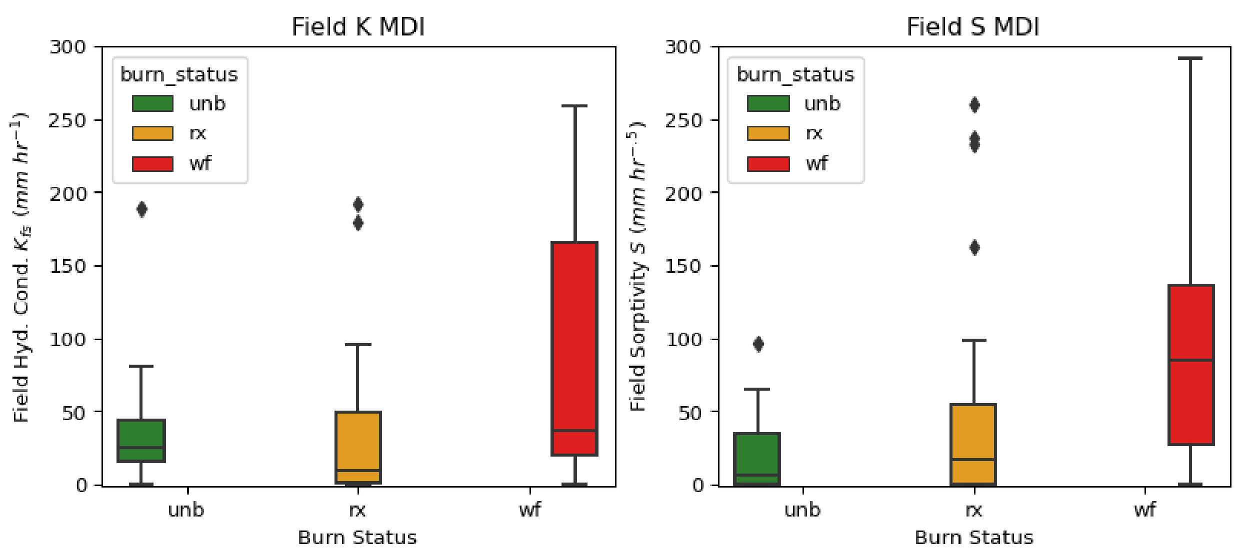


Figure 17 Field hydraulic conductivity and sorptivity for unburned, prescribed fire, and wildfire sampling periods.

Science Delivery Activities

The science delivery activities of this project to date are listed in other areas of the report (*Implications for Management*, below, and Appendices), so will be only briefly summarized here. The hydraulic property changes found in this study are already being preliminarily implemented in an ongoing modeling study to explore wildfire impacts to surface hydrology in the Oregon Cascades. The information learned about the responses of Sycan Marsh dry forest soils to both prescribed fire and wildfire has already been shared with the very interested land owner, The Nature Conservancy, which works to adaptively manage a wide variety of forest types while facilitating applied research, as well as several other types of scientists and managers also involved in prescribed and wildfire. Once results are mature and peer-reviewed, they will likewise be shared with the Fremont National Forest staff, the lands of which abut The Nature Conservancy's Sycan Marsh. Some of the methods and data from this work were shared with a new set of collaborators who reached out mid-project, from Colorado School of Mines, and became a portion of student Caroline Bedwell's MS thesis there (completed), in addition to contributing to expanding the Student Investigator's dissertation work. Project progress or preliminary results have been shared at five national/international earth science conferences or local/topical symposia (see Appendix B) and will be peer-reviewed and published in at least two journal manuscripts, in preparation. Metadata are being posted to the Forest Service Research and Development Data Archive as per required to close-out this project. The actual project data and data products/results are being backed-up to the CUASHI Hydroshare (NSF-supported & approved) public archive as they are developed, and will be released for public view once manuscripts have been peer-reviewed and accepted, or within the timelines specified by this and/or other related funding.

Conclusion

Key Findings

Findings from this study suggest several key takeaways useful for examining post-fire effects on surface hydraulics.

In the temperate rainforests of the western Cascade range, wildfire induced hydrophobicity is strongly controlled by several factors, with the most important correlate being residual sub-surface organic matter content. For field conditions, the degree of hydrophobicity at the surface shortly after wildfire is decreased with increasing soil moisture content, with volumetric moisture content above 35% reducing most hydrophobic effects within the top several centimeters. At deeper layers, this hydrophobicity-moisture content interaction is reduced, which may be an important factor for runoff, erosion, and debris flow generation in these very wet and often very steep terrains. Texture was found to play a significant role in moderating the hydrophobicity-moisture content interaction as well, with finer grained clay loam and silt loam soils promoting a stronger response.

In the wildfire-burned soils of these temperate rainforest hillslopes of the western Cascades, the degree of water repellency was a strong controlling factor when using any of the three methods of infiltration measurements used in this study, though not all samples exhibited repellency. When samples were hydrophobic, there was a significant lower range of infiltration rates. The strongest responses were found in clay loam and silt loam samples, however this effect was seen in all texture classes. Notably, for saturated infiltration values, hydrophobicity significantly decreased infiltration for all but sandy loam soils.

In the dry pine forests of the eastern Cascades foothills and northern basin and range, at Sycan Marsh's surrounding uplands, this study found that prescribed fire reduced infiltration rates only slightly. However, after subsequent reburning by a low-severity wildfire, infiltration rates increased. These infiltration findings were paralleled by hydrophobicity data after the prescribed fire, whereas only a few samples remained hydrophobic after the subsequent wildfire burn-over. In this case, repeated burning likely destroyed or reduced the degree of repellency.

Although the prescribed burning in the dry pine forest of Sycan Marsh uplands increased soil repellency and decreased infiltration, the magnitude of change was much lower than seen in the soils of the temperate rainforests of the western Cascades burned by the Labor Day fires. The prescribed burning of this type in this ecosystem is likely to not have promoted runoff generation in these typically well-drained soils. Still, higher repellency caused by prescribed fire in similar dry forest system could affect surface soil moisture dynamics, particularly if a forest stand is more on the marginal edge of moisture limitation such that a small infiltration reduction could be ecological consequential.

Implications for Management /Policy and Future Research

The integration of results from these new measurements with literature and existing practice/parameters to begin to develop transfer functions predicting post-fire soil hydraulic properties from pre-fire soil database and parameter values and minimal fire data is still in progress. These relations are intended for use to improve post-fire hydrology, erosion, and forest management modeling, as noted in the original proposal, but at this time require further work. The exceptional, if somewhat catastrophic, opportunities afforded by the Labor Day and Bootleg fires pushed more of the research effort during this project into field, and then extensive laboratory, work such that modeling is still ongoing now. The hydraulic property changes found in this study are already being preliminarily implemented in an ongoing modeling study to explore wildfire impacts to surface hydrology in the Oregon Cascades, however. These improvements will bolster the applicability of such models for this region, which has historically been understudied with regard to wildfire effects on hydrology, perhaps because of the longer fire return intervals in the wetter forest systems. However, when these wetter forests do burn, the greater accumulation of fuel over time and due to abundant moisture can cause them to burn extensively, hot, and catastrophically as mega-fires. With human expansion ever into the wildlands, and with climate change, continued fire, whether at still-long or now shortened return intervals should be expected in both the very wet and very dry forests, both exemplified in this study. Catching data and analysis on wet forest soils' responses to fire up to the more established field of dry forests' effects from fire is therefore an aim that might be well shared across the research community. Even in dry forests in which fire is beginning to be taken as more of a given, and prescribed fire rigorously applied, such as at Sycan Marsh, the information provided by this study or similar efforts can still be immediately useful to forest managers, who may have deeper backgrounds and connections in silviculture and forest ecology but may lack much data, or even exposure, to potentially relevant soils and geomorphology issues. The information learned about the responses of Sycan Marsh dry forest soils to both prescribed fire and wildfire has already been shared with the very interested land owner, The Nature Conservancy, which works to adaptively manage a wide variety of forest types while facilitating applied research, as well as several other types of scientists and managers also involved in prescribed and wildfire. Once results are mature and peer-reviewed, they will likewise be shared with the Fremont National Forest staff, the lands of which abut The Nature Conservancy's Sycan Marsh, to the degree that Fremont and Sycan prescribed fire teams even regularly work together across and on either side of the shared boundary and forest stands. Finally, ongoing in this work but of importance for the rest of this research community will be cross-comparison of results from various field and laboratory sampling and measurement methods as we (and others, increasingly) find that several common methods of quantifying hydrophobicity, or measuring infiltration, often give somewhat different results. Although some of these differences are reasonably attributed to known soil physics and mechanical differences in the measurements, others are less well understood, even as the wide variety of nature and functions of soil hydrophobicity, both before and after wildfire, are not utterly well resolved yet in the literature.

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Appendix A: Contact Information for Key Project Personnel

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Appendix B: Science Delivery Products

Articles in peer-reviewed journals
(* indicates SI and PI)

*Quinn, D.S., K. Sauerbray, C. Bienz, *K.B. Moffett. (*in preparation*) Prescribed Fire and Wildfire Effects on Soil Hydraulics and Infiltration Properties in a Dry Conifer Forest of the Eastern Cascades, Oregon

*Quinn, D.S., *K.B. Moffett (*in preparation*) Wildfire Effects on Soil Hydraulic Properties Across the Seasonal Temperate Rainforests of the Oregon Cascades.

Graduate Dissertation

*Quinn, D.S., Ph.D. Dissertation Chapters (*in preparation*)
- Wildfire Effects on Soil Hydraulic Properties
- Prescribed Fire Effects on Soil Hydraulic Properties

Conference and Symposium Presentations

*Quinn, D. S., *Moffett, K. B. (2022). Prescribed Fire Effects on Soil Properties at Sycan Marsh, Oregon. Oral presentation at the 2022 Sycan Science Gathering, Sycan Marsh, OR, 11-14 July 2022

From 11-14 July 2022, The Nature Conservancy, Oregon, hosted a three day gathering of practitioners and researchers interested in wildfire and prescribed fire in the Sycan Marsh Preserve.

Attendees and affiliations: TNC: Pete Caligiuri , Kerry Metlen, Darren Borgias, Katie Sauerbrey, Thomas Stokely, Craig Bienz, Sarah Ratay, Michael Case; USFS: Andrew Hudak; WA DNR: Derek Churchill; UW: Van R. Kane, C. Alina Cansler, Astrid Sanna; WSU: Dylan Quinn, Gordon Davies; UIdaho: Nuria Sánchez López, Ryan McCarley; PSU: Cody Evers

*Quinn, D. S., *Moffett, K. B., Bienz C., Sauerbray K. (2022) Prescribed Fire and Wildfire Effects on Soil Hydraulics and Infiltration Properties in a Dry Conifer Forest of the Eastern Cascades, Oregon, Poster presentation at the 2022 AGU Fall Meeting, Chicago, IL, Dec. 2022

*Quinn, D. S., *Moffett, K. B. (2021). Wildfire Effects on Soil Hydraulic Properties in the Western Cascade Range: Impacts from the 2020 Riverside, Lionshead, Beachie Creek, and Holiday Farm Fires. Poster presented at the 2021 AGU Fall Meeting, New Orleans, LA, 11–15 Dec. 2021

Bedwell, C., Roth, D., McCoy, S., Cavanaro, D., Delgado N., *Quinn, D. S., *Moffett K. B., Rengers, F., Perkins, J., Prancevic, J. (2021). Variability in Post-Wildfire Soil Hydraulic Properties Related to Local and Regional Climatological, Geological, and Burn Characteristic Factors. Poster presented at the 2021 AGU Fall Meeting, New Orleans, LA, 11–15 Dec 2021

*Quinn, D. S., *Moffett, K. B., Bienz C., Sauerbray K. (2020) Prescribed Fire Effects on Soil Hydraulics and Infiltration Properties in a Dry Conifer Forest of the Eastern Cascades. Poster presented at the 2020 WSU Vancouver Graduate Research Symposium, 21 Feb 2020.

Appendix C: Metadata

Metadata Description

Data and metadata are stored in the CUAHSI Hydroshare Repository and will be accessible at following sites:

Quinn, D., K. Moffett (2022). Oregon 2020 - 2021 Wildfire Effects on Soil Hydraulic Properties, HydroShare, http://www.hydroshare.org/resource/6f1b4be078c641a99db9c0d4e8cf3ed9

Quinn, D., K. Moffett (2022). Sycan Marsh - Fire Effects on Soil Hydraulic Properties, HydroShare, http://www.hydroshare.org/resource/d8cfa2bf051c4a19b4845bc771c6cc03

Concurrent with publication in a peer reviewed journal, these resources will be assigned a permanent DOI and publically released, or at the time required by this or other related funding, whichever is sooner.