Final Report to the California State Board of Forestry and Fire Protection Monitoring Effectiveness Committee

EMC -2018-003 Alternative Meadow Restoration

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Executive Summary:

The goal of the EMC -2018-003 Alternative Meadow Restoration project was to test the effectiveness of meadow and wet area restoration as an alternative to watercourse and lake protection (WLPZ) rules; as specified in 14 CCR § 933.4 [e] of the California Forest Practice Rules (FPR). The project quantifies the hydrologic response, water quality, and soil disturbance before and after timber harvest operations on three meadows in Northern California following removal of WLPZ vegetation and encroached *Pinus contorta* in historic meadow habitat.

The meadows: Marian Meadow (MM), Control Meadow (CM), and Rock Creek Meadow (RCM) were studied using a before, after, control, intervention (BACI) study design. The meadows are located on private timberland owned and managed by the Collins Pine Company. MM and CM have been paired in a study beginning in the 2014 water year continuing to the present. RCM and MM were paired with monitoring beginning in RCM in the 2019 water year. MM and RCM had encroached *Pinus contorta* removed in 2016 and 2020 respectively to restore meadow habitat, including removal of all trees within the watercourse and lake protection zone (WLPZ). In 2021, the Dixie Fire impacted the meadows and surrounding watersheds adding an unplanned disturbance to the study.

Hydrologic conditions of increased groundwater and soil moisture were found to be improved toward restoring meadow habitat. These increases were nuanced by wet and drought water years, soil, and varied spatially due to differing physical conditions. Herbaceous vegetation was observed to have an increase in facultative wetland plant percentage and diversity indices by the second year following restoration in wetter areas of RCM. In the drier area of RCM, greater disturbance from ground yarding activities and fire roads appeared to limit the meadow vegetation recovery.

Within the WLPZ, no increase in soil compaction was measured following the forest harvest. Forest practice rule 14 CCR § 933.4 [e] allowed the removal of the class I WLPZ forest vegetation during meadow restoration. However, WPLZ equipment operations were still limited within the WLPZ. The limitations included only allowing equipment trails perpendicular to the watercourse, keeping equipment off of stream banks, and keeping the density of trails in the WLPZ to a minimum. The soil cover in the WLPZ was found to be slightly disturbed, 15.3% of soil cover disturbed, by the logging equipment during removal of the encroached *Pinus contorta*. The percentage of equipment disturbance was reduced by 4% in the 2nd year following harvest operations, compared to the 1st year, from vegetation recovery of the disturbed soil cover. However, the amount of disturbed soil cover increased to 32.5% in the 2nd year following treatment primarily due to loss of vegetation cover, 21.2%, from the Dixie Fire.

Stream water temperatures below the harvest area increased by 2-3 degrees Celsius in the summer following WLPZ forest vegetation removal. Stream water temperatures had a similar increase, compared to before WLPZ removal, following the Dixie Fire. However, stream water temperatures were elevated by the same amount above the project site due to loss of riparian canopy from the fire. Stream particle size distribution and cobble size particle embeddedness increased, while pool residual depths and percentage of habitat decreased following the meadow restoration operations and Dixie Fire.

Introduction

This project monitored the effectiveness of 14 CCR § 933.4 [e] of the California Forest Practice Rules (FPR), which states:

> All trees within aspen stands (defined as a location with the presence of living aspen *Populus tremuloides*), meadows and wet areas may be harvested or otherwise treated in order to restore, retain, or enhance these areas for ecological or range values.

14 CCR § 933.4 [e] (5) requires that the project proponent state explicit goals and measures of success for restoration. Furthermore, 14 CCR § 933.4 [e] (7) states that a monitoring report every 5 years to the State Board of Forestry and Fire Protection (BOF) regarding the effectiveness of the rules in achieving the desired outcome(s) and the occurrence of post-harvest adverse environmental impacts resulting from the use of the Rule. This report will provide the BOF with findings regarding Rule effectiveness for restoring meadows and wet areas within 3 meadow systems in and around Plumas County, California.

The project is related to the EMC Strategic Plan, Theme 1: Watercourse and Lake Protection Zone (WLPZ) Riparian Function. Specifically, it addresses the critical question of whether 14 CCR § 933.4 can be effective in maintaining and restoring water quality while limiting soil disturbance.
The project quantifies the hydrologic response, water quality, and soil disturbance before and after meadow restoration across three meadows in Northern California following removal of encroached *Pinus contorta* (lodgepole pine) within historic meadow habitat and WLPZ of the meadows. The final year of the project unexpectedly included the effect of the Dixie fire on the meadow restoration.

Goal and Objectives

The goal of the EMC -2018-003 Alternative Meadow Restoration project was to test the effectiveness of meadow and wet area restoration as an alternative to watercourse and lake protection (WLPZ) rules. The project included evaluation of the effect WLPZ removal had on water quality and soil disturbance before and after meadow restoration on meadows in Northern California.

The monitoring of the meadow restoration allowed by FPR 933.4 [e] was guided by the following objectives:

- Objective 1. Quantify the hydrologic and vegetative response from removal of encroached *Pinus contorta* to restore meadow and wet area habitat across varied locations.
- Objective 2. Determine if key water quality metrics are affected by meadow restoration and WLPZ removal in Rock Creek Meadow by evaluation of streambed sediment and stream temperatures within or downstream of the restoration site.
- Objective 3. Quantify the amount of soil disturbance and compaction within the WLPZ and meadow following meadow restoration.

Instream habitat restoration activities, coupled with the timber harvest plan for Rock Creek Meadow restoration, but not part of this study documented a few conflicts for consideration (detailed in Appendix B).

Background and Justification:

Meadows serve several valuable hydrological and ecological functions integral to the maintenance of healthy ecosystems such as promotion of faunal and floral biodiversity and increased late season base flow (UC Davis, 2007). Meadows in the Sierra Nevada and Cascades face a myriad of threats, including overgrazing, habitat degradation associated with recreation, fire prevention/regime alteration, residential/ commercial development, and habitat fluctuations tied to climate change (Stillwater Sciences, 2012). Degradation of meadow habitat generally manifests itself in the form of a reduction in seasonal soil moisture content, a decreased water table, a loss of endemic meadow species, and the influx of pioneer vegetation such as conifers and xeric plant species.

Historically, fires in the western United States occurred more frequently and at a lower intensity than today. In a review that synthesized multiple studies from across the Sierra Nevada, it is estimated that the pre-1900 fire return interval for red fir, mixed conifer-fir, mixed conifer-pine, and pine forests types were 26, 12,15, and 11 years, respectively (Skinner and Chang, 1996). These small, low intensity fires, often started by lightning strikes or Native Americans, resulted in a spatially complex pattern of montane meadows that had limited net conifer encroachment (Norman and Taylor, 2003). However, due to fire suppression polices that were implemented in the early 20th century, it is estimated that the fire return intervals of these forest types are now 1,644, 644, 185, and 192 years respectively (McKelvey et al., 1996). In a study that assessed the fire interval directly adjacent to meadows in northeastern California, it was estimated that the mean fire interval from 1750 to 1849 was 13 years. From 1850 to 1905, it was determined that the mean fire interval was 19.6 years, and from 1906 to 1996 it was determined that the mean fire frequency was 333 years (Norman and Taylor, 2003). The effects of fire suppression on conifer establishment within meadows is believed to be amplified by historical grazing practices, especially during the first wave of accelerated conifer encroachment in the early 20th century.

Conifer encroachment (also frequently referred to as invasion) is a blanket term for movement of conifers into meadow biotic communities. Depending on elevation, and geomorphic position, *Pinus contorta* may colonize wet meadows opportunistically during times of drought to avoid plant water stress (Gross and Coppoletta, 2013). During wetter and colder periods, soil water may act as a limiting factor on the expansion of most conifer species into wetlands and meadows due to their intolerance for prolonged saturation in their root zone. Conversely, successful recruitment of trees into dry/mesic meadow habitats has been related to the onset of wetter summers and discontinuation of sheep grazing (Miller and Halpern, 1998).

Increasingly forest restoration treatments are done in conjunction with timber harvest in California. Efforts to promote and simplify permitting for forest restoration will benefit private forest landowners through efficiencies and cost reductions, but also incentivize the restoration by providing environmental mitigations for forest management. Understanding how exceptions, such as 14 CCR § 933.4 [e] of the California Forest Practice Rules, can be best implemented is useful for long term management of California's timber lands.

Methods

Study Areas

There were three meadows used in the study: Marian Meadow (MM), Control Meadow (CM), and Rock Creek Meadow (RCM) (Table 1; Figures 1-3). The meadows are located within Lassen and Plumas Counties in the Collins Pine Almanor Forest (CPAF) owned by the Collins Pine Company. The three meadows are considered dry meadows based on its observed hydrology and vegetation according to the classification system devised by Weixelman et al. (2011), although mesic (wetter) meadow conditions exist along RCM's riparian corridor and in openings near the stream; the western portion of RCM. Dry meadows occur where the main source of water is precipitation or runoff with groundwater generally deeper than 1 m for most or all the growing season. Vegetation for dry meadows is typically comprised of grasses, dryland sedges, and dryland rushes (Weixelman et al., 2011). All three meadows were encroached primarily by *Pinus contorta* (lodgepole pine) with basal areas ranging from 109-127 ft^2/acre prior to restoration for MM and RCM (Table 1). The forest surrounding the meadows were composed of mixed conifer species. The mixed conifer species include *Pinus ponderosa, Pinus jefferyi, Pinus monticola, Pinus contorta, Psuedotsuga mensiezii, Calecedrus decurrens,* and *Quercus velutina*. The meadows are in a transitional zone between the Cascade and Sierra Nevada Mountains, USA (Figure 1). The average annual precipitation recorded at Chester, California, USA was 975 mm (38.4 in). Precipitation is a mix of rain and snow. The mean summer air temperatures are 27 ^{o}C (80 °F) and mean winter temperatures are -6 ^{o}C (21.4 °F). Soils in the meadows are derived primarily from volcanic parent material with some alluvial material of mixed rock types (Soil Survey Staff, 2020) (Table 1). RCM is the largest meadow and had two distinct soil and soil moisture regimes. The road that runs through the main body of the meadow (Figure 3) generally divides a drier eastern portion from a moister western portion closer to the watercourse.

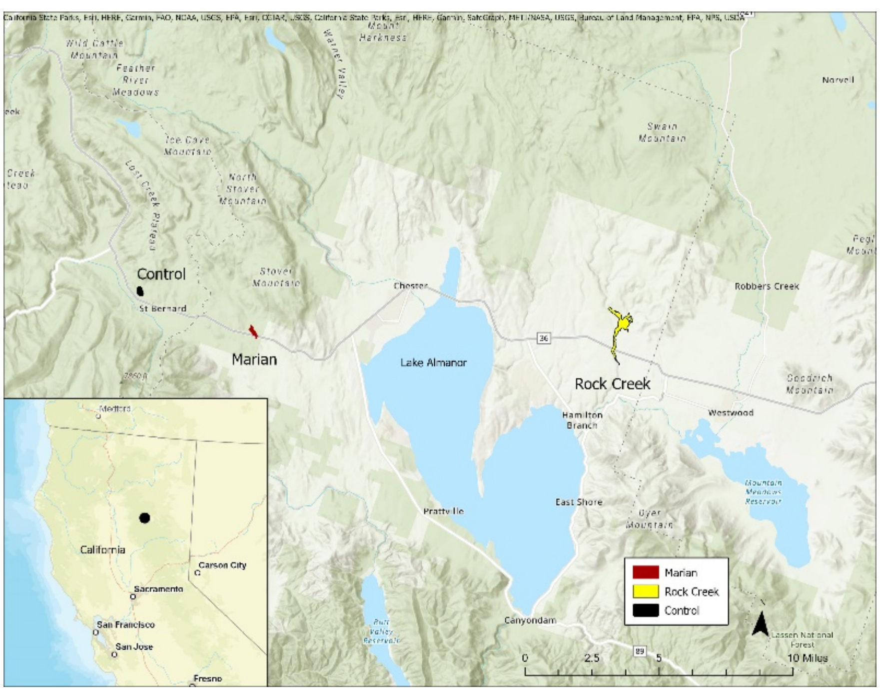


Figure 1. Locations of the three study meadows, for effectiveness monitoring of meadow restoration 933.4 [e] FPR, near Chester and Lake Almanor, California. The Meadows are on land owned by the Collins Pine Company.

Study Design

This study used a before, after, control, intervention (BACI) study design. There were two pairs of control intervention areas used. MM and CM have been paired in a study beginning in the 2014 water year continuing to the present. RCM and MM were paired as part of the research associated with this funding with monitoring beginning in RCM in the 2019 water year. Previous research had established that MM hydrology had stabilized following the 2016 restoration (Surfleet et al., 2020). Evaluation and comparison of groundwater and soil moisture time series showed a similar relationship between MM and RCM, a better relationship than RCM and CM.

Meadow Pair 1:

MM and CM are located adjacent to Highway 36 approximately 7 and 12 miles respectively west of the town of Chester, California (Figure 1 and 2). The meadows had soil moisture, groundwater, and climate measurement instruments installed in 2013. Encroached *Pinus contorta* trees were removed from approximately 45 acres of MM in fall 2015, at the start of the 2016 water year (Treatment) (Table 1). A Class III, intermittent watercourse, flows through MM. Forest thinning of approximately 10-15% of the forest volume in the watershed above MM occurred from 2016-2017. However, no hydrologic change was detected in MM due to this low level of forest thinning (Fie, 2018; Surfleet et al., 2020).

Table 1. *Characteristics of Marian Meadow, Control Meadow, and Rock Creek Meadow based on soil survey data (Soil Survey Staff, 2022).*

	Marian Meadow	**Control Meadow**	**Rock Creek Meadow**
Coordinates (latitude and longitude)	40.2636 N 121.3157 W	40.2639 N 121.3945 W	40.329 N 121.088 W
Area of meadow	111 ha (45 ac)	49 ha (20 ac)	457 ha (185 ac)
Area of contributing watershed (mi^2)	1943 ha (7.50 mi^2)	233 ha (0.9 mi^2)	6735 ha (26.0 mi^2)
Elevation (ft)	1375 m (4500 ft)	1465 m (4800 ft)	1525 m (5000 ft)
Surface soil texture (%sand-%silt-%clay)	Clay (32-26-42)	Clay Loam (47-16-37)	*West side: Loam (31-44-25) *East side: Gravelly Sandy Loam (50-37-13)
Pre-restoration *Pinus contorta* basal area	25 m^3/ha (109 ft^2/ac)	-	*West side 29 m3/ha (127 ft^2/ac) *East side 25 m^3/ha (109 ft^2/ac)

*Soil moisture and groundwater is higher in the western portion of the meadow compared to the eastern portion because of its proximity to Rock Creek watercourse and shallow confining layer of the groundwater aquifer.

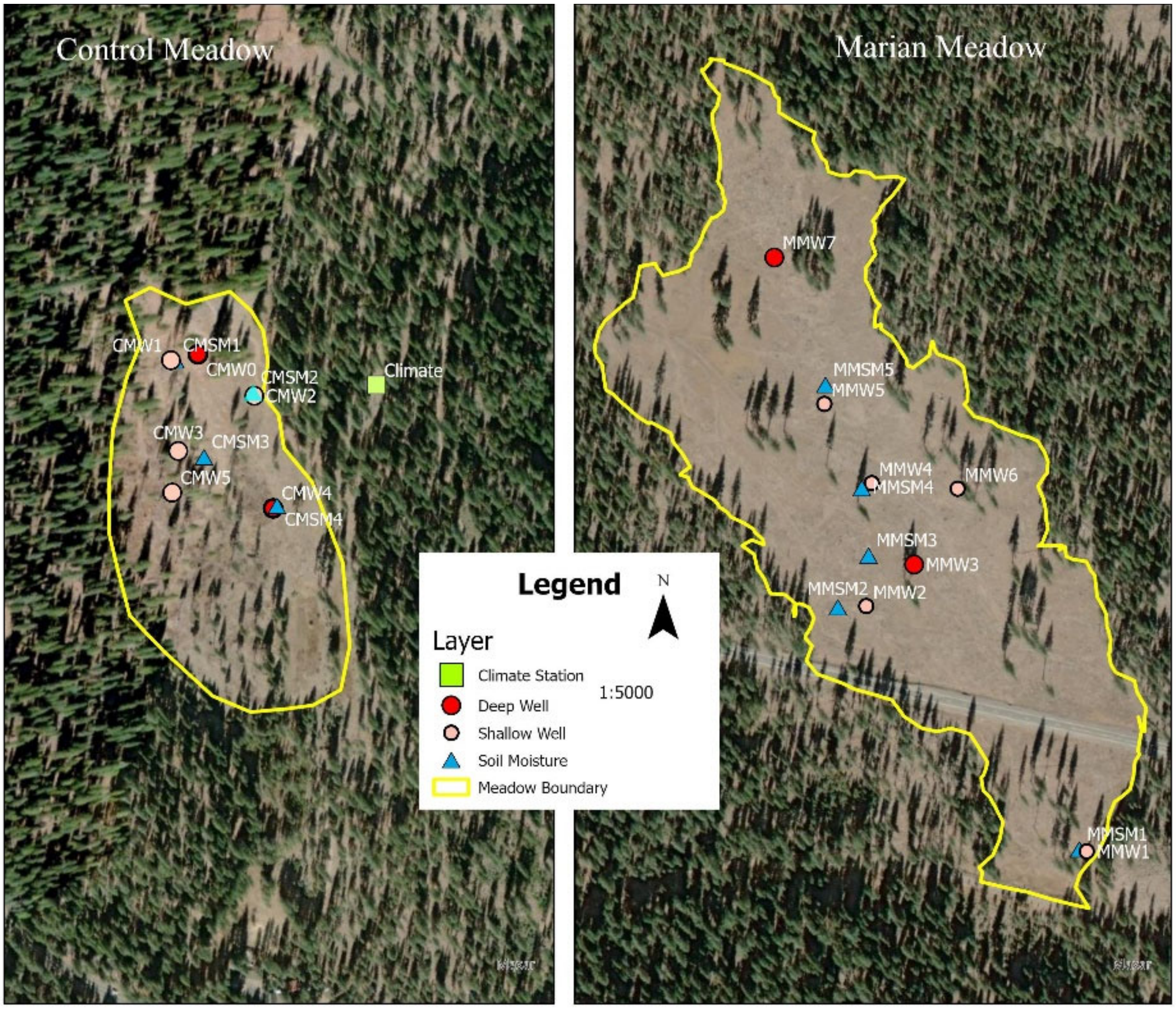


Figure 2. Control Meadow (left plate) and Marian Meadow (right plate) instruments and boundaries.

Meadow Pair 2:

The control for RCM (Figure 3) was MM, within 15 miles of RCM (Figure 1). Previous research had established that MM hydrology had stabilized following the restoration (Surfleet et al., 2020). Evaluation and comparison of groundwater and soil moisture time series between RCM, MM, and CM showed a similar relationship of groundwater response and recession between MM and RCM. RCM had soil moisture, groundwater, and climate measurement instruments installed in 2019. RCM underwent restoration by removal of *Pinus contorta* beginning in August 2020. The majority of the *Pinus contorta* was removed from RCM during fall 2020, including around the measurement locations used in this study. A small portion of the RCM conifer removal, not in the primary study area, was completed during summer 2021 (Treatment).

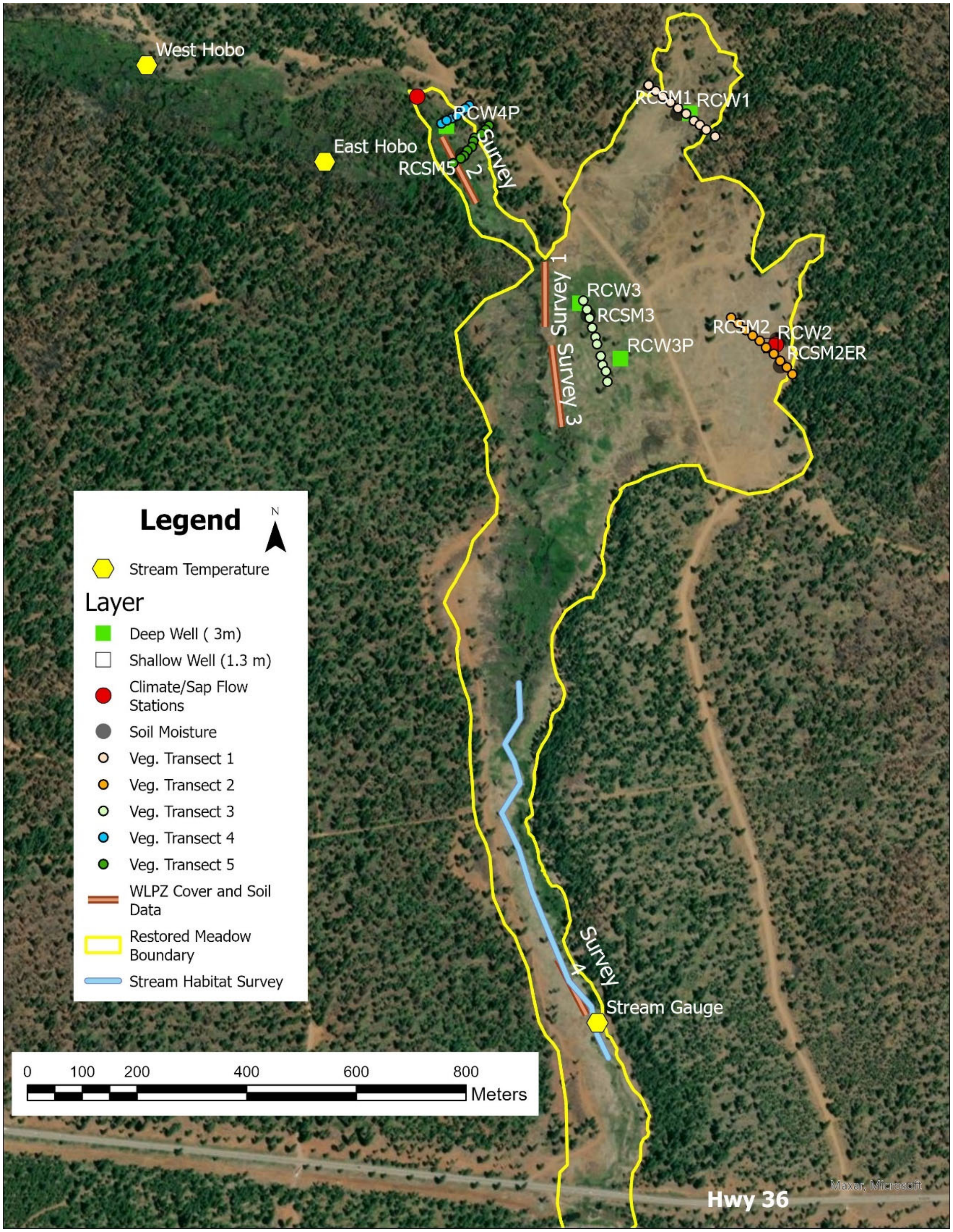


Figure 3. Rock Creek meadow restoration area with hydrologic instrument, vegetation transects, sap flow, soil disturbance survey, and stream habitat survey locations. The satellite base map is showing completion of the Pinus contorta removal. The drier eastern portion of the meadow is in the north east part of the meadow east of the access road, where transects and instrument sites 1 and 2 are located.

Dixie Fire:

In the summer of 2021, the Dixie Fire burned through and around the three study meadows (Figure 4). This event had varied effects on vegetation of the study meadows and contributing watersheds. Wildfire and the resulting consumption of forest and understory vegetation will likely influence meadow hydrology. This impact was an unexpected change to the study design. The percentage of moderate and high burn severity in the watershed above each meadow is shown (Table 2). MM and RCM and their respective surrounding watersheds were impacted, while CM had a low percentage of fire effect.

Table 2. Description of burn severity in the watershed and meadow vegetation from the Dixie Fire to study meadows.

Meadow	Watershed Contributing Area km^2 ($mile^2$)	Percentage Moderate and High Burn Severity in Watershed	Meadow Vegetation Post Fire
Marian Meadow (MM)	19.4 (7.5)	87%	Moderate to high burn severity in the meadow
Rock Creek Meadow (RCM)	67.3 (26)	48%	Patches of burned vegetation with varied burn severity.
Control Meadow (CM)	2.3 (0.9)	3%	No meadow vegetation burned.

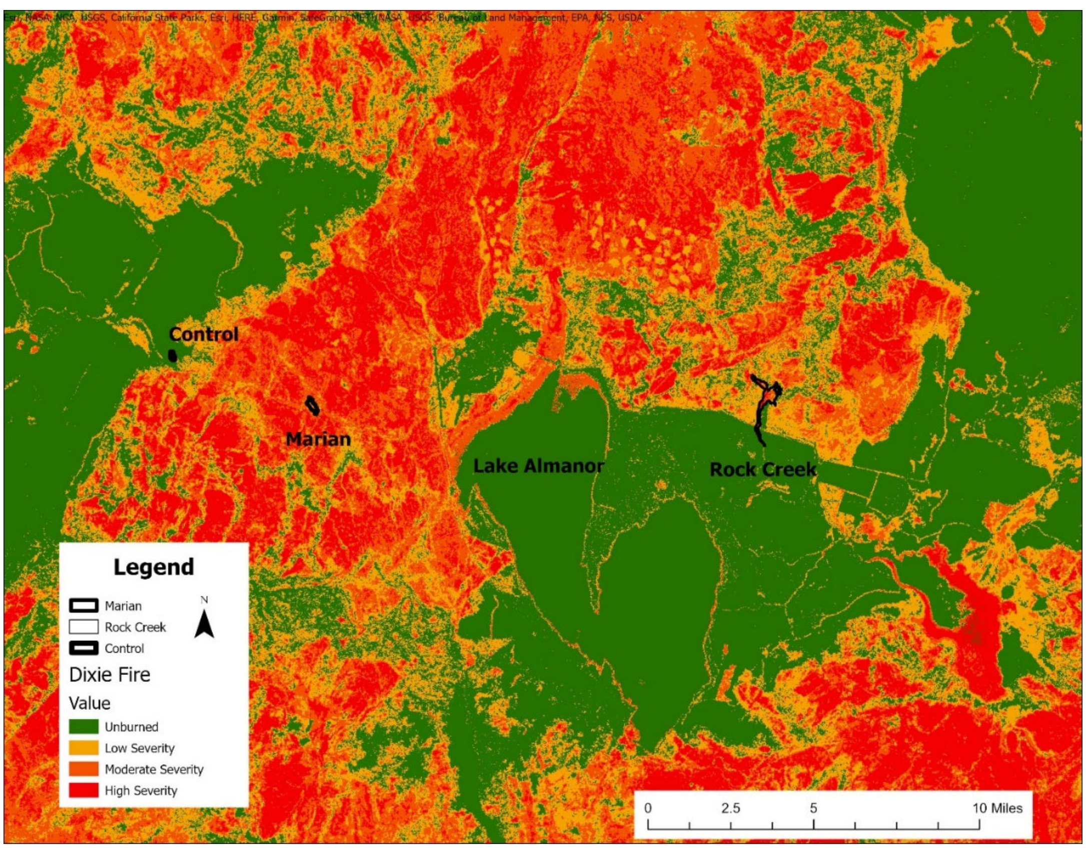


Figure 4. Soil burn severity for the Dixie Fire in area around the research meadows.

Figure 5. Patches of burnt meadow vegetation in Rock Creek Meadow from the Dixie Fire. Notice the stumps in the right photo from the Pinus contorta removal. Photo taken one month after fire, September 2021.

Figure 6. Left photo shows moderate to high burn severity adjacent to data logger case for soil moisture measurement in Marian Meadow. The right photo shows the remains of our sap flow instruments in Rock Creek Meadow, this was one of the few instruments that were a total loss. Photo taken one month after fire, September 2021.

Methods to Meet the Research Objectives:

Objective 1. Quantify the hydrologic and vegetation response from removal of encroached Pinus contorta to restore meadow and wet area habitat across varied locations.

Soil Moisture and Groundwater Response

We monitored volumetric soil water content (VWC), groundwater depth (GWD), and climate at RCM, MM, and CM. VWC was monitored at five locations in RCM (Figure 3), four- five locations in MM and CM (Figure 2). In 2014 MM and CM had five VWC measurement sites each at 30 cm, then changed to four VWC in 2019 at depths of 10, 30, and 100 cm. Initially, Odyssey soil moisture sensors were used. Over time, Onset TDR soil moisture sensors were added to increase the distribution and reliability of measurements. Both instruments were calibrated prior to use. By 2019 only Onset TDR soil moisture sensors were used in MM and CM. In RCM a mix of Onset TDR soil moisture sensors and SoilVUE 10 (Campbell Scientific, Logan, UT, USA) were deployed in 2019. The VMC using Onset soil moisture sensors were located at RCSM1 and RCSM5 at depths of 10, 30, and 100 cm (Figure 3). The SoilVUE soil moisture sensors were located at RCSM2 and RCSM3 measuring VWC at 9 depths from 5 -100 cm in depth. Due to calibration and manufacturer firmware problems, the SoilVUE 10 measurements are not considered reliable until after 2020.

Water level loggers (Odyssey Dataflow Systems Pty., Christchurch, New Zealand) were installed within 1.5 m wells, shallow wells. There were seven shallow groundwater wells on Marian Meadow, and five shallow groundwater wells on the Control Meadow (Figure 2). In August 2018 two 3-m wells, deep wells, were installed at Marian and Control Meadows respectively instrumented with Onset U20L water level recorders. In 2018 the 1.5 m wells the Onset U20L water level recorders replaced the Odyssey water level loggers (Figure 2). At RCM three 3 m wells were installed at RCW1, RCW3, and RCW6. An additional 1.5 meter well was installed at RCW2. These wells used Onset U20L water level recorders. The RCW6 well was completely damaged during the forest treatment operation. The Plumas Corporation installed two 3 m wells at RCW4P and RCW3P and were used in this study (Figure 3). Water level in the Plumas Corporation wells were measured using Level TROLL 500 instruments (In-Situ Inc., Fort Collins, CO, USA).

Climate has been measured at CM and RCM using climate stations (Onset). The station at RCM was installed in 2019 and was equipped with sensors for air temperature, relative humidity, wind speed, wind direction, barometric pressure, precipitation, and incoming and outgoing shortwave solar radiation (Figure 3). At CM air temperature, relative humidity, wind speed, wind direction, barometric pressure, and incoming shortwave solar radiation are measured. Daily precipitation data for MM and CM were collected from the Chester, CA NOAA station (station ID USC00041700).

Standard least squared regression will be used to test changes in groundwater depth, volumetric soil moisture content between treated and control meadows for pre-restoration and post-restoration time periods. Differences in the slopes and intercepts of the regression relationships will be compared to determine if a change is detected.

Electrical Resistivity Imaging (ERI) is a non-invasive geophysical method that measures spatial variations (in one-, two, or three-dimensions) in the electrical resistivity properties of subsurface geologic materials. Subsurface electrical resistivity values can then be interpreted for geological material and state (e.g. saturated, clay-bearing) with experimentally derived values and knowledge of the local geology (Palacky, 2012).

Electrical resistivity tomography (ERT) surveys were used episodically to define the groundwater level across a broader spatial extent and evaluate for groundwater confining layers in MM, CM, and later in RCM. Electrical resistivity data is collected by inserting a profile (for two-dimensional data) or grid (for three-dimensional data) of electrodes approximately 0.5-1 foot into the ground. Electrical currents are applied to two electrodes, and voltages are recorded at other electrode pairs. The electrical current and voltage readings can then be converted to a value of electrical resistivity based on the geometry of the current and voltage electrodes (Mussett et al., 2000). By repeating the measurement for other current and voltage electrode pairs, spatial variation in the electrical resistivity parameter can be mapped.

A two-dimensional image at Marian Meadow was collected with the objective of determining if point measurements from groundwater wells represented a continuous depth across the meadow. Three-dimensional electrical resistivity data before and after tree harvesting was collected on July 8th, 2020 and July 9th, 2021 at RCM.

Pre-treatment Pinus contorta Transpiration by Sap flow

Sap flow was measured in two stands of *Pinus contorta* using three-probe configuration heat pulse velocity sensors (East 30 Sensors, Pullman, WA, USA) following the design described in Burgess et al. (2001) and in a Master of Science thesis by Simon Marks (2022). The probes were first installed in July, 2019 in a 25 m x 25 m plot in eastern RCM, adjacent to RC2SM (Figure 3). Within the plot eight lodgepole pine were selected for instrumentation capturing a range of diameter at breast height (DBH) (10 cm - 40 cm). The measurements collected in this eastern RCM are the primary sap flow data used for estimation of lodgepole pine transpiration for the larger meadow, prior to treatment. The probes were re-installed in western RCM, August 2020, with the purpose of providing validation data for the calibrated model. Transpiration was estimated through measurement of heat velocity from the sap flow sensors improved by thermal diffusivity calculations. Adjustments were made due to probe misalignment and tree wounding. For a complete description of these calculations see Marks (2022). Transpiration for the lodgepole pine was extrapolated to RCM, prior to lodgepole pine removal, by a tree survey in 10 random plots (25 m x 25 m) as part of a stratified random sampling design. The 10 sample random plots were equally allocated between two strata delineated in RCM; the meadow access road demarcated the border between east (drier) and west (wetter) strata (Figure 3). Soil moisture is typically higher and depth to groundwater lower in the western portion of the meadow compared to the eastern portion because of its proximity to Rock Creek watercourse. DBH was measured for all lodgepole pine in the 25 m x 25 m plots. Tree diameter at breast height (DBH) along with soil moisture measurements, for select plots, were used with a calibrated modified Jarvis-Stewart model to extrapolate transpiration estimates of lodgepole pine to RCM (Marks, 2022).

Meadow vegetation Response to Removal of Encroached *Pinus contorta*

There were 5 vegetation transects, traveling either through or by soil moisture and well measurement sites (Figure 3) in RCM. The plots at each transect were evaluated over two to three days from 2019-2023 in late June to early July, approximately the peak time of flowering to aid in plant identification. The data from 2019-2020 was prior to restoration, 2021-2022 following restoration. The 2023 data set was not evaluated for this report due to the reporting deadline of this contract. The transects were oriented to capture a transition from the upland, forested community at the meadow's edge to the forb/graminoid dominated community towards the meadow's center, particularly those associated with perennial and ephemeral waterways within RCM. The only transect to not run between the upland meadow edge and meadow is transect 3. Transect 3 runs parallel to Rock Creek on the west side of the access road. It is wetter here, and the transect follows a line between two monitoring wells. The length of the transects are variable, ranging from 70 m to 200 m, depending on the distance from the upland community at the meadow's edge to the watercourse. Each transect has 10 - 1 m^2 plots, established at even intervals. The interval between the 1 m^2 plots was determined by equally dividing the length of the transect after determining a randomly selected start location in the first 10% of the transect.

The transect start was monumented with a piece of rebar hammered into the ground and capped with a plastic cap for ease of relocating. A measuring tape was stretched between the transect beginning and end markers. The lower (in relation to the transect start) righthand corner of the plot was marked using a pin flag. Working in groups of two or three, the field team read each plot. In each plot all individual plant species were identified and relative percent cover by Daubenmire cover class was estimated. The Daubenmire cover classes of the ground covered by litter, rock, wood, or bryophytes were also identified by plot. Over-story tree cover was measured at each plot, if applicable, using a spherical densiometer. Data was entered from data sheets into excel spreadsheets, and plant identifications were quality controlled. Each plant identified to the specific level was assigned a wetland functional group based on the National Wetland Plant List Indicator Rankings (Table 1).

Table 1: Wetland Plant Indicator Status Definitions (USACE, 2021).

Abbr.	Indicator Status	Definition
OBL	Obligate	Almost always occurs in wetlands
FACW	Facultative Wetland	Usually occur in wetlands, but may occur in non-wetlands.
FAC	Facultative	Occur in wetlands and nonwetlands.
FACU	Facultative Upland	Usually occur in non-wetlands, but may occur in wetlands.
UPL	Upland	Almost never occur in wetlands.

Evaluation of vegetation characteristics by transect utilized the percentage of cover of plants for each wetland indicator. The distribution of wetland plant cover percentage for each transect was presented by a box and whisker plot by year. Plant characteristics were categorized by year of survey and separated by east and west portions of Rock Creek Meadow by indices of species richness, Shannon-Wiener diversity index, and Simpson diversity index.

Plant Indices Defined:

- Species Richness: The number of species in a defined region. Does not take into account the abundances of species.
- Shannon-Wiener Diversity: an index that measures biodiversity. It considers the number of species living in an area (richness) and their relative abundances. Better at capturing rare species.
- Simpson Diversity: an index that measures biodiversity. It considers the number of species living in an area (richness) and their relative abundances. Greater diversity, greater number. Weighted towards dominant species, not good for rare species.

Objective 2. Determine if a key water quality metrics are affected by meadow restoration and WLPZ removal in Rock Creek Meadow by evaluation of streambed sediment and stream temperatures within or downstream of the restoration site.

Stream Temperature Measurement and Evaluation in Rock Creek[1]

Stream temperature sensors were deployed upstream and downstream of the treatment area using hobo stream temperature probes (Onset). There were two stream temperature probes, East and West Hobo, placed upstream of the treatment area due to multiple channels of Rock Creek at this location (Figure 3). These measurements occurred during spring and summer when streamflow was present from 2018-2022. One stream temperature measurement occurred downstream of treatment area using

[1] Rock Creek was the only class I watercourse with streamflow beyond the winter precipitation events and snow melt.

a temperature measurement from a water depth recorder (Level TROLL 500 instrument; In-Situ Inc., Fort Collins, CO, USA) in Rock Creek for calculation of streamflow. Metrics of the seven-day rolling average of average daily stream temperature and maximum daily stream temperature were evaluated. The maximum weekly maximum temperature (MWMT) and maximum weekly average temperature (MWAT) were determined for each year with streamflow. This provided the ability to make comparisons between upstream and downstream temperatures before and after treatment.

Stream Sediment Change Detection

Streambed particle size, cobble embeddedness, pool to riffle percentages, and residual pool depth measurements occurred during the summer of 2019 before restoration and repeated the summer of 2022 approximately two years following restoration. The plan was to do the post treatment stream measurements in the summer of 2021, but Rock Creek had no surface water in that year due to low precipitation. The measurements selected provide metrics that can indicate accelerated erosion and subsequent sediment delivery to the stream channel.

A 2000-foot section of stream was evaluated at the downstream end of the Rock Creek meadow treatment. A random number between 0 and 500, in this case 397, defined the start point below the stream gauge in feet. Streambed particle size distribution was evaluated at 500, 1000, 1500, 2000 feet of this section of Rock Creek. At each location 100 particles were randomly selected using a random step-toe procedure. The particle size was determined by measurement of the intermediate axis (Leopold et al., 1964). The particle sizes for all four measurement sites were plotted into cumulative distribution curves for comparison. During the pebble count the percentage that each cobble sized particle (64 mm-256 mm) was embedded in the stream bed was determined. The distributions of the proportion of embeddedness pre- and post-treatment were used for comparison.

For the entire 2000-foot stream segment the length of pool and riffle habitats were measured. The total length of pool and riffle habitats allowed the calculation of percent pool and riffle habitats in the segment. At each pool the residual pool depth was determined. This was the maximum pool depth (the deepest location) minus the depth at the pool tail out or exit. These values were used for pre- and post-treatment evaluations of stream habitat change.

Objective 3. Quantify the amount of soil disturbance and compaction within the WLPZ following meadow restoration.

Soil Disturbance and Compaction in WLPZ

To determine the amount of ground cover disturbance in Class I WLPZ following the meadow treatments, line surveys of ground cover were used within the WLPZ before and after treatment. A total of four survey locations were used (Figure 3). The start points were randomly selected. At each start point three 500 foot transects were laid out parallel to the watercourse at 30 feet, 50 feet, and 70 feet from the bankfull channel edge. At one foot increments the ground cover was recorded as covered or bare soil. The following designations were given to the type of undisturbed or disturbed cover of soil (Table 3). A third category of burnt ground was added to quantify the impact on the WLPZ soil cover from the Dixie Fire. The relative contribution of each cover designation at the three distances from the watercourse were determined before treatment in 2019, the first year after treatment in 2021, and the second year after treatment and the summer after the Dixie Fire, 2022.

Table 3. Types of cover for undisturbed and disturbed soil

Undisturbed (fully covered)	Disturbed (uncovered)	Burnt
Vegetation	Equipment or vehicle tracks	Bare and scorched soil
Litter	Divots from tree yarding	Fire road – created for Dixie fire suppression
Rock or gravel	Road	
Bare soil from natural conditions		

Along each line transect (30, 50, 70 feet) soil bulk density samples were taken. There were two samples of topsoil of exact volume randomly sampled at undisturbed and two samples randomly sampled at disturbed soil on each of the three lines per survey site. At the collection point coarse organic material (litter) was brushed away. The soil samples were collected in a two-inch diameter by two-inch tall cylinder within a heavier metal cylinder hammered into the ground using a slide hammer (Art's Manufacturing & Supply Inc. (AMS), American Falls, Idaho). The soil sampled was approximately 2 inches below the ground surface. The soil samples were oven dried and weighed to determine soil bulk density (grams/cubic centimeter). The relative change in soil bulk density for disturbed and undisturbed soil were determined before and after the WLPZ disturbance from the treatment.

RESULTS AND DISCUSSIONS

Objective 1 Results: Quantify the hydrologic response from removal of encroached *Pinus contorta* to restore meadow and wet area habitat across varied locations.

Groundwater Response

The mean depth to groundwater and precipitation are shown for 2014-2022 water years (Figure 7). The depth to groundwater pre- and post-conifer removal was determined to be, on average, 0.06 m closer to the surface in Marian Meadow following the removal of encroached conifers (2016-2022 water years). Several water years had a larger increase in groundwater while select years had a decrease (Table 4).

The seven post-restoration years were statistically different compared to pre-restoration (Table 4). The slopes and intercepts of the different years varied providing some interpretations of the groundwater response. The post-restoration water years of 2018, 2019, and 2022 (years 3, 4, and 7 post restoration respectively) had different slopes than the pre-restoration model (Table 4; Figure 8). The 2018 and 2019 water years (post restoration years 3 and 4) had a greater slope than pre-restoration but a lower intercept indicating reduced depth to groundwater in the winter and a slight reduction in groundwater in the drier periods. The water years of 2020 and 2021 had a greater depth to groundwater in MM compared to CM as indicated by the higher intercept value, but same model slope. These two water years were very low precipitation years (Table 4) impacting the hydrologic response of the meadows.

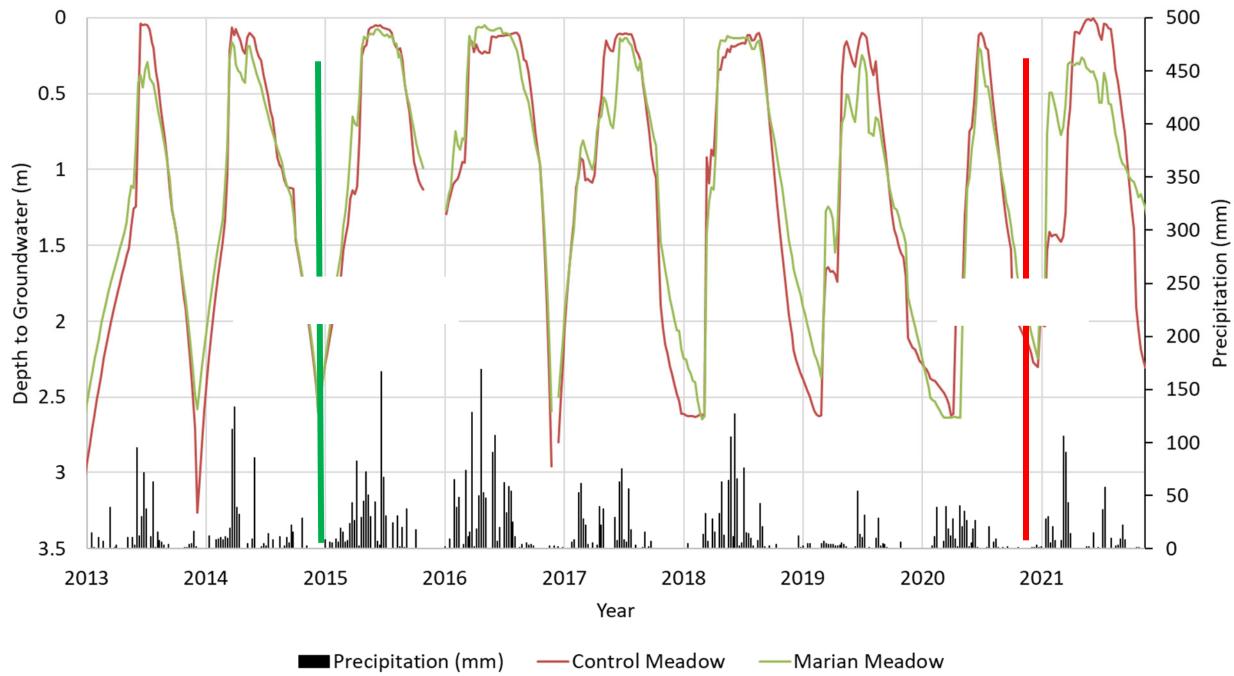


Figure 7. Weekly average depth to groundwater and weekly total precipitation for Marian and Control Meadows for the 2014-2022 Water Years. The time of the Pinus contorta removal and Dixie Fire are shown as well as weekly precipitation.

Table 4. Regression coefficients and statistics for depth to groundwater regression models for pre-restoration (2014–2015 WY) and each year after restoration (2016–2022 WY). Mean annual precipitation is shown.

Term	Water Years	Precipitation (mm/yr)	Slope Coefficient	Intercept	p-value
Pre-restoration	2014-15	558	0.653	0.263	<0.001
Year 1 post-restoration	2016	937	0.653	0.070	0.02
Year 2 post-restoration	2017	1169	0.653	0.129	0.05
Year 3 post-restoration	2018	605	0.798	0.107	0.05
Year 4 post-restoration	2019	1019	0.717	0.138	<0.001
Year 5 post-restoration	2020	210	0.653	0.416	<0.001
Year 6 post-restoration	2021	351	0.653	0.926	<0.001
Year 7 post-restoration	2022	501	0.476	0.324	<0.001

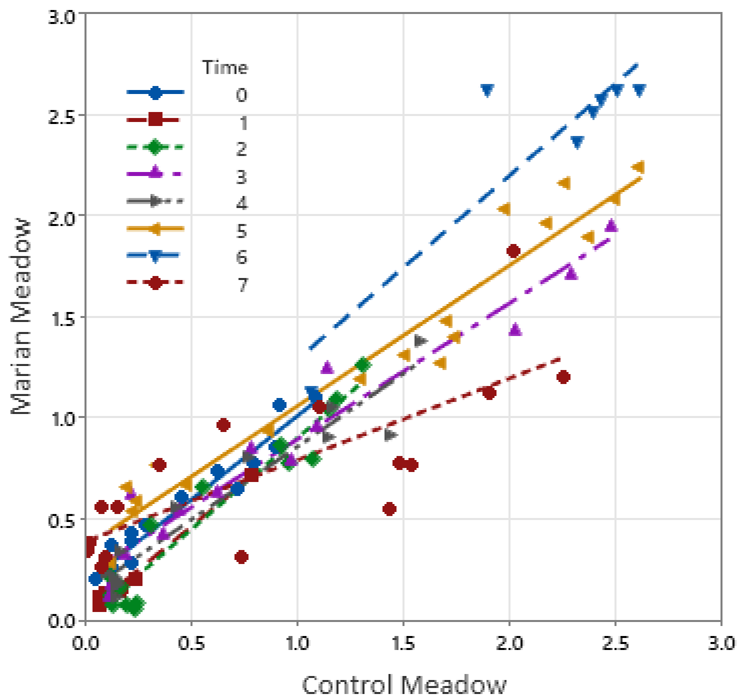


Figure 8. Regression plots by year between Marian and Control Meadows 2014-2022 for depth to groundwater in meters. Time is the sequence of water years since restoration with Time = 0 the water years prior to restoration (2014-2015 WY). Time = 7 is the water year following the Dixie Fire (2022 WY).

The 2022 water year (Time =7; Figure 8) had a reduced slope and slightly higher intercept for the regression model indicating more groundwater in MM compared to pre-restoration, except during the winter period. The 2022 water year was the first year following the Dixie Fire. The CM watershed and meadow had 3% of its area in high or moderate burn severity (Table 2, Figure 4). The MM watershed and meadow had 87% of its area in high or moderate burn severity. The linear regression analysis of the relationship between MM and CM for six post restoration water year prior to the Dixie Fire and the water year following the Dixie Fire indicated a statistically significant difference in MM depth to groundwater (Table 5). This indicates groundwater persisted closer to the surface in MM following the Dixie Fire for all but the wettest time periods.

Table 5. Regression coefficients and statistics for depth to groundwater regression models for Marian and Control meadows following restoration but before the Dixie Fire (2016–2021 WY) and the water year after the Dixie Fire (2022 WY). Mean annual precipitation is shown for the average of the pre-fire water years and the post fire water year of 2022.*

Term	Water Years	Precipitation (mm/yr)	Slope Coefficient	Intercept (m)	p-value
Pre-Dixie Fire	2016-21	715*	0.8741	0.157	<0.001
Following Dixie Fire	2022	501	0.4039	0.386	0.02

Figure 9 shows an electrical resistivity profile in MM before and after meadow restoration, collected one year apart. The estimated groundwater level (approximately 2.5 meters) is nearly unchanged in the two surveys. Furthermore, the repeated survey indicates relatively uniform depth to groundwater along the linear profiles. This was a validation that the point measurements from wells were representative of the depth to groundwater across the meadow. Above the water table, a qualitative interpretation of vadose zone soil moisture can be made. Prior to restoration (Figure 7A), electrical resistivity values are generally greater than 450 $\Omega \cdot m$ and locally as high as 650 $\Omega \cdot m$. After restoration (Figure 7B), electrical resistivity values are less than 450 $\Omega \cdot m$ with some regions showing a decrease in electrical resistivity by a factor of three. Only one location shows a region where electrical resistivity increased. Qualitatively, then, the vadose zone has responded uniformly to meadow restoration with lowered electrical resistivity values, which can be interpreted as an increase in soil moisture.

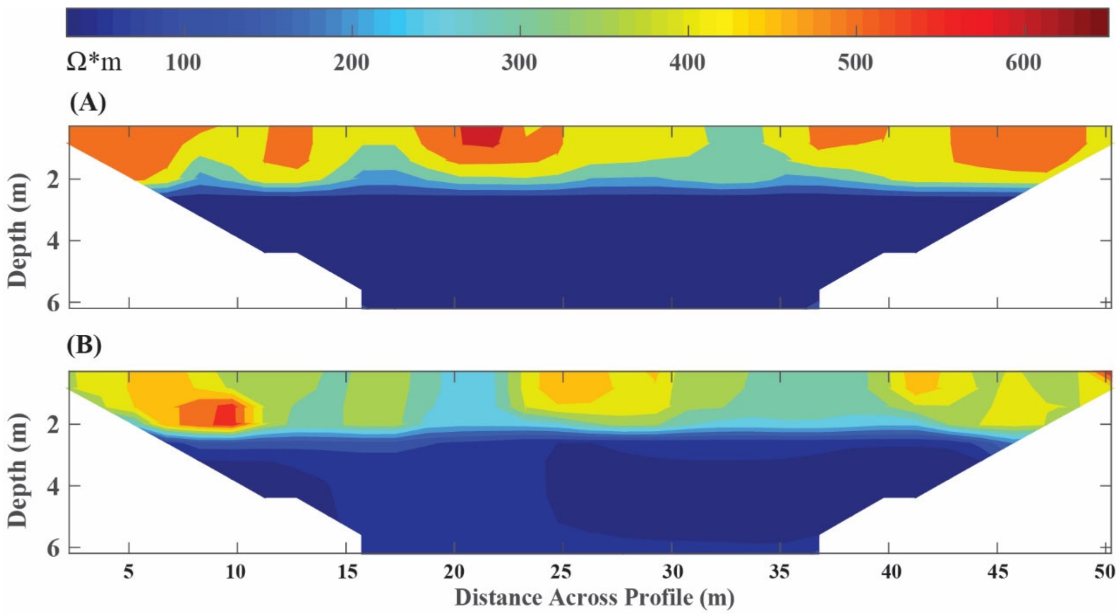


Figure 9. Inverted electrical resistivity profile before and after harvesting in Marian Meadow. The same profile and color bar of electrical resistivity values is represented in both panels. (A) Data collected on 7 September 2014. (B) Data collected on 9 September 2015. RMS inversion error: (A) 1.45% and (B) 1.43%.

<u>Marian Meadow Soil Moisture (VWC) Response to Meadow Restoration</u>

The hydrograph of weekly average soil moisture for 2014–2022 WY for CM and MM is shown (Figure 10). There was a statistically significant relationship between CM and MM soil moisture pre-restoration (Table 2). The analysis of covariance of the intercepts and slopes of linear relationships for post-restoration water years were significantly different from the pre-restoration model. The resulting pre-restoration regression equation had an intercept of 10.71 percent soil moisture (p-value <0.001) while the post-restoration regression equations had varied intercepts and slopes by year post restoration (Table 6, Figure 11). This difference in slopes and intercepts for the post-restoration year models suggests both positive and negative differences in soil moisture depending on the magnitude of the soil moisture. At lower soil moistures, post-restoration MM soil moisture percentages decreased while, at higher soil moisture percentages, MM soil moisture increased when compared to CM (Figure 12). There was not a statistically significant difference between the post-restoration soil moisture (2016-2021 WY) and the year following the Dixie Fire (2022 WY) soil moisture in MM when compared to the CM, p-value = 0.88 (Figure 12)

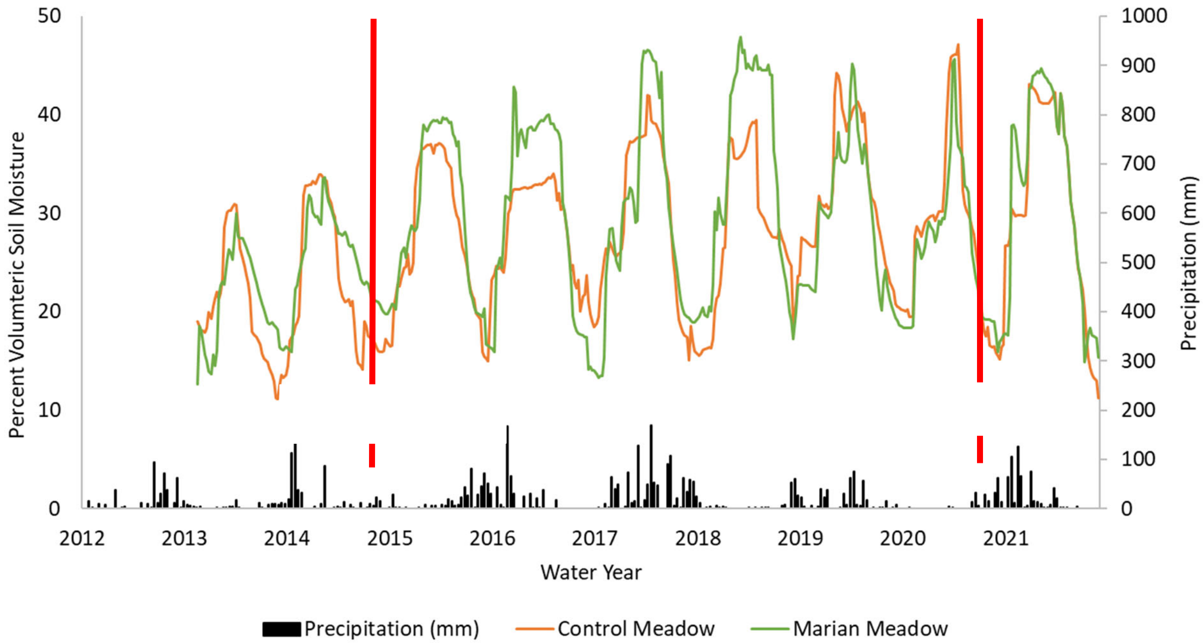


Figure 10. Week-averaged volumetric soil moisture (%) and total weekly precipitation (mm) for Marian and Control Meadows, 2014-2022 WY. The time of the Pinus contorta removal and Dixie Fire are shown.

Table 6. Regression coefficients and statistics for volumetric soil moisture percentage regression models for pre-restoration (2014–2015 WY) and each year after restoration (2016–2022 WY).

Term	Water Years	Slope Coefficient	Intercept	p-value
Pre-restoration	2014-15	0.564	10.71	<0.001
Year 1 post-restoration	2016	1.06	0	<0.001
Year 2 post-restoration	2017	1.84	-20.3	<0.001
Year 3 post-restoration	2018	1.09	0	<0.001
Year 4 post-restoration	2019	1.23	0	<0.001
Year 5 post-restoration	2020	0.952	0	<0.001
Year 6 post-restoration	2021	0.791	4.4	0.02
Year 7 post-restoration	2022	0.993	0	<0.001

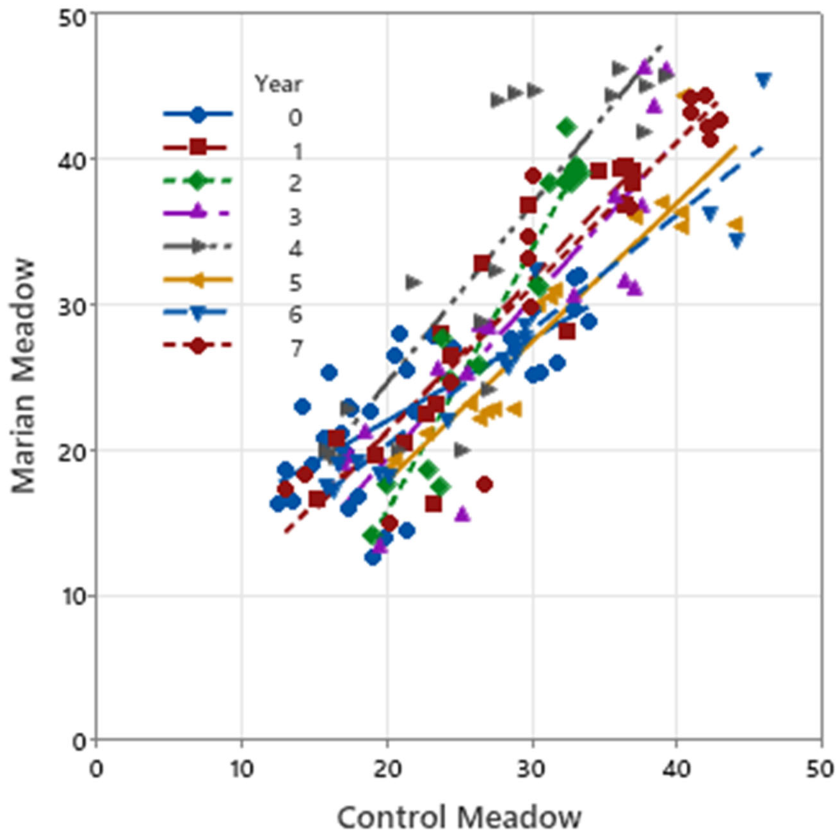


Figure 11. Regression plots by year between Marian and Control Meadows 2014-2022 for percent soil volumetric water content (VWC). Time is the sequence of water years since restoration with Time = 0 the water years prior to restoration (2014-2015 WY). Time = 7 is the water year following the Dixie Fire, seven years after restoration (2022 WY). The varied regression model slopes and intercepts are evident.

<u>Rock Creek Meadow Groundwater Response to Meadow Restoration</u>

The average depth to groundwater and weekly precipitation for the western and eastern portions of RCM compared to MM are shown for 2019-2022 water years (Figure 12). The average depth to groundwater pre- and post-conifer removal was determined to be, on average, 0.56 m deeper at Rock Creek following the removal of encroached conifers (2021-2022 water years). The regression analysis of Rock Creek western portion compared to Marian Meadow showed a statistically significant decrease in groundwater the 1st year (2021 WY) following the restoration but no difference the 2nd year (2022 WY following the Dixie Fire) (Table 7; Figure 13). The eastern portion of Rock Creek Meadow only had measurable groundwater for a short portion in the pre-restoration year (2020 WY) and the 2nd year post-restoration (2022). The 2021 water year was a drought year, there were instrument malfunctions for portions of 2020 and 2022 water years that were partially responsible for the incomplete groundwater data set for the eastern portion of RCM. Therefore, no statistical evaluation was performed on the RCM East measurements. Only the western portion of RCM was used for statistical evaluation.

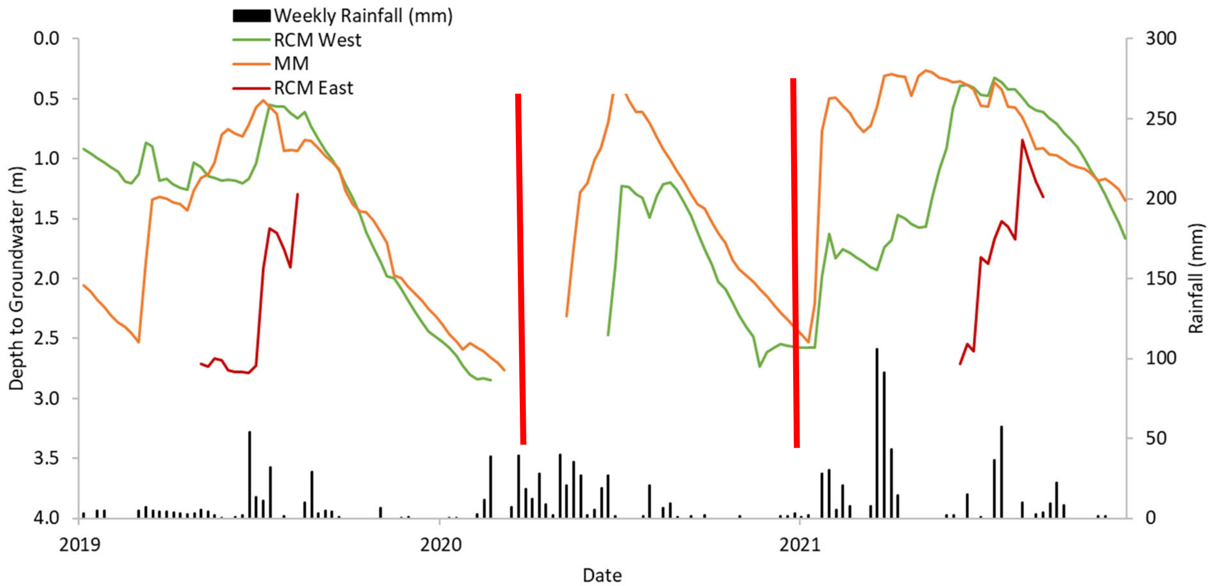


Figure 12. Weekly average depth to groundwater and weekly total precipitation for Marian and Rock Creek Meadows for the 2014-2022 Water Years. The time of the Pinus contorta removal and Dixie Fire are shown as well as weekly precipitation.

Table 7. Regression coefficients and statistics for depth to groundwater regression models for pre-restoration (2020 WY) and each year after restoration (2020–2022 WY).

Term	Water Years	Slope Coefficient	Intercept	p-value
Pre-restoration	2020	0.416	0.68	<0.001
Year 1 post-restoration	2021	0.416	1.49	0.02
Year 2 post-restoration	2022	0.416	0.16	0.34

*Table 8. Regression coefficients and statistics for depth to groundwater regression models for RCM western portion and MM before the Dixie Fire (2020–2021 WY) and the water year after the Dixie Fire (2022 WY). Mean annual precipitation is shown for the average of the pre-fire water years*of 2019-2021 and the post fire water year of 2022. Although groundwater data for 2020-2022 is evaluated, the 2019 water year was highly influential on the 2020 groundwater levels.*

Term	Water Years	Precipitation (mm/yr)	Slope Coefficient	Intercept (m)	p-value
Pre-Dixie Fire	2020-21	566*	0.636	0.641	0.008
Following Dixie Fire	2022	501	0.636	0.076	0.71

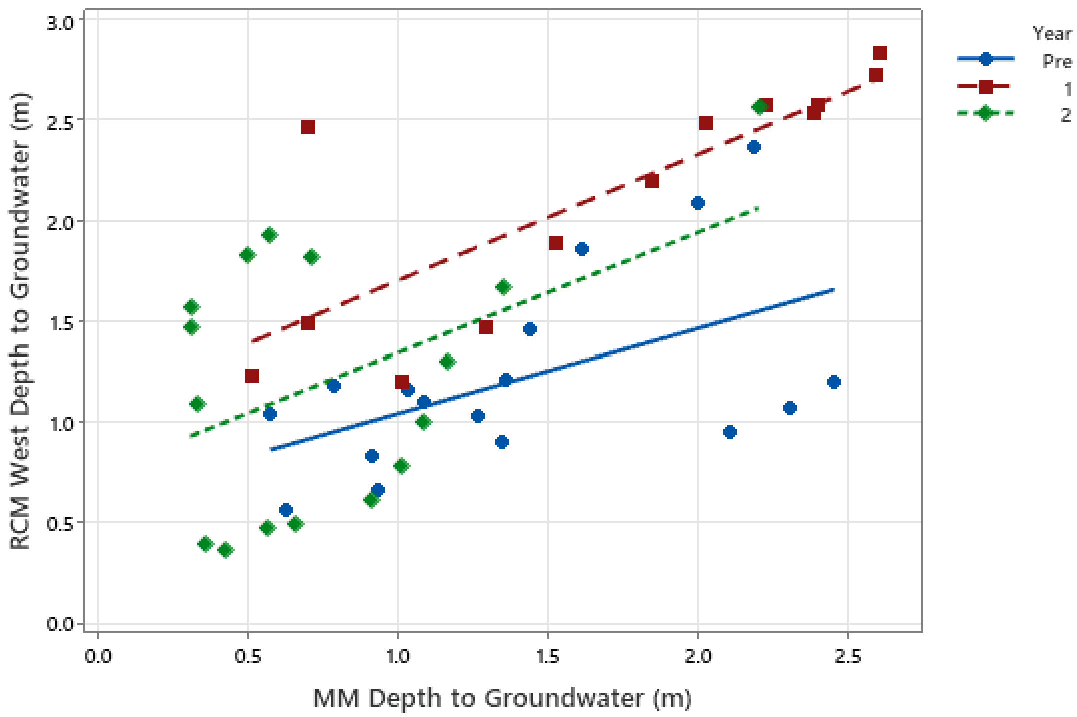


Figure 13. Regression plots by year between Rock Creek western portion and Marian Meadows 2020-2022 for depth to groundwater in meters. Year is the sequence of water years since restoration Year = 2 is the water year following the Dixie Fire (2022 WY). Note that year 2 is not statistically different from pre-restoration year (p value = 0.34).

The groundwater results following restoration at Rock Creek showed an average decrease following restoration. This result was not expected. When comparing the long-term results from Marian Meadow, the 2020 and 2021 water years were found to not be statistically different from the pre-restoration levels. The reasoning is the extreme drought conditions for those years. The 2022 water year precipitation was below the annual average but substantially improved compared to 2020 or 2021 water years. However, the 2022 water year was the first year following the Dixie Fire. Marian Meadow groundwater in 2022 water year was statistically greater than pre-restoration levels. The watershed contributing to Marian meadow had 87% of its area in high and moderate burn severity from the Dixie Fire. The Rock Creek watershed had 48% in high and moderate burn severity from the Dixie Fire. Marian Meadow would be expected to have greater runoff and groundwater recharge potential due to greater loss of forest vegetation (e.g. Saxe et al., 2018; Niemeyer, 2019). Marian Meadow is also being used as the control for Rock Creek Meadow. The significance of Rock Creek Meadow not being statistically different in the 2022 water year, even when compared to a meadow and watershed with greater area of burn severity than Rock Creek Meadow suggests an increase in groundwater in Rock Creek Meadow. Rock Creek Meadow depth to groundwater was statistically greater than pre-restoration in 2022 but not statistically different from Marian Meadow, which had greater groundwater in 2022.

Factors, besides the effects of the Dixie Fire, confounding the statistical analysis of the Rock Creek Meadow groundwater is twofold: 1) the peak groundwater levels are slightly later at Rock Creek

Meadow than Marian Meadow (Figure 12) based on the spring 2019 hydrograph for Rock Creek Meadow, with annual precipitation almost equal to the sum of the 2020-2022 precipitation, there appears to be a time lag for groundwater level effect. The Rock Creek Meadow had greater groundwater in the spring of 2019 following several high precipitation years. With the drier 2020-2022 water years, Rock Creek groundwater did not appear to be as responsive as Marian Meadow.

A two-dimensional ERI profile was collected in a linear clearing at the Rock Creek site to examine the deeper subsurface geologic structure of the area (Figure 14). The maximum depth of 58 meters in the data image is significantly deeper than the other electrical resistivity surveys collected at RCM, MM, and CM. Large regions of high resistivity values (thousands of Ohm-m) indicate igneous rock. The igneous rock is inferred to be rhyolitic in composition based on rock outcrops in the area. The igneous rock is also inferred to be in discrete units with the yellow color surrounding the high-resistivity red units an artifact of contouring in the image. It is likely the subsurface igneous, also rock, contains fractures based on observations of the rock outcrop at the survey site.

The low resistivity values contoured in blue in a roughly horizontal band near the top of Figure 1 indicate a sediment/soil that contains discrete regions with laterally varying amounts of clay minerals. Below this are two light blue contoured regions (~ 100 Ohm-m) that suggest water from rains and snowmelt is recharging to the deep subsurface through preferential pathways. The recharge rate depends on the hydraulic conductivity of the subsurface and is likely to significantly vary in three dimensions. It is important to note that Figure 14 is a two-dimensional slice through a three-dimensional structure with significant variation of material type. Regions with very shallow igneous rock that is not fractured (or, without a connected fracture network) may allow water, and thus soil moisture, to perch rather than recharge, which may have an effect on meadow vegetation restoration as well as represent an unaccounted-for aspect of the groundwater budget.

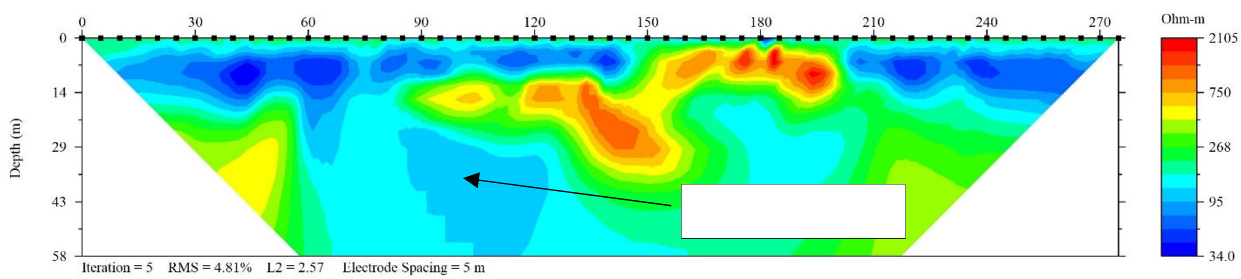


Figure 14. Rock Creek Deep Electrical Resistivity Profile. This profile trends from the road bisecting Rock Creek Meadow toward instrument and vegetation transect site 1 (Figure 3). The right side of the image (horizontal position of 275 meters) is located at (40.3307º, -121.0873º), with a heading of 40º. The electrode spacing is 5 meters. Data was collected with a dipole-dipole-gradient pattern.

The hydrograph of weekly average soil moisture for 2020–2022 WY for Rock Creek Meadow and Marian Meadow at depths of 10, 30, and 100 cm is shown (Figure 15).

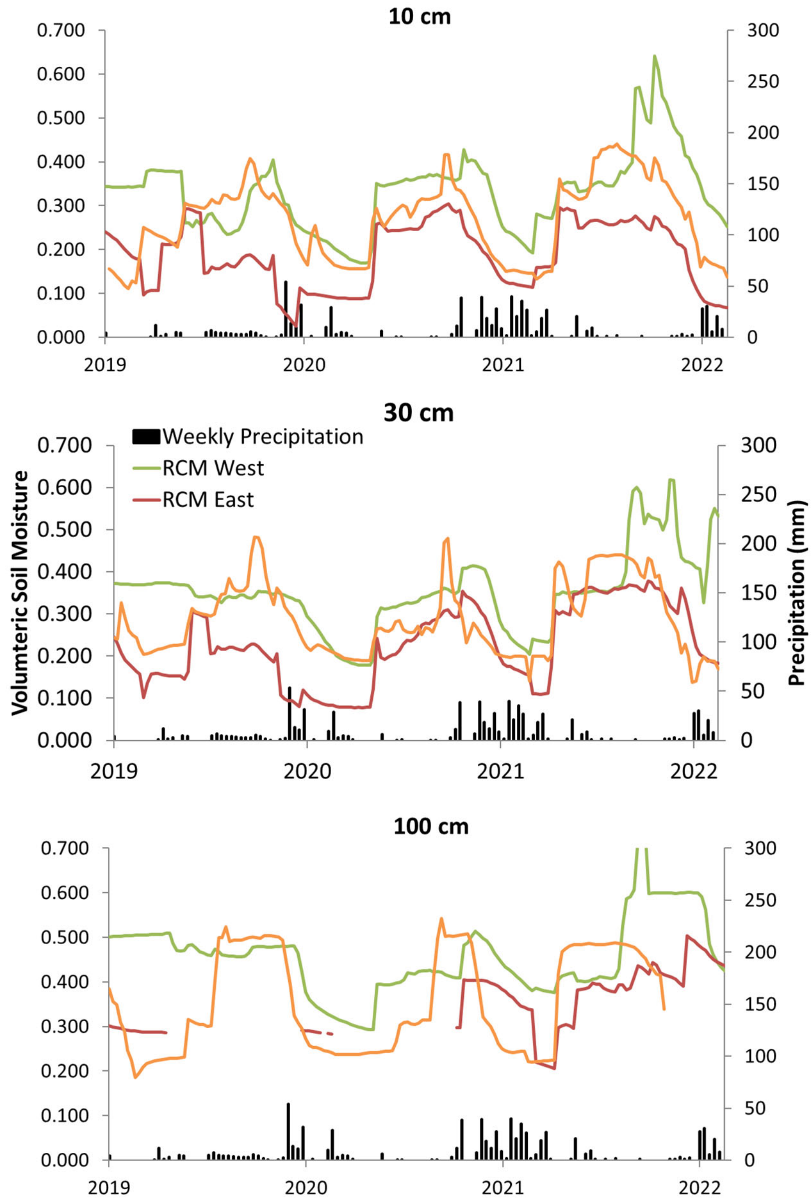


Figure 15. Weekly average volumetric soil moisture and total weekly precipitation for 2020–2022 WY for Rock Creek Meadow western and eastern portions and Marian Meadow at depths of 10, 30, and 100 cm.

The average soil moisture at Rock Creek Meadow increased by 8% following restoration compared to Marian Meadow over the 2021 and 2022 water years. The first-year post restoration (2021) there was no statistically detectable change in average soil moisture, while in 2nd year post restoration there was a 9% increase in soil moisture (Table 9, Figure 16).

Table 9. Regression coefficients and statistics for volumetric soil moisture percentage regression models for pre-restoration (2020 WY) and each year after restoration (2021–2022 WY).

Term	Water Years	Slope Coefficient	Intercept	p-value
Pre-restoration	2020	0.289	0.198	<0.001
Year 1 post-restoration	2021	0.289	0.212	0.45
Year 2 post-restoration	2022	0.289	0.29	<0.001

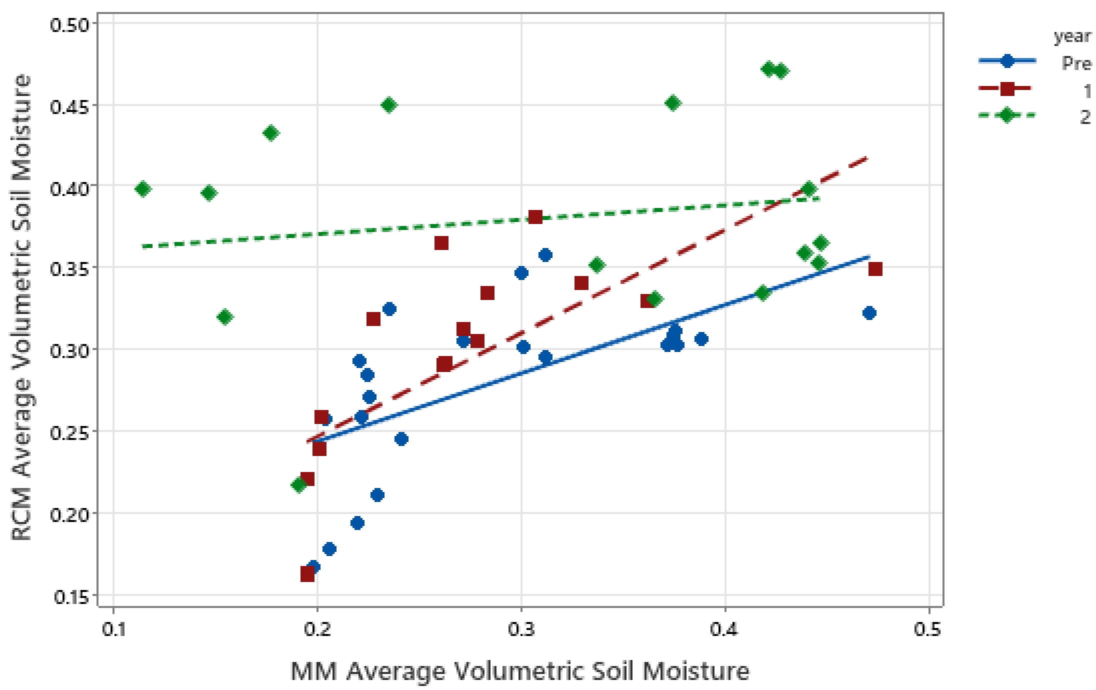


Figure 16. Regression plots by year for the average weekly volumetric soil moisture for Rock Creek and Marian Meadows 2020-2022. Year is the sequence of water years since restoration Year = 2 is the water year following the Dixie Fire (2022 WY) and is statistically different from pre-restoration year, while Year =1 is not statistically different; p values <0.001 and 0.45 respectively (Table 9). In contrast to Marian and Control Meadows there was not a statistical difference in the slopes of the regression lines, even though the fitted lines are illustrated at different slopes.

Soil moisture differences over time did vary at different depths measured (Figure 15). An additional statistical analysis was done for the 30 cm depth between the western and eastern portions of Rock Creek Meadow and Marian Meadow (Table 10). The 30 cm depth was considered indicative of the highest root density of herbaceous vegetation roots. This analysis demonstrated a statistical difference for years 1 and 2 post restoration for the eastern portion and year 2 post restoration for the western portion of RCM. This demonstrates that the drier, eastern portion of RCM had a greater soil moisture response from the conifer removal. The increases for the 30 cm depth in the eastern portion of RCM were 6.6% and 11.1% for year 1 and 2 following the conifer removal respectively (Table 10).

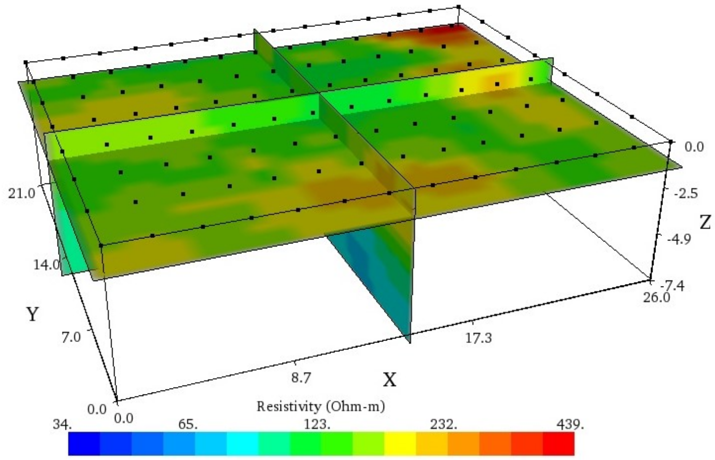
Table 10. Regression coefficients and statistics for volumetric soil moisture percentage regression models for pre-restoration (2020 WY) and each year after restoration (2021–2022 WY).

Term	Water Years	Slope Coefficient	Intercept	p-value
RCM West Pre-restoration	2020	0.25	0.261	<0.001
RCM West Year 1 post-restoration	2021	0.25	0.242	0.46
RCM West Year 2 post-restoration	2022	0.25	0.34	0.004
RCM East Pre-restoration	2020	0.56	0.014	<0.001
RCM East Year 1 post-restoration	2021	0.56	0.08	0.002
RCM East Year 2 post-restoration	2022	0.56	0.125	<0.001

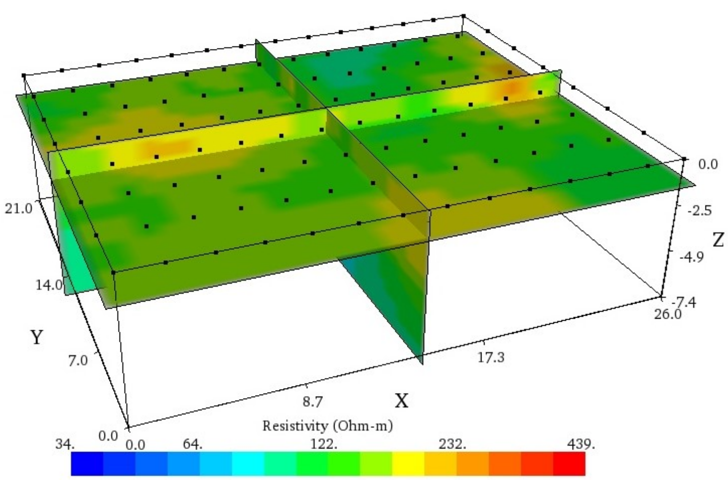
Soil moisture had the greatest increase in the 2nd year post restoration in Rock Creek Meadow. This 2nd year was also the first water year following the Dixie Fire and much higher precipitation than the previous 2 years of measurements. It is suggested that this increase in soil moisture was a result of greater soil water infiltration due to the loss of interception and transpiration of the *Pinus contorta* removed from the meadow. Although the Dixie Fire did affect the Rock Creek meadow's watershed, it only burned small patches of the meadow vegetation at low burn severity (for example Figure 5). Further, this increase in soil moisture in the 2022 water year at Rock Creek was in comparison to Marian Meadow that received a higher percentage of moderate and high burn severity from the Dixie Fire not only in its watershed but the meadow itself (see Figure 6). This is interpreted that the increase in soil moisture in Rock Creek meadow is influenced by the restoration and not just a result of the Dixie Fire.

Three-dimensional electrical resistivity data before and after tree harvesting was collected on July 8th, 2020, and July 9th, 2021, at the Rock Creek study site (Figure 17). Soil water has lower resistivity than the surrounding soil media. A horizontal slice at approximately one-meter depth is extracted from the three-dimensional volume from each of the 2020 and 2021 data. In the 2020 data, the higher resistivity values shown in red contours are located where the thickest tree clumps of *Pinus contorta* existed prior to removal for meadow restoration. These areas of sediment and soil have a low water content, thus high resistivity values, due to soil water usage by the trees. Moderate electrical resistivity values in green contours indicate sediments with varying amounts of saturation. At depths beginning from four to five meters, lower resistivity values in blue contours probably indicate the sediments contain a higher clay content from the weathering of the igneous source rocks.

The 2021 data indicates a strong qualitative change in the volumetric water content of the sediment and soil after the tree harvesting, with values of electrical resistivity dropping to at least half of the pre-harvest value. Local field-site quantitative relationships between electrical resistivity and volumetric water content are being derived for these data sets using subsurface soil moisture probes, the electrical conductivity of the subsurface water and properties of the soil. A horizontal slice at approximately one-meter depth was extracted from the three-dimensional volume from each of the 2020 and 2021 data.



A)



B)

Figure 17. Three dimensional images of electrical resistivity in A) 2020 pre-restoration and, B) 2021 following Pinus contorta removal. The XYZ coordinates are in units of meters. Lower resistivity values reflect high soil water, while higher resistivity values demonstrate drier soil media.

Pre-treatment *Pinus contorta* Transpiration by Sap flow

Average total transpiration for the eastern portion of RCM (the drier, less vegetated portion) was estimated by the simple scaling approach between 149.74 ± 12.06 mm for the monitoring period (mid-July 2019 to mid-August 2020). This estimation was produced assuming that the radial profile of sap velocity declined linearly across tree sapwood to zero at the heartwood-sapwood boundary. The eastern RCM per-plot estimate for the 2020 partial growing season (April to mid-August 2020) was given as 67.82 ± 5.46. The western portion (the wetter, more vegetated portion of the meadow) approximately doubled the eastern stratum estimate for these periods, between 288.64 ± 54.71 mm for the entire campaign and between 130.73 ± 24.78 mm for the 2020 partial growing season. Average total transpiration for the entire meadow was estimated at 220.57 ± 25.28 for the campaign and 100.22 ± 11.49 mm for the 2020 partial growing season.

The differences in transpiration between the western and eastern portions of Rock Creek Meadow not only indicate a wetter, higher soil moisture environment for the western portion but indicates where there was greater water gained by the removal of the *Pinus contorta*. The wetter environment created denser and larger trees utilizing the higher soil moisture. Larger and denser trees intercept more snow and rain, resulting in greater evaporative losses during the winter season. The lower transpiration in the eastern portion indicates lower soil moisture available with the likelihood of *Pinus contorta* transpiration reaching the wilting point of soil moisture in the latter part of the growing season. The removal of these trees resulted in the increased soil moisture measured at RCM with greater benefit to the drier eastern portion of the meadow.

Meadow Vegetation Response

The percentage of facultative wetland plants, species richness, Shannon-Weiner diversity index, and Simpson diversity index are presented in Figures 18-21. Additional figures for other wetland indicators are located in Appendix A.

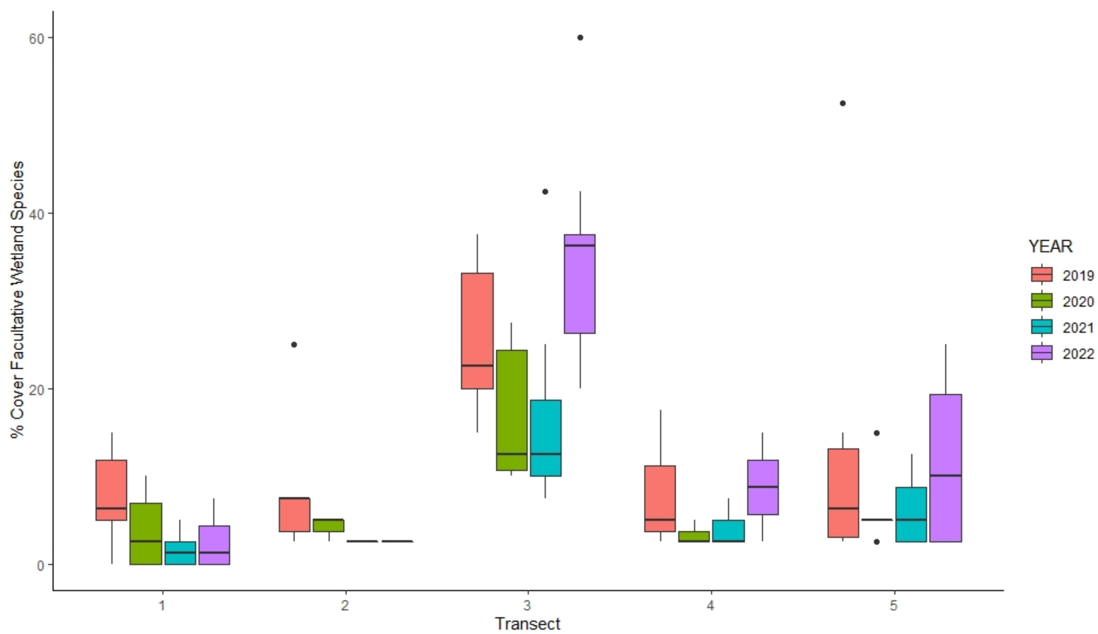


Figure 18. Percentage cover of facultative wetland indicator plants by transect and year. Transects 1 and 2 are located in the drier, eastern portion of Rock Creek Meadow. Transects 3-5 are located in the wetter, western portion of Rock Creek Meadow.

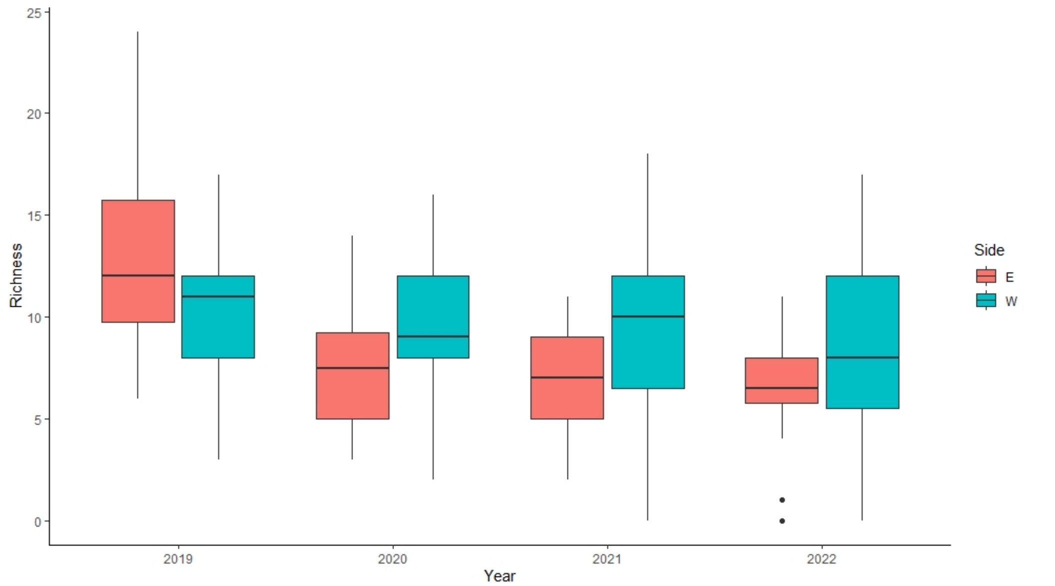


Figure 19. Species richness by eastern (red) and western (blue) portions of Rock Creek Meadow.

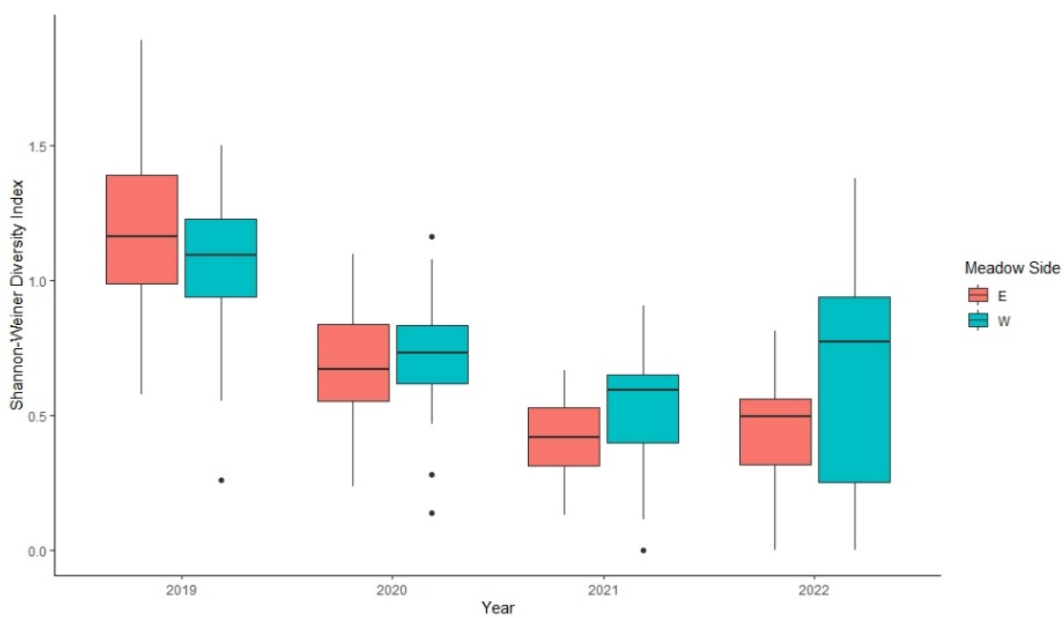


Figure 20. Shannon-Weiner diversity index by eastern (red) and western (blue) portions of Rock Creek Meadow by year.

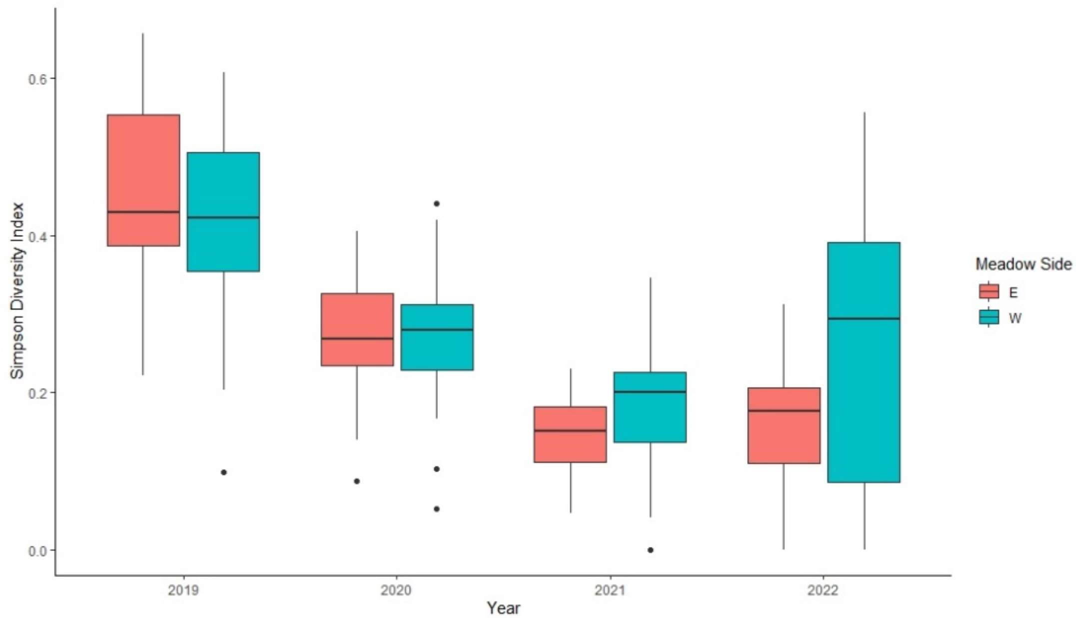


Figure 21. Simpson diversity index by eastern (red) and western (blue) portions of Rock Creek Meadow by year.

The plant surveys in the years 2019 and 2020 were prior to restoration, while 2021-2022 followed restoration. There was a marked contrast in meadow vegetation response between the wetter western portion and drier eastern portion of RCM. The percentage of facultative wetland plants slightly decreased in the first year after restoration, presumably due to a low rainfall year and disturbances from the tree removal operations. The percentage of facultative wetland plants increased in 2022, the 2nd year following restoration in the transects in the western portion (Transects 3-5) and decreased in the drier eastern portion. Transect 2 had the greatest amount of disturbance following tree removal (2021) and the 2022 survey also reflected a fire road bulldozed through it during Dixie Fire suppression activities. Species richness remained relatively the same throughout all years. The Shannon-Weiner and Simpson Diversity indices become lower, indicating lower plant diversity, both years following restoration in the drier eastern portion. While both recovered in 2022 in wetter western portion.

The meadow vegetation relied on the local seed sources; no special seeding or planting was done. The 2019 water year had above average precipitation, almost as much precipitation as the 2020-2022 combined. This is reflected in the higher percentage of cover in facultative wetland plants and increased species richness and diversity. The 2022 water year, increased precipitation compared to 2020 and 2021, saw an uptick in the facultative wetland percentage and diversity indices for the western portions of Rock Creek Meadow. The eastern portion was drier and had more disturbance which appears to be limiting the meadow vegetation recovery.

Objective 2. Determine if key water quality metrics are affected by meadow restoration and WLPZ removal in Rock Creek Meadow by evaluation of streambed sediment and stream temperatures within or downstream of the restoration site.

Stream Temperature

The seven-day rolling average of daily and maximum daily stream temperatures for RCM from 2017-2022 are shown (Figure 22). Stream temperature measurements were started in 2017 at the downstream location of Rock Creek. The upstream stream temperature measurements were started in

2018. However, the 2018 downstream measurement was not used due to poor data quality. The year 2021 did not have streamflow for stream temperature measurements. The MWMT and MWAT by year for Rock Creek from 2017-2022 are also shown (Table 11).

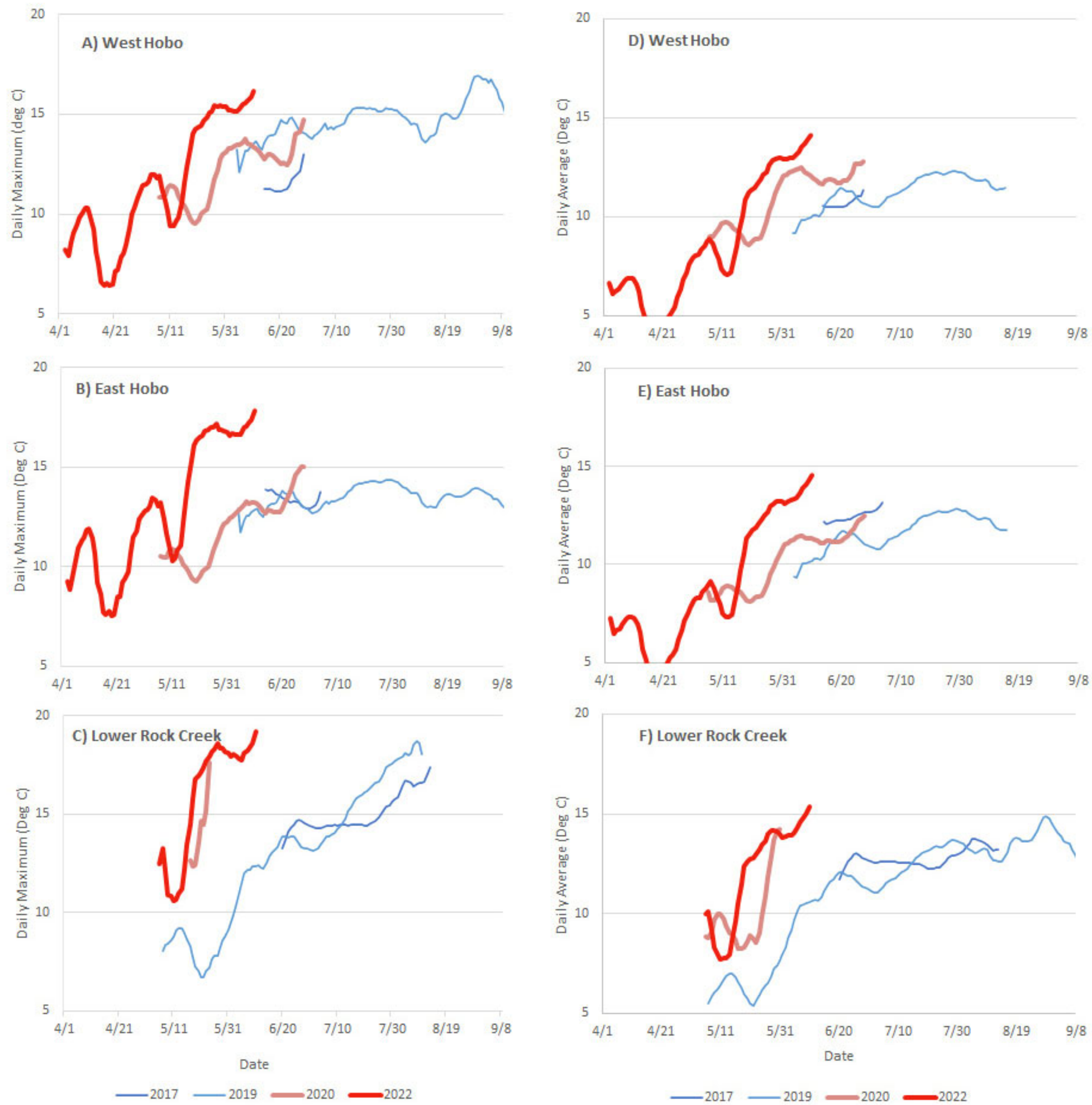


Figure 22. Seven day rolling average daily stream temperatures for Rock Creek (2017-2022). Blue lines are pre-treatment, red lines post-treatment. The dark red lines (2022) are post Dixie Fire. A) Upstream West Hobo maximums, B) Upstream East Hobo maximums, C) Lower Rock Creek maximums, D) Upstream West Hobo average daily, E) Upstream East Hobo average daily, F) Lower Rock Creek average daily. Temperatures are in degrees Celsius.

Table 11. The maximum weekly average daily (MWAT) and weekly maximum daily stream temperature (MWMT) values for Rock Creek 2017-2022. The upstream temperature values were recorded at two locations due to multiple channels of streamflow. The locations of the measurements are shown in Figure 3. There was no streamflow in 2021.

Year	Location	MWAT (C^o)	MWMT (C^o)
2017	Upstream - East, West Hobos	-	-
	Downstream – Lower Rock Creek	13.8	17.4
2018	Upstream - East, West Hobos	13.2, 11.3	13.9, 13.0
	Downstream – Lower Rock Creek	-	-
2019	Upstream - East, West Hobos	13.0, 13.1	14.4, 16.9
	Downstream – Lower Rock Creek	14.9	18.7
2020	Upstream - East, West Hobos	15.7, 15.7	15.2, 14.7
	Downstream – Lower Rock Creek	14.2	17.6
2022	Upstream - East, West	14.6, 14.1	17.8, 16.1
	Downstream – Lower Rock Creek	15.4	19.2

The MWMT and MWAT stream temperatures increased following the WLPZ clearing (2020) and Dixie Fire (2022) (Table 11). Generally, the downstream MWMT values have been 2-3 degrees Celsius higher than the upstream MWMT values following clearing. While MWAT values were within a 1-2 degrees Celsius difference upstream and downstream. This was consistent pre- and post-restoration, post Dixie Fire. However, the timing of these values shifts to earlier in the year at the lower Rock Creek site in 2020, the first year following restoration, and all sites in 2022 following the Dixie Fire. The 2020 runoff year was very low with the downstream measurements ending prior to summer and before the upstream hobo sites went dry. Both upstream hobo sites had higher stream temperatures in 2022, following the Dixie Fire. There was a significant loss of riparian stream cover at and upstream of the East and West hobo sites (Figure 23). This suggests that the Dixie Fire created a greater effect on the stream temperatures in Rock Creek than the WLPZ removal from the restoration. Certainly, the downstream temperatures in 2020, directly following WLPZ clearing and before the Dixie Fire are just as high. The difference is that in 2020 the downstream streamflow dried up prior to summer suggesting the reduced streamflow might be partly responsible. The lower depth of streamflow provides less water volume to heat, increasing the stream temperature. Further the downstream temperature measurement was a relatively open area with little riparian shade before WLPZ clearing. In 2022 Rock Creek still had reasonable flow when the stream temperature probes were removed from the stream. The early removal was due to constraints on timing for data analyzed for this report.

The MWMT value in Rock Creek both pre- and post-WLPZ and post-Dixie Fire exceeded the 18-degree Celsius water quality targets suggested for *Oncorhynchus mykiss* as steelhead trout. However, these targets may not apply to the inland resident *Oncorhynchus mykiss* as Rainbow trout.

Figure 23. Riparian stream cover was substantially reduced upstream of the restoration site following the Dixie Fire, photo taken in summer 2022.

Stream Sediment and Habitat

There was a statistically significant change in the means of streambed cobble embeddedness and residual pool depths in the Class I watercourse in the Rock Creek Meadow. The mean percentage of cobble embeddedness increased by 14% while residual pool depths decreased 0.24 ft. The distribution of the cobble embeddedness and residual pool depth measurements are shown in box plot form (Figures 24 and 25).

Table 12. Statistical comparison of stream cobble embeddedness (%) and residual pool depth (ft) between pre-treatment (2019) and post-treatment (2022).

Description	**Mean**	**Standard Deviation**	**Degrees of Freedom**	**P-Value**
Pre-treatment cobble embeddedness	21%	25%	-	-
Post-treatment cobble embeddedness	35%	28%	209	<0.001
Pre-treatment residual pool depth (ft)	1.0	0.21	-	-
Post-treatment residual pool depth (ft)	0.76	0.25	35	0.003

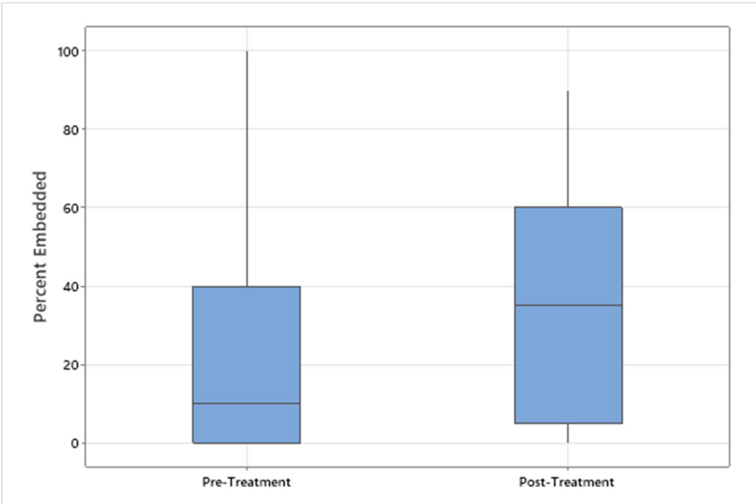


Figure 24. Distribution of percentage of cobble sized particles embedded in the streambed. Pre-treatment measurements in Rock Creek in summer of 2019, post-treatment measurements in summer of 2022.

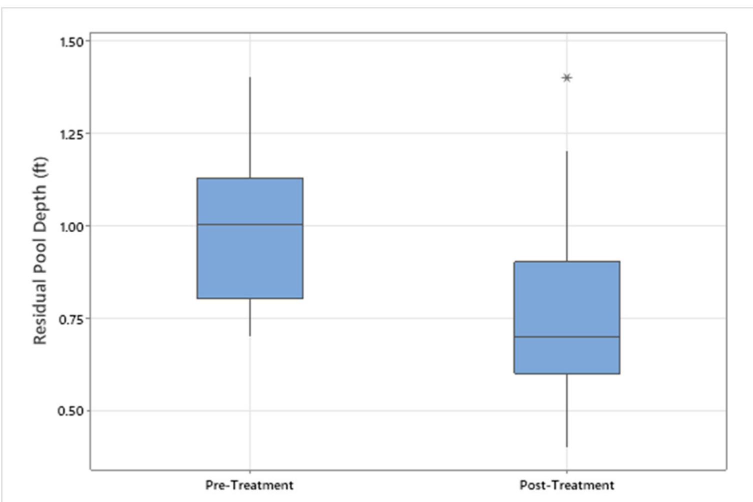


Figure 25. Distribution of residual pool depths in Rock Creek before and after meadow restoration and the Dixie Fire. Residual pool depth is the difference between the maximum depth and depth at the riffle pool transition or pool tail-out. Pre-treatment measurements in Rock Creek in summer of 2019, post-treatment measurements in summer of 2022.

The particle size distribution of the streambed, as measured by Wolman pebble counts, became slightly coarser compared to pre-restoration (Figure 26). The median particle size (50th percentile, Figure 9) was approximately 32 mm pre-treatment and approximately 39 mm post treatment. Further the percentage of sand size or smaller particles decreased from 19% to 10% following treatment and Dixie Fire. The percentage of coarse gravel, cobble, or boulder sized particles (>40 mm) did not change following treatment or fire.

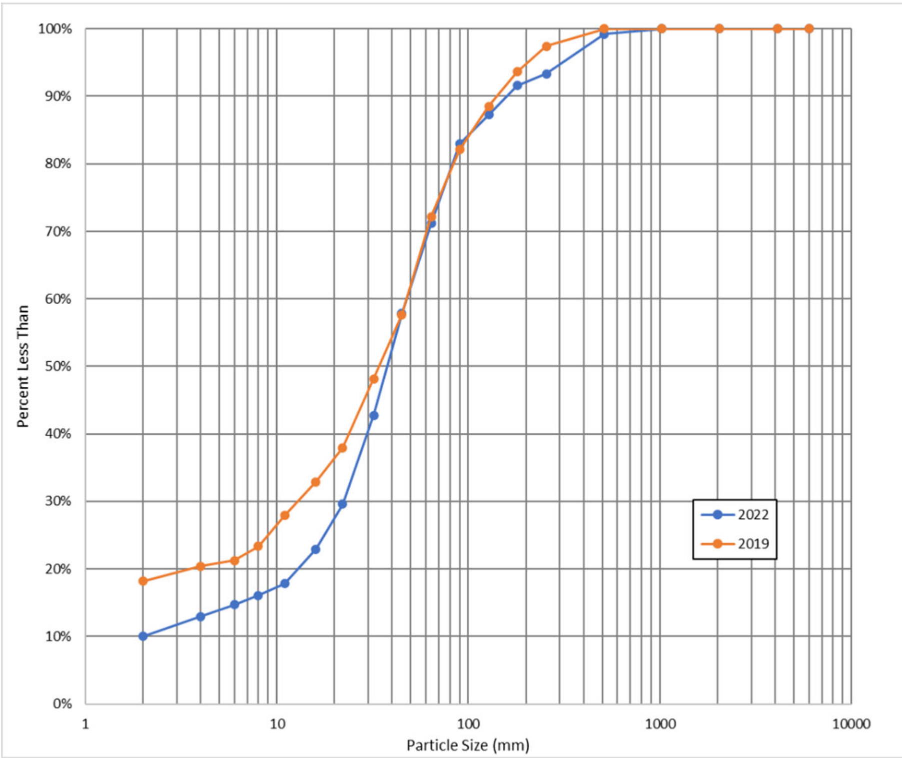


Figure 26. Distribution of particle sizes from Rock Creek pre-treatment (2019) and post-treatment and post-Dixie Fire (2022).

Rock Creek's streambed sediment changed following the restoration. This was exhibited by increased cobble embeddedness, decreased residual pool depths, and a decrease in pool habitat. These changes are indicative of higher sediment supply in the watercourse. In contrast the particle size distribution of the streambed became coarser, indicating the higher sediment supply was more likely due to coarse sediment distribution. The pre-treatment measurements were taken in the summer of 2019 and the post treatment measurements were taken in the summer 2022, two years after treatment and following the Dixie Fire. The Rock Creek watercourse only had limited surface flow in 2021 due to low precipitation and streambed measurements could not be taken (Table 12).

Objective 3. Quantify the amount of soil disturbance and compaction within the WLPZ following meadow restoration.

<u>Soil Cover Disturbance in the WLPZ</u>

The soil cover in the WLPZ was found to be slightly disturbed, 15.3% of soil cover disturbed, by the logging equipment during removal of the encroached *Pinus contorta* (Figure 27). The amount of disturbed soil cover increased to 32.5% the 2nd year following treatment primarily due to burnt soil cover, 21.2%, from the Dixie Fire (see Figures 27, 5, and 6). The percentage of equipment disturbance was reduced by 4% in 2022 compared to 2021 from vegetation recovery of the disturbed soil cover.

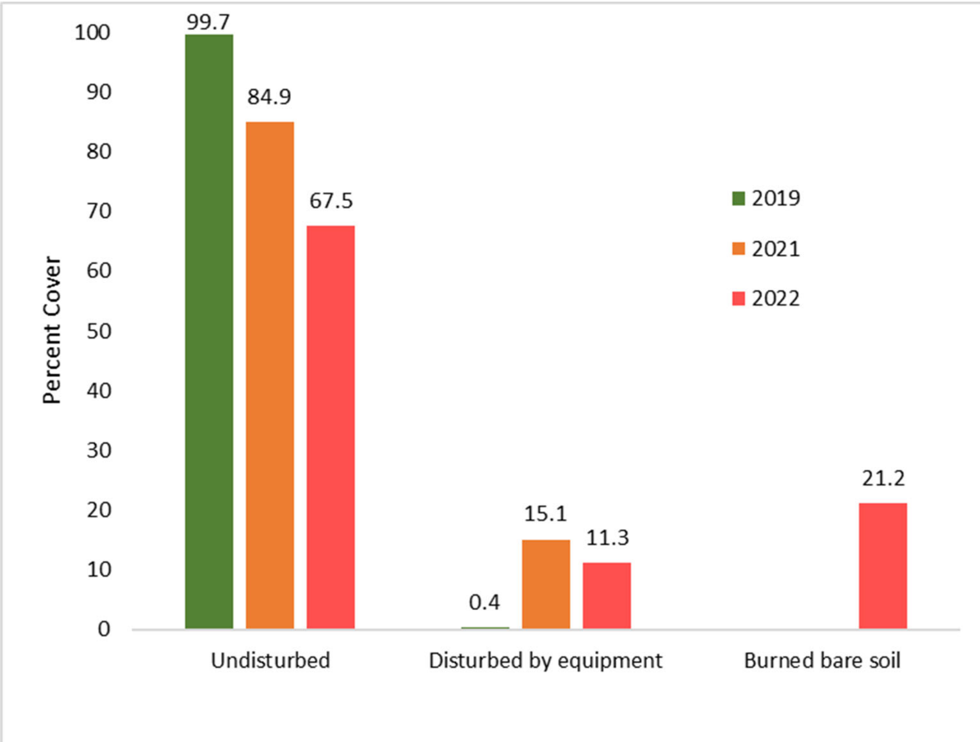


Figure 27. Percent of undisturbed and disturbed soil cover pre-treatment (2019), post-treatment (2021), and 2 years post-treatment after the Dixie Fire (2022) in the Class I WLPZ for Rock Creek Meadow.

In areas outside of the WLPZ ground yarding operations and the Dixie Fire created greater disturbance in the eastern portions of RCM (Table 13). Transects 1 and 2, in the eastern portion of RCM had 2-3 times the amount of bare soil in the vegetation surveys indicating greater disturbance. The western portion of RCM had low soil disturbance following the forest removal. The amount of bare soil increased in all vegetation transects in 2022 following the Dixie Fire with patches of meadow vegetation burned and transects 2 and 3 having a fire road bisect the transects.

Table 13. The percentage of bare soil in the vegetation transects at Rock Creek Meadow from pre-restoration (2019-2020) and post restoration (2021-2022) and post Dixie Fire.

Year	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
2019	9%	18%	0%	4%	1%
2020	7%	35%*	0%	2%	2%
2021	28%	39%	1%	4%	3%
2022	47%	48%	12%	25%	37%

* disturbance occurred from trampling of vegetation by a field measurement crew prior to bare soil measurement.

Soil Compaction in the WLPZ

There was no statistically significant difference in the means of the soil bulk density measurements between the pre-treatment measurements (2019) and the disturbed measurements following treatment in fall 2020 and summer 2022 (Table 5; Figure 28).

Table 5. Statistical comparison of soil bulk density pre-treatment and post-treatment by year for disturbed and undisturbed measurements.

Measurement	Mean Bulk Density (g/cm³)	Standard Deviation (g/cm³)	Degrees of Freedom	P-Value
Pre-treatment	0.75	0.22	-	-
Post-treatment Undisturbed Fall 2020	0.63	0.12	22	0.35
Post treatment Disturbed Fall 2020	0.67	0.08	18	0.71
Post treatment Undisturbed Summer 2022	0.73	0.11	30	0.70
Post treatment Disturbed Summer 2022	0.77	0.13	32	0.76

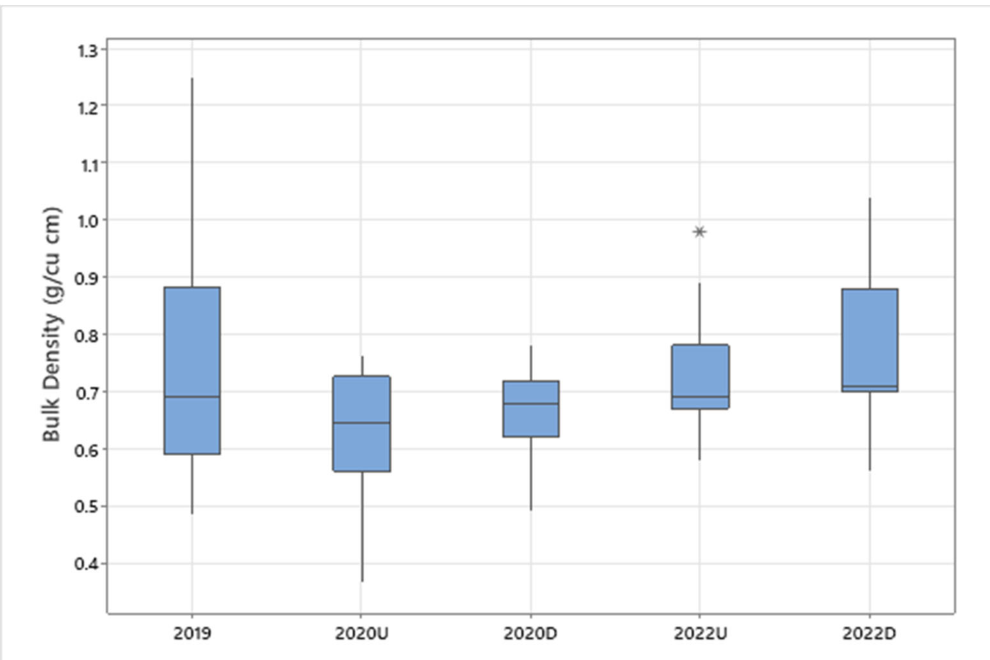


Figure 28. Box and whisker plots of the soil bulk density measurements at Rock Creek Meadow. The 2019 measurements were pre-treatment. The 2020U and 2022U were post treatment undisturbed measurements for 2020 and 2022 respectively. The 2020D and 2022D were post treatment disturbed soil measurements for 2020 and 2022 respectively.

The lack of change of soil bulk density in the WLPZ between pre- and post-forest clearing indicates a lack of soil compaction. This was partly due to the high organic matter of the WLPZ soils as indicated by mean bulk densities of 0.7 g/cm³. Forest practice rule 14 CCR § 933.4 [e] allowed the removal of the class I WLPZ forest vegetation during meadow restoration at RCM. However, equipment operations were still limited within the WLPZ. Limitations included only allowing equipment trails perpendicular to the watercourse, keeping equipment off of stream banks, and keeping the density of trails in the WLPZ to a minimum.

Conclusions

The EMC -2018-003 Alternative Meadow Restoration project tested the effectiveness of meadow and wet area restoration as an alternative to WLPZ rules as specified in 14 CCR § 933.4 [e] of the California Forest Practice Rules (FPR). The meadows studied were classified as dry meadows making them more susceptible to loss of meadow habitat to conifer encroachment. This restoration of meadow habitat was executed under the alternative treatment allowed in the FPR. The restoration involved removal of encroached *Pinus contorta* from Marian and Rock Creek Meadows and removal of all trees in the Class I WLPZ of Rock Creek Meadow in 2016 and 2020 respectively. This restoration improved hydrologic conditions, through increased groundwater and soil moisture, toward restoring meadow habitat over the 7 years monitored at Marian Meadow. Improvement in hydrologic conditions in Rock Creek Meadow were mixed, primarily due to extremely low precipitation years following restoration. Soil moisture was found to increase, while groundwater did not increase in the first year following restoration in Rock Creek Meadow. However, the groundwater in the 2nd year following restoration showed recovery toward pre-restoration levels as precipitation increased. Herbaceous vegetation was observed to have an increase in facultative wetland plant percentage and diversity indices by the second year following restoration in wetter areas of Rock Creek Meadow. In the drier area of Rock Creek Meadow, greater disturbance from ground yarding activities and fire roads appeared to limit the meadow vegetation recovery.

Within the WLPZ at Rock Creek Meadow, no increase in soil compaction was measured following the forest harvest. Forest practice rule 14 CCR § 933.4 [e] allowed the removal of the class I WLPZ forest vegetation during meadow restoration. However, WPLZ equipment operations were still limited within the WLPZ. The limitations included only allowing equipment trails perpendicular to the watercourse, keeping equipment off of stream banks, and keeping the density of trails in the WLPZ to a minimum. However, the amount of disturbed soil cover increased to 32.5% in the 2nd year following treatment primarily due to loss of vegetation cover, 21.2%, from the Dixie Fire.

Stream water temperatures below the harvest area increased by 2-3 degrees Celsius in the summer following WLPZ forest vegetation removal. However, stream water temperatures were elevated by the same amount above the project site due to loss of riparian canopy from the fire. Stream habitat showed a slight decrease in quality however, the post restoration survey also after the Dixie Fire had affected the area. Stream particle size distribution and cobble size particle embeddedness increased, while pool residual depths and percentage of habitat decreased following the meadow restoration operations and Dixie Fire.

ACKNOWLEDGEMENTS

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APPENDIX A: **Wetland indicator plant percentages by transect for facultative upland, facultative, and upland species.**

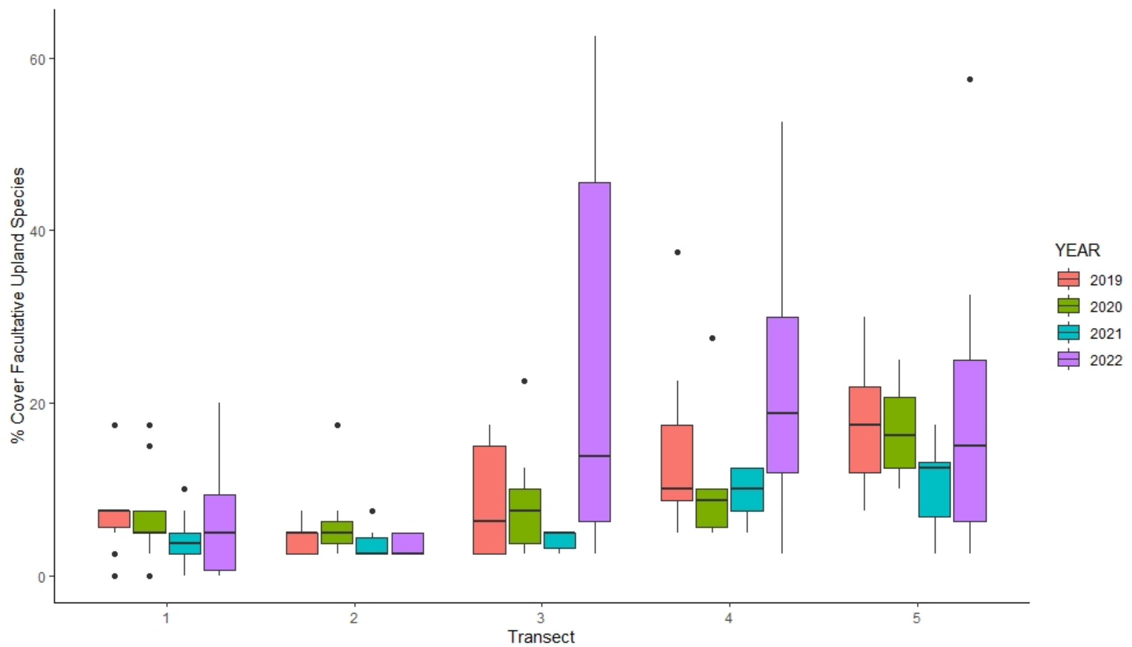

Figure A-1. Percentage cover by transect and year of facultative upload species at Rock Creek Meadow

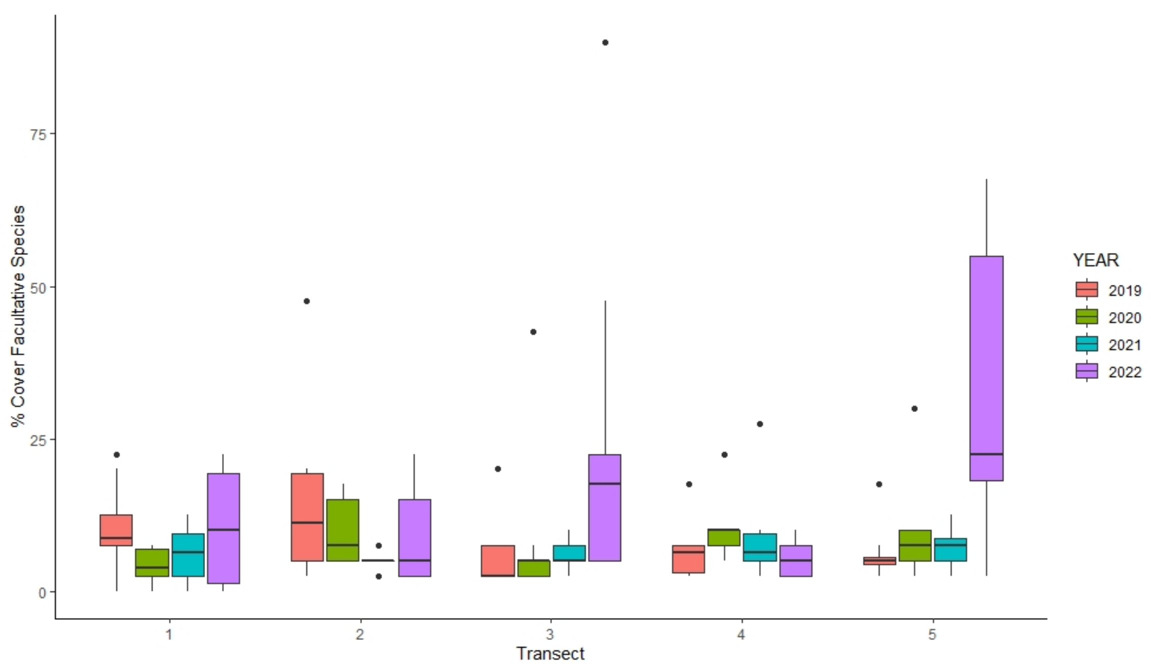

Figure A-2. Percentage cover by transect and year of facultative species at Rock Creek Meadow

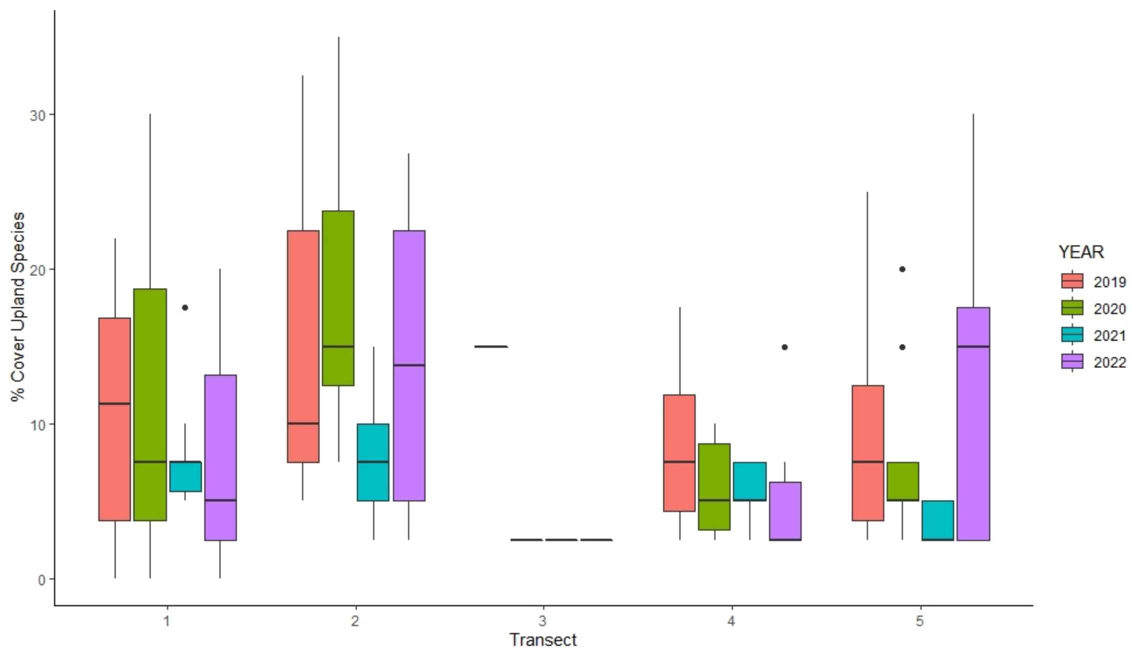

Figure A-3. Percentage cover by transect and year of upland species at Rock Creek Meadow

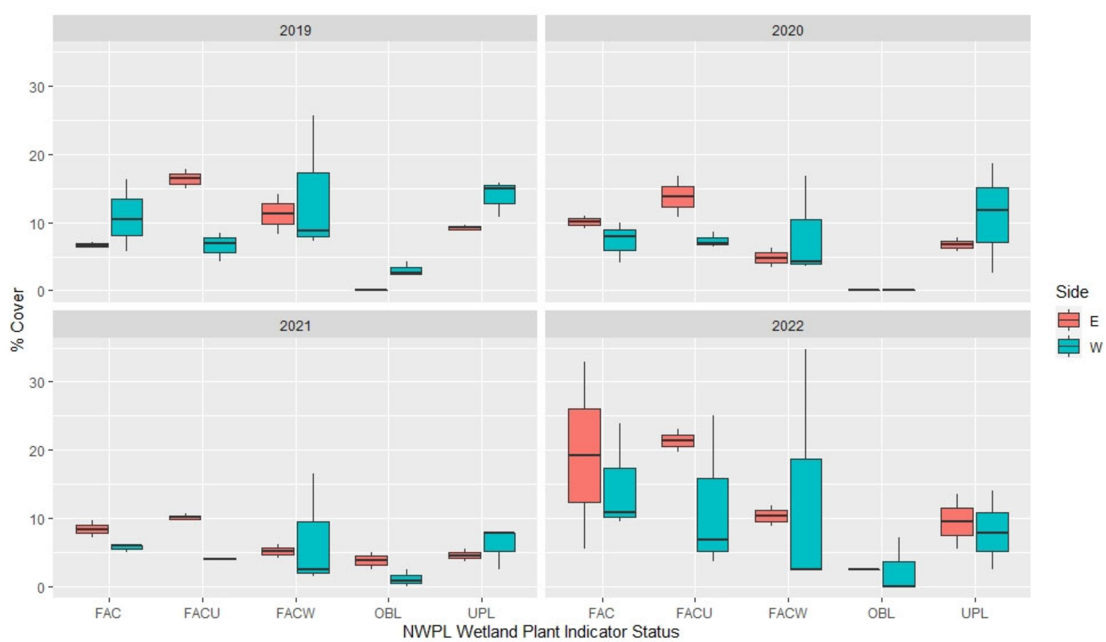

Figure A-4. Percentage cover wetland species type by eastern (red) and western (blue) portions of Rock Creek Meadow

APPENDIX B: Notes on conflicts with the integration of the Timber Harvest Planning and instream habitat structure placements permitted under the timber harvest plan.

- Leslie Mink of the Plumas Corporation

These notes are respectfully submitted by Leslie Mink of the Plumas Corporation on planning, collaboration, and implementation of the Rock Creek Meadow Restoration Project on Collins Pine property (12/20/21), as part of a review of the California Forest Practice Rules Meadow Prescription. This was a new type of project for most participants because it included both hydrologic and forestry work. It is noteworthy that even language posed some difficulty for melding these two worlds together. Participants agreed that they each had a better understanding of how to combine hydrologic and timber project implementation at the end of this project.

Planning and Regulation:

1. Regulatory Environment: In a nutshell, the regulatory requirements were unclear. I offered the Burney Gardens THP and permitting file as a template for Rock Creek. The Water Quality regulator stated that the CWA 401 and 404 permits for Burney Gardens were unnecessary, and therefore Burney Gardens was not a good template. Being from the hydrology world, I appreciated the good communication in the pre-consultation field meetings with regulators. It was unfortunate that no Calfire regulator attended because they were a key player, and seemed to not be on the same page with the other regulators. To illustrate the confusion, at the field meetings, CDFW & Waterboard representatives insisted that no permits for channel work were needed because everything was covered under the THP and California Forest Practice Rules (CFPR) regulatory environment. I disagreed on numerous occasions, arguing that permits were needed. My (approximately three) phone calls to Calfire seeking clarification were never returned.

Towards the end of the planning process, I was firmly directed by regulators and the landowner representative to not apply for permits for the channel work. At the pre-harvest inspection, which occurred after the THP was approved and just before harvest began (I was informed of the PHI, and was not present), the CalFire regulator issued permit conditions that directly contradicted what was stated by the other agencies at all of the previous meetings. The pre-harvest inspection report included these requirements: 1) a CDFW 1600 permit is needed for the channel work; and 2) the timber work around the channel must be completed before the channel work can begin. Because Plumas Corporation has years of experience with channel project implementation and permitting, we took the initiative to apply to the Army Corps of Engineers and the Waterboard for the appropriate permits at the same time that the 1600 permit was application was submitted. Neither agency issued a permit, alluding that no permit was necessary. The 1600 permit was quickly approved by CDFW. A CDFW Timber Unit regulator visited the project area a few days after notification that implementation would begin. There were no issues with the 1600 permit.

Another anecdote regarding the lack of communication between the regulatory agencies involved my own one-on-one on-site discussions with Calfire and CDFW, which occurred at two different times. I mentioned how the lack of communication, and unwillingness to integrate the channel and timber work resulted in less efficient, and more costly, implementation. Calfire blamed it on CDFW, citing past requirements by botanists that riparian areas not be touched. CDFW blamed it on Calfire, citing a lack of flexibility with Forest Practice Rules. The landowner, the grantee, the project implementation team, and all regulatory agencies recognize the need for integrating riparian and channel management into timber management. Despite this widespread recognition and agreement, there was a lack of willingness by Calfire to actually change implementation requirements or to meaningfully participate in project planning. This project represents an unfortunate missed opportunity for innovative collaboration in the science of riparian forest management that is so desperately needed.

I wish I had kept tally of the number of times that the phrase “this requirement is so stupid” was uttered by everyone involved in project implementation. It would have been great if we had not been required to blindly follow rules that were not actually meeting the intended objective. Two cases in point: 1) The feller-buncher was not allowed to turn or travel parallel to the channel (I agree – that’s a great rule to protect soft soils usually fund in riparian areas. It should be a “rule of thumb,” though; perhaps worded as “minimize” turning and travel parallel to channel, rather than “no” turning etc). In several instances, much less ground disturbance would have occurred if on-site personnel would have been allowed to travel short distances parallel to the channel. This would have been especially appropriate late in the season when there would have been no ruts caused by the travel, and in areas where channel incision dried out the riparian area. By just following a blanket rule, there was more-than necessary disturbance. Also, several ruts were caused in early 2021, but they were perpendicular to the channel, so while the rule was not violated, significant damage was caused to the meadow soil and vegetation because seasonal soil moisture is not a consideration under the rule. 2) Timber removal around the riparian area was slowed down by not allowing reasonable movement of the feller-buncher. Consequently, riparian timber removal ended up being the last thing accomplished, not the first, as originally planned. If channel work had been allowed to proceed in concert with timber work, as was planned, much more woody debris would have been incorporated into the channel, more bank trees could have been used for stabilization, the feller-buncher could have used one or more of the riffles to cross the channel and complete the riparian treatment, and the water truck and post-cutting fire watch could have been used for both operations simultaneously. The excavator also would have been on-site to repair any damage from the few number of feller-buncher crossings. By not allowing the two treatments together, timber operations along the channel were not completed before the Dixie Fire ran through the project area (thankfully, the burn was not severe in most of the project area).

Suggestions:

a) On-the-ground regulators need to understand Federal Clean Water Act regulations as well as California Forest Practice Rules.
b) All regulators need to attend pre-consultation meetings. This would ensure that requirements are not contradictory, and that project personnel understand regulatory requirements, and can prepare to meet those requirements during the planning process, not at the last minute.
c) When hydrology (i.e. channel) work is included in a timber project, the hydrologic lead person should be involved in the Pre-Harvest Inspection.
d) When channel work is included in a timber project, there needs to be a recognition of the flow-dependent implementation window for in-channel work. Perhaps a deadline could be placed on the timber work, or allow both treatments to be implemented simultaneously.
e) The regulatory framework should be more flexible to allow both the on-site regulators and project personnel to make real-time on-site decisions that allow for the best implementation of a project. This could perhaps include: review/ or additional annual or project-level certification of experienced individual foresters (and/or hydrologic consultants) that can be trusted (or not)

to "bend" the rules to protect or enhance resources; documentation of the rationale for the deviation from a rule; real-time and/or forensic monitoring to determine if there are any ill effects from the deviation from a rule; and/or two or more qualified professionals to agree in real time that the deviation is an on-site best practice.

2) On-the-ground CalFire regulators need to understand meadow restoration constraints (i.e., soil moisture, stream flow, CWA permit requirements), and not create unnecessary administrative requirements. The reasoning given for requiring channel work to wait until timber completion was that equipment in the channel would confuse the regulatory inspection process. As implemented, this additionally meant that not even hand work could place any material in the channel until a "partial completion" was granted by the regulator. There was no effort on the part of the CalFire regulator to work with project managers to accommodate channel work associated with timber work.

3) Sierra Institute Project Management: Communication would be key to melding timber and water together in an implementation project, but there was very little facilitated communication by the grantee to bring these two disciplines together. My guess is that SI staff were inexperienced in this arena. Experience levels of other partners and team members did not seem to be a valued resource by the grantee, resulting in some unnecessarily extensive back and forth on issues such as contracting, and lack of full team participation in some key meetings.

4) Contracting: Due to the lack of transparency and compartmentalizing of partners involved in this project, I am not fully aware of how the timber contract was structured. There seemed to be somewhat of a mismatch between the Licensed Timber Operator (LTO) needs and the needs of the project. Case in point is the timing - I don't know if there were any deadlines that took the needs of channel work implementation into account. Timing of the channel work needs were clearly expressed. After planning to implement as soon as the ground and channel were ready, and then adjusting to the need to wait for a partial completion, I was then told that the riparian timber work would be completed first so that to channel work could be completed at the nadir of streamflow. However, the riparian areas were NOT treated first, thus delaying channel work. The delay potentially could have resulted in issues with precipitation and streamflow. Thankfully, we were lucky that this did not happen, and the weather was dry. A service contract or time & materials contract with the LTO may have led to a better connection of project needs and compensation of the LTO.