EMC Completed Research Assessment
Initial Draft: August 20, 2024
Revision Date: Nov. 14, 2024
Approved by the EMC: Nov. 14, 2024
Approved by the Board of Forestry & Fire Protection: December 11, 2024
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EMC-2018-003 Alternative Meadow Restoration
Final Report dated July 31, 2023

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1. Fulfills and addresses scientific question(s) posed in proposed research?

A. Does the study inform the intended rule, numeric target, performance target, or resource objective?

The completed research addresses scientific questions posed in the context of the Code of Federal Regulations (CFR) § 933.4[e] regarding Meadows and Wet Areas restoration and detailed in the research project's final report. The rule also applies to aspens stands. The rule allows harvest or other treatments to "restore, retain or enhance these areas for ecological or range values" with the overall goal being to "balance the protection and regeneration of aspen stand, Meadows and Wet Area habitats in California's forest ecosystems with the other goals of forest management as specified in Title 14 California Code of Regulations (CCR) § 897".

The primary conditions imposed by the rule to allow this significant departure from standard practices for harvest in the Watercourse and Lake Protection Zone (WLPZ) are:

- Identifying the type of project and showing in on plan maps showing locations of planned operations for harvesting and treatment types (CFR § 933.4[e](1), (2), and (3)).
- Describing the condition of aspens stands and Meadows and Wet Areas in the project area; with respect to Meadows and Wet Areas, this entails the spatial extent, species composition, stand structure and character, and relevant Watercourse condition factors per Board of Forestry and Fire Protection ('Board') Technical Rule Addendum #2 and other indicators of geomorphic and hydrologic function (CFR § 933.4[e](4)).
- Identifying project goals and measures of success defined as *"criteria related to a physical condition that can be measured using conventional forestry equipment or readily available technology to indicate the level of accomplishment of the project goals."* (CFR § 933.4[e](5))
- *"… [P]roject goals and measures of success shall be based on the condition assessment… and identification of problematic… conditions and their agents/causes. Information shall include a description of factors that may be putting… Meadows and Wet Areas at risk, and*

presence of unique physical conditions. Projects shall be designed to contribute to rectifying factors that are limiting restoration, to the extent feasible" (CFR § 933.4[e](5)(A)).

- Finally, a review by the Department of Forestry & Fire Protection ('Department') of post-harvest field conditions, to include photo point records of where the "*restoration silvicultural prescription*" was applied, summarized in a report every five years for the Board. The report is to summarize the "*level of achievement of measures of success*", "*post-harvest environmental impacts resulting from the prescription*", "*regulatory compliance issues*", and "*other significant findings resulting from the review*".

The study informs the limited performance targets and broad resource objectives of Meadows and Wet Areas restoration as set forth in CFR § 933.4[e] as described below. The study was proposed to address two critical questions identified under EMC Research Theme 1 pertaining to WLPZ Riparian Function:

- Maintaining and restoring stream water temperature; data was collected to address this critical question; a combination of extreme drought in 2021 and direct impacts of the Dixie Fire in 2022 were confounding factors in the two years of post-treatment monitoring and it is not possible to draw a conclusion regarding this critical question in the context of Meadows and Wet Area environments.
- Managing WLPZs to reduce or minimize potential fire behavior and rate of spread; **although noted in the project proposal, the study objectives did not address this critical question.**

B. Does the study inform the Forest Practice Rules?

The study informs the specific Forest Practice Rules (FPRs) pertaining to alternative practices in the WLPZ to restore Meadows and Wet Areas with respect to several measures of riparian zone function:

- Hydrologic and vegetative response to removal of *Pinus contorta* encroaching on meadows (Objective 1 of the study).
- Evaluation of water quality metrics (streambed sediment and stream temperature) in response to tree removal and meadow restoration (Objective 2 of the study).
- Evaluation of soil disturbance and compaction in response to tree removal and meadow restoration (Objective 3 of the study).
- Instream habitat restoration activities associated with a Timber Harvest Plan (THP) for meadow restoration (but not part of this study) revealed a lack of clarity in regulatory requirements and processes.

2. Was the study carried out pursuant to valid scientific protocols (i.e., study design, statistical analysis, peer review)?

This study employed scientific methods appropriate to the context, scale, and breadth of the study, which is a before-after-control-intervention (BACI) design. The study was ambitious in that its scope included a wide range of wet meadow ecosystem characteristics touching on hydrology, soils, water quality, vegetation, and stream conditions. The elements of the study pertaining to meadow hydrology, vegetation, and soils (study Objectives 1 and 3) were conducted using

methodology and statistical analyses that are comparable to what would be expected in peer-reviewed journals. Elements of the study pertaining to water quality in streams draining the meadows (Objective 2) utilized some of the standard methodologies for monitoring water temperature and streambed condition consistent with Technical Rule Addendum #2; however, limitations of the study design and duration of monitoring limited the ability to separate treatment effects of meadow restoration from the effects of extreme drought (2021 and 2022) and extreme wildfire (2022 Dixie Fire).

3. Is the study scalable? What does the study tell us? What does the study not tell us? Do findings apply to other areas of the State?

This study has relatively narrow applicability with respect to state-wide FPR's. The rule allows for alternative forest harvest practices in WLPZ settings where aspen stands or montane wet meadow ecosystems have been impaired by encroachment by lodgepole pine stands, in part owing to past management practices such as cumulative effects of fire suppression on forest and meadow vegetation and poor range management prior to regulatory requirements. The rule promotes restoration of wet meadow ecosystems by allowing harvest in the WLPZ and requires project-specific identification of a range of natural resource conditions and causes of impaired conditions, measures of success appropriate to the treatments and causes of impairment, and reports by the Department at five year intervals to evaluate the degree of success of the project and identify other environmental impacts and regulatory compliance issues.

The study provided a scientifically based analysis of pre- and post-treatment conditions of the project area, supplemented by information from two other comparable areas previously under investigation. The project area that was the focus of this project, Rock Creek Meadow (RCM), was monitored for three years prior to treatment and two years post-treatment. Analysis was supplemented with data from Marian Meadow (MM), which was monitored for 7 years post conifer removal, and also served as the control for RCM. While developed specifically for the RCM project, the structure and methods of the study, in addition to some of its findings, have applicability for other Meadow and Wet Area restoration projects. In addition, the study provides detailed data sets and analysis that could be used by the Department to develop the required reporting to the Board at five-year intervals. The project was implemented in 2021 and the report to the Board would be expected in 2026.

The principal scientific findings and perspectives developed by the study pertain to natural resource conditions of the Meadow and Wet Area restoration project before and after the project. It must be noted that environmental conditions during the two-year post-project monitoring period included two consecutive years of extreme drought (Water Years 2021 and 2022) and the Dixie Fire in 2022. Consequently, any conclusions based on environmental conditions post-project should be subjected to consideration of these significant influences on environmental conditions generally unrelated to the restoration project treatments.

Synthesis of Key Findings

Objective 1: Changes in water availability post conifer removal. Hydrological effects of tree removal were generally positive across years, across lines of evidence and across the two study

meadows. Vegetation response of wetland species seemed mixed (and complicated by the Dixie Fire) but generally positive or neutral.

- **Groundwater** responses were complicated but showed positive effects of treatment on average:
    - Removal in MM meadow resulted in decreased depth to groundwater in 2 years, increased depth to groundwater in 2 years and increased summer but decreased winter depth to groundwater in 2 years (see Project Report Figure 8, reproduced below). Most regression lines except for the drought years of 2020 and 2021 ('Time' 5 and 6 in the figure) fall below the Time=0 (2014) pre-treatment relationship between the treated meadow (MM) and the Control Meadow, indicating decreased depth to groundwater post treatment.
    - Removal in RCM resulted in decreased groundwater in Year 1 post treatment, and then Year 2, was complicated by the Dixie Fire (though likely increased compared to pre-treatment).

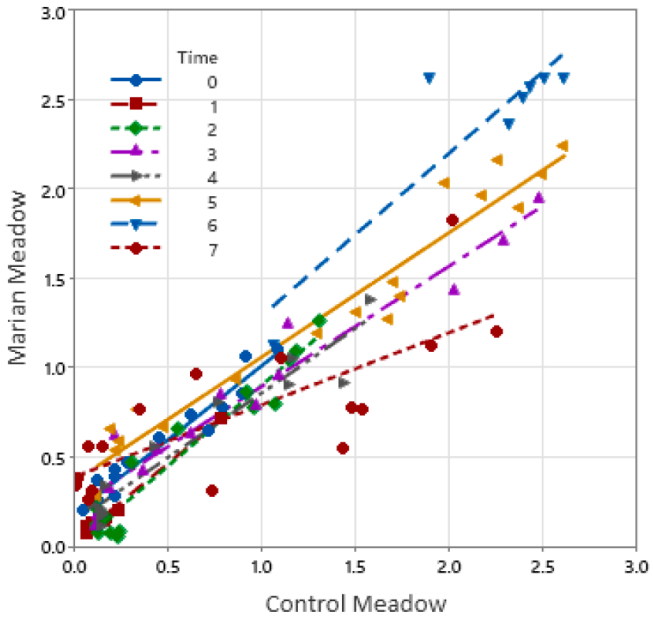

Figure 8. Regression plots by year between Marian and Control Meadows 2014-2022 for depth to groundwater in meters. Time is the sequence of water years since restoration with Time = 0 the water years prior to restoration (2014-2015 WY). Time = 7 is the water year following the Dixie Fire (2022 WY).

- **Soil moisture** showed more obvious increases post treatment:
    - Decreased soil moisture when dry but increased soil moisture when wet in MM following treatment.
    - Increased soil moisture in RCM by Year 2 (despite the Dixie Fire) (see Figure 16 from the Project Report, reproduced below) comparing soil moisture in the RCM meadow to the MM meadow used as a control. Shift of regression line upward in Year 1 and Year 2 indicates greater soil moisture post treatment).

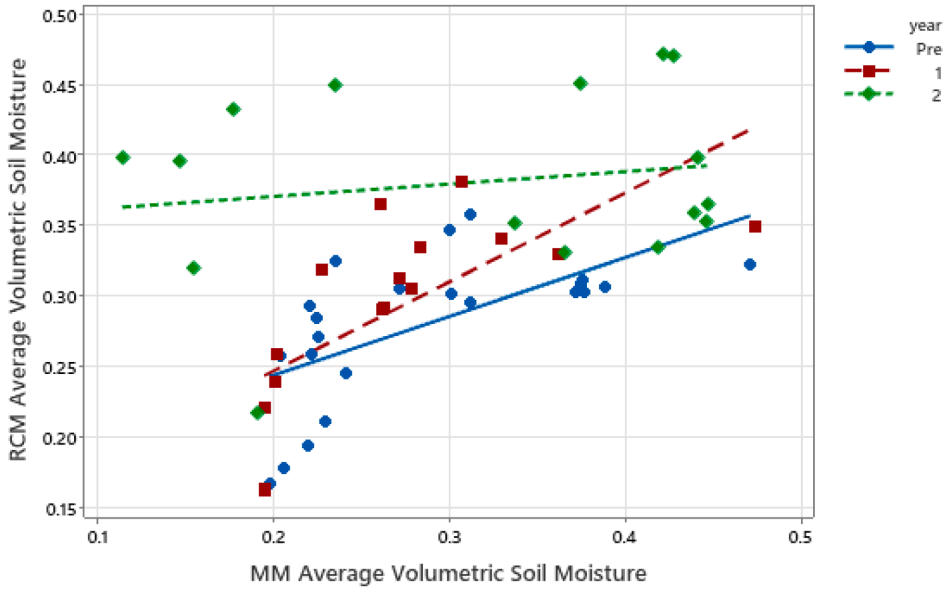

Figure 16. Regression plots by year for the average weekly volumetric soil moisture for Rock Creek and Marian Meadows 2020-2022. Year is the sequence of water years since restoration Year = 2 is the water year following the Dixie Fire (2022 WY) and is statistically different from pre-restoration year, 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 increased more in drier side of RCM than wetter side.
- Supported by repeated Electrical Resistivity Surveys showing decreased resistivity (and likely increased soil moisture) after tree removal (see Figure 17 of the Project Report, lower resistivity represented by green colors in panel B) compared to higher resistivity reds and yellows indicate an increase in soil moisture post treatment).

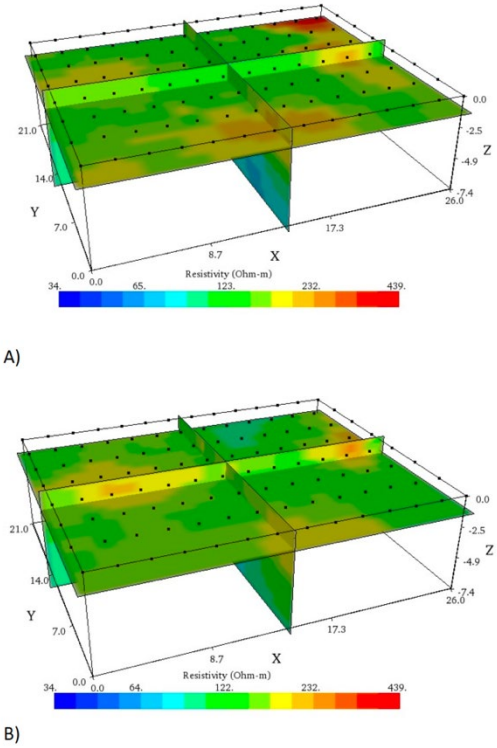

Figure 17. *Three dimensional images of electrical resistivity in A) 2020 pre-restoration and, B) 2021 following Pinus contorta removal. The XYZ coordinates are in units of meters. Lower resistivity values reflect high soil water, while higher resistivity values demonstrate drier soil media.*

- **Pine transpiration** estimates from sapflow suggest that soil moisture was improved by removing 220+/-25mm transpiration[1] (more on the wet side of the meadow than the dry side) from April to mid-August (much of the growing season).
- **Vegetation response** – decrease in cover and diversity on the dry side of RCM (disturbance + drought + Dixie Fire and secondary disturbance from a fire road). Recovery of cover and more stable diversity on wet side after the drought and Dixie Fire. The vegetation metrics were compared directly without statistical inference.

Objective 2: Effects of treatment on water quality. Effects of specific treatment on water quality metrics were difficult to disentangle from the effects of the Dixie Fire, and thus largely inconclusive.

- **Stream temperature** - Greater effect of Dixie Fire on stream temps than WLPZ vegetation removal. Stream temps post Dixie Fire exceeded 18°C (target for steelhead trout) (see Table 11 from the Project Report, reproduced below).
- **Sediment** – Cobble embeddedness increased by 14% and pool depth decreased by 0.24ft. Particle size distribution became slightly coarser. This includes both treatment and Dixie Fire effects.

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°)	MWMT (C°)
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

Objective 3: Soil disturbance and compaction Vegetation cover surveys and soil bulk density analysis generally did not show substantial impacts of restoration treatment (harvest of *Pinus contorta* occupying the meadow).

[1] *Marks S, Surfleet C, Malama B. 2024. Estimating and Modeling Pinus contorta Transpiration in a Montane Meadow Using Sap-Flow Measurements. Forests 15: 1786.*

- **Soil disturbance in WLPZ** – 15% disturbed by treatment in 2021, an additional 21% by fire in 2022. This metric was compared directly without statistical inference.
- **Bulk Density** showed no change following treatment (or fire). Restrictions on equipment in the WLPZ appear to have succeeded.

4. Part 4. More research needed?

A. Literature Review Sufficient?

We believe there is a developing literature regarding problems with mountain meadow habitats, but also believe that there is not a great deal known about meadow restoration treatments. Given the circumstances of this research project, we believe the literature review included in the report is sufficient.

B. Further Funding Needed?

We do not feel that significant further funding for research of this type is a high priority for the EMC. Outstanding questions remain about impacts of alternative practices for Meadows and Wet Areas on stream temperatures and managing WLPZs to reduce or minimize potential fire behavior or rate of spread. This study demonstrated positive effects of meadow restoration on hydrology and minimal impacts on soil compaction, but ultimately captured only one treatment in one meadow with high organic matter content in the WLPZ (average bulk density of 0.7g/cm3). Scalability to other meadows in other geologic/edaphic/hydrological/ecological contexts remains uncertain. A meta-study of other meadow restoration projects that have occurred could be of substantial value in the future.

C. What is the relationship between this study and any others that may be planned, underway or recently completed?

This study is related to EMC-2018-006[2] and EMC-2023-002[3] in terms of monitoring FPR effects on stream temperature, and completed EMC-2015-002[4] about filtering sediment from treatment roads before they reach the WPLZ, but otherwise there are no other ongoing EMC-supported projects about meadow restoration.

5. Part 5. Scientific Applications - What is the scientific basis that underlies the rule, numeric target, performance target, or resource objective that the study informs? How much of an incremental gain in understanding do the study results represent?

The impacts of fire suppression, past grazing practices, and climate change on tree encroachment into Meadows and Wet Areas is extensively documented in the Sierras. The ability of the FPRs to "balance the protection and regeneration of aspen stand, Meadows and Wet Area habitats in

[2] Effectiveness of Class II Watercourse and Lake Protection Zone Forest Practice Rules and Aquatic Habitat Conservation Plan (AHCP) Riparian Prescriptions at Maintaining or Restoring Canopy Closure, Stream Water Temperature, and Primary Productivity

[3] Assessing Fire Hazard, Risk, and Post Fire Recovery for Watercourse and Lake Protection Zones (WLPZ) and riparian areas of California

[4] Forest Practice Rules Implementation and Effectiveness Monitoring (FORPRIEM) ver. 2.0

California's forest ecosystems with the other goals of forest management as specified in 14 CCR § 897", is bolstered but not conclusively demonstrated by this study. This study demonstrates the generally positive hydrological impacts of removing encroaching *Pinus contorta* from montane wet meadows in two separate treated meadows using multiple lines of evidence. This study also does not document substantial negative impacts of treatment on vegetation cover or soil compaction in the WLPZ, with 15% disturbed soil cover and no identified soil compaction in the WLPZ one year after *P. contorta* were harvested following using restricted equipment operation protocols (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, due in part to the confounds of the Dixie Fire, this study could not rigorously test the impacts of canopy removal on water quality characteristics.

The broader restoration project did, however, reveal a lack of clarity in regulatory requirements and processes for merging silvicultural prescriptions of tree removal with instream habitat restoration activities associated with a THP for meadow restoration (but not part of this study, see Appendix B of the Project Report[5] for full details on issues encountered for this relatively novel project type). In particular, uncertainty/difficulty in coordinating the requirements between the Department's FPRs and California Department of Fish and Wildlife (CDFW)/Water Board regulations, and restrictions on equipment movement/project sequencing from the FPR side that did not always minimize the impacts of equipment in the WLPZ when combined with in-stream restoration work were cited as potential areas for improvement by Leslie Mink of the Plumas Corporation.

In summary, this research project represents a partial validation of the current FPRs, particularly CFR § 933.4[e] regarding Meadows and Wet Areas restoration, but generally incremental progress in our understanding of how to balance meadow restoration 'other goals of forest management'.

[5] https://bof.fire.ca.gov/media/ftfea1y3/emc-2018-003-alternative-meadow-restoration-report-rev1.pdf