Pole Hill Monitoring Report

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COLORADO FOREST RESTORATION INSTITUTE
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CSU Land Acknowledgment: Colorado State University acknowledges, with respect, that the land we are on today is the traditional and ancestral homelands of the Arapaho, Cheyenne, and Ute Nations and peoples. This was also a site of trade, gathering, and healing for numerous other Native tribes. We recognize the Indigenous peoples as original stewards of this land and all the relatives within it. As these words of acknowledgment are spoken and heard, the ties Nations have to their traditional homelands are renewed and reaffirmed. CSU is founded as a land-grant institution, and we accept that our mission must encompass access to education and inclusion. And, significantly, that our founding came at a dire cost to Native Nations and peoples whose land this University was built upon. This acknowledgment is the education and inclusion we must practice in recognizing our institutional history, responsibility, and commitment.

Document Development: This report was developed to describe results of CFRI's monitoring at the Pole Hill Forest Restoration project. Monitoring methods and data collection were implemented in collaboration with Larimer Conservation District to measure their forest management goals aimed at enhancing forest resilience and reducing wildfire risk. Monitoring protocol development was coordinated with the Peaks to People Water Fund science committee and conducted on behalf of the Peaks to People Water Fund. The aim of this report is to evaluate treatment effectiveness in relation to project goals, and compare modeled fire behavior informed by field data to fire behavior predicted by the Peaks to People Watershed Investment Tool.

Acknowledgements: Special thanks to the landowners who volunteered to have monitoring plots installed on their land and Matt Marshall from the Larimer County Conservation District for providing treatment information, gaining permission for monitoring activities from individual landowners, collaborating on implementation of monitoring protocols, and reviewing the draft report with his colleague Auston Palenik. Project supervision and thoughtful review and feedback from Camille Stevens-Rumann and Brett Wolk improved this report. We thank Ben Gannon for performing initial project evaluations for the Pole Hill project in the WIT, and for his contributions to development and application of the WIT tool and PPWF monitoring framework. Thank you to the dozens of CFRI students, field technicians, and crew leaders that participated in collecting field data at Pole Hill in 2019 and 2021.

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Table of Contents

Executive Summary

The Peaks to People Water Fund provided funding for the Pole Hill restoration project to thin the forest and reduce fuel loading in a high fire risk area adjacent to residential homes and utility infrastructure. This report summarizes changes to forest structure, surface fuels, and modeled fire behavior following treatment in addition to comparing modeled fire behavior informed by field monitoring data to the fire behavior predictions from the Watershed Investment Tool (WIT). Pole Hill's treatment retained large ponderosa pine trees while reducing the number of trees per acre, basal area, and canopy cover. Future projects could focus on raising canopy base height, although monitoring other sites on the Front Range demonstrated this is not usually accomplished by thinning alone. The slash treatment at Pole Hill was effective at limiting the increase in woody surface fuel loadings post-treatment. Predicted fire behavior from both the field data and the WIT shows a decrease in active crown fire following treatment, although the WIT modeled more passive crown fire pre- and post-treatment. Treatment decreased, but did not eliminate, the potential for high severity wildfire. Overall, the forest thinning and fuels reduction treatment at Pole Hill was beneficial and met the majority of the project's goals.

Introduction

The Peaks to People Water Fund provides funding for forest restoration and fuel reduction treatments to reduce wildfire risk to water supplies and other values in the Cache la Poudre and Big Thompson watersheds. The Colorado Forest Restoration Institute (CFRI) partners with Peaks to People Water Fund (PPWF) to develop and apply monitoring tools that measure outcomes of these investments. The aim of this monitoring program is to ensure investments are developed to be strategic and impactful, to measure progress towards achieving project and program goals, and to support continued learning and improvement with Peaks to People partners. CFRI monitors individual projects to characterize their ecological and wildfire risk reduction benefits, and leverages project level monitoring results to inform progress towards PPWF program goals using the Watershed Investment Tool.

PPWF provided funding for the Pole Hill Restoration Project, which involved forest thinning and fuels reduction within 246 acres of the Big Thompson watershed. The project was of high priority for PPWF due to the high fire risk in close proximity to a residential community, the Pole Hill Powerplant, Pinewood Reservoir, and Carter Lake. Pinewood Reservoir is a key component of the Colorado-Big Thompson Project power system and helps regulate water for peak power demands. CFRI was brought on as a partner to monitor whether the project level forest treatment goals were met and to facilitate adaptive management processes that improve the effectiveness of future treatments and PPWF investments. Monitoring and evaluating treatment outcomes are critical steps in the adaptive management process. We worked with Matt Marshall from the Larimer County Conservation District to determine an appropriate sampling strategy for the site. This report summarizes treatment results and may be used for treatment planning and communication with landowners in future projects.

Monitoring data collection and analysis sought to answer the following questions:

1. How have forest structure, surface fuel conditions, and modeled fire behavior changed following treatment?
2. How does modeled fire behavior informed by CFRI's field monitoring data compare to fire behavior predictions from the Watershed Investment Tool?

Treatment Background

The forest type surrounding this area is ponderosa pine (Table 1). Tree species composition has been stable over the past few hundred years; however, tree densities have increased and average tree age has decreased over roughly the past 100 years similar to other areas across the Colorado Front Range (Battaglia et al. 2018). Forest management activities were designed to enhance forest resilience and reduce wildfire risk with specific goals to: 1) increase spatial heterogeneity of forest cover, 2) increase ratio of ponderosa pine to other conifers, 3) increase age class diversity of trees, 4) decrease modeled crown fire activity and fire intensity, and 5) increase understory plant abundance.

Table 1. Project Information.

Project Management	Larimer County Conservation District
Year Completed	2021
Project Acres	246
Acres Treated	100
Forest Type	Ponderosa pine
Implementation Method	Mechanical & hand thinning
Slash Treatment	Mastication & log removal
Years Monitored	2019 & 2021

Methods

In 2019, CFRI installed 22 monitoring plots on four private properties, each approximately 30 acres in size, in the Pole Hill treatment area. Each property had 5-6 monitoring plots randomly located within the areas targeted for management (Figure 1). Plots were measured again in 2021 following treatment (Figure 2). During both pre- and post-treatment sampling visits, at each monitoring plot a series of pictures were taken, topographical information was recorded, and a fire behavior fuel model was assigned (Colorado Forest Restoration Institute, 2019). Variable radius plots were used to measure overstory trees. Each tree's species, diameter, height, crown base height, and decay class (if dead) were recorded. Tree regeneration (<5 inches

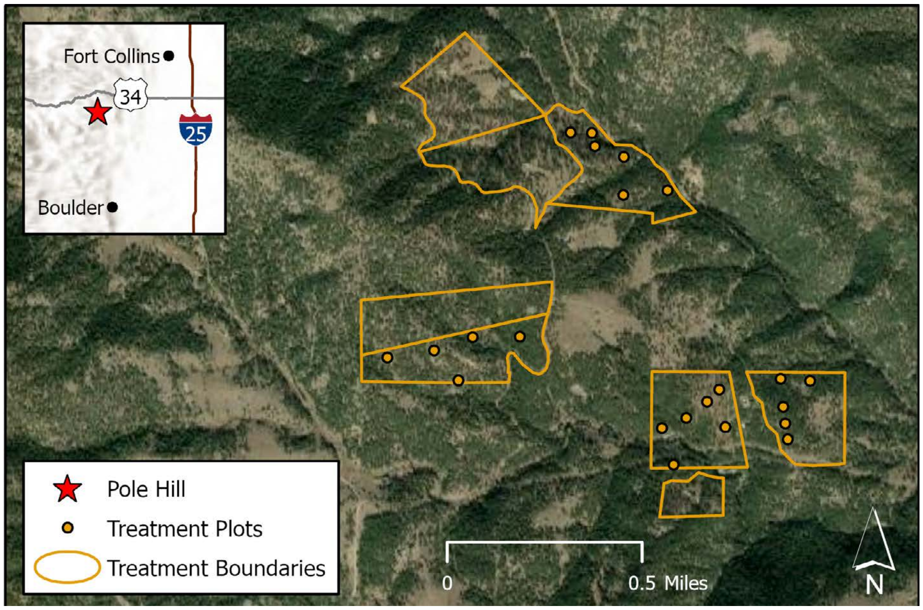

Figure 1. Map of Pole Hill's location, unit boundaries, and monitoring plots. Treatment boundaries represent the project area; treated areas are not displayed. Treatments were scattered across the project area, based on where they were most practical and useful.

BEFORE

AFTER

Figure 2. Examples of forest conditions before and after treatment.

diameter) was measured in 1/100th acre fixed radius plots. All pieces of coarse wood (>3 inches diameter) within the 1/100th acre fixed radius plot were measured, and three 1m² quadrats were used to assess fine wood loading (<3 inches diameter) using the photoload sampling technique (Keane & Dickinson, 2007). Litter and duff depths were taken at the four corners of each quadrat. Although the 3 herbaceous plant species covering the greatest area of each quadrat were recorded, sufficient data to assess treatment's impact on understory plant abundance was not collected. Shrubs were measured along a 50 foot transect; species, height, and transect intercept distance were recorded (Colorado Forest Restoration Institute, 2019).

CFRI puts field data through a series of quality control checks and analyzes it using R (R Development Core Team, 2021) and the Fire and Fuels Extension to the Forest and Vegetation Simulator (FFE-FVS; Reinhardt & Crookston, 2003). The four units were analyzed separately as well as combined. Results from the combined analysis are presented here because all units responded similarly to treatment. Differences between pre- and post-treatment values were analyzed using pairwise t-tests or Kruskal-Wallis tests when assumptions of the t-test were not met.

The Watershed Investment Tool (WIT) models water supply risk by quantifying expected sediment impact costs to water resources following wildfire and prioritizes treatments to achieve the largest return on investment that maximizes risk reduction relative to forest treatment costs (Gannon, 2020). The WIT tool integrates LANDFIRE fuels data and weather data to map crown fire activity as a proxy for burn severity using the FlamMap fire modeling software (Gannon, 2020; Finney et al., 2015). The crown fire activity categories are unburned, surface fire, passive crown fire, and active crown fire. Unlike FFE-FVS, there is no conditional crown fire category in FlamMap to describe areas where active crown fire is expected but torching is not. For each PPWF project, FlamMap is run once with pre-treatment conditions and again with the simulated thinning treatment where baseline LANDFIRE fuels were adjusted to reflect estimated post-treatment canopy and surface fuels. These pre- and post-treatment fire behavior outputs are then integrated into the WIT to measure changes in wildfire risk, post-fire erosion, and sediment impacts to watershed resources as a result of the forest management activities (Gannon, 2020). Here we compared project level modeled fire behavior from FFE-FVS with fuels adjustments made in FlamMap.

Results and Discussion

Stand Structure and Composition

Field monitoring results show that the thinning treatment affected stand structure and composition by reducing the number of trees, especially those of smaller diameters. Treatment removed 384 trees per acre ($P<0.001$; Table 2); and decreased basal area by over 60% ($P<0.001$). Post-treatment canopy cover was roughly a quarter of what it was pre-treatment ($P<0.001$). Although there was a large decrease in the number of seedlings per acre following treatment, this change was not statistically significant ($P>0.05$). There was also no significant change in the percent of ponderosa pine by basal area since trees of other species are rare at Pole Hill ($P>0.05$, Table 2). The quadratic mean diameter increased by over 3 inches, indicating treatment removed mostly small diameter trees ($P<0.001$; Table 2; Figure 3). Crown base height of overstory trees and saplings was unchanged following treatment ($P>0.05$; Table 2).

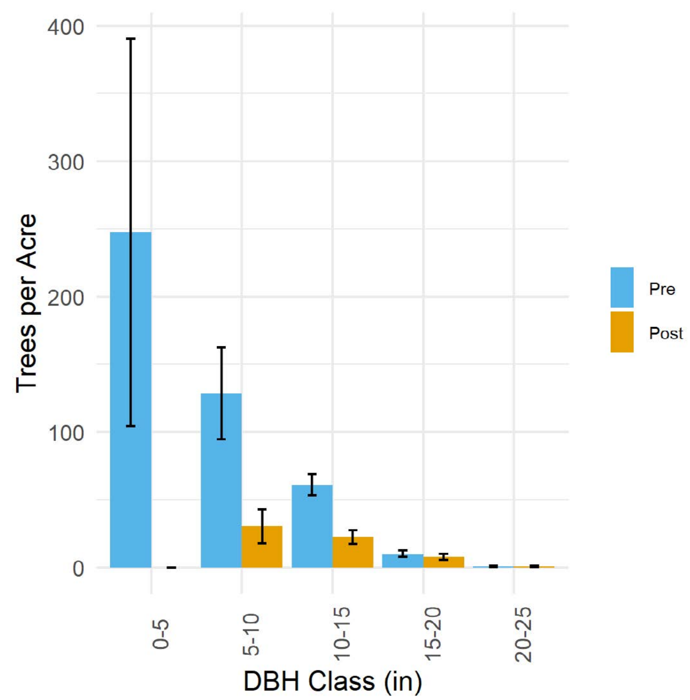

Figure 3. Number of overstory trees and saplings by diameter class. All trees measured pre- and post-treatment were ponderosa pine.

Table 2. Stand characteristics (mean ± standard deviation) pre and post forest thinning. Asterisks (*) denote a statistically significant difference at an α=0.05 level.

Visit	Trees per Acre	Basal Area (ft²/ac)	Canopy Cover (%)	Seedlings per Acre	Ponderosa by Basal Area (%)	Quadratic Mean Diameter (in)	Crown Base Height (ft)
Pre	*446 ± 659	*111 ± 54	*60 ± 25	176 ± 399	100	*9.1 ± 2.9	12.0 ± 5.3
Post	*62 ± 56	*42 ± 25	*16 ± 20	24 ± 109	100	*12.7 ± 3.1	11.2 ± 5.3

Pole Hill's treatment was effective at meeting its forest structure and composition goals, although there is room for improvement with respect to crown base height. Treatment did not change species composition of the almost pure ponderosa pine stands. Old trees were also retained, which will maintain the age diversity at Pole Hill over time. Lastly, treatment significantly reduced mean forest canopy cover, basal area, and tree density.

Fuels and Fire Behavior

Woody surface fuels increased slightly following treatment; litter and duff depths and shrub cover had minor decreases. The increase in fine woody fuel loading was statistically significantly (P<0.001) but loading remained relatively low at 1.24 tons/acre (Table 3). For comparison, a literature review of mulching impacts on other Colorado ponderosa pine forests saw an average fine woody fuel loading of 14.9 tons/acre post-treatment (Battaglia et al., 2010). Coarse woody fuel loading increased by over 400%, a change which was statistically significant (P=0.036). The minor decrease in total depth of litter and duff was statistically significant (P=0.010). Similar changes to litter and duff depths were seen at other CFRI monitoring sites in Front Range ponderosa pine forests (Slack et al., 2021). The small change in shrub cover was not statistically significant (P>0.05). Shrub cover returns to pre-treatment levels within 2-4 years following treatment, as others have found (Fornwalt et al., 2017).

Table 3. Surface fuel conditions (mean ± standard deviation) pre and post forest thinning. Asterisks (*) denote a statistically significant difference at an α=0.05 level.

Visit	Fine Woody Fuel Loading (tons/acre)	Coarse Woody Fuel Loading (tons/acre)	Litter/Duff Depth (inches)	Shrub Cover (%)
Pre	*0.64 ± 0.38	*0.35 ± 0.63	*1.86 ± 0.79	4.14 ± 8.52
Post	*1.24 ± 0.62	*1.48 ± 3.07	*1.28 ± 0.81	2.56 ± 6.19

Table 4. Modeled fire behavior results from field monitoring data using FFE-FVS.

	Pre		Post	
Fire Weather Conditions	Moderate	Severe	Moderate	Severe
Total Flame Length (feet)	0.6	18.7	0.9	4.0
Surviving Tree Basal Area (%)	76	52	82	65

Fire behavior is predicted to be less severe post-treatment under both moderate and severe fire weather conditions (Figure 4). Fire effects are predicted for all plots pre- and post-treatment under moderate fire weather conditions. The small changes found post-treatment are comparable to results from other treatments along the Front Range under moderate fire weather (Table 4; Morici et al., 2019; Slack et al., 2021). Modeled fire behavior metrics under severe fire weather conditions changed more noticeably than under moderate conditions. Total flame length decreased by more than 14 feet and surviving tree basal area increased by 13% (Table 4). Pole Hill's treatment was more effective than treatments at other PPWF sites in reducing flame lengths and increasing surviving tree basal area (Morici et al., 2019). There was a range of modeled fire types pre-treatment, with several plots predicted to burn as active crown fires. Post-treatment, all plots are expected to support either surface or passive crown fire.

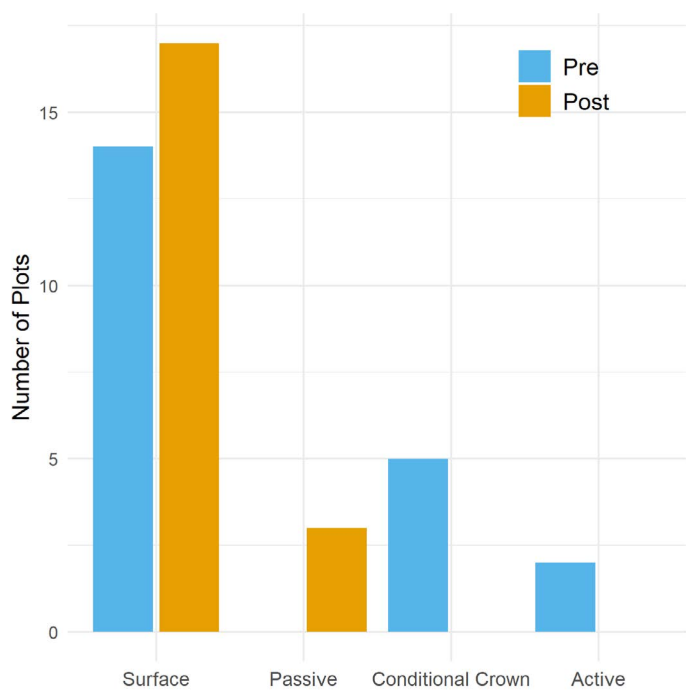

Figure 4. Number of pre- and post-treatment plots within each modeled fire type under severe fire weather conditions.

Torching index, the wind speed needed to initiate crown fire activity, became more variable post-treatment (Figure 5). Torching or passive crown fire is predicted to occur under severe fire weather conditions in some plots post-treatment (Figure 4). However, the majority of plots have torching indices exceeding wind speeds typically seen at Pole Hill. Crowning index, the wind speed needed to carry an active crown fire, increased following treatment (Figure 5). The changes to Pole Hill's torching and crowning indices are consistent with what was seen at other PPWF sites, other CFRI monitoring sites, and other thinned ponderosa pine forests (Morici et al., 2019; Slack et al., 2021; Fulé et al., 2012). Although crowning index increased and no plots are predicted to burn as active crown fires post-treatment (Figure 4), the wind speed needed to initiate active crown fire for more than half the plots is below 50 miles per hour. While the treatment met the goal of decreasing modeled crown fire at Pole Hill, the potential for severe fire behavior has not been eliminated. Because historical ponderosa pine forests in the Front Range had scattered, dense tree groups, patches of severe fire behavior are typical (Battaglia et al. 2018). Due to the overall reduction in tree density across Pole Hill (Table 2), fire intensity across the entire landscape is likely to be lower than it would have been pre-treatment. Severe fire behavior post-treatment is most likely to occur in dense tree groups, which is consistent with historical fire behavior.

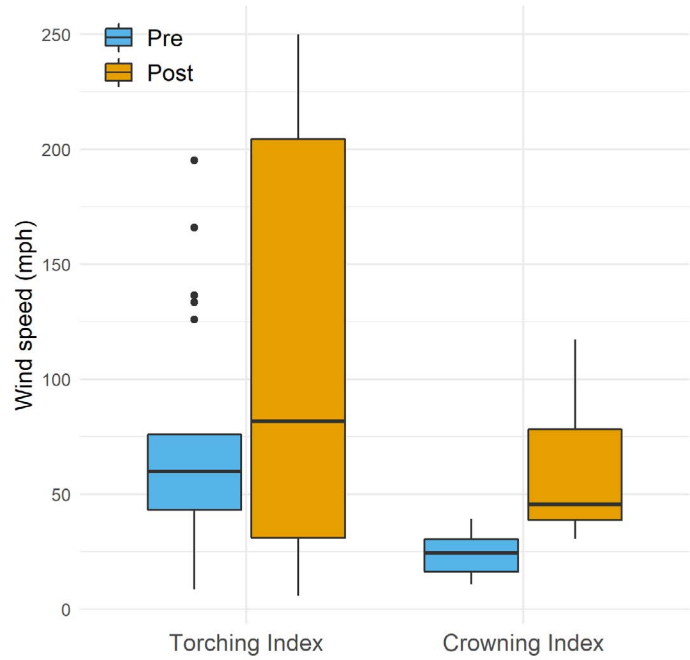

Figure 5. Boxplots showing the range of windspeeds predicted to support torching (Torching Index) and active crown fire (Crowning Index) within pre- and post-treatment plots.

Watershed Investment Tool Comparison

The WIT models fire behavior with FlamMap using fuels data from LANDFIRE and simulates forest treatments by adjusting baseline LANDFIRE data to reflect the effects of a typical treatment on canopy and surface fuels (Gannon, 2020). Crown fire activity predictions from the WIT differ from predictions using field data and FFE-FVS due to different data sources and model assumptions (Morici et al., 2019). Comparing the WIT outputs to field data and FFE-FVS can help improve the WIT's simulated treatments.

Table 5. Fire activity predicted using FlamMap-based methods in the WIT and using field data with FFE-FVS. The WIT results are presented as the percent of area predicted to support different fire types. The field data results are presented as the percent of monitoring plots predicted to burn as each fire type.

		Pre	Post
WIT & FlamMap (% area)	Surface	2.5	2.5
	Passive	57.2	92.8
	Active	40.3	4.7
Field Data & FFE-FVS (% plots)	Surface	66.7	85.7
	Passive	0	14.3
	Conditional Crown	23.8	0
	Active	9.5	0

Following treatment at Pole Hill, both methods show a reduction in the area predicted to support active crown fire. Although both agree that treatment reduced the risk of severe wildfire, the WIT predicts more passive crown fire pre- and post-treatment (Table 5). The other thinned PPWF sites which have been previously compared to the WIT also had more passive crown fire predicted from the WIT (Morici et al., 2019).

The two methods have numerous assumptions and limitations which could be contributing to this discrepancy. Of the 246 acre project area, about 100 acres were actively treated due to restrictions in operable area and the discretion of property owners. Field data was collected at 22 plots, only one of which did not show signs of treatment. In contrast, the WIT uses LANDFIRE data from the entire project area using 30x30m pixels (Gannon, 2020). A pixel is roughly twice the size of a plot, so the LANDFIRE data will not include smaller-scale variations which plots may capture. In addition, the WIT simulated a thinning treatment across the entire project area, which in this case does not perfectly correspond to the area where treatment occurred. This lack of variability in the WIT's input is also seen with crown base heights (CBHs). At other PPWF sites, pre-treatment CBHs measured in the field were substantially higher than CBHs from LANDFIRE (Morici et al., 2019; Morici & Gannon, 2021). Post-treatment, the WIT uses an adjustment factor of 1.2 to increase all CBHs, simulating a thinning which uniformly affects every tree (Gannon, 2020). Another possible reason the WIT predicts more passive crown fire is that the LANDFIRE data tends to have more grass and shrub fuel models than FFE-FVS (Morici et al., 2019). These fuel models have more intense surface fire behavior than the timber litter fuel models commonly assigned by field crews during monitoring data collection, so lower wind speeds are required to initiate torching in the WIT. There are limitations for both approaches, although both modeling exercises showed a very similar trend of improving forest resilience to wildfire following the thinning treatment.

Conclusions

Monitoring revealed a decrease in tree density and modeled fire behavior, with a slight increase in surface fuel loading after Pole Hill's treatment. Treatment met the stand structure and composition goals. An additional consideration for future projects is raising tree crown base height through preferential removal of trees with low crowns. We recognize from monitoring at many other projects that raising tree crown base height, while important in moderating crown fire behavior, is not often achieved through thinning on the Front Range (Morici et al., 2019; Slack et al., 2021; Fulé et al., 2012). Slash management techniques, especially log removal, limited increases in post-treatment woody surface fuel loadings, enhancing fuels treatment effectiveness of mechanical thinning methods. Modeled fire behavior is less severe following treatment and the amount of active crown fire has decreased. When the FFE-FVS predictions are compared with those of the WIT's FlamMap, the WIT modeled more passive crown fire pre- and post-treatment. Pole Hill's treatment was beneficial in reducing, but not eliminating, the potential for high severity wildfires which would threaten nearby homes and water resources.

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