ASSESSMENT OF MILLER FORK WATERSHED SOIL BURN SEVERITY

MAPPING FOLLOWING THE CAMERON PEAK FIRE

by

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ABSTRACT

The Cameron Peak Fire (CPF) burned 84,544 hectares (208,913 acres) within the Arapaho and Roosevelt National Forest in Northern Colorado between August and December 2020. The burn occurred over vast, rugged, and mainly U.S. Forest Service (USFS) land. After starting in the Cache la Poudre Watershed, the fire crossed into the Big Thompson Watershed and became Colorado's largest wildfire on October 14, 2020. Post-fire assessments concluded that the Big Thompson Watershed was at a high risk of sedimentation and other impacts, specifically originating from the remote Miller Fork Watershed and surrounding areas. A key element in post-fire risk assessments is the Burned Area Emergency Response (BAER) process. Just 7-10 days after this portion of the fire was contained, the USFS BAER team generated a soil burn severity map of the area using aerial drone surveys and remote sensing data and did sporadic field spot-checks to verify the mapping of relative burn severity. BAER mapping after the CPF faced unusual difficulties due to late season weather that affected imagery and restricted field validation, potentially reducing accuracy within the Big Thompson portion of the burn. Therefore, to evaluate accuracy of mapping under these challenging conditions, I conducted field work within the burn scar to spot check the BAER soil burn severity map. I focused on the Miller Fork Watershed, which was identified as a watershed of immediate concern post-burn and compared the fall 2020 BAER soil burn severity map to fall 2021 field observations made one year after the burn. I examined 16 areas mapped by the BAER method as unburned, low, moderate, or highly burned, with four plots in each of the four burn severity categories. Using 9 m x 9 m plots with 1 m x 1 m subplots, I evaluated ground condition/cover, canopy cover, vegetative regrowth, burn severity, and signs of erosion. My assessment suggests that the BAER soil burn severity maps are slightly inaccurate for the Miller Fork Watershed and not representative of field conditions. Therefore, utilizing BAER soil burn severity maps for a small area of a burned area need to be ground truthed further to ensure the maps are representative of the field conditions.

INTRODUCTION

Wildfires have become more prevalent and characteristic of the western United States over recent years (Marlon et. al 2012). Wildfire is a key component of western, Rocky Mountain forests and ecosystems as many species rely on wildfire to sustain their populations and “reset the system” (CSFS 2012). Although wildfire is a necessary component of western forests, it often conflicts with human objectives, and Colorado and other western states have actively tried to suppress fires over the past century (Halofsky et. al 2020). Fire suppression became normalized when settlers began moving west in the pursuit of timber harvesting, mining, and farming and did not want their newly acquired forests and homesteads to be destroyed. The basic problem is that there is now a large source of fuel in these forests (Luo et. al 2013). A combination of historic fire suppression and forest insect infestations that have killed large portions of western forests have produced large amounts of highly combustible fuel that can create intense wildfires under the right conditions. Fire suppression that seemed beneficial has unintentionally created forests full of dry, dead, and ready-to-burn fuel, which is one of the necessary ingredients for starting a wildfire (Luo et. al 2013).

Due to fire suppression, other forest fuel producing activities, and the increasing impacts of climate change, wildfires are and will continue to be common, widespread, and intense within the western United States (Marlon et. al 2012). Productive and efficient post-fire management will be paramount, and this depends on accurate risk assessments.

Wildfires can be severe, intense, and alarming while they are actively burning but the after-effects of wildfires can also cause significant damage to landscapes. Short-term watershed impacts following wildfires may include erosion, sedimentation, landslides, debris flows, changes to stream morphology, and increased runoff (Neary et. al 2003). It is important to note that there are also medium to long-term watershed impacts following wildfires such as altered evapotranspiration, water balance, and snowmelt in addition to the short-term risks that are the focus of this project (USGS n.d.).

One major concern is soil alteration by wildfire, which plays a central role in watershed degradation. Notably, when soils are exposed to wildfire, they can be changed and made hydrophobic (Lentile et. al 2007). When soils are hydrophobic after being burned, they can promote a “flashy” runoff response when a precipitation or snowmelt event occurs, which can lead to erosion, transport of sediment into surface waters, and can cause sediment deposition in channels (Kalendovsky 1997). After a wildfire burns through a forest, the forest floor can be burned and with that the plant and litter cover can be lost. With this layer of the forest burned, it causes the forest soils to be exposed to the fire during the burn and also leaves it exposed to the elements post-burn (Huffman et. al 2001). Understanding what happened to the soils during the fire can inform land managers and other decision makers of the state of the burned area and help prepare them with how to respond.

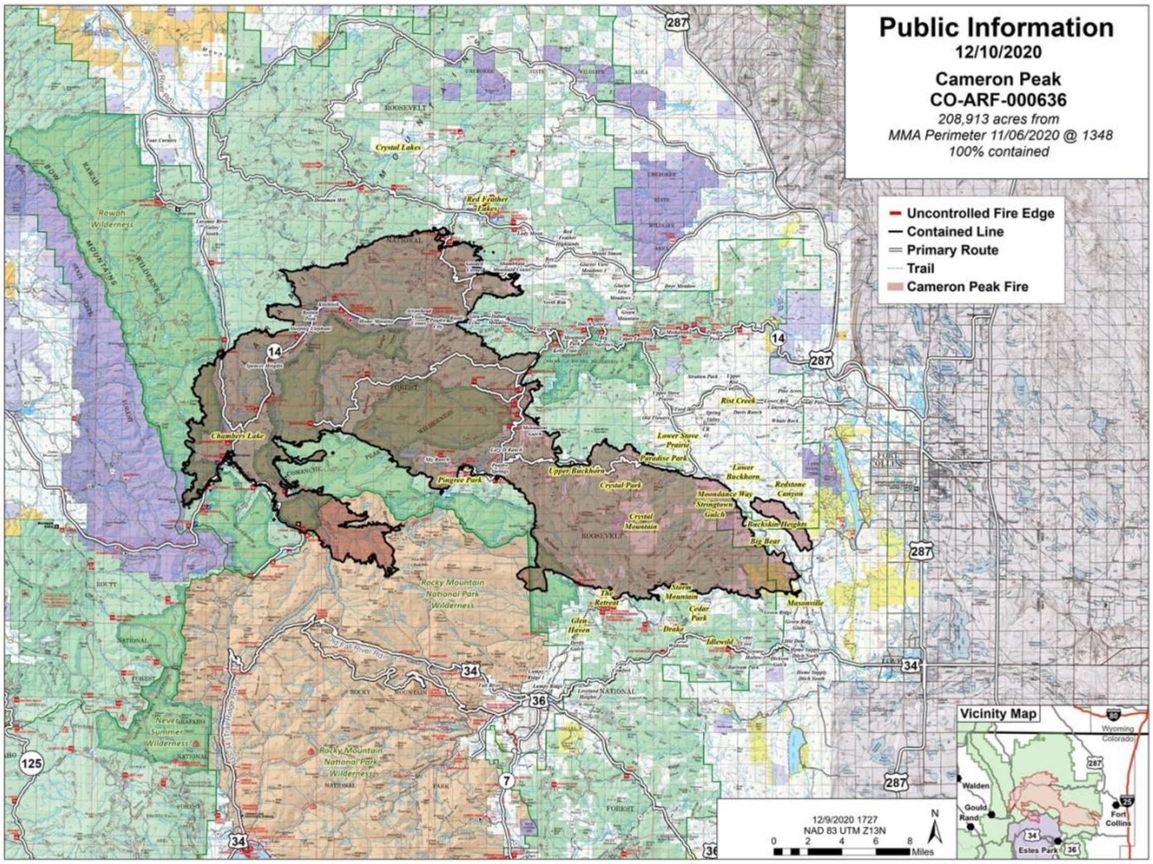

Figure 1. Map of the final Cameron Peak Fire boundary InciWeb (2021).

<u>Cameron Peak Fire Background</u>

The Cameron Peak Fire ignited on August 13, 2020 near Cameron Pass in Larimer County, Colorado and burned 84,544 hectares (208,913 acres) within the Arapaho and Roosevelt National Forests in Northern Colorado, which made this wildfire the largest in state history (InciWeb 2021). The Cameron Peak Fire was largely in terrain that is steep, rocky, and has limited roads and access (Figure 1). Hot temperatures, low humidity, rugged terrain, limited access, large fuel loads, and high winds contributed to the quick and massive spread of this fire from August to December 2020.

The headwaters of the Cache la Poudre and Big Thompson Rivers were severely burned, resulting in debris flows, small landslides, and turbid sediment and ash-contaminated waters during the summer of 2021 (Blumhardt 2021, Figure 2). In many areas, forest soils were burned, exposed, or made hydrophobic by heating (Moench 2020). Because the worst damage tends to be concentrated in the two years immediately following a burn (U.S. Forest Service 2021), there is a sense of urgency to work to prevent more cascading impacts to the watersheds following an event of this magnitude.

Figure 2. Photo of the Cameron Peak Fire and the Cache la Poudre River taken August 21, 2020 (InciWeb 2021).

Even though the majority of the burned area is within the Cache la Poudre watershed, scientists and local government officials believe some of the worst impacts will be within the Big Thompson watershed (Big Thompson Watershed Coalition 2021). Post-fire analysis accounting for burn severity, topography, and proximity to waterways found that the most damage, including sedimentation, was expected during runoff, particularly over the two years following the burn (U.S. Forest Service 2021). Therefore, ground monitoring and field surveys are needed to understand watershed impacts and begin treatment of the burned areas within the Big Thompson watershed as quickly as possible to prevent excessive erosion and sedimentation.

Burned Area Emergency Response (BAER) Program

The Burned Area Emergency Response (BAER) Program is a standard part of rapid response to fires on U.S. Forest Service (USFS) lands (Parsons et. al 2010). Typically, the BAER team performs aerial drone surveys to assess the burned area and capture a value for each type of ground cover present post-burn. This remote sensing activity helps to determine what type of ground cover and condition is present in the field, which is called the Burned Area Reflectance Classification, or BARC. Next, field checks are performed to ensure the BARC data are accurate compared to what is found in the field post-burn (Parsons et. al 2010). The BAER team then updates the BAER map accordingly to accurately depict, as best as possible, the field conditions post-fire. This process is performed 7-10 days after the fire is contained so these activities happen rapidly.

It is important to note that when ground cover and soils are exposed to fire and then burned it can have a large impact on runoff and erosion. After forest soils and ground cover are burned or removed in a fire, it can cause an increased amount of runoff as the precipitation does not infiltrate into the soil as well as pre-fire which causes the water to run off faster and can sometimes lead to increased erosion (MacDonald and Huffman 2004). This increased erosion and runoff can effect the overall watershed by increasing sedimentation and flow rates within the nearby streams and rivers (USGS n.d.). These impacts are not beneficial to the overall health of the watershed and can negatively impact water quality. The BAER mapping method and the data it provides are so important to understand the potential impacts to the burned watersheds. Knowing how much exposed soil, burned soil, burned vegetation, etc. exists post-fire can all aid with remediation efforts and communicate where and what to focus on after the fire is extinguished (Parsons et. al 2010). The BAER method is not perfect in capturing the post-fire soil burn severity data, but it is a start to understand what is being observed from remote sensing methods and field spot checks to understand quickly the general problems a fire may pose on a landscape (Hudak et. al 2004).

Post-Fire Assessments

To assess watershed-related hazards within the Cameron Peak Fire, J.W. Associates used soil burn severity maps created by the USFS BAER team. These soil burn severity maps were generated through aerial surveys, remote sensing imagery, and some spot-checking in the field. The BAER process specifically relies on BARC maps produced from aerial surveys to generate BAER Soil Burn Severity maps (Parsons et. al 2010).

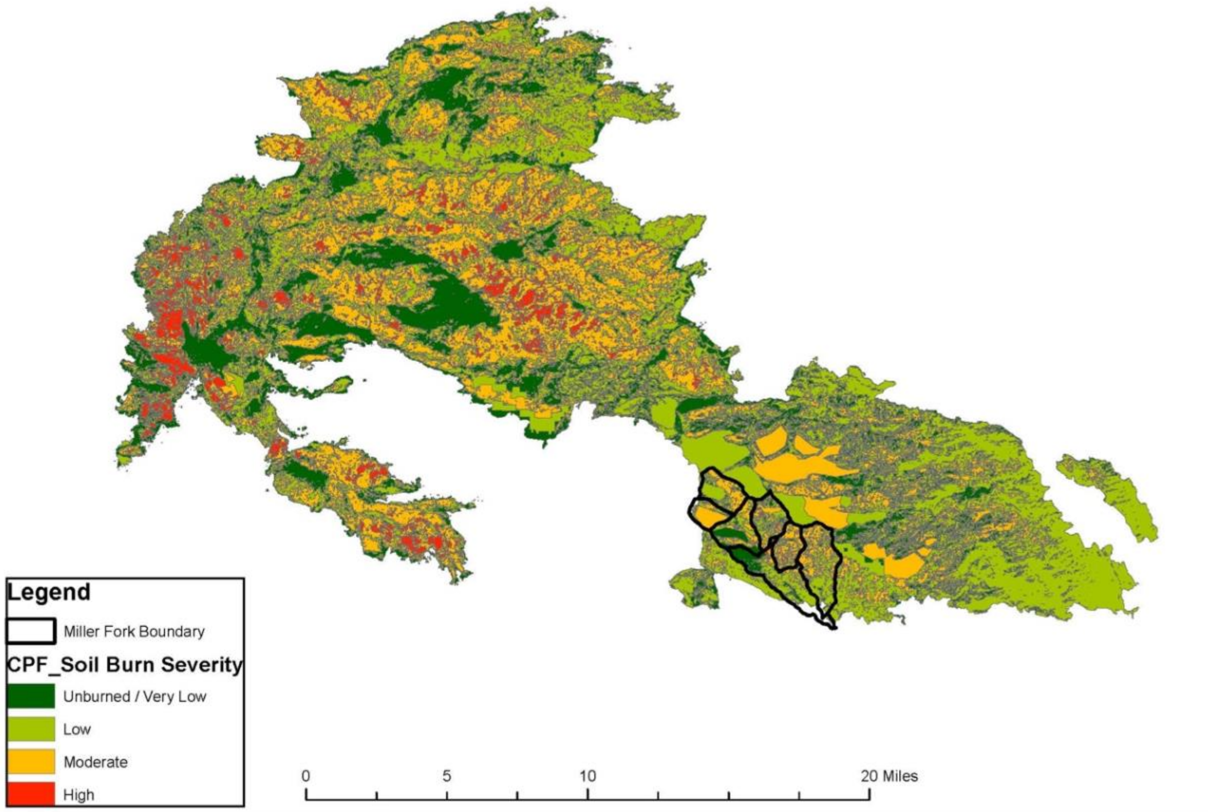

Figure 3. Map of the Cameron Peak Fire (CPF) Boundary with the BAER Soil Burn Severity map and the Miller Fork watershed.

The BAER process for the Cameron Peak Fire, specifically in the later areas of the burn within the Big Thompson watershed, was hindered by the rapid onset of winter weather when the BARC map was being produced (Figure 3). The winter weather affected the quality of the aerial drone imagery used to produce the BARC map and limited the amount of field validation that could be done to spot-check the BARC map. The BAER team created two maps, one that was deemed too inaccurate due to the snow and then the second that was created later which was considered to be more accurate (USDA 2020). Since the BAER soil burn severity map had to be recreated, this pushed the process into the winter months even further which did not allow much time for the BAER team to perform the necessary field checks to ground truth and spot check what the BARC maps were showing.

Figure 4. Photo of the Cameron Peak Fire burning after snow started falling which contributed to a challenging BAER process; taken September 14, 2020 (InciWeb 2021).

Need for Case Study

My project is a small, focused study of the accuracy of BAER soil burn severity mapping within one subwatershed of the Big Thompson drainage. Although soil burn severity mapping is one of the key components of post-fire hazard evaluation and management planning, there has been relatively limited prior research validating soil burn severity mapping and specifically BARC mapping. The Cameron Peak Fire was the largest wildfire to burn in the state of Colorado, which lends interest as a topic of study. Studying a small area within this large fire allowed me to gain a better understanding of the type of data and mapping that is generated and learn how it can be utilized.

Figure 5. Photo of the Cameron Peak Fire taken August 20, 2020 (InciWeb 2021).

I chose to work in the Miller Fork watershed because it was determined by multiple agencies to be a watershed of high risk to producing sedimentation in post-fire assessments which was largely due to the estimated soil burn severity (USDA 2020). At the beginning of this project, I consulted the Big Thompson Watershed Coalition and spoke to their staff about their major concerns following the Cameron Peak Fire (Big Thompson Watershed Coalition 2021). The staff mentioned that not much attention was being given to the Miller Fork watershed, which was projected to be the watershed at the highest risk within the Big Thompson watershed based on the CPF Hazard Assessment by J.W. Associates. The watershed also experienced a wide range of soil burn severity, as mapped by the BAER program, which made it a good place to examine variation in soil burn severity. Finally, the Miller Fork watershed is relatively small and therefore manageable to study.

Goals and Objectives

The overall goal of my project was to assess whether the BARC maps created as part of the BAER process accurately represent the relative soil burn severity, and implicitly erosion and sedimentation potential, in the Miller Fork watershed.

My specific objectives were to:

1. Conduct field sampling within the Miller Fork watershed to observe indicators of soil burn severity and related factors (vegetation regrowth, exposed soil, soil hydrophobicity, etc.) one-year post-burn.
2. Compare BAER soil burn severity maps to field observations, specifically evaluating whether exposed soil and soil burn severity observed within field plots corresponds to mapped burn severity categories from unburned to high.

Although the BAER mapping technique is necessary and extremely useful in a situation like the Cameron Peak Fire, this broad-brush analysis type is only a starting point in the study of understanding what the true impacts will be following the event on the watershed scale. Because this wildfire burned over 200,000 acres, the Miller Fork watershed, which is just under 9,000 acres, is only generally captured in these initial assessments. Performing field sampling within the Miller Fork watershed to examine the amount of exposed soil remaining and assess soil burn severity on the ground one-year post-burn will be a necessary exercise to truly understand what damage was done during the fire and in turn ground truth the BAER method at this scale.

METHODS

Study Area

The Miller Fork watershed (HUC 12 - 101900060103) is a subwatershed within the Big Thompson watershed in Northern Colorado. It is forested, rural, located between elevations of 1889 and 3352 meters (6,200 and 11,000 feet), and covers 3615 hectares (8,933 acres) (USGS 2013). Approximately 80% of the Miller Fork watershed was burned during the Cameron Peak Fire and it was determined to be a high risk for potential hazards including erosion and sedimentation (USDA 2020). The Miller Fork watershed was determined early in the post-fire assessments to be at high risk for damage due to the steep slopes, amount of burned area, potential for debris flows, and limited access. It was projected to see large increases in runoff post-fire -- a more than six-fold increase for the five-year recurrence interval, one-hour design storm event, for example, according to the Cameron Peak Fire BAER Executive Summary.

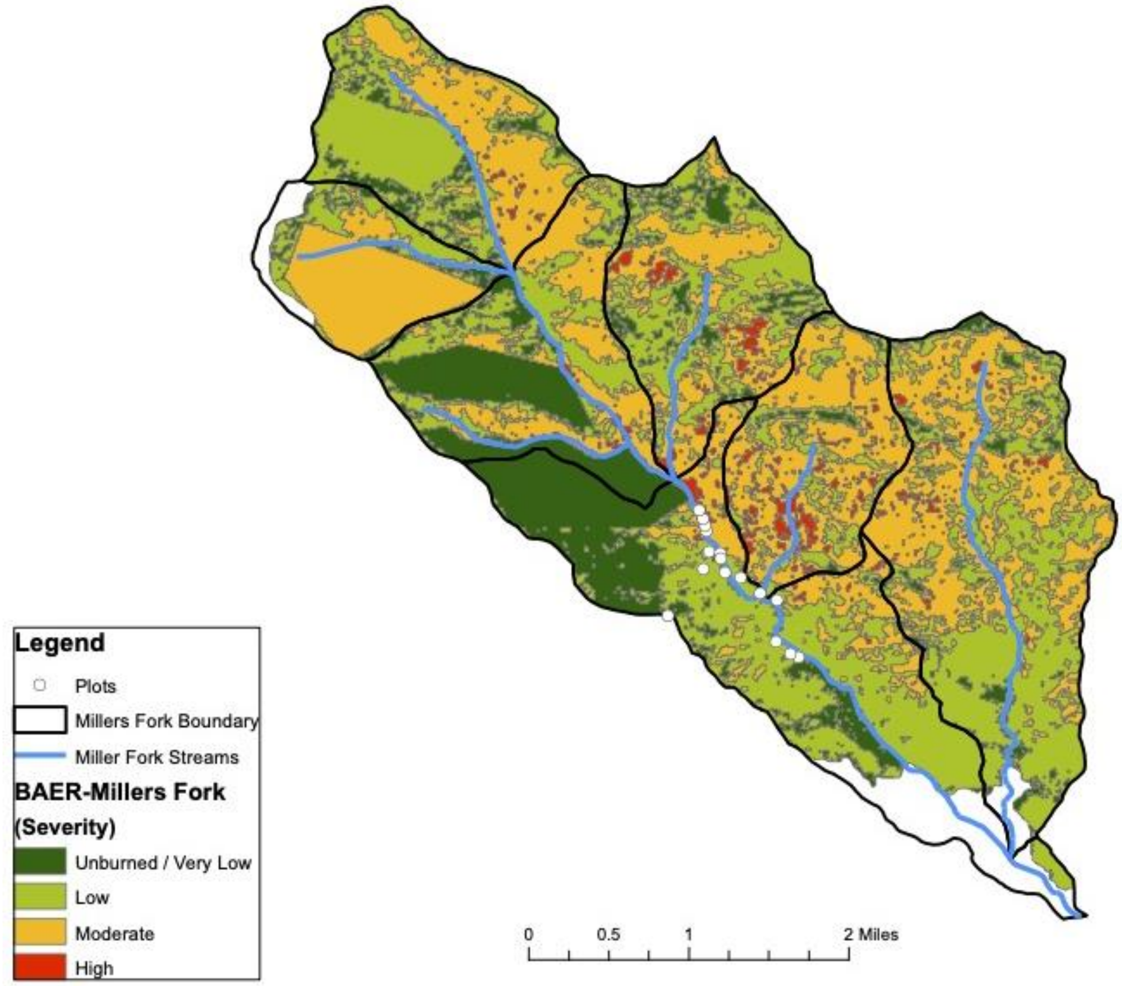

Figure 6. Map of Miller Fork with BAER Soil Burn Severity (SBS).

Fire behavior and timing help with understanding the challenges of burn severity mapping here. On October 13, 2020, high speed winds of 31+ meters per second (70+ miles per hour) and exceptionally dry conditions pushed the Cameron Peak Fire into the Big Thompson watershed (InciWeb 2021). Between October 13 and 18, the fire grew by another 68,000 acres and caused the fire to become the largest in Colorado's state history (Karashinski 2021). This portion of the fire spread quickly through the Big Thompson watershed, which is primarily rugged, roadless, and forested, all of which make firefighting very challenging. The rapid spread and variable weather, topography, and fuels resulted in large differences in soil burn severity, ranging from unburned, low, moderate, to highly burned classes (USDA 2020). As noted in the introduction, the fact that the fire was only suppressed with the onset of winter also made the BARC mapping process more challenging.

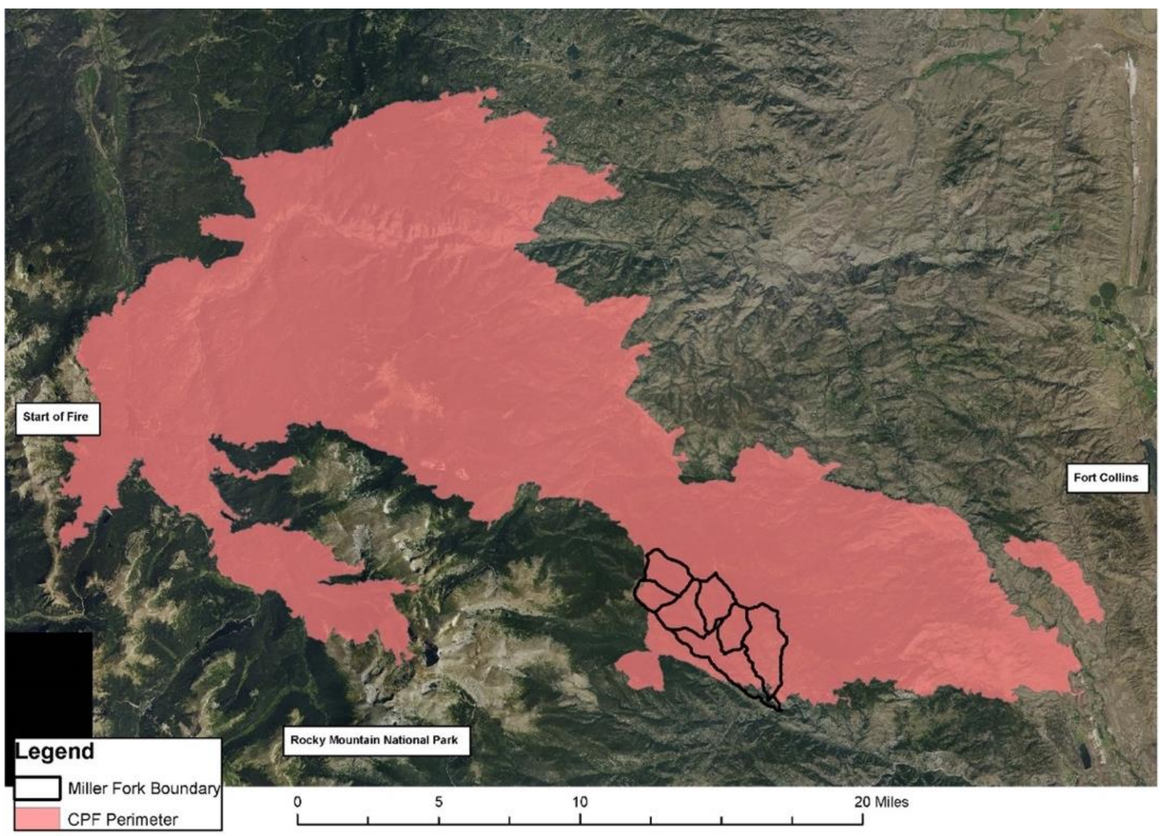

Figure 7. Map of the Cameron Peak Fire Boundary with the Miller Fork watershed outlined.

Figure 8. Photo of the Cameron Peak Fire taken from Boyd Lake in Loveland, Colorado after the fire spread into the Big Thompson watershed; photo taken October 14, 2020 via InciWeb.

Access into the Miller Fork watershed is limited to two access points as of 2021: one is through the Bulwark Ridge on the southwestern side of the watershed and the other is through a private neighborhood near Glen Haven at the southern, downstream end of the watershed (USFS 2021). Both access trails have been burned and left unmaintained following the fire. Large woody debris, snags, and erosion make access challenging and limited in areas. Steep, rocky slopes also hinder access.

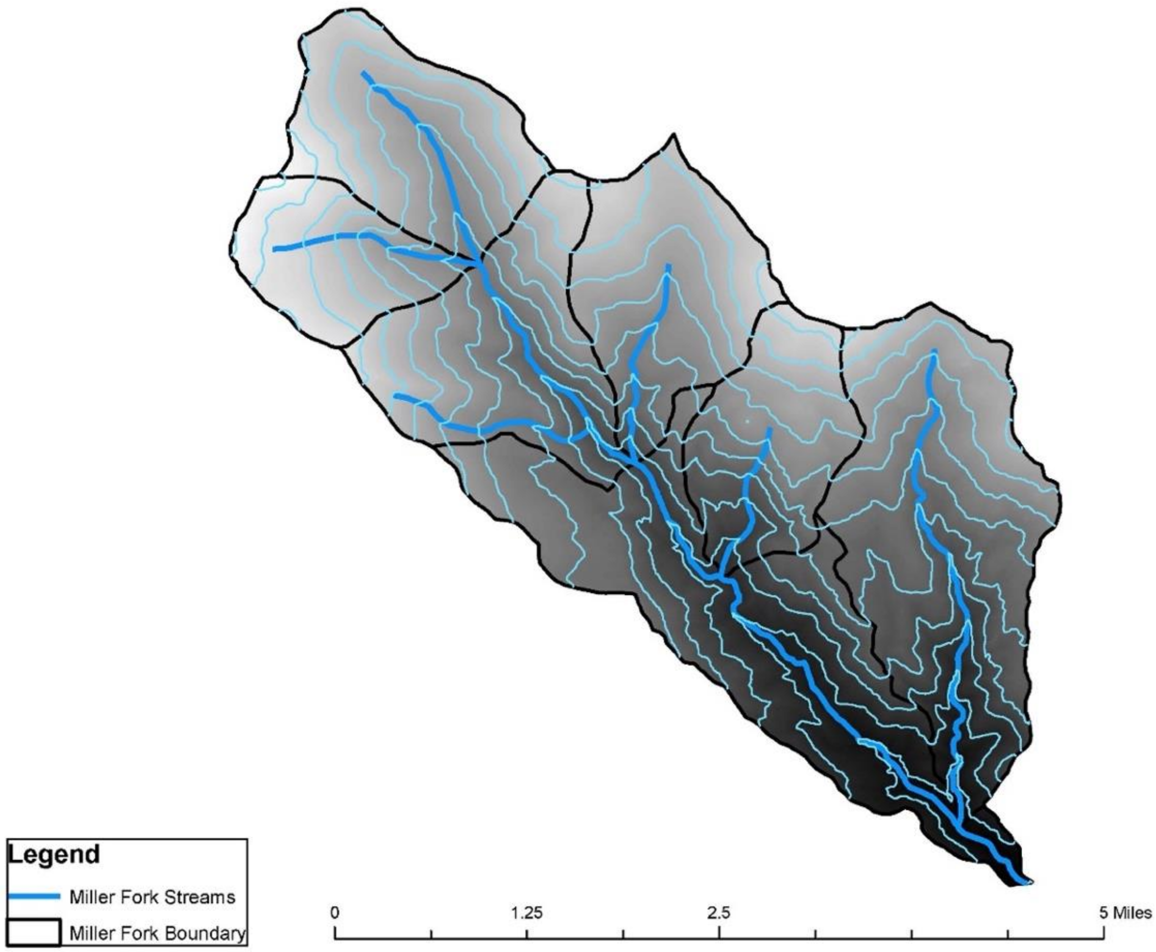

Figure 9. Map of the Miller Fork Watershed with streams and topography.

Miller Fork Watershed

The Miller Fork watershed, which is a subwatershed and tributary of the Big Thompson watershed, was identified early on post-burn by multiple local agencies through post-fire assessments to be one of the higher risk watersheds that needed remediation. J.W. Associates, a consulting firm of watershed scientists out of Breckenridge, Colorado, worked to generate a Cameron Peak Fire (CFP) Hazard Assessment to assess the risk posed to the burned watersheds following the Cameron

Peak Fire. This risk assessment examined soil burn severity, debris flow potential, roads, hillslope, and estimated peak flow within the watersheds to determine a 5-category risk ranking from lowest, low, moderate, high, and highest. The Miller Fork watershed was rated as moderate, high, and highest. These risk maps were generated to quickly identify the watersheds and subwatersheds of most concern post-fire.

Overview of Study Approach

My working hypothesis was that the BAER soil burn severity maps compiled after the Miller Fork watershed burned were not accurate because the manner in which they were generated was problematic. Specifically, the snow that finally extinguished the fire compromised the mapping process, and weather limited field validation (USDA 2020). This project is a preliminary, informal evaluation of mapping accuracy. I used largely visual observations and methods based on existing post-fire sampling protocols to quantify conditions in the field. Sample number and location were limited by time and access. Therefore, my evaluation of accuracy is logical but not statistically rigorous.

GIS Component. I mapped watershed features in ArcGIS to provide background information and context for the overall project and to plan sampling. Data included the following layers: the Cameron Peak Fire Boundary, the soil burn severity maps from the BAER analysis, and the CPF Hazard/Risk Assessment from JW Associates; soil type, forest type, streams, watershed boundaries, roadways, private land parcels, slope and topography (e.g. DEM Hillshade), and 100-m contours; and the 16 field plot locations that I collected with the Avenza GPS application.

For this project I used the BAER Soil Burn Severity map and compared those BARC surveys to what was observed in the field survey component of this project. Then I calculated the percent of hydrophobicity within each of the subplots and generated visual representations of the field data to compare to the BAER map (Appendix).

Field Component. I adapted field methods from Hudak et al. (2004). They examined multiple wildfires from the western US and performed field surveys to collect post-burn observations of exposed soils, vegetative regrowth, and burn severity. According to Hudak et al. (2004), their surveys were conducted “80-300 meters from the nearest access road, in random locations within a broadly representative area of consistent forest stand [type] and [burn] severity condition.” They did not describe a specific site selection or randomization procedure. The team collected nine 9 m x 9 m plots along transects bisecting a 130 m x 130 m area at each of their 35 sites. Within each 9 m x 9 m plot, the team also sampled 15 1 m x 1 m subplots to closely examine ground cover (Hudak et. al 2004).

I sampled 16 9 m x 9 m plots total, four within the each of the four different BARC soil burn severity classes (unburned/very low, low, moderate, and high) to represent varied conditions of soil burn severity (Figure 6). Due to limited access and steepness of terrain, I placed the plots adjacent to the Miller Fork Trail, which had a total length of 5.6 km (3.5 mi). Some of the trail was within private property so the 16 plots were placed only within public lands. Along the trail, random locations within the four BAER soil burn severity classes were selected via GIS before the field sampling to allow a comparison of what is observed in the field vs. what was documented, described, and categorized in the post-fire BAER mapping analysis. Then once in the field, these plot locations were located via GPS. Some locations that were selected from GIS were not safe or accessible, so a new site was selected adjacent to the original location.

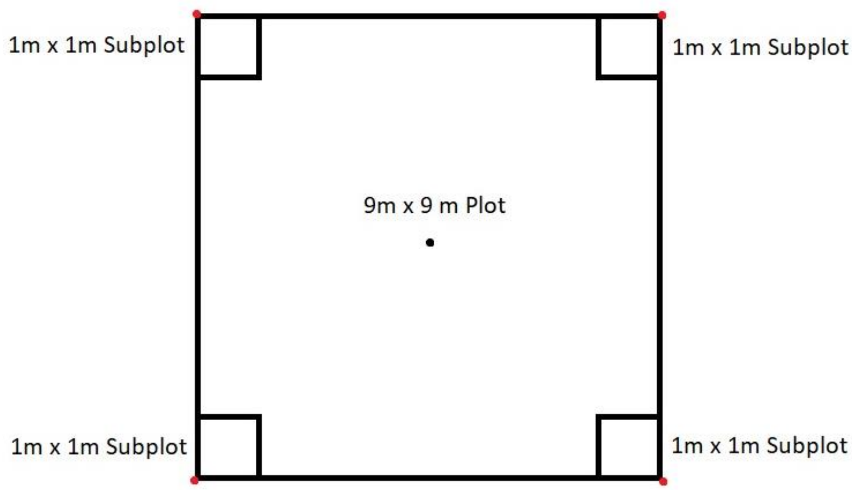

Figure 10. Diagram of plot and subplot layout.

Plot Level Assessment. Each 9 m x 9 m plot fell within varying BAER soil burn severity classes on varying sides of the stream within the Miller Fork watershed. The primary access for this area was via the Miller Fork Trail near Glen Haven, Colorado so the 16 plots were accessed from this trail or in nearby areas. For these 16 plots, I surveyed different levels of BAER soil burn severities and collected data on varying aspects, slopes, and locations along Miller Fork. The plots helped to capture field data of varying soil burn severities as identified by the Cameron Peak Fire BAER map.

At each plot, I took photos to document the amount of exposed soils remaining, vegetative regrowth, and general ground cover percentages. I documented the aspect, elevation, and topographic position of each plot (Appendix). I also took photos of the canopy above the center of the plot, looking upslope, looking right, looking downslope, and looking left. I performed a basic site assessment within the plot to document the type of ground cover present at the time of sampling, based on methods on how to capture field data within a plot (Christensen 1991). Part of this assessment included assessing canopy cover where I took photos of the canopy cover from the center of the plot looking up and documented canopy cover, by using a densiometer, and canopy burn status. I also documented any signs of erosion, such as rills or gullies forming post-burn within the plot.

Subplot Level Assessment. At the four corners of each 9 m x 9 m plot, 1 m x 1 m subplots were collected to examine and calculate the percent ground cover (Figure 6). I marked the four corners with flags and placed four 1 m x 1 m subplots at the corners. I documented the percent of exposed soil, rock, vegetative regrowth, large woody debris, etc. present and took photos of each subplot. Burned, water repellent soils have reduced infiltration rates which result in increased runoff so testing the soil's hydrophobicity within each subplot was an important activity in gauging how severe the fire was

(Parsons 2010). Burned, hydrophobic soils can be a large source of increased runoff and erosion, making hydrophobicity an important factor to measure (Huffman et. al 2001). I used the University of Idaho's Cooperative Extension System method, which tests the soil 12.7 to 76.2 mm (0.5 to 3 in) below the mineral soil surface (Brooks n.d.). To locate the layers of the soil that might be hydrophobic, I scraped away the top few millimeters of a section of the subplot then used a pipette to drop beads of water on the soil. If the water remained beaded up after a minute, I determined the subplot to be hydrophobic. If the water did not bead up after a minute then I determined the subplot to not be hydrophobic. Since there were four subplots in each plot, I took the average of the four subplots to create a percentage of hydrophobicity observed in the field.

The Cameron Peak Fire was extremely variable due to the length of time the fire burned, seasonal temperature and weather patterns, topography, and fuel load and with that so are the results of the soil burn severity throughout the burn scar. The Miller Fork watershed is very rugged with limited roads, trails, and access points which made the field collection and surveying challenging. Collecting random, un-biased field data was the utmost goal of my project, but safety and practicality were also major deciding factors for selecting realistic field sites for the sample plots.

Data Analysis

To analyze the data collected in the field, graphical and statistical evaluation of whether field observations are related to BAER soil burn severity mapping classes were performed. To determine if the field conditions were matching the BARC class, I used the plot and subplot ground cover composition and the results of the hydrophobicity soil bead test to see how well they matched with the BARC classes. I referred to the Parsons et al. (2010) reference document that details the BAER process and how field checks of the BARC classes are performed to make a determination if the BARC class matched what was observed in the field. The "Field Guide for Mapping Post-Fire Soil Burn Severity" details the severity indicators of each BARC class (Unburned/Very Low, Low, Moderate, High) and discusses what type of surface organic layers should be visible in the field, how much of the roots were scorched, canopy status, etc. (Parsons et. al 2010). The amount and condition of ground cover is also discussed in Parsons et al. (2010) which gives photographic examples of what type of ground cover is considered low, moderate, or high soil burn severity. I used these references to compare to my field observations at each plot to make a determination if the BARC class matched what I observed in the field. This process was somewhat informal and not statistically rigorous, but it provided me with a good basis on how to compare field conditions to the BARC classes.

The Appendix section of this document contains the raw data from each plot and subplot. The ground cover composition data that were collected in the field is documented in tables and the subplot ground cover composition is also provided in pie charts.

RESULTS

The 16 plots were located adjacent to or nearby the Miller Fork Trail (Figure 11). The area shown in Figure 11 was the general area that had good access points as well as varying BARC soil burn severity classes. Refer to the Appendix of this document for plot and subplot specific tables and figures. The data are parsed by plot and subplot and includes the raw field data collected in tables and also figures.

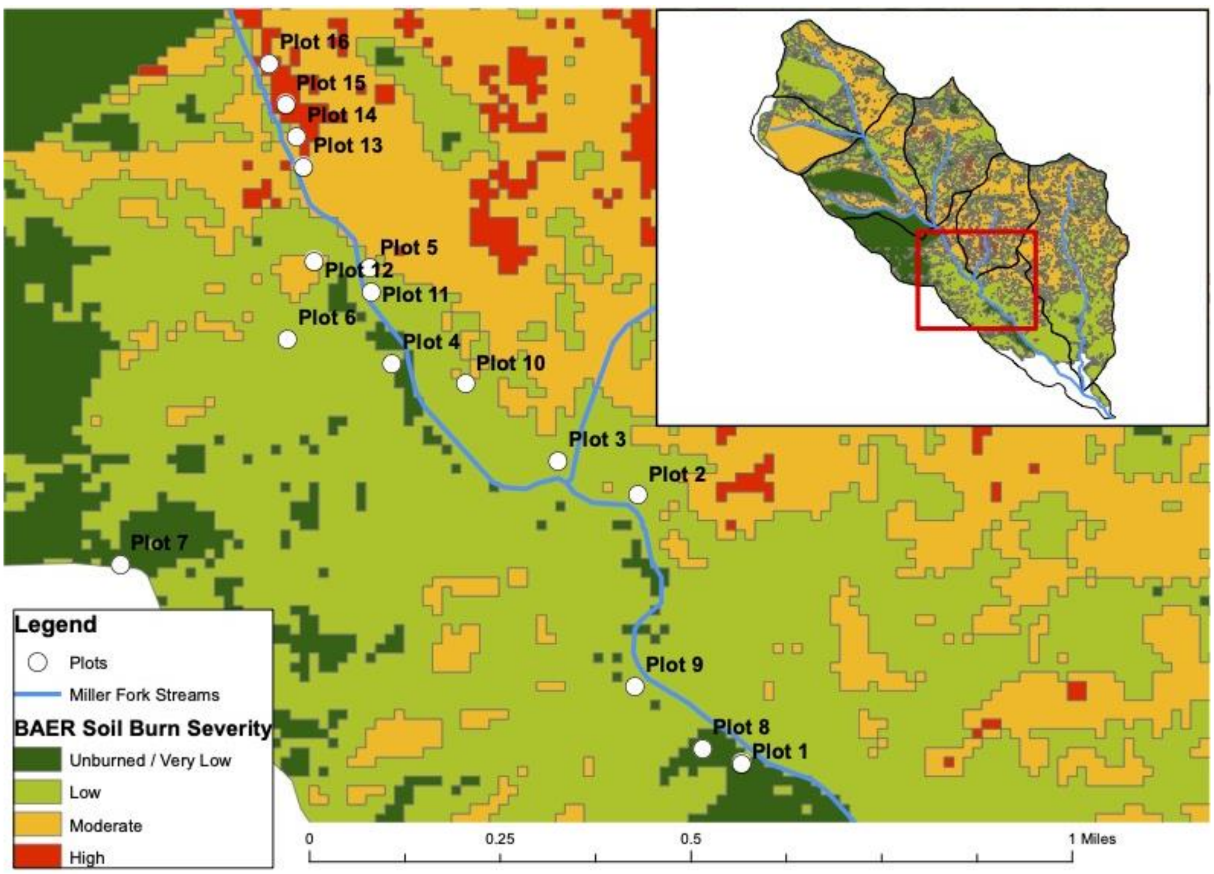

Figure 11. Map of Miller Fork Watershed with 16 plots.

There were four plots within each of the four BAER soil burn severity classes (Table 1). This was selected to be able to compare the soil burn severity classes to what was observed in the field. Some of the plot markers cover the BAER soil burn severity class due to some of the BARC grid cells being somewhat small (Figure 11).

Table 1. Hydrophobicity of BAER Soil Burn Severity (SBS) classes and plots.

BAER Soil Burn Severity (SBS) Classes							
Unburned/Very Low (U)		*Low (L)*		*Moderate (M)*		*High (H)*	
Plot 1	0% Hydrophobic	Plot 2	75% Hydrophobic	Plot 5	100% Hydrophobic	Plot 13	50% Hydrophobic
Plot 7	100% Hydrophobic	Plot 3	75% Hydrophobic	Plot 10	75% Hydrophobic	Plot 14	75% Hydrophobic
Plot 8	50% Hydrophobic	Plot 4	75% Hydrophobic	Plot 11	50% Hydrophobic	Plot 15	25% Hydrophobic
Plot 9	0% Hydrophobic	Plot 6	100% Hydrophobic	Plot 12	100% Hydrophobic	Plot 16	0% Hydrophobic
Averaged Totals:	37.5		81.25		81.25		37.5

Site conditions related to soil alteration and cover were variable between plots and mapped soil burn severity classes (Table 2). Percentage of hydrophobic subplots varied widely within each BAER soil burn severity class, with no consistent differences between classes. Similarly, the percentage of exposed soil showed no consistent differences between BAER soil burn severity classes. The most variability seemed to be with the Low to Moderate classes. The High class plots were consistent in matching their respective BARC class (Table 3).

Table 2. Field data for plots 1-16.

Plot Data				
	BAER SBS Class	**Est. Soil Burn Severity**	**% Hydrophobic**	**Exposed Soil %**
Plot 1	Unburned/Very Low	Low - Moderate	0%	5%
Plot 7	Unburned/Very Low	High	100%	45%
Plot 8	Unburned/Very Low	Low	50%	5%
Plot 9	Unburned/Very Low	Low	0%	0%
Plot 2	Low	Moderate - High	75%	40%
Plot 3	Low	Low - Moderate	75%	30%
Plot 4	Low	High	75%	35%
Plot 6	Low	High	100%	20%
Plot 5	Moderate	Moderate - High	100%	30%
Plot 10	Moderate	Low - Moderate	75%	10%
Plot 11	Moderate	Low - Moderate	50%	0%
Plot 12	Moderate	Moderate	100%	10%
Plot 13	High	High	50%	10%
Plot 14	High	High	75%	20%
Plot 15	High	High	25%	20%
Plot 16	High	High	0%	25%

One way to judge the accuracy of the BARC mapping is to ask how often its burn severity classification matches a field rating of burn severity which was performed. Only 9 of the 16 plots sampled in the field (56%) matched their respective BAER soil burn severity class (Table 3). That leaves the remaining 7 plots (44%) different from their designated BAER soil burn severity class.

Table 3. BAER Soil Burn Severity (SBS) Class vs. Estimated SBS, and comparison per plot.

BAER Soil Burn Severity (SBS) Class vs. Estimated Soil Burn Severity			
	BAER SBS Class	**Est. Soil Burn Severity**	**Matching**
Plot 1	Unburned/Very Low	Low - Moderate	No
Plot 7	Unburned/Very Low	High	No
Plot 8	Unburned/Very Low	Low	Yes
Plot 9	Unburned/Very Low	Low	Yes
Plot 2	Low	Moderate - High	No
Plot 3	Low	Low - Moderate	Yes
Plot 4	Low	High	No
Plot 6	Low	High	No
Plot 5	Moderate	Moderate - High	Yes
Plot 10	Moderate	Low - Moderate	No
Plot 11	Moderate	Low - Moderate	No
Plot 12	Moderate	Moderate	Yes
Plot 13	High	High	Yes
Plot 14	High	High	Yes
Plot 15	High	High	Yes
Plot 16	High	High	Yes

% of Plots that match SBS	**56%**
% of Plots that don't match SBS	**44%**

The site assessments of each plot showed that the BAER soil burn severity classification was not always correct. Plots 3, 5, 8, 9, 12, 13, 14, 15, and 16 were somewhat accurate when comparing field observations to BAER soil burn severity classes. Plots 1, 2, 4, 6, 7, 10, and 11 varied from their BAER soil burn severity classification.

Plot 9 is a good example of an area that matches its Low BAER soil burn severity classification. The plot had an unburned tree canopy and no burn scars were observed on the trees (Figures 12 and 13). None of the four subplots were hydrophobic. There was no exposed soil in this plot and a substantial amount of leaf litter on the forest floor. This plot was indeed Unburned/Very Low.

Figure 12. Photo of Plot 9 looking uphill.

Figure 13. Photo of Plot 9's canopy.

A contrasting example of a plot that matched the BAER soil burn severity ranking was Plot 14. This plot was classified as having High soil burn severity and the field observations confirmed this rating. The subplots were 75% hydrophobic and the trees were all burned to the canopy with 5% of the canopy cover remaining (Figures 14 and 15 and Appendix – Table 31).

Figure 14. Photo of Plot 14 looking uphill.

Figure 15. Photo of Plot 14's canopy.

Plot 4 stands out as an example of a plot that did not match its BAER soil burn severity classification. Plot 4 had a Low BAER soil burn severity classification yet looked as though it should have been rated as High. The trees within the plot were all black and none of the canopy cover remained (Figures 16 and 17 and Appendix – Table 10). There was minimal leaf litter on the ground within this plot and 35% of the plot was exposed soil. Plot 4 was also 75% hydrophobic. These observations are all indicators of a much higher severity burn compared to the Low BAER soil burn severity rating determined for this area.

Figure 16. Photo of Plot 4 looking uphill.

Figure 17. Photo of Plot 4’s canopy.

Plot 4 also had “craters” that were formed as the roots of the trees burned and caused the overlying soil to collapse (Figure 18). A root fire indicates that the fire was burning very hot and was most likely in contact with the soils around the roots.

Figure 18. Photo from Plot 4 and the craters and evidence of root fire.

Another example of a plot that differed greatly from the BAER soil burn severity classification was Plot 6 (Figures 19 and 20). This plot was classified by the BAER map as Low soil burn severity. The four subplots were all hydrophobic and averaged 20% exposed soil (Appendix – Tables 14 and 15). The trees within this plot were burned to the canopy and only 15% canopy cover remained (Figure 20).

Figure 19. Photo of Plot 6 looking uphill.

Figure 20. Photo of Plot 6's canopy.

One final plot that varied from the BAER soil burn severity ranking was Plot 7. On first glance, this plot appears to have been severely burned, leaving minimal vegetation and debris behind. However, the BAER soil burn severity classification was Unburned/Very Low. This plot was located on the top of Bullwark Ridge on the southwestern portion of the watershed. There was 0% canopy cover remaining and all of the trees within the plot were blackened (Figures 21 and 22). All of the four subplots were hydrophobic (Appendix – Table 17).

Figure 21. Photo of Plot 7 looking uphill.

Figure 22. Photo of Plot 7's canopy.

DISCUSSION

Less than half (seven) of the 16 plots sampled had an incorrect BAER soil burn severity classification rating based on my field observations. The sample size of four plots for each of the four BAER soil burn severity classes for a total of 16 is not adequate to evaluate the accuracy of the BAER maps rigorously, but the limited field data I collected indicate that the Miller Fork maps most likely are not very accurate.

Mapping soil burn severity is inherently challenging. Wildfires and the landscapes in which they occur can be extremely variable. The BAER mapping method has its limitations and is not foolproof and is not considered a soil burn severity map until it is ground truthed (Parsons et. al 2010). It would be challenging to capture these data perfectly from remote sensing alone so it is imperative that field validation occurs in response to events of this magnitude. Thus, the BAER program uses BARC classifications and field validations concurrently to create the soil burn severity maps to help ensure the data are as representative of the field conditions as possible (Parsons et al. 2010).

The usefulness of remote sensing imagery can sometimes be limited in cases where there are water bodies or snow present (Parsons et al. 2010). Another issue is that the physical characteristics of the land and vegetation surface that are captured by the remote sensing method do not correspond directly to the physical soil characteristics that affect runoff and erosion, such as hydrophobicity. The BARC method can counteract some of these common issues like snow cover and other vegetation differences, but it is not perfect. It is credible but also a loose connection, again stressing the importance of the field work and ground truthing that must be performed post-fire to create the BAER map (Parsons et al. 2010).

Observations from the field varied from the BAER soil burn severity maps within seven of the 16 plots sampled. The remaining nine plots sampled were consistent with the BAER maps. Wildfires can be extremely variable and so are the landscapes in which they encounter. It would be nearly impossible to capture these data perfectly from remote sensing alone, so it is imperative that field validation occurs in response to events of this magnitude. Knowing that the BAER team was working up against the winter months and snowfall which made the BARC maps slightly incorrect in areas makes field validations even more important. The team's field validation process was extremely limited due to poor access and steep slopes, which is very similar to this study's limitations (USDA 2020).

Knowing that the Cameron Peak Fire BAER team was working up against early winter field conditions and snowfall, it is not surprising that the BARC maps were not highly accurate in some areas. Challenging conditions that interfered with the BARC remote sensing approach made field validation of mapping even more important than usual, but they also impeded the field work that was needed. The team's field validation process was extremely limited due to poor access and steep slopes as well as adverse weather (USDA 2020). Some of the same conditions that interfered with remote sensing also interfered with fieldwork that could have helped improve the final BAER soil burn severity map.

Examining the Hudak et al. (2004) paper, similar observations were observed within the 16 sampled plots in Miller Fork. They found that the BAER method was not all that accurate over the 4 western wildfires they studied. Their study was more widespread and had a larger sample size as compared to this study, but a similar result was found. They conducted a large study very similar to the one I performed and sampled partly based on access and efficiency, which again was similar to how I selected my sample sites. It does not appear that the BARC mapping method is accurate on a finer scale when considering the Miller Fork watershed specifically. This part of the fire was just a small fraction of the overall burn scar.

This mapping method is able to explain, with relative accuracy, the implications for erosion and sedimentation risk throughout a whole burned area, by mapping the soil burn severity classes but falls short on the smaller watersheds, such as Miller Fork. This is evident when seeing almost 50% of the plots observed to have an incorrect soil burn severity classification. With that said, the BAER method is beneficial when looking at a burn scar as a whole but when examining a small watershed within the burn scar may not be as accurate.

Limitations of my project include the time of year the field work was done, the limited time that has lapsed since the fire was extinguished, limited access to the study area, and the steep terrain within the study area. As stated previously, safety was the number one consideration in selecting plot locations, and that severely limited where the plots could be located. Sampling in other areas throughout the watershed and increasing the sample size would have provided more representative data. Specifically, my samples were concentrated in the valley bottom, while hillsides far away from the trail were not sampled because access to those areas was restricted. Even with all these limitations, the project did address an important problem in post-burn risk analysis, and my observations underline the need for caution when using BARC burn severity maps.

Expected outcomes of this study were to be able to better understand the relative accuracy of BAER soil burn severity mapping performed under urgent but non-ideal conditions following a catastrophic wildfire event. This assessment was able to help inform the use of these post-fire BAER maps in the future and identify what these maps are telling the reader on a smaller scale. This exercise provided me with an understanding of the post-fire watershed-wide threats pertaining to sedimentation and erosion potential within the Miller Fork watershed following a similar wildfire event of this magnitude in the future. Comparing the post-fire BAER soil burn severity map to the field sampling within the Miller Fork watershed one-year post-burn was able to help illustrate that the post-fire mapping and analyses were somewhat inaccurate for the small, Miller Fork watershed. This information can hopefully be used after other cataclysmic wildfire events occur in the future and improve upon the methods used to examine the risk to the watersheds post-burn.

The next steps that I recommend for assessing the Miller Fork watershed following the Cameron Peak Fire would be to perform more field work to identify the specific areas of the watershed that should be the focus of remediation efforts. I plan to continue working with the Big Thompson Watershed Coalition and J.W. Associates as we continue to study the Miller Fork watershed and the larger Cameron Peak Fire and in turn attempt to work to limit sedimentation risk within the watershed and also the greater Big Thompson watershed.

CONCLUSION

The Cameron Peak Fire burned rapidly, had a large amount of available forest fuel, and was difficult to access which made fighting it extremely challenging. In that same vein, post-fire work has been challenging since access to the burned area is so limited. The same is true for the burned Miller Fork watershed; terrain is steep and rocky with limited access points. The BAER analysis post-fire exhibited that the Miller Fork watershed observed all four categories of soil burn severity. Field validation performed in 2021, one-year post-burn, did not reflect reality for the Miller Fork watershed when compared to the initial post-fire BAER map. Collecting field data throughout the Miller Fork watershed from the four soil burn severity classes showed that the real soil burn severities were different than originally designated; and actually much more severe than originally determined. These baseline soil burn severity maps created by the BAER team are oftentimes the only post-fire assessments performed prior to restoration work needs to be completed.

The same was true for the Cameron Peak Fire which has affected the level of accuracy seen in post-fire risk assessments. Without being too critical of these immediate, post-fire assessments, some sort of baseline assessment needs to be done and the BAER method is the only one currently used on federally burned lands. Ideally these assessments would last longer than 7-10 days post-fire and have more field validation to accompany these BAER maps, to ensure the data is accurate. Unfortunately, with these large-scale fires occurring more and more frequently throughout the American West, doing more than this may not be feasible nor realistic just yet. Having this sense of appreciation and understating of what the BAER teams are up against post-fire sheds some light and validity on the work they do. It may not be perfect and of course it could be better, but it is the best we have currently with the amount of funding these fires require. Maybe in the future when these technologies are less expensive and more attainable for government and emergency response organizations, some improvements could be made to the BAER method.

My suggestion for future large wildfire events is to focus on monitoring and field validating smaller watersheds to gain a better understanding of what is really going on in the field. That information is extremely valuable for the agencies tasked with remediation efforts post-fire and can be used as management plans and goals post-fire are set. As with everything, utilize the BAER maps with an understanding of how they're created and their limitations but know that they can be a good starting point on which to build a post-fire management plan. One cannot ultimately conclude that the BAER method is imperfect or perfect (and no model is perfect for that matter) because this case study did not examine the value the BAER maps provide but more field validations immediately post-fire and one to two years post-fire will be beneficial for these large-scale, unique fires, such as the Cameron Peak Fire, to better understand the true validity of these initial soil burn severity maps.

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APPENDIX

Plot 1 – Unburned/Very Low (BAER Class)

Table 4. Plot 1 Data

Plot 1	
Aspect:	34° NE
Topographic Position:	Toeslope, Lower Watershed
Time:	10:40 AM
Date:	8/28/21
Elevation:	7520'
Slope:	35-40%
Forest Type:	Lodgepole, some spruce-fir
Canopy Cover:	40%
Canopy:	Green & brown needles
Burn scars:	10-15' up tree trunks
Burn Intensity:	Low-Moderate (90%, 10%)
Ground Cover Comp:	fines (needles, brown) 40%
	plants/veg. 25%
	downed LWD 10%
	rock 5%
	exposed soil 5%
	trees 15%
BAER Class:	Unburned/Very Low

Table 5. Plot 1, subplot 1-4 ground cover composition data

Subplot 1 - NW Corner	
fines	55%
rock	5%
plants/veg	25%
mod. WD	5%
exposed soil	10%
pine regen	0.05%
grass	0.05%
LWD	
trees	
aspen regen	
Not Hydrophobic	

Subplot 2 - NE Corner	
fines	45%
rock	10%
plants/veg	33%
mod. WD	5%
exposed soil	5%
pine regen	
grass	2%
LWD	
trees	
aspen regen	
Not Hydrophobic	

Subplot 3 - SE Corner	
fines	55%
rock	5%
plants/veg	10%
mod. WD	10%
exposed soil	20%
pine regen	
grass	
LWD	
trees	
aspen regen	
Not Hydrophobic	

Subplot 4 - SW Corner	
fines	55%
rock	10%
plants/veg	15%
mod. WD	15%
exposed soil	5%
pine regen	
grass	
LWD	
trees	
aspen regen	
Not Hydrophobic	

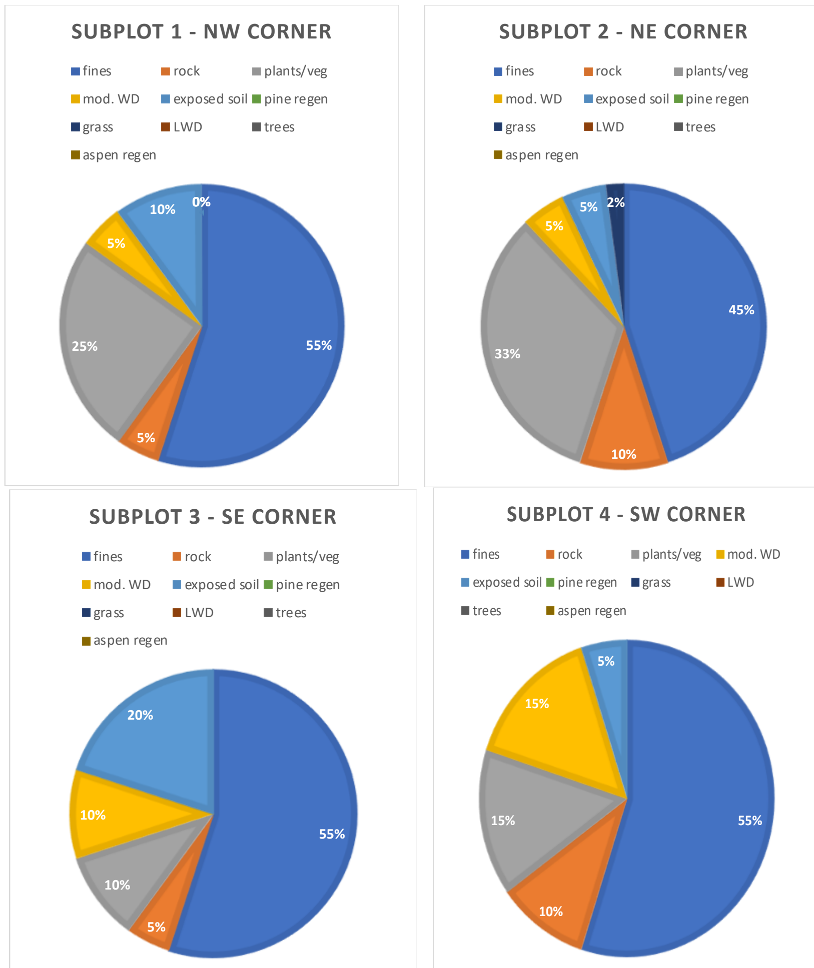

Figure 23. Pie charts of the ground cover composition within each subplot of plot 1

Plot 2 – Low (BAER Class)

Table 6. Plot 2 Data

Plot 2	
Aspect:	180° S
Topographic Position:	Toeslope, uphill from Riparian
Time:	12:15 PM
Date:	8/28/21
Elevation:	7620'
Slope:	35%
Forest Type:	Pondo; dry-mixed conifer
Canopy Cover:	10%
Canopy:	Black & brown needles (burned)
Burn scars:	trees fully burned
Burn Intensity:	Moderate-High (20%, 80%)
Ground Cover Comp:	fines (needles, brown) 2.5%
	plants/veg. 35%
	downed LWD 2.5%
	rock 10%
	exposed soil 40%
	burned trees, standing 10%
BAER Class:	Low

Table 7. Plot 2, subplot 1-4 ground cover composition data

Subplot 1 - SE Corner		Subplot 2 - SW Corner		Subplot 3 - NW Corner		Subplot 4 - NE Corner	
fines	1%	fines	5%	fines	5%	fines	5%
rock		rock	5%	rock	15%	rock	30%
plants/veg	9%	plants/veg	50%	plants/veg	45%	plants/veg	19%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	90%	exposed soil	40%	exposed soil	35%	exposed soil	45%
pine regen		pine regen		pine regen		pine regen	
grass		grass		grass		grass	1%
LWD		LWD		LWD		LWD	
trees		trees		trees		trees	
aspen regen		aspen regen		aspen regen		aspen regen	
Hydrophobic		Hydrophobic		Not Hydrophobic		Hydrophobic	

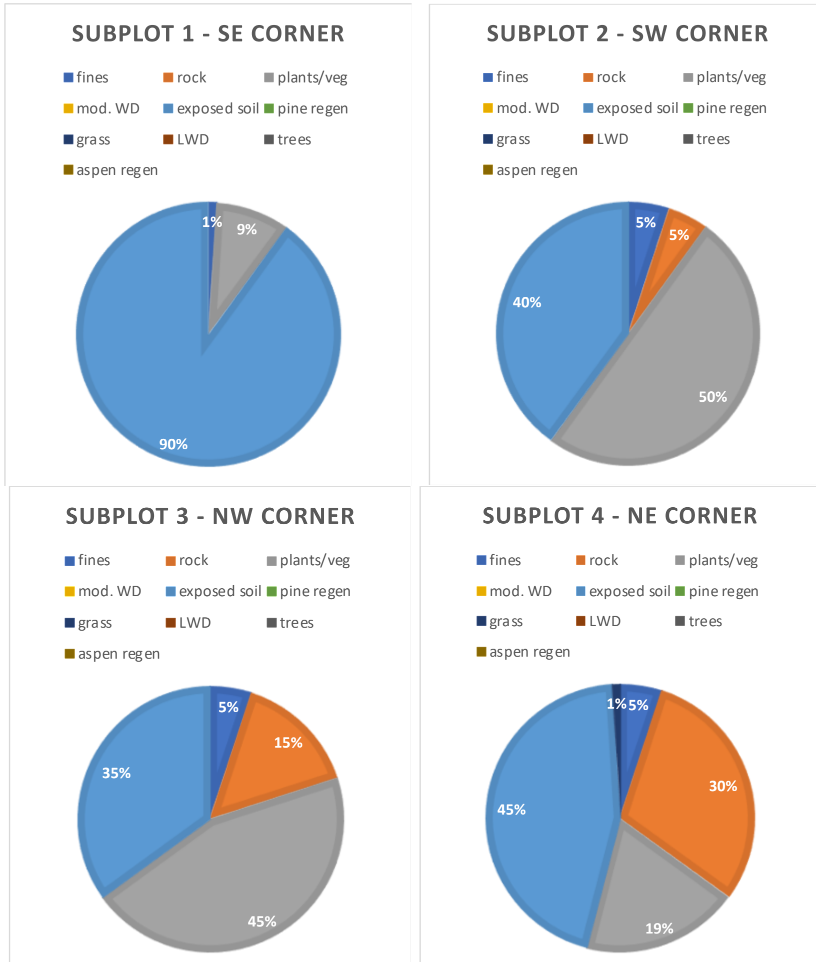

Figure 24. Pie charts of the ground cover composition within each subplot of plot 2

Plot 3 – Low (BAER Class)

Table 8. Plot 3 Data

Plot 3	
Aspect:	163° S
Topographic Position:	Midslope
Time:	1:10 PM
Date:	8/28/21
Elevation:	7770'
Slope:	50%
Forest Type:	Dry-mixed conifer
Canopy Cover:	40%
Canopy:	Green needles (unburned)
Burn scars:	10-20' up tree trunks
Burn Intensity:	Low-Moderate (30%, 70%)
Ground Cover Comp:	fines (needles, brown) 25%
	plants/veg. 13%
	mod. WD 5%
	rock 15%
	exposed soil 30%
	burned trees, standing 10%
	grass 2%
BAER Class:	Low

Table 9. Plot 3, subplot 1-4 ground cover composition data

Subplot 1 - SE Corner		Subplot 2 - SW Corner		Subplot 3 - NW Corner		Subplot 4 - NE Corner	
fines	60%	fines	5%	fines	5%	fines	5%
rock	15%	rock	20%	rock	15%	rock	20%
plants/veg	15%	plants/veg	19%	plants/veg		plants/veg	
mod. WD	5%	mod. WD		mod. WD		mod. WD	
exposed soil	5%	exposed soil	55%	exposed soil	80%	exposed soil	45%
pine regen		pine regen		pine regen		pine regen	
grass		grass	1%	grass		grass	
LWD		LWD		LWD		LWD	30%
tree		tree		tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Not Hydrophobic		Hydrophobic		Hydrophobic		Hydrophobic	

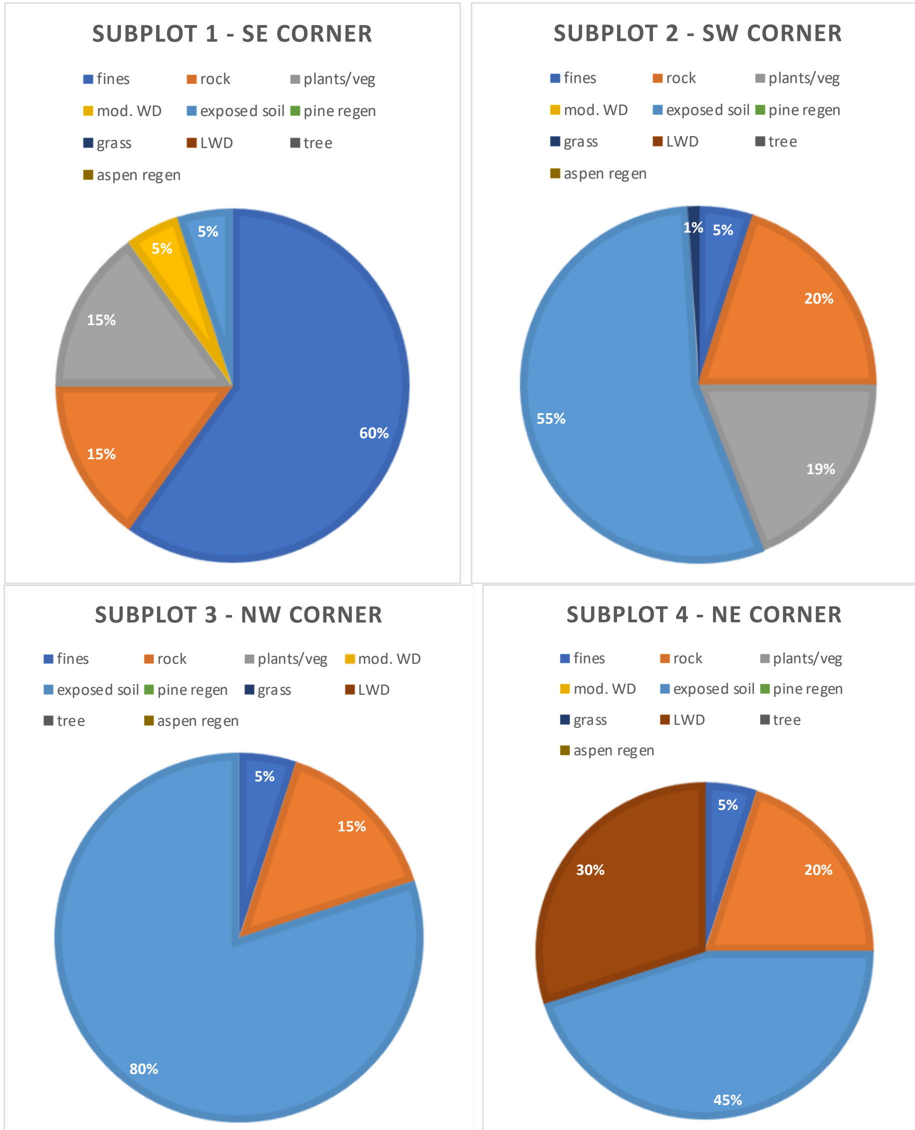

Figure 25. Pie charts of the ground cover composition within each subplot of plot 3

Plot 4 – Low (BAER Class)

Table 10. Plot 4 Data

Plot 4	
Aspect:	87° E
Topographic Position:	Midslope
Time:	2:15 PM
Date:	8/28/21
Elevation:	7850'
Slope:	35-40%
Forest Type:	Lodgepole
Canopy Cover:	0%
Canopy:	No needles remain (burned)
Burn scars:	trees fully burned
Burn Intensity:	High/Severe (100%)
Ground Cover Comp:	plants/veg. 30%
	LWD 5%
	rock 15%
	exposed soil 35%
	burned trees, standing 15%
BAER Class:	Low

Table 11. Plot 4, subplot 1-4 ground cover composition data

Subplot 1 - NE Corner		Subplot 2 - SE Corner		Subplot 3 - SW Corner		Subplot 4 - NW Corner	
fines	35%	fines	5%	fines	5%	fines	3%
rock		rock	10%	rock	10%	rock	
plants/veg	30%	plants/veg	2%	plants/veg	24%	plants/veg	41%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	20%	exposed soil	43%	exposed soil	55%	exposed soil	45%
pine regen		pine regen		pine regen		pine regen	
grass		grass		grass	1%	grass	1%
LWD		LWD		LWD		LWD	
tree		tree	40%	tree		tree	
aspen regen	15%	aspen regen		aspen regen	5%	aspen regen	10%
Hydrophobic		Not Hydrophobic		Hydrophobic		Hydrophobic	

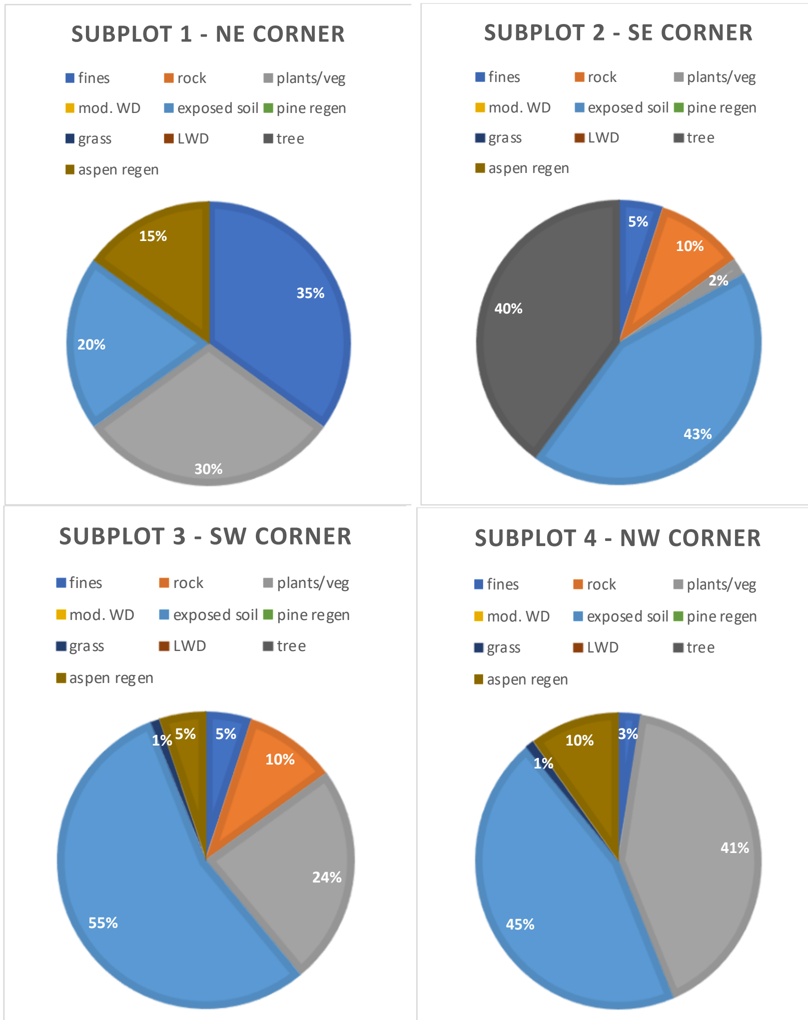

Figure 26. Pie charts of the ground cover composition within each subplot of plot 4.

Plot 5 – Moderate (BAER Class)

Table 12. Plot 5 Data

Plot 5	
Aspect:	270° W
Topographic Position:	Midslope
Time:	3:00 PM
Date:	8/28/21
Elevation:	7840'
Slope:	45%
Forest Type:	Lodgepole dom; wet-mixed conifer
Canopy Cover:	5-10%
Canopy:	Some brown/black needles remain (burned)
Burn scars:	trees fully burned
Burn Intensity:	Moderate-High (30%, 70%)
Ground Cover Comp:	plants/veg. 2.5%
	LWD 5%
	rock 35%
	exposed soil 30%
	burned trees, standing 10%
	fines 15%
	grasses 2.5%
BAER Class:	Moderate

Table 13. Plot 5, subplot 1-4 ground cover composition data

Subplot 1 - SW Corner		Subplot 2 - NW Corner		Subplot 3 - NE Corner		Subplot 4 - SE Corner	
fines	15%	fines	15%	fines	15%	fines	15%
rock	40%	rock	45%	rock	40%	rock	30%
plants/veg	2%	plants/veg	5%	plants/veg	5%	plants/veg	2%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	40%	exposed soil	30%	exposed soil	40%	exposed soil	30%
pine regen		pine regen		pine regen		pine regen	
grass	3%	grass	5%	grass		grass	
LWD		LWD		LWD		LWD	23%
tree		tree		tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Hydrophobic		Hydrophobic		Hydrophobic		Hydrophobic	

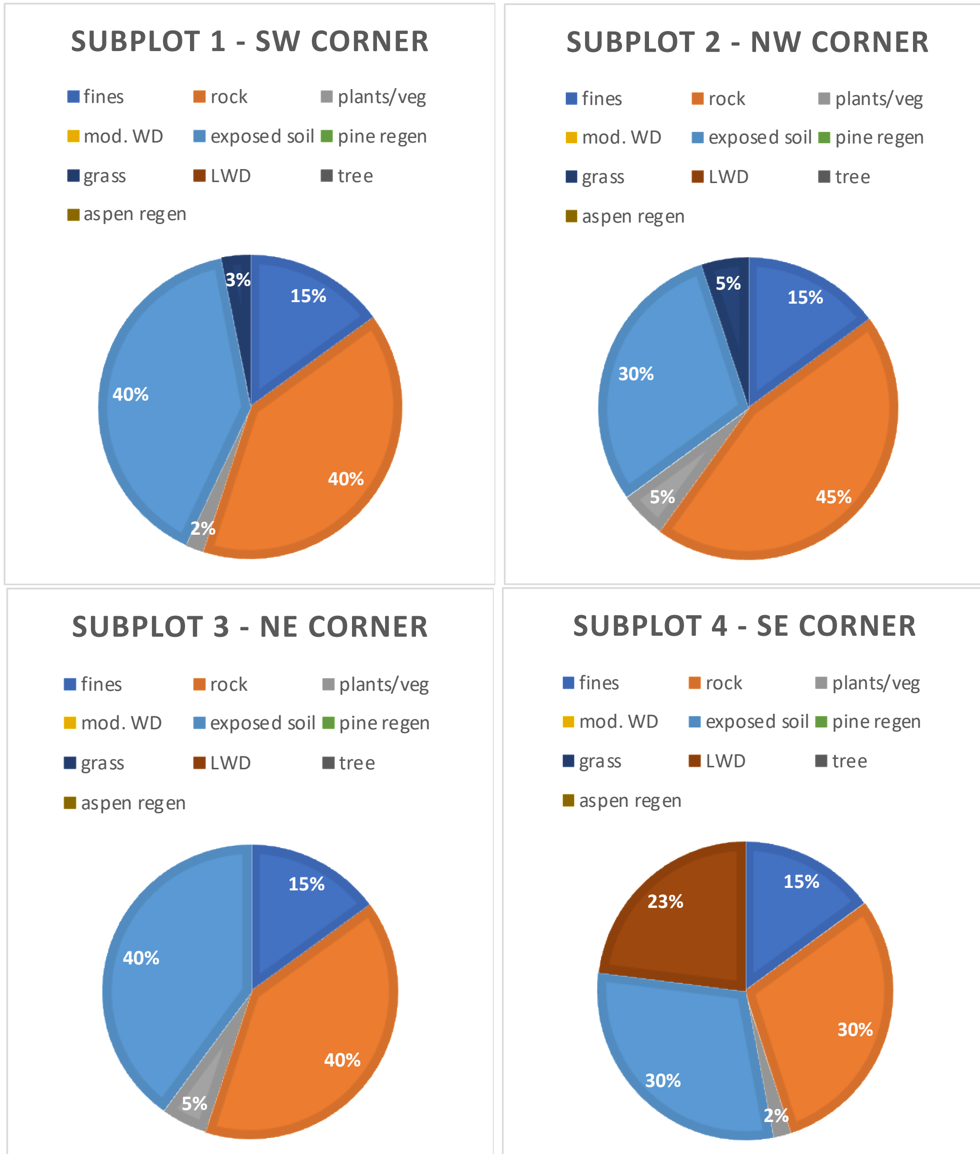

Figure 27. Pie charts of the ground cover composition within each subplot of plot 5

Plot 6 – Low (BAER Class)

Table 14. Plot 6 Data

Plot 6	
Aspect:	36° NE
Topographic Position:	Midslope
Time:	4:00 PM
Date:	8/28/21
Elevation:	8000'
Slope:	35%
Forest Type:	Lodgepole
Canopy Cover:	15%
Canopy:	brown/black needles (burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High (100%)
Ground Cover Comp:	plants/veg. 2.5%
	LWD 10%
	rock 10%
	exposed soil 20%
	burned trees, standing 10%
	fines 40%
	grasses 2.5%
	mods. WD 2.5%
	pine regen 2.5%
BAER Class:	Low

Table 15. Plot 6, subplot 1-4 ground cover composition data

Subplot 1 - NW Corner		Subplot 2 - NE Corner		Subplot 3 - SE Corner		Subplot 4 - SW Corner	
fines	40%	fines	30%	fines	70%	fines	50%
rock	15%	rock	15%	rock	5%	rock	5%
plants/veg		plants/veg	15%	plants/veg		plants/veg	
mod. WD		mod. WD		mod. WD	5%	mod. WD	
exposed soil	40%	exposed soil		exposed soil	15%	exposed soil	40%
pine regen	5%	pine regen	5%	pine regen	5%	pine regen	5%
grass		grass		grass		grass	
LWD		LWD	20%	LWD		LWD	
tree		tree	15%	tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Hydrophobic		Hydrophobic		Hydrophobic		Hydrophobic	

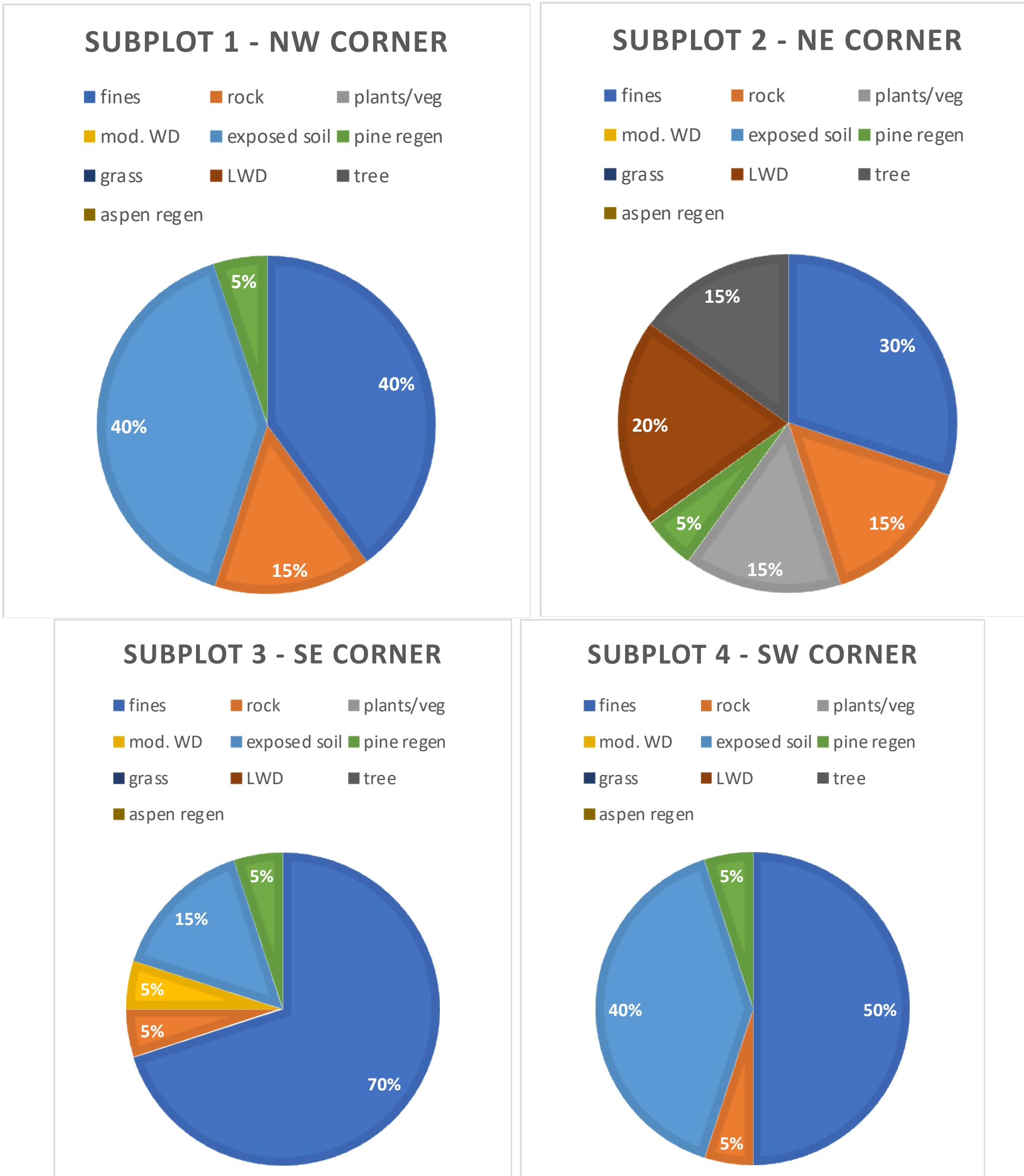

Figure 28. Pie charts of the ground cover composition within each subplot of plot 6

Plot 7 – Unburned/Very Low (BAER Class)

Table 16. Plot 7 Data

Plot 7	
Aspect:	38° NE
Topographic Position:	Ridge
Time:	7:00 PM
Date:	9/1/21
Elevation:	8720'
Slope:	20%
Forest Type:	Lodgepole
Canopy Cover:	0%
Canopy:	no needles remain (all burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High (100%)
Ground Cover Comp:	plants/veg. 5%
	LWD 10%
	rock 10%
	exposed soil 45%
	burned trees, standing 10%
	fines 5%
	grasses 5%
	mods. WD 5%
	pine regen 5%
BAER Class:	Unburned/Very Low

Table 17. Plot 7, subplot 1-4 ground cover composition data

Subplot 1 - SE Corner	
fines	5%
rock	30%
plants/veg	
mod. WD	
exposed soil	55%
pine regen	
grass	
LWD	
tree	10%
aspen regen	
Hydrophobic	

Subplot 2 - NE Corner	
fines	5%
rock	38%
plants/veg	5%
mod. WD	2%
exposed soil	50%
pine regen	
grass	
LWD	
tree	
aspen regen	
Hydrophobic	

Subplot 3 - NW Corner	
fines	2%
rock	10%
plants/veg	
mod. WD	
exposed soil	86%
pine regen	
grass	2%
LWD	
tree	
aspen regen	
Hydrophobic	

Subplot 4 - SW Corner	
fines	3%
rock	15%
plants/veg	
mod. WD	
exposed soil	70%
pine regen	3%
grass	
LWD	
tree	10%
aspen regen	
Hydrophobic	

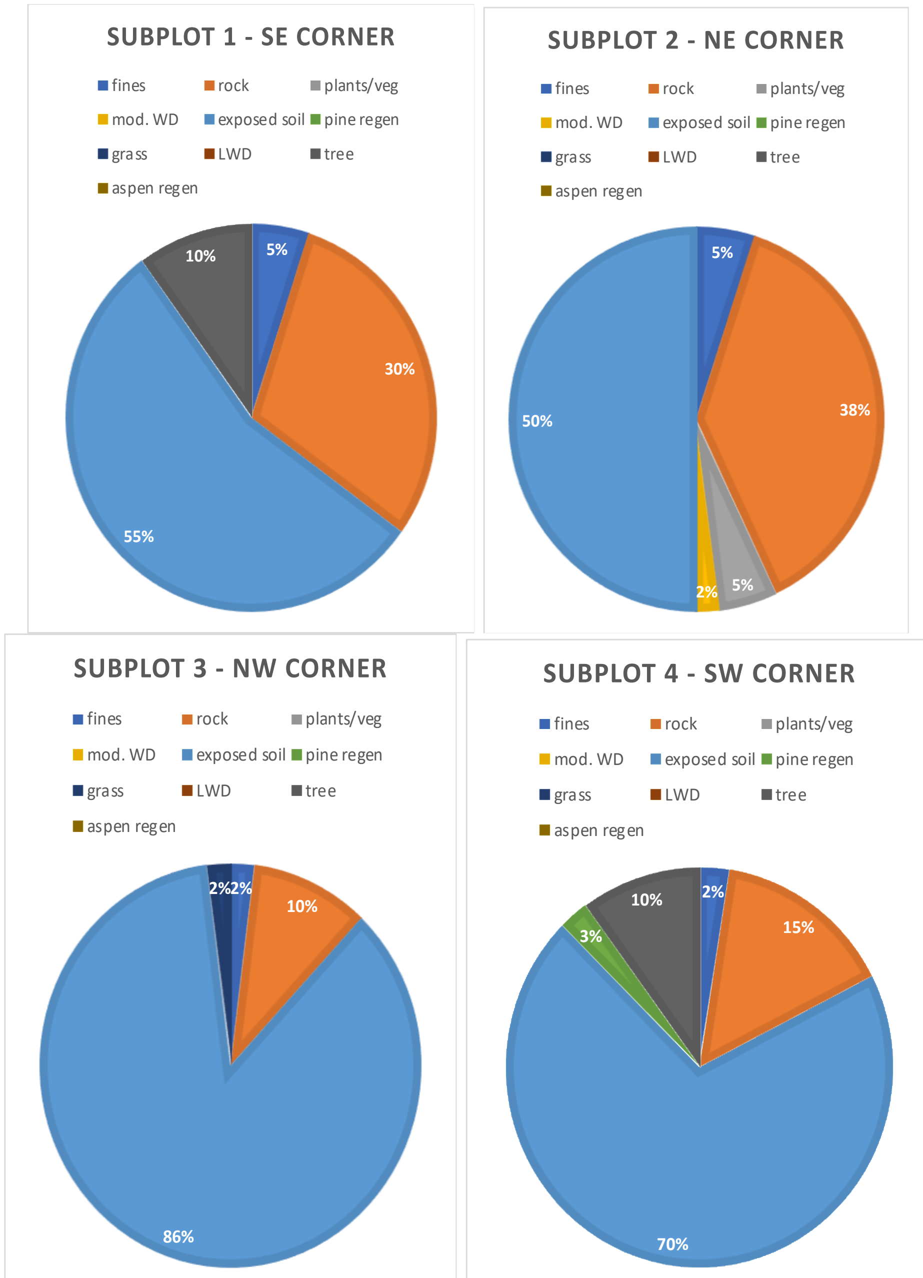

Figure 29. Pie charts of the ground cover composition within each subplot of plot 7

Plot 8 – Unburned/Very Low (BAER Class)

Table 18. Plot 8 Data

Plot 8	
Aspect:	77° E
Topographic Position:	Toeslope - Midslope
Time:	9:49 AM
Date:	10/5/21
Elevation:	7560'
Slope:	25%
Forest Type:	Lodgepole
Canopy Cover:	60%
Canopy:	unburned, green needles
Burn scars:	minimal
Burn Intensity:	Low
Ground Cover Comp:	plants/veg. 10%
	LWD 10%
	rock 20%
	exposed soil 5%
	burned trees, standing 10%
	fines 40%
	grasses 5%
BAER Class:	Unburned/Very Low

Table 19. Plot 8, subplot 1-4 ground cover composition data

Subplot 1 - NE Corner		Subplot 2 - SE Corner		Subplot 3 - SW Corner		Subplot 4 - NW Corner	
fines	65.0%	fines	70%	fines	50%	fines	65%
rock	5.0%	rock	5%	rock	10%	rock	
plants/veg	2.5%	plants/veg	10%	plants/veg	15%	plants/veg	
mod. WD	20.0%	mod. WD	5%	mod. WD	15%	mod. WD	
exposed soil	5.0%	exposed soil	10%	exposed soil	5%	exposed soil	20%
pine regen		pine regen		pine regen		pine regen	
grass	2.5%	grass		grass	5%	grass	
LWD		LWD		LWD		LWD	15%
tree		tree		tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Hydrophobic		Not Hydrophobic		Not Hydrophobic		Hydrophobic	

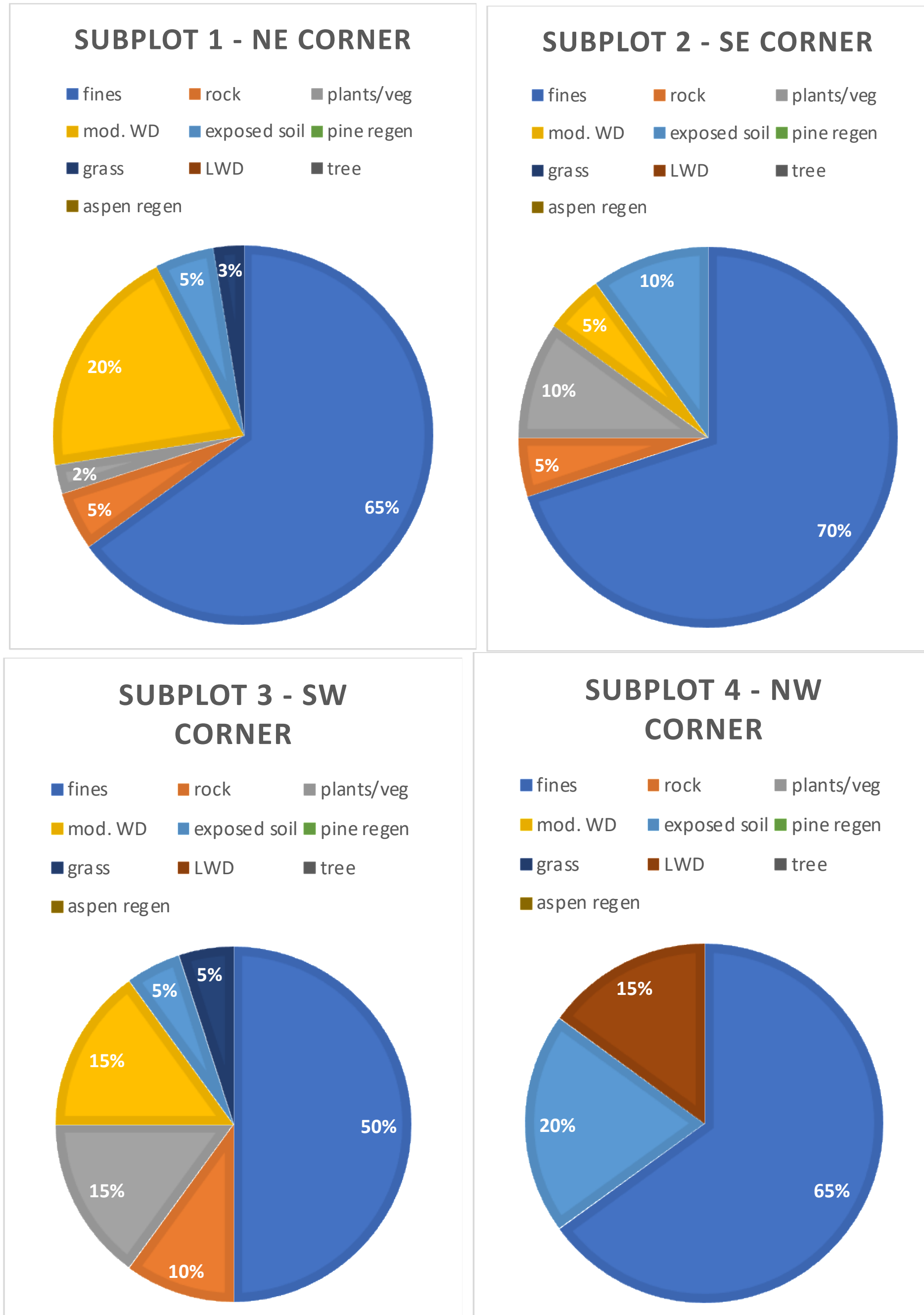

Figure 30. Pie charts of the ground cover composition within each subplot of plot 8

Plot 9 – Unburned/Very Low (BAER Class)

Table 20. Plot 9 Data

Plot 9	
Aspect:	15° N
Topographic Position:	Toe/Riparian
Time:	10:27 AM
Date:	10/5/21
Elevation:	7550'
Slope:	30%
Forest Type:	Spruce-Fir
Canopy Cover:	90%
Canopy:	unburned, green needles
Burn scars:	none
Burn Intensity:	Low
Ground Cover Comp:	plants/veg. 5%
	LWD 15%
	rock 5%
	trees, standing 20%
	fines 45%
	mods. WD 10%
BAER Class:	Unburned/Very Low

Table 21. Plot 9, subplot 1-4 ground cover composition data

Subplot 1 - NE Corner	
fines	50%
rock	20%
plants/veg	28%
mod. WD	
exposed soil	
pine regen	3%
grass	
LWD	
tree	
aspen regen	
Not Hydrophobic	

Subplot 2 - SE Corner	
fines	80%
rock	
plants/veg	
mod. WD	10%
exposed soil	
pine regen	
grass	
LWD	
tree	10%
aspen regen	
Not Hydrophobic	

Subplot 3 - SW Corner	
fines	85%
rock	
plants/veg	5%
mod. WD	10%
exposed soil	
pine regen	
grass	
LWD	
tree	
aspen regen	
Not Hydrophobic	

Subplot 4 - NW Corner	
fines	50%
rock	10%
plants/veg	5%
mod. WD	
exposed soil	15%
pine regen	
grass	
LWD	20%
tree	
aspen regen	
Not Hydrophobic	

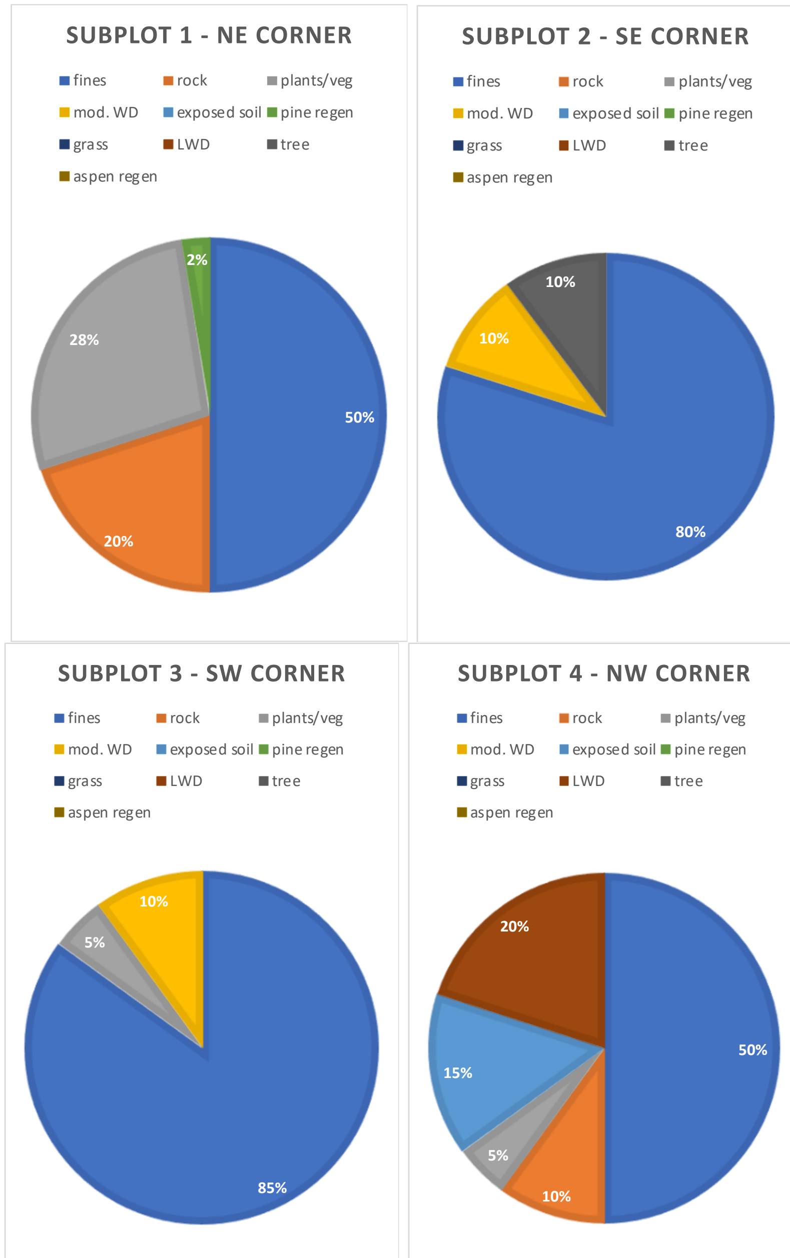

Figure 31. Pie charts of the ground cover composition within each subplot of plot 9

Plot 10 – Moderate (BAER Class)

Table 22. Plot 10 Data

Plot 10	
Aspect:	194° S
Topographic Position:	Midslope
Time:	11:25 AM
Date:	10/5/21
Elevation:	7810'
Slope:	45%
Forest Type:	Fir-Pine
Canopy Cover:	50%
Canopy:	unburned
Burn scars:	10-15' up tree
Burn Intensity:	Low-Moderate
Ground Cover Comp:	plants/veg. 10%
	LWD 2.5%
	rock 30%
	exposed soil 10%
	burned trees, standing 10%
	fines 35%
	grasses 2.5%
BAER Class:	Moderate

Table 23. Plot 10, subplot 1-4 ground cover composition data

Subplot 1 - SW Corner	
fines	70%
rock	15%
plants/veg	
mod. WD	
exposed soil	10%
pine regen	
grass	
LWD	
tree	5%
aspen regen	
Hydrophobic	

Subplot 2 - NW Corner	
fines	50%
rock	10%
plants/veg	25%
mod. WD	
exposed soil	15%
pine regen	
grass	
LWD	
tree	
aspen regen	
Not Hydrophobic	

Subplot 3 - NE Corner	
fines	3%
rock	70%
plants/veg	10%
mod. WD	
exposed soil	10%
pine regen	
grass	3%
LWD	
tree	5%
aspen regen	
Hydrophobic	

Subplot 4 - SE Corner	
fines	60%
rock	15%
plants/veg	5%
mod. WD	10%
exposed soil	10%
pine regen	
grass	
LWD	
tree	
aspen regen	
Hydrophobic	

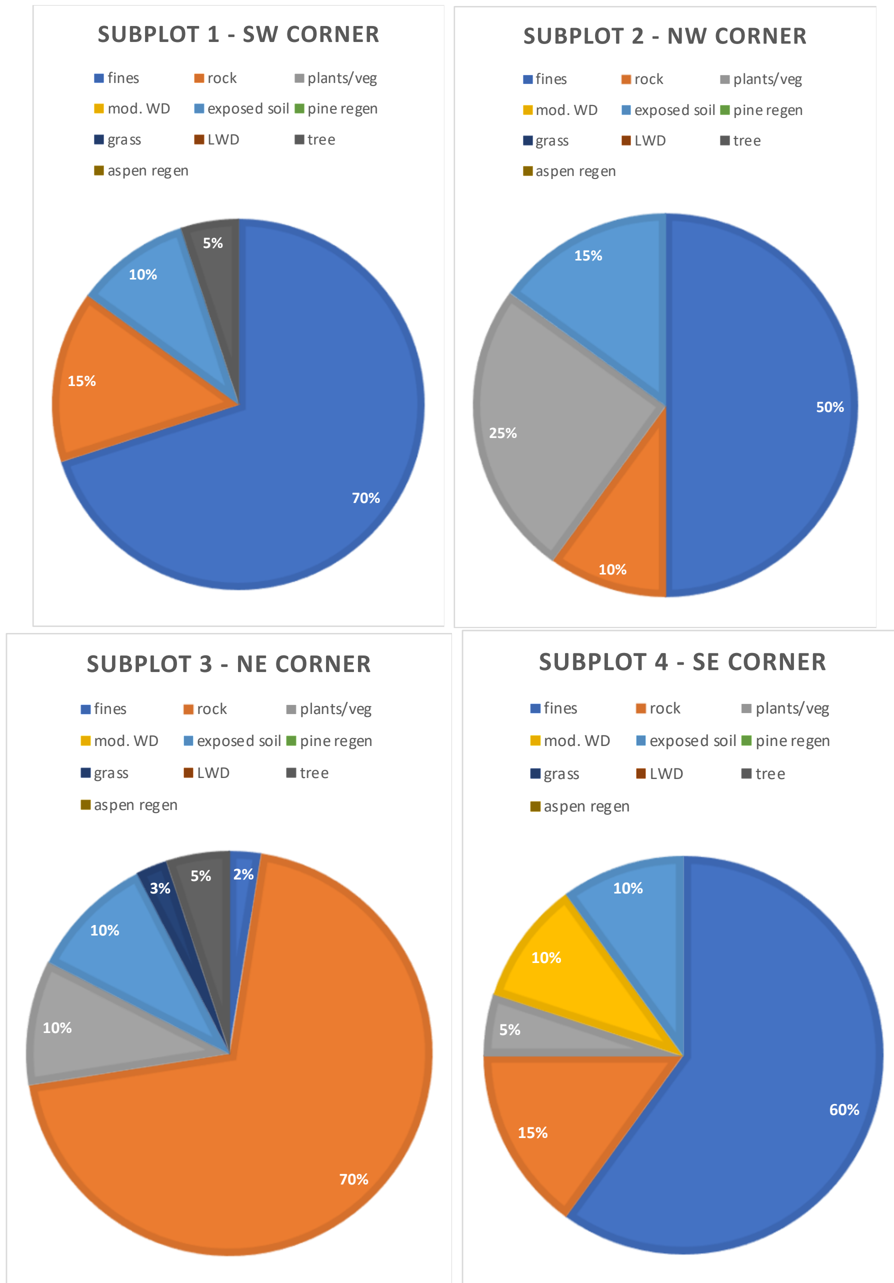

Figure 32. Pie charts of the groundcover composition within each subplot of plot 10

Plot 11 – Moderate (BAER Class)

Table 24. Plot 11 Data

Plot 11	
Aspect:	195° S
Topographic Position:	Toeslope
Time:	12:05 PM
Date:	10/5/21
Elevation:	7820'
Slope:	25%
Forest Type:	Fir - Pine
Canopy Cover:	40%
Canopy:	burned, some green
Burn scars:	10-20' up tree, some canopy
Burn Intensity:	L-M
Ground Cover Comp:	plants/veg. 10%
	rock 10%
	burned trees, standing 10%
	fines 30%
	grasses 40%
BAER Class:	Moderate

Table 25. Plot 11, subplot 1-4 ground cover composition data

Subplot 1 - SW Corner	
fines	10%
rock	3%
plants/veg	3%
mod. WD	
exposed soil	15%
pine regen	
grass	70%
LWD	
tree	
aspen regen	
Not Hydrophobic	

Subplot 2 - NW Corner	
fines	65%
rock	5%
plants/veg	10%
mod. WD	
exposed soil	15%
pine regen	
grass	5%
LWD	
tree	
aspen regen	
Not Hydrophobic	

Subplot 3 - NE Corner	
fines	50%
rock	
plants/veg	5%
mod. WD	5%
exposed soil	10%
pine regen	
grass	30%
LWD	
tree	
aspen regen	
Hydrophobic	

Subplot 4 - SE Corner	
fines	55%
rock	10%
plants/veg	
mod. WD	
exposed soil	10%
pine regen	
grass	
LWD	
tree	25%
aspen regen	
Hydrophobic	

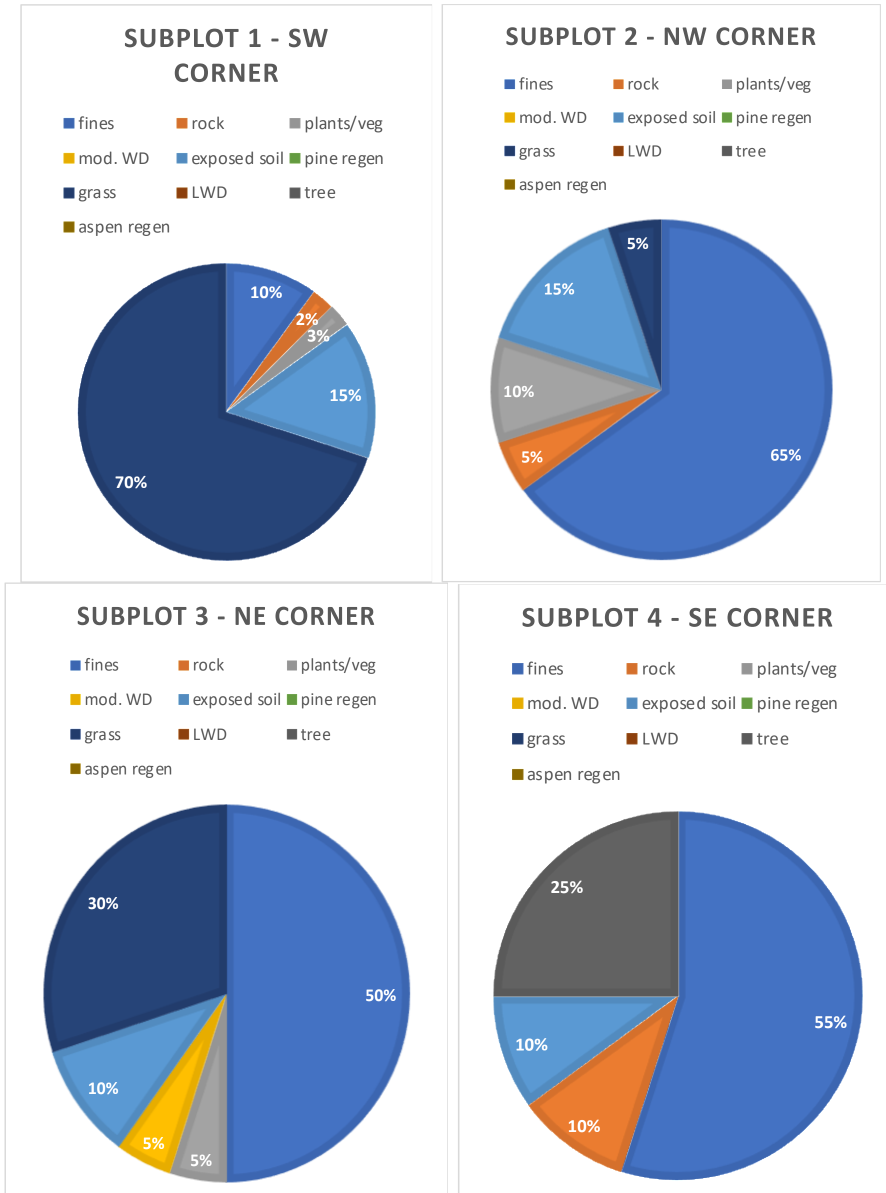

Figure 33. Pie charts of the ground cover composition within each subplot of plot 11

Plot 12 – Moderate (BAER Class)

Table 26. Plot 12 Data

Plot 12	
Aspect:	103° E
Topographic Position:	Midslope
Time:	12:34 PM
Date:	10/5/21
Elevation:	7890'
Slope:	35%
Forest Type:	Lodgepole
Canopy Cover:	25%
Canopy:	burned, brown needles
Burn scars:	burned halfway up trees (30')
Burn Intensity:	Moderate
Ground Cover Comp:	plants/veg. 20%
	rock 30%
	exposed soil 10%
	burned trees, standing 10%
	fines 25%
	grasses 5%
BAER Class:	Moderate

Table 27. Plot 12, subplot 1-4 ground cover composition data

Subplot 1 - SE Corner		Subplot 2 - SW Corner		Subplot 3 - NW Corner		Subplot 4 - NE Corner	
fines	40%	fines	55%	fines	10%	fines	45%
rock	20%	rock	20%	rock	40%	rock	15%
plants/veg		plants/veg	10%	plants/veg	10%	plants/veg	20%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	30%	exposed soil	10%	exposed soil	30%	exposed soil	15%
pine regen		pine regen		pine regen		pine regen	
grass	5%	grass	5%	grass		grass	5%
LWD		LWD		LWD	10%	LWD	
tree		tree		tree		tree	
aspen regen	5%	aspen regen		aspen regen		aspen regen	
Hydrophobic		Hydrophobic		Hydrophobic		Hydrophobic	

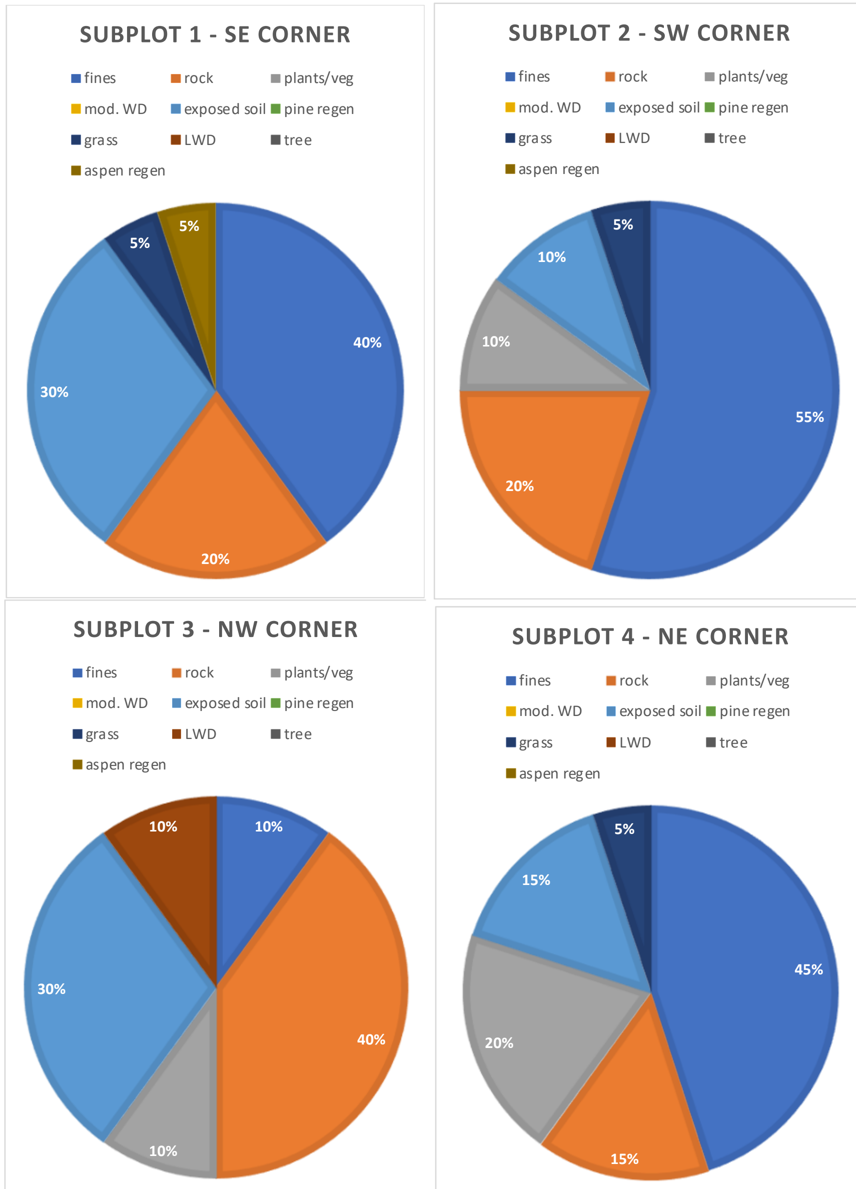

Figure 34. Pie charts of the ground cover composition within each subplot of plot 12

Plot 13 – High (BAER Class)

Table 28. Plot 13 Data

Plot 13	
Aspect:	262° W
Topographic Position:	Adjacent to Riparian
Time:	1:00 PM
Date:	10/5/21
Elevation:	7880'
Slope:	15%
Forest Type:	Dry mixed conifer
Canopy Cover:	5%
Canopy:	no needles remain (all burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High
Ground Cover Comp:	plants/veg. 40%
	LWD 10%
	rock 20%
	exposed soil 10%
	burned trees, standing 10%
	fines 5%
	grasses 5%
BAER Class:	High

Table 29. Plot 13, subplot 1-4 ground cover composition data

Subplot 1 - SW Corner		Subplot 2 - NW Corner		Subplot 3 - NE Corner		Subplot 4 - SE Corner	
fines	5%	fines		fines		fines	5%
rock		rock	10%	rock	20%	rock	5%
plants/veg	55%	plants/veg	45%	plants/veg	55%	plants/veg	15%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	25%	exposed soil	25%	exposed soil	20%	exposed soil	70%
pine regen		pine regen		pine regen		pine regen	
grass	15%	grass	20%	grass	5%	grass	
LWD		LWD		LWD		LWD	5%
tree		tree		tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Not Hydrophobic		Not Hydrophobic		Hydrophobic		Hydrophobic	

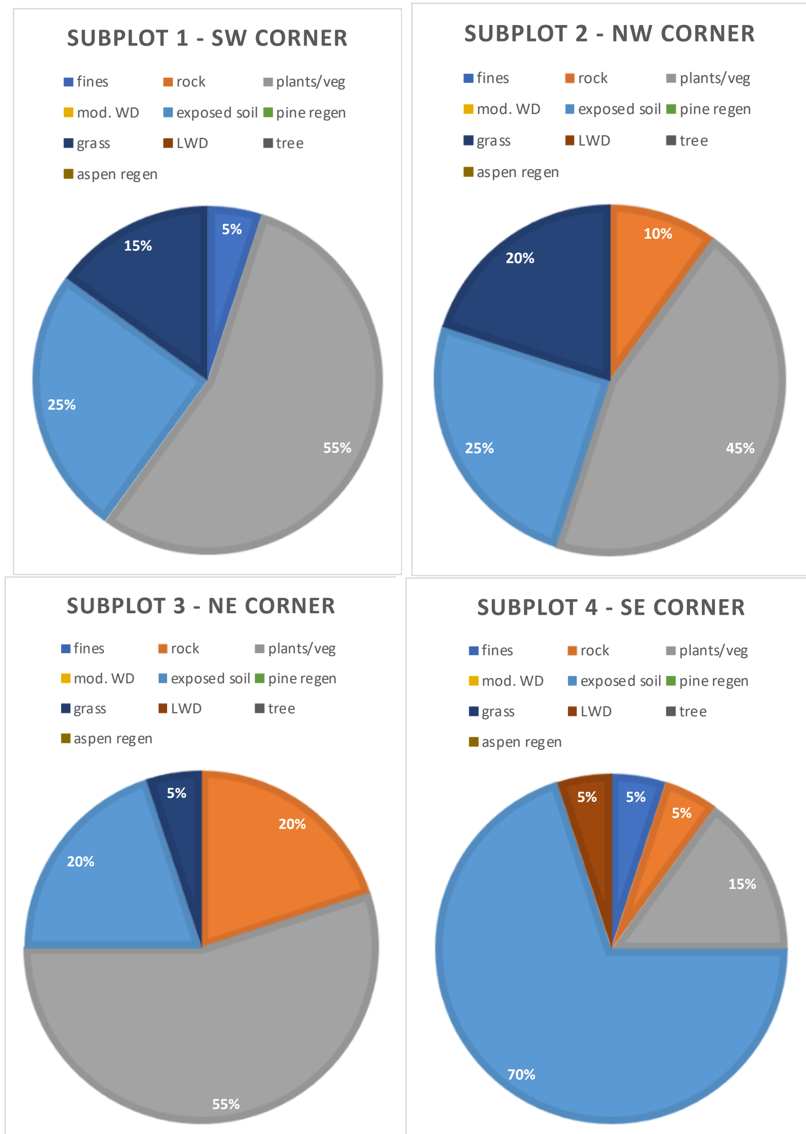

Figure 35. Pie charts of the ground cover composition within each subplot of plot 13

Plot 14 – High (BAER Class)

Table 30. Plot 14 Data

Plot 14	
Aspect:	237° SW
Topographic Position:	Toeslope
Time:	1:30 PM
Date:	10/5/21
Elevation:	7900'
Slope:	60%
Forest Type:	Spruce-Fir (dry mixed conifer)
Canopy Cover:	5%
Canopy:	no needles remain (all burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High
Ground Cover Comp:	plants/veg. 30%
	rock 30%
	exposed soil 20%
	burned trees, standing 15%
	fines 2.5%
	grasses 2.5%
BAER Class:	High

Table 31. Plot 14, subplot 1-4 ground cover composition data

Subplot 1 - NW Corner		Subplot 2 - NE Corner		Subplot 3 - SE Corner		Subplot 4 - SW Corner	
fines		fines		fines	5%	fines	
rock	15%	rock	35%	rock	10%	rock	35%
plants/veg	50%	plants/veg	40%	plants/veg	25%	plants/veg	15%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	30%	exposed soil	20%	exposed soil	60%	exposed soil	50%
pine regen		pine regen		pine regen		pine regen	
grass	5%	grass		grass		grass	
LWD		LWD		LWD		LWD	
tree		tree		tree		tree	
aspen regen		aspen regen	5%	aspen regen		aspen regen	
Hydrophobic		Hydrophobic		Not Hydrophobic		Hydrophobic	

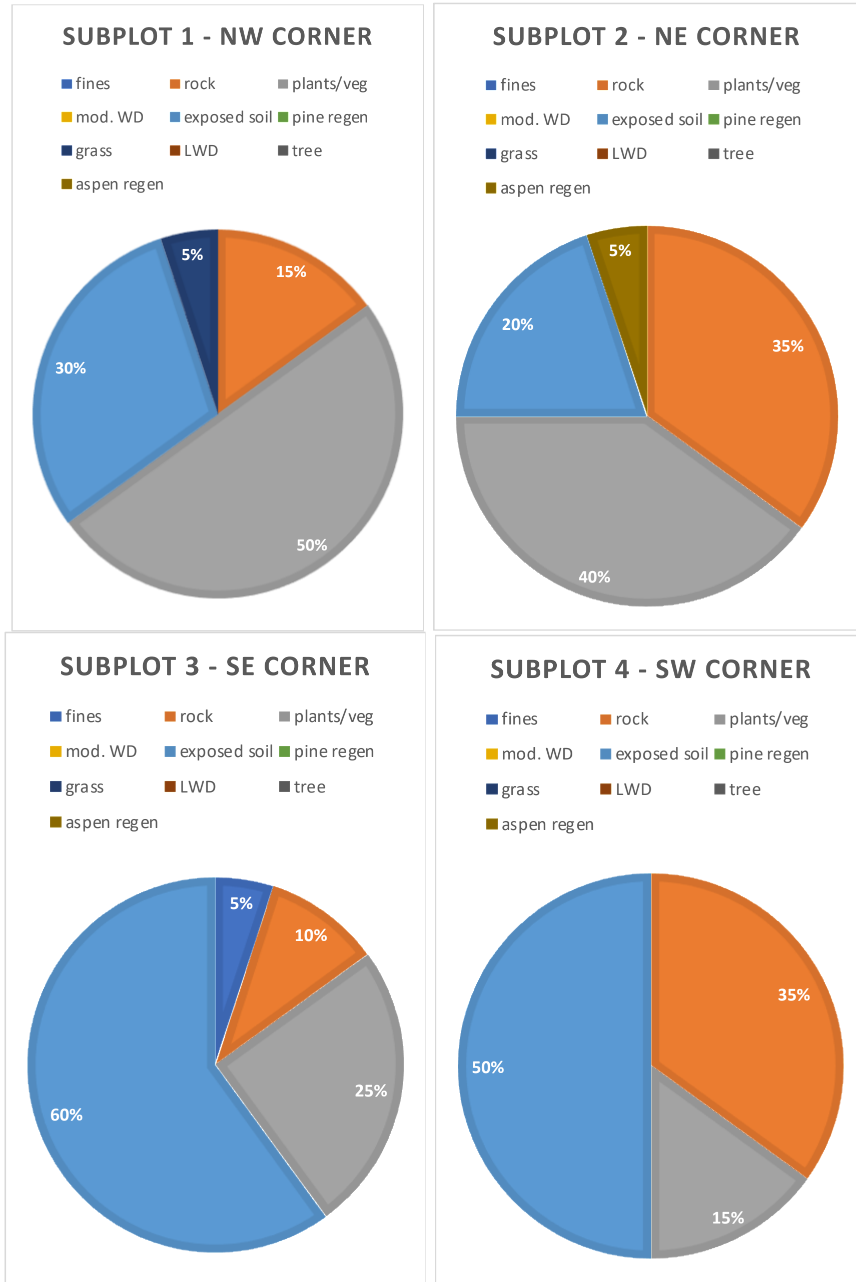

Figure 36. Pie charts of the ground cover composition within each subplot of plot 14

Plot 15 – High (BAER Class)

Table 32. Plot 15 Data

Plot 15	
Aspect:	255° W
Topographic Position:	Toeslope
Time:	1:45 PM
Date:	10/5/21
Elevation:	7920'
Slope:	25%
Forest Type:	Spruce-Fir (dry mixed conifer)
Canopy Cover:	5%
Canopy:	no needles remain (all burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High
Ground Cover Comp:	plants/veg. 40%
	LWD 5%
	rock 20%
	exposed soil 20%
	burned trees, standing 10%
	grasses 5%
BAER Class:	High

Table 33. Plot 15, subplot 1-4 ground cover composition data

Subplot 1 - NW Corner		Subplot 2 - NE Corner		Subplot 3 - SE Corner		Subplot 4 - SW Corner	
fines		fines		fines		fines	
rock	15%	rock	40%	rock	10%	rock	20%
plants/veg	50%	plants/veg	30%	plants/veg	40%	plants/veg	40%
mod. WD		mod. WD		mod. WD		mod. WD	5%
exposed soil	30%	exposed soil	25%	exposed soil	50%	exposed soil	20%
pine regen		pine regen		pine regen		pine regen	
grass	5%	grass	5%	grass		grass	15%
LWD		LWD		LWD		LWD	
tree		tree		tree		tree	
aspen regen		aspen regen		aspen regen		aspen regen	
Not Hydrophobic		Not Hydrophobic		Not Hydrophobic		Hydrophobic	

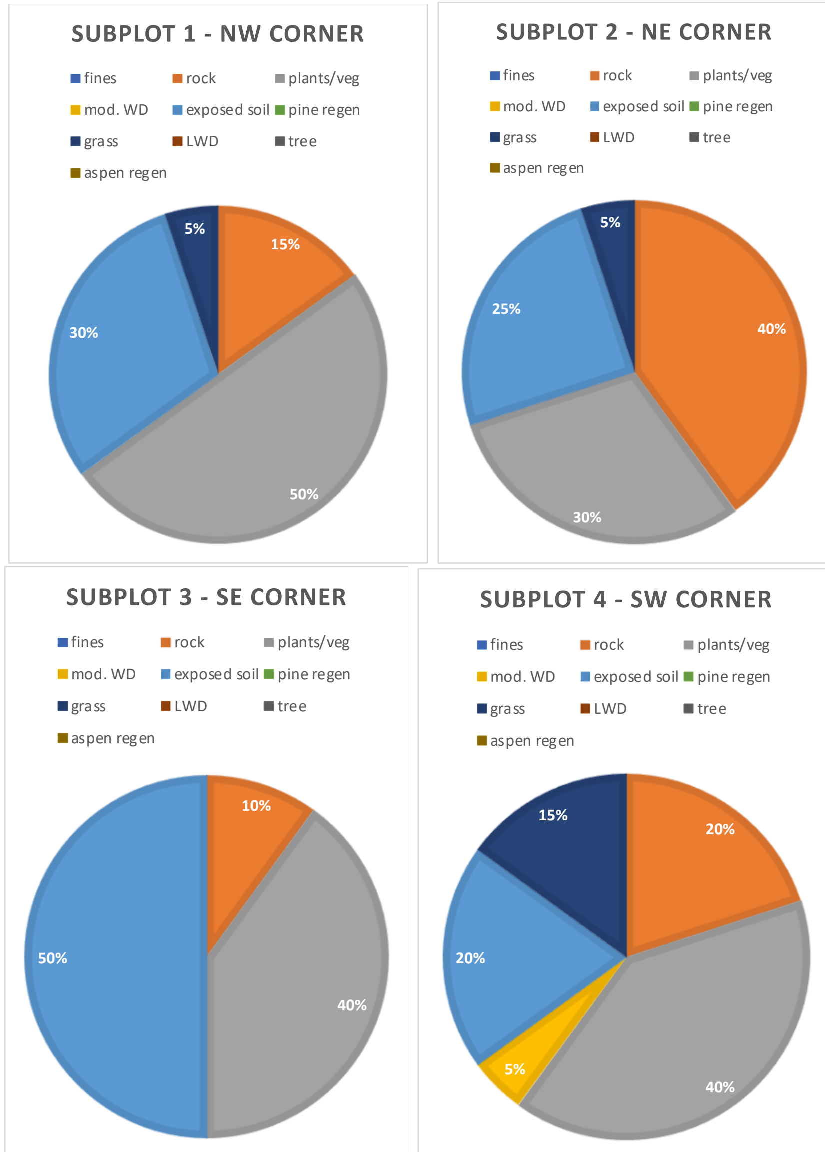

Figure 37. Pie charts of the ground cover composition within each subplot of plot 15

Plot 16 – High (BAER Class)

Table 34. Plot 16 Data

Plot 16	
Aspect:	296° NW
Topographic Position:	Midslope
Time:	2:00 PM
Date:	10/5/21
Elevation:	7940'
Slope:	35%
Forest Type:	Spruce-Fir (dry mixed conifer)
Canopy Cover:	0%
Canopy:	no needles remain (all burned)
Burn scars:	trees burned to canopy
Burn Intensity:	High
Ground Cover Comp:	plants/veg. 15%
	LWD 10%
	rock 15%
	exposed soil 25%
	burned trees, standing 15%
	fines <.5%
	grasses 5%
	aspen regen 15%
BAER Class:	High

Table 35. Plot 16, subplot 1-4 ground cover composition data

Subplot 1 - NW Corner		Subplot 2 - NE Corner		Subplot 3 - SE Corner		Subplot 4 - SW Corner	
fines		fines	5%	fines		fines	
rock	30%	rock	45%	rock	60%	rock	
plants/veg	10%	plants/veg	20%	plants/veg	20%	plants/veg	35%
mod. WD		mod. WD		mod. WD		mod. WD	
exposed soil	35%	exposed soil	25%	exposed soil	20%	exposed soil	50%
pine regen		pine regen		pine regen		pine regen	
grass	5%	grass		grass		grass	5%
LWD	5%	LWD		LWD		LWD	
tree	10%	tree		tree		tree	
aspen regen	5%	aspen regen	5%	aspen regen		aspen regen	10%
Not Hydrophobic		Not Hydrophobic		Not Hydrophobic		Not Hydrophobic	

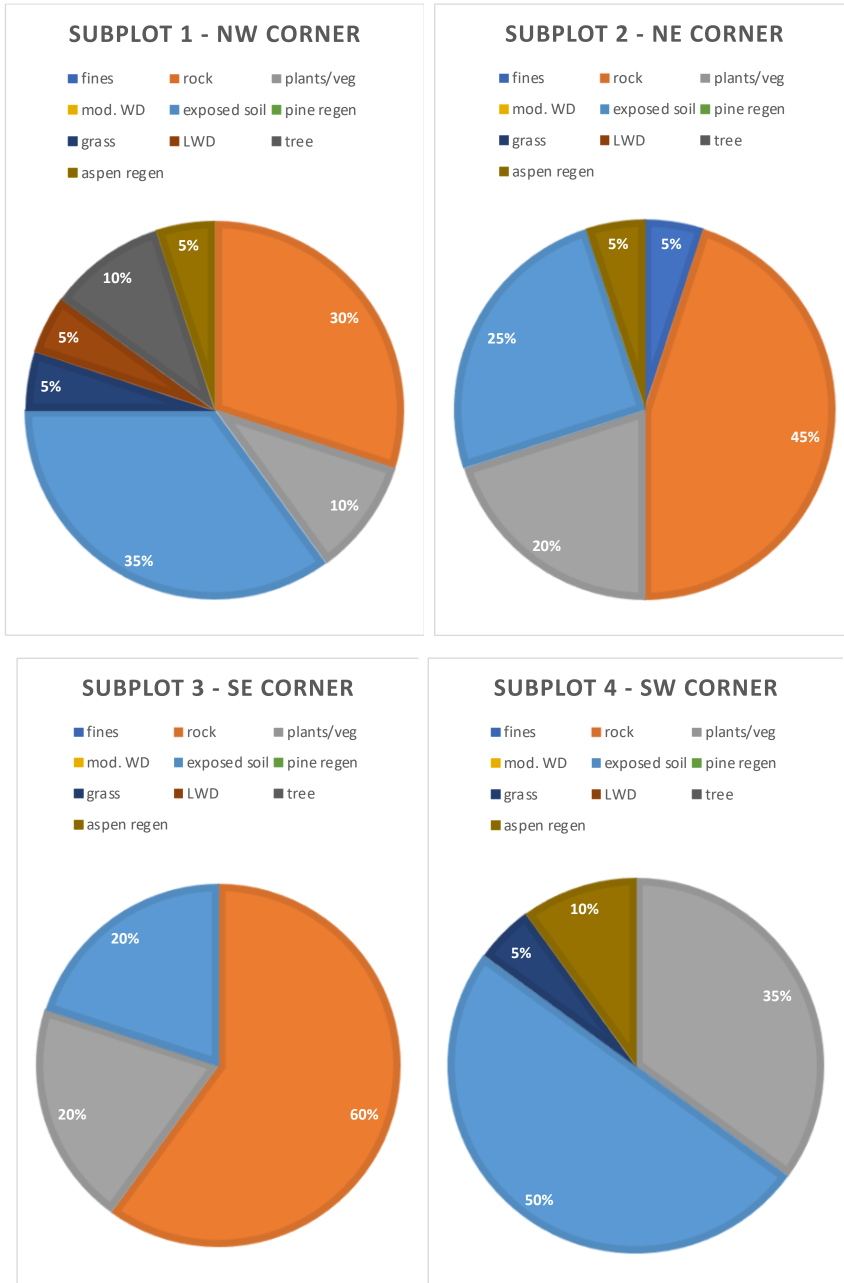

Figure 38. Pie charts of the ground cover composition within each subplot of plot 16