SIGNAL FIRE TREATMENT EFFECTIVENESS MONITORING

MONITORING SEEDING EFFECTIVENESS IN THE SOUTHWEST

U.S.D.A. FOREST SERVICE, REGION 3

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INTRODUCTION

Seeding was implemented on 1,525 acres of high and moderate soil burn severity areas on the Signal Fire in southwest New Mexico within the Gila National Forest. This report discusses the history of the burn, climate of the region, and methods and results from a 3 year treatment effectiveness monitoring study.

SIGNAL FIRE HISTORY AND BURN SEVERITY

The Signal Fire started on May 11th, 2014 as a result of a human caused ignition. The fire was located in southwestern New Mexico on the southern portion of the Gila National Forest approximately 10 miles northwest of Silver City, NM and was the result of a human caused ignition. The fire had burned approximately 4,700 acres by the evening of May 12th, 2014. A Burned Area Emergency Response (BAER) team was assembled on May 19th and the fire was contained (100%) on May 23rd, 2014 totaling 5,522 acres.

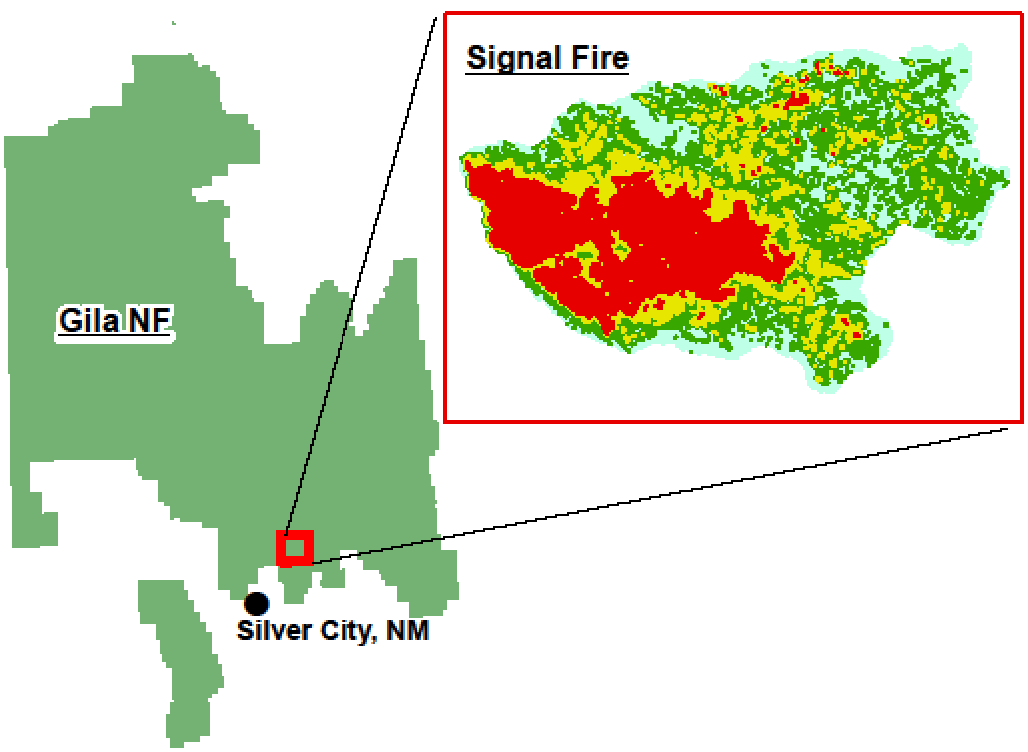

Figure 1. Signal Fire location map with burn severity.

The total high soil burn severity for the Signal Fire was 1,244 acres, with 65% of these acres occurring on steep slopes over 40%. The moderate soil burn severity was 697 acres and the low and unburned soil burn severity totaled 3,581 acres. Soil burn severity classes indicate the ecosystems response to different structural and below ground characteristics based on the intensity and severity of the fire. High soil burn severity is usually associated with complete consumption of both canopy and ground fuels and can result in gray to white ash 1-3 cm thick, often leaving minimal effective ground cover. The vegetation types within the Signal Fire associated with high soil burn severity were in the mixed conifer and ponderosa pine ecosystems. These systems have thicker litter layers as compared to woodland types and generally have more coarse woody material which has the potential to increase fire intensity, severity and residence times. Longer residence times can result in the formation of water repellent layers, charring of roots beneath the surface and destruction of soil structure.

Water repellency is when water cannot easily penetrate the soil and causes the water to bead on the surface. This can happen when the soil is heated to a specific temperature during a fire and organic compounds are volatilized and then accumulate through condensation within the soil where the temperature is slightly cooler. Water repellent layers can also be formed during periods of drought when decaying organic matter becomes dry, from specific plant exudates, or from microbial by-products (Neary et. al, 2005). Water repellency can be short term or long term and can depend on how long and how often water stays in contact with the soil. When water is unable to penetrate into the soil; it increases the potential for erosion to occur. When water repellency (either fire induced or through other causes such as prolonged drought) is combined with little effective cover in which to mitigate rain drop impacts; soil erosion can greatly increase. When rain drops impact the soil surface, they can loosen and disperse fine soil particles and start the process of erosion (Neary et. al, 2005). Effective ground cover like litter, rock fragments, basal area and cryptogams absorb the energy of rain drops and increase surface roughness which can slow water movement downslope. Canopy cover also provides a barrier for rain drop impact. The degree of water saturation of the soil prior to a precipitation event (antecedent soil moisture) can also influence water movement through the soil and has the potential to increase overland flow and soil erosion through sheet, rill or gully formation.

Soil erosion is a natural process, but when certain thresholds are reached the amount of soil lost can have long term impacts on the landscape due to the interconnected relationship between soil and other ecosystem components. Pedogenesis is the process of soil formation; involving the interaction between parent material, topography, climate and organisms throughout time and space. Specific types of parent materials or rocks and their associated minerals are weathered over time to develop soil. These materials can include recent wind (aeolian) or river deposits (alluvium), material that has moved downslope (colluvium), or older consolidated deposits like those formed from dormant volcanoes or brought to the surface from tectonic activity (residuum). The type of parent material influences the kind of soil formed and the inherent susceptibility to erosion.

Topography of the landscape is another major influence. The elevation of the landscape or the orographic effect of mountain ranges influence temperature and precipitation on the landscape. The shape and steepness of the slope influences how quickly and where water and sediment moves or collects on the landscape. Topography influences air current flow through the system which effects temperature and moisture content of the site. Aspect influences the amount of direct solar radiation a site receives, southern aspects receive more direct solar radiation while northern aspects receive less direct solar radiation. The northern aspects tend to be cooler and retain moisture longer as compared to southern aspects.

Climate is another major soil forming factor. The average annual changes in temperature and the amount, timing and type of precipitation a region receives influences how long and what type of soil may form in that region. Precipitation influences the development and movement of organic residues left by decaying plant matter and inorganic compounds like clay and calcium carbonate through the soil profile. Ranges in temperature affect freeze-thaw cycles which help physically breakdown rocks. Temperature and precipitation affect the amount and kind of organisms that can live in or on that landscape. Organisms include microorganisms, vegetation and animals. Vegetation can influence the physical structure of the soil by growing roots which benefits soil stability and by adding or subtracting chemical components. Symbiotic relationships with mycorrhiza increase the surface area roots are in contact with the soil and the chemical exchanges within the soil profile. Time is an important factor in soil formation. It can take at least 100 years to form 1 inch of soil and could even take thousands of years depending on all the above factors and disturbances which change the components of the ecosystem (NRCS, 2015). Soil is therefore “non-renewable” at least within the context of a single human lifespan if not that of generations of people in certain landscapes.

REGIONAL CLIMATE AND TOPOGRAPHY

Elevations on the Signal Fire range from 2095 to 2740 meters. Mean annual precipitation of the resource area ranges from 25-35 inches and mean annual air temperature ranges from 34-59^{o}F (PRISM). Precipitation in southwestern New Mexico is characterized by summer monsoonal rain which can be characterized by high intensity, short duration precipitation events. The monsoon season generally begins in late June to early July and lasts through September. The onset of monsoon season is defined by the Southwest Area Wildland Fire Predictive Service as the time period when the minimum relative humidity consistently stays above 20% for five or more days a week (SWCC, 2014). The spring time is generally dry and windy with scattered rain events. Fire season is generally during late spring to early summer before the monsoon has strongly developed. Conditions are normally dry and lightning caused fires are common with the potential to stay active until the monsoon has set and enough precipitation has accumulated to mitigate and suppress fires. There is a very short window between the time a fire starts and when the majority of precipitation for the region will fall, especially in lower elevations. Lower elevations receive most of the mean annual precipitation during April through September. Higher elevations will receive more precipitation in the form of snowfall from October through March, but still experience the short high intensity rainfall events of the monsoon. These higher elevations are where mixed conifer and spruce fir forests are found.

The southwest in general has been experiencing drought conditions. The Climatic Division of National Oceanic and Atmospheric Administration (NOAA) produces standard precipitation and drought indices using the National Weather Service (NWS) Cooperative Observing (COOP) program weather station network, National Interagency Fire Center (NIFC) Remote Automatic Weather Stations (RAWS) network and the USDA Snow Telemetry (SNOTEL) network. The Palmer Hydrological Drought Index (PHDI) is a monthly index that indicates the severity of a wet or dry period. It is based on moisture supply and demand and does not factor in man-made changes such as increased irrigation, new reservoirs and added industrial water use into the computation (NCDC, 2015). Negative values indicate drought and positive values indicate wetter conditions. Figure 2 is a summary for New Mexico's southwestern mountain region for the PHDI since 1982 (summarized from data downloaded from NCDC, 2015).

In general the southwestern mountains in New Mexico have been on a drying trend since a wetter period of time in the 1980's and again in the 1990's with sporadic periods of wetness and drought. The past 4 years or so have been particularly dry and conditions of extreme drought have developed. During this time the Gila National Forest has experienced some of the largest wildfires in recent history, the Whitewater-Baldy being the largest fire to date in New Mexico at 290,000 acres. Figure 3 shows the PDHI focused over the past 5 years within New Mexico's southwestern mountains and other large fires in that time period (summarized from data downloaded from NCDC, 2015).

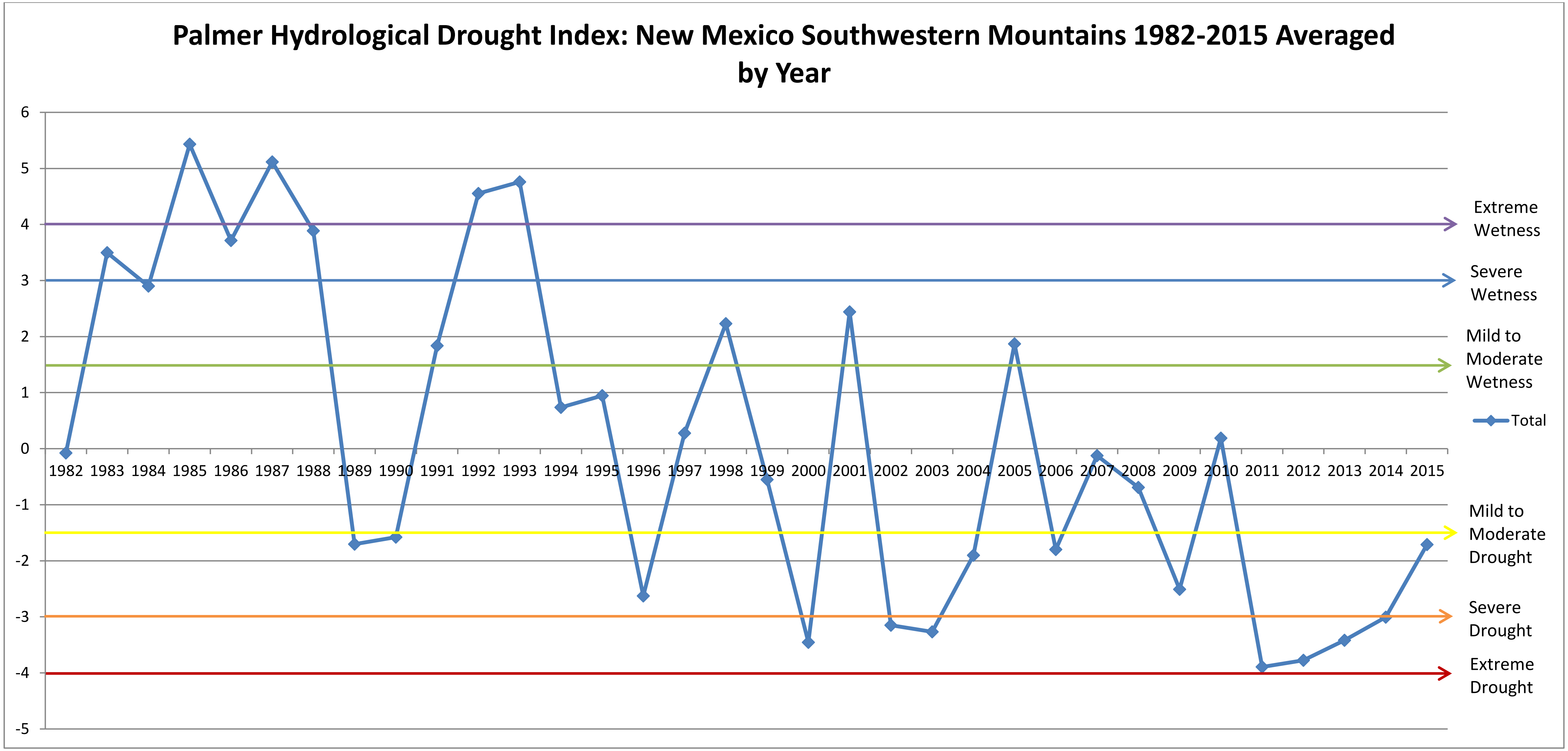

Figure 2: Palmer Hydrological Drought Index for New Mexico southwestern mountains averaged by year from 1982 to 2015. Negative numbers are drought and positive numbers are periods of wetness (summarized from data downloaded from NCDC, 2015).

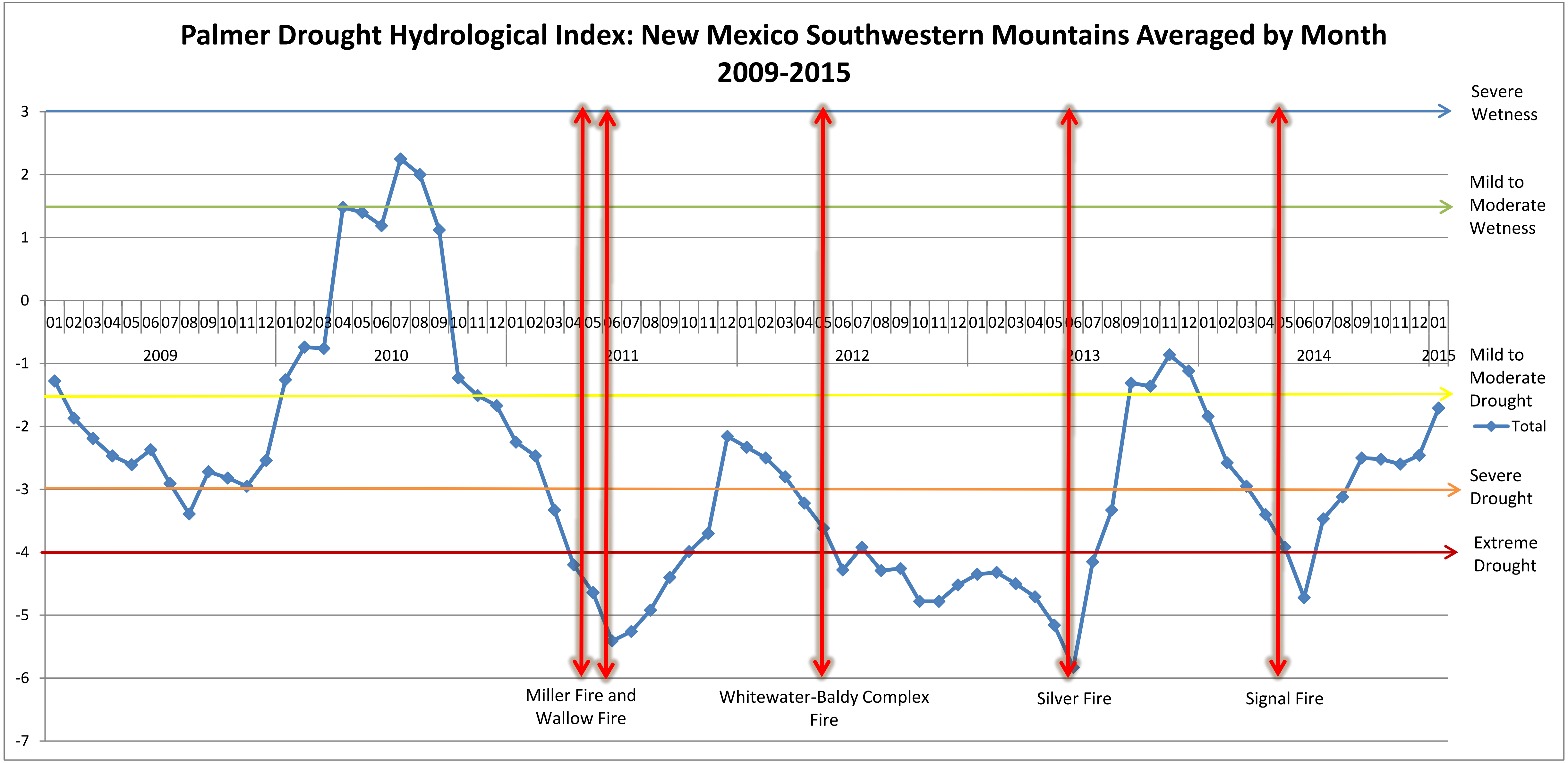

Figure 3: Palmer Hydrological Drought Index for New Mexico southwestern mountains averaged by year from 2009 to 2015 with recent Gila National Forest Fire history.

BURNED AREA EMERGENCY RESPONSE (BAER)

The BAER assessment for the Signal Fire was started on May 14th and completed May 24th. Critical values at risk must be determined, the probability and magnitude of consequences of potential damage are considered, and appropriate actions to manage unacceptable risks must be taken quickly. Treatments must be implemented timely, be effective in reducing risk, they must be practical and technically feasible and need to consider the cost of alternatives. Treatments must be in place before the first damaging storm.

Aerial seeding operations for the Signal Fire began on July 9th, 2014. The seed mix was a combination of native perennial grass seeds and annual barley seed which was certified weed-free. The annual barley is quick growing while the native perennial grasses take longer to establish and provide canopy cover. The annual barley and native seeds are more likely to establish if there is sufficient soil moisture, which is more probable at the mixed conifer elevation and at some lower elevations on northern aspects during and after a normal monsoon season. Once the grass is established it can provide substantial canopy cover which reduces rain drop impact and through root retention provides stability to the soil. The fibrous root structure can increase water infiltration and hold soil in place (Robichaud et. al, 2000). Annual cereal grains are generally inexpensive and readily available in large quantities, but questions remain as to how long annual cereal grains persist on the landscape and whether these grasses or seeding in general delays the recovery of native flora (Robichaud et. al, 2000). Winter temperatures at higher elevations in the mixed conifer life zone can get low enough to kill off the annual cereal grains and resulting snow pack can flatten the senescent grass and create mulch for the following year which can lessen rain drop impact and erosion. Table 1 gives a detailed description of the Signal Fire grass seed mix used for aerial seeding and the approximate seeding application rate.

Species	Planting Rate (pounds/acre)	Seeds per Square Feet
Barley (*Hordeum vulgare*)	41.80	12.00
Prairie junegrass (*Koeleria macrantha*)	0.09	5.00
Muttongrass (*Poa fendleriana*)	0.25	5.00
Mountain brome (*Bromus marginatus*)	3.40	5.00
Bottlebrush squirreltail (*Elymus elymoides*)	0.23	1.00
Total	**45.77**	**28.00**

Table 1: Grass seed mix for Signal Fire treatment.

There are two kinds of BAER treatment monitoring, one is focused on implementation and the other is for effectiveness. One of the objectives from the BAER assessment was to perform effectiveness monitoring for aerial seeding. This is done to determine if the aerial seeding treatment is functioning as planned and if it is meeting specific emergency objectives. Aerial seeding was done for the Signal Fire to reduce soil erosion and lessen the impact on soil productivity and hydrologic function, decrease risk to infrastructure including roads and to decrease risk to human life and safety as people travel these roads and trails. Post-fire areas with steep slopes, high severity burns and little effective ground cover have increased probability of mass movement or large erosional events which can cause substantial damage. Aerial seeding was implemented to reduce erosion and the potential impacts to critical resources. This monitoring project will focus on impacts to soil productivity and hydrologic function. The monitoring was done at the level II scale which is quantitative and appropriate for the forest or regional scale. This monitoring project spanned 3 years. The purpose of this monitoring is to share the results of the effectiveness of aerial seeding for the greater southwest area where it would be most applicable.

OBJECTIVES

The main focus of this study is to provide information pertaining to seeding effectiveness as it relates to post fire erosion rates in the southwest and to present these results in order to improve decision making within the BAER program.

- To determine the persistence of annual barley
- To determine if this treatment introduces invasive species
- To determine if this treatment delays or has a negative effect on natural recovery and diversity
- To determine how effective seeding is in increasing vegetative ground cover
- To determine if this treatment reduces erosion rates
- To determine the effect that post fire seeding has on maintenance of site/soil productivity

METHODS

DETERMINATION OF MONITORING PLOT LOCATIONS

Monitoring plots for the Signal Fire were established in locations that minimized the natural variability in the landscape in order to better compare treated (seeded) areas with those that were untreated. Draft Terrestrial Ecological Unit Inventory (TEUI) data, burn severity class, geologic maps, topographic contours and digital elevation model derivatives; slope, aspect and elevation were used to identify similar locations that would also provide reasonable access in order to establish and monitor the plots over a 3 year period. TEUI draft map unit 569 was determined to be a suitable map unit for the study plot locations. This map unit is comprised of Douglas fir (*Pseudotsuga menziesii)*, Ponderosa pine (*Pinus ponderosa var. scopulorum)* and Gambel oak (*Quercus gambelii)* on 40-80% slopes with moderately deep to deep, darker colored and relatively productive (mollic), sometimes rocky with lighter textured (loamy-skeletal to fine-loamy) soils formed in basalt, basaltic andesite or andesite parent material. There was one TEUI transect and one ecological site description within the Signal Fire perimeter that had data collected prior to the fire within map unit 569. Appendix A is a summary of species richness and relative abundance collected before the Signal Fire from map unit 569 site and transect data within the fire perimeter. Ground cover ranges and soil family phase information are listed from the site and transect data in Tables 2 and 3 below.

Ground Cover	Percent Cover Range
Total Basal Area	3 – 8
Litter	55 – 85
Bare Soil	1 – 10
Total Rock Fragments	5 – 40
Rock Outcrop	0 – 6

Table 2: Pre-Signal Fire range in percent ground cover from draft TEUI site and transect data in map unit 569 near Signal Peak.

Soil Family Phase
Pachic Argiudolls, HSC, 6, -1, fine-loamy, mixed, superactive, frigid, moderately deep, loam
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Pachic Argiudolls, HSC, 6, -1, loamy-skeletal, mixed, superactive, frigid, moderately deep, very gravelly loam
Pachic Argiudolls, HSC, 6, -1, loamy-skeletal, mixed, superactive, frigid, deep, gravelly loam
Pachic Hapludolls, HSC, 6, -1, loamy-skeletal, mixed, superactive, frigid, moderately deep, loam
Pachic Hapludolls, HSC, 6, -1, loamy-skeletal, mixed, superactive, frigid, moderately deep, loam
Rock Outcrop

Table 3: Soil family phase and miscellaneous areas from draft site and transect data in map unit 569 near Signal Peak.

Both monitoring plots were established within map unit 569 and the high soil burn severity class. Figure 4 depicts the location of the monitoring plots, draft TEUI map unit polygons, site and transect locations for map unit 569, and the soil burn severity classes for the Signal Fire.

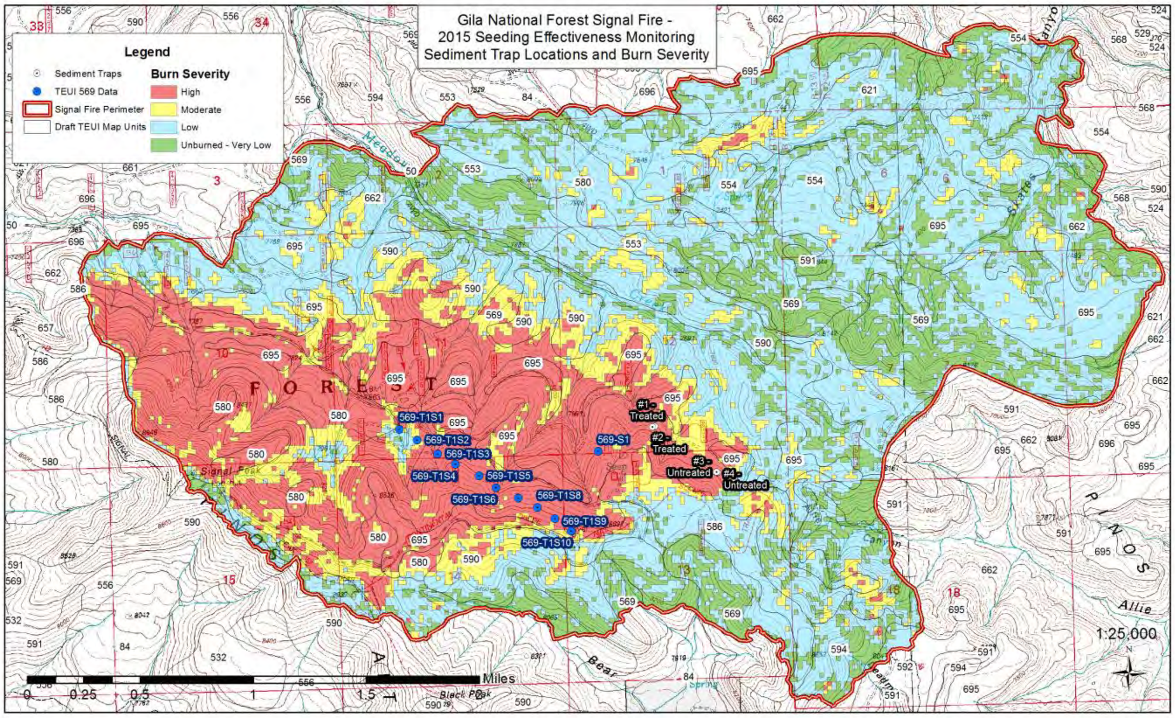

Figure 4: Signal Fire burn severity map, location of TEUI draft 569 map unit data and location of monitoring plots.

Within the Signal Fire burn perimeter faulting and intermingled layers of lithology are common. The upper elevation northerly aspects in the high severity burn tend to be over 40% gradient, but there are small benches of less than 40% within these aspects. There are two such benches approximately 30 meters upslope from each monitoring plot. These act as a natural slope break (along with felled logs) and help to define the contributing erosional area of the monitoring plots. There is a change in lithology as you move upslope. The geology of the area was determined using USGS "Geologic Map of the Twin Sisters Quadrangle, Grant County, New Mexico" (Finnell, 1976). The summit directly above the monitoring plots is listed as "Tbaa", which is described as porphyritic basaltic andesite. Just below the summit is a small delineation of "Tgra", which is described as arkosic sandstone grading to conglomerate. The monitoring plots were established just below the thin delineation of "Tgra" and are within the "Ttu" formation which is listed as non-welded and welded ash flow tuffs (upper member). The parent material for both plots is colluvial basaltic andesite over residuum derived from ash-flow tuff.

Figures 5, 6 and 7 depict digital elevation model (DEM) derivatives; percent slope, aspect and elevation along with locations of the monitoring plots. The TEUI draft data, burn severity, geologic formations and DEM derivatives determined the general location of the monitoring plots. Field verification was done to refine exact elevation, percent slope, aspect, surface rock fragments, burn severity class, and determination of slope shape and length.

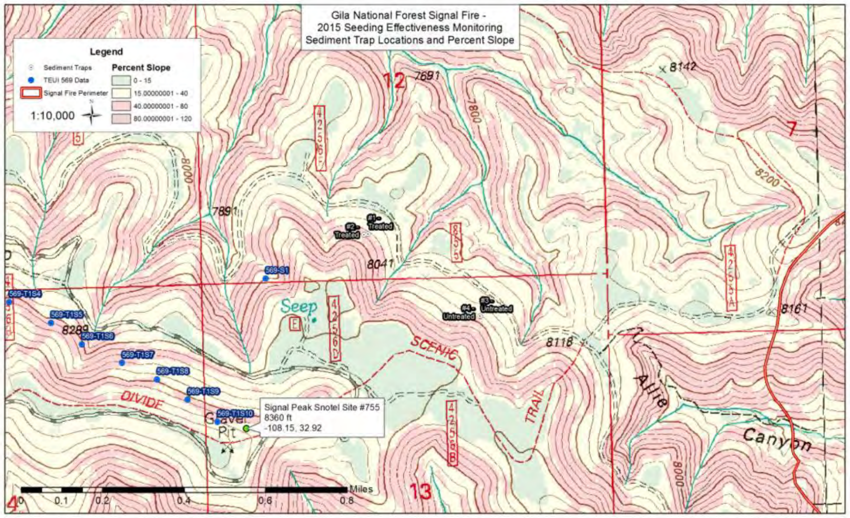

Figure 5: Monitoring plot locations with percent slope.

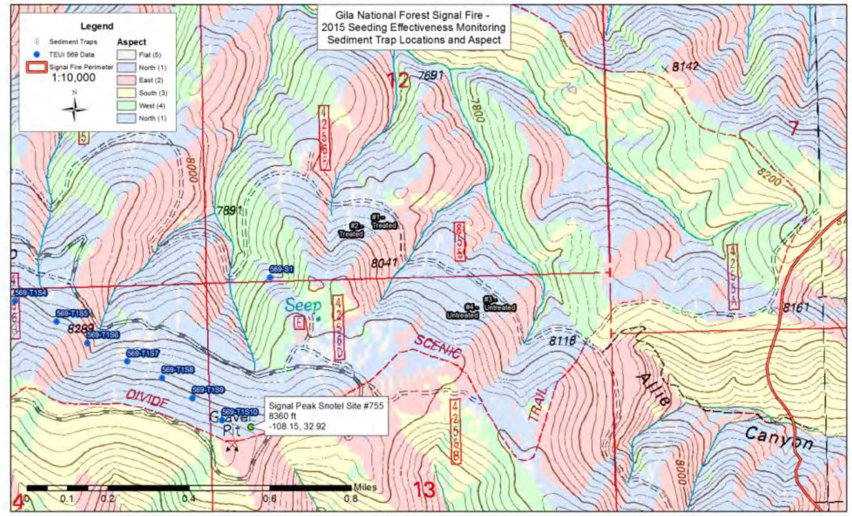

Figure 6: Monitoring plot locations with aspect.

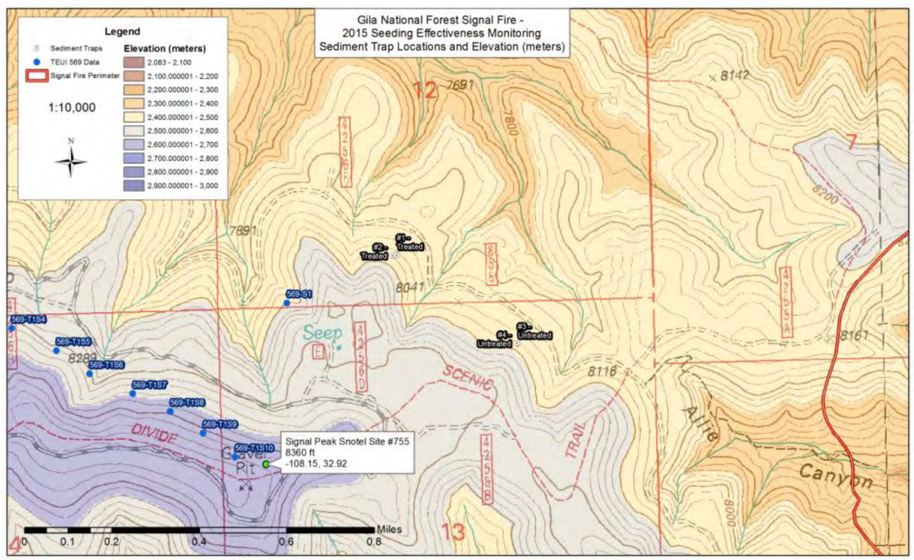

Figure 7: Monitoring plot locations with digital elevation in meters.

GROUND COVER AND CANOPY COVER METHODS

Further characterization of the monitoring plots was conducted during field visits by establishing permanent cover frequency analytical plots, ocular macroplots, and photo points. The soil and general site characteristics; percent slope, aspect, elevation, slope shape, slope length, climate class, location, geomorphology, parent material and geologic formation were assessed using the front side of the TEUI ecological site description form (Appendix B is an example of the site description form). The soil profile was located and described downslope from the sediment trap locations so as not to influence sediment delivery within the plot. This is not a permanent plot and was only described to determine soil profile characteristics. A permanent ocular macroplot was established within the center of each monitoring plot and marked with a stake. This plot was established to account for species not identified in the cover frequency analytical plots. Photo points were taken directly above each ocular macroplot center stake throughout the 3 year monitoring project.

Surface components were estimated using a cover frequency analytical plot which provides a measure of species abundance, composition by cover and frequency (USDA FS, 2008). This method is repeatable and a statistically rigorous way to detect change (USDA FS, 2008). On each treatment type, two permanent cover frequency transects were established, each 25 meters long and 15 meters apart from one another. Permanent transect starting and ending points were marked with stakes. Data was collected along a transect (measuring tape) and both vegetative canopy cover by species and ground cover components were measured at 1 meter intervals within a frame (.10 m^2). The initial cover frequency measurements were made before seeding operations on May 28th, 2014. Table 4 summarizes data from the initial site description macroplot (soil and general site characteristics) and the cover frequency plot canopy cover (initial canopy cover values were null due to complete consumption) and ground cover characteristics for both treatments.

Parameters	Treated (Seeded) Plot	Untreated Plot
Elevation (meters)	2476	2490
Aspect (degrees)	32	30
Percent Slope	50	50
Horizontal Slope Shape	Linear	Linear
Vertical Slope Shape	Linear	Linear
Slope Length (meters)	40	40
Parent Material	COLL BAAN/RESI TUFF	COLL BAAN/RESI TUFF
Geomorphology	Tectonic, Fault Block, Hillslope	Tectonic, Fault Block, Hillslope
Soil Family Phase	Pachic Argiudolls, clayey-skeletal*, mixed, superactive, frigid, deep, very gravelly sandy clay loam	Pachic Argiudolls, clayey-skeletal*, mixed, superactive, frigid, deep, gravelly sandy loam
NAD 83 UTM 12N coordinates	3646790 N 767001 E	3646448 N 767455 E

Parameters	Treated (Seeded) Plot	Untreated Plot
Mean Annual Precipitation PRISM (cm)	73.6	73.6
Calculated (cm)	69.3	71.0
Climate Class	HSC 6,-1	HSC 6,-1
Burn Severity Class	High	High
	Ground Cover (%)	
Bare Soil	**76**	**87**
Litter (> 1.25 cm thick)	**2**	**0.9**
Total Basal Area	**0.5**	**0.3**
Forb Basal Area	-	-
Graminoid Basal Area	-	-
Shrub Basal Area	-	0.1
Tree Basal Area	0.5	0.2
Total Surface Fragments	**21**	**12**
Fine Gravels (0.2 – 0.5 cm)	10	5
Medium Gravels (0.5 – 2.0 cm)	4	3
Coarse Gravels (2.0 – 7.5 cm)	4	3
Cobbles (7.5 – 25.0 cm)	2	1
Stones (25.0 – 60.0 cm)	1	-
Boulders (> 60 cm)	-	-
Rock Outcrop	**-**	**-**
Cryptogams	**-**	**-**

Table 4: Monitoring plot initial components for treated and untreated plots. Values are rounded.

* "clayey-skeletal": the weighted-average clay in the particle-size control section for both the treated and untreated was 34.7%. Both of these values round up to 35% which classifies these soils into the clayey-skeletal particle size class, but they are borderline loamy-skeletal.

PRODUCTION ESTIMATES AND SPECIES RICHNESS

Production estimates were collected for graminoid and forb cover on both treatments. Each monitoring plot had ten 0.96 square foot circular plots clipped for production data during the fall when most grasses are in their mature stage and have set seed. The clipped vegetation was separated by forb or graminoid and bagged by sample plot. Each sample bag was dried and weighed. Production is reported in dry weight pounds per acre.

SILT FENCE CONSTRUCTION AND RAIN GAUGE INSTALLATION

Silt fences were installed and cleaned out prior to seeding operations. Each treatment had two silt fences constructed. Two large diameter standing dead trees were cut and felled parallel to the slope contours on each monitoring plot. These cross-felled logs established the beginning point for the contributing area to each silt fence. After the trees were secured in place a trench was dug upslope and silt cloth was installed to make a seal between the trench and the upslope side of the log. The trench, silt cloth and log would catch sediment from further upslope and prevent this sediment from contributing to the silt fence below. The trench was cleaned out periodically throughout the project. Each monitoring plot had two silt fences installed. One silt fence was 66 feet downslope of a felled log and one silt fence was 80 feet downslope of a separate felled log on each treatment type. Each silt fence was 10 feet wide parallel to the slope, approximately 3 feet tall and 5 feet long perpendicular to the slope.   The silt fences were cleaned out at the end of each growing season (October). The sediment was weighed and summed by silt fence number. The soil was dried and the water content was estimated to determine the dry weight of sediment. Precipitation events occurred prior to seeding operations which resulted in sediment accumulating in the silt fences. This sediment was removed prior to the seeding operation. Table 5 lists the labels and dimensions of each silt fence.

Photo 1: Final installation of silt fence on Signal Fire monitoring plots.

Silt Fence (#/treatment type)	Width (feet)	Slope Length (feet)	Contributing Area (square feet)
1 (treated)	10	66	660
2 (treated)	10	80	800
3 (untreated)	10	66	660
4 (untreated)	10	80	800

Table 5: Labels and dimensions of silt fences for Signal Fire monitoring project.

One tipping bucket rain gauge was installed at each treatment type. Before installation, each tipping bucket rain gauge was field calibrated with a controlled flow of water through the tipping-bucket mechanism. The calibration accuracy is reported to be plus or minus 1 percent (Onset, 2001). The rain gauges were located in an area that was clear and unobstructed by standing dead trees. Each rain gauge is equipped with a HOBO event data logger that is used to download data. Data was imported into the Onset BoxCar Pro 4 software and analyzed in Microsoft Excel.

RESULTS

PRECIPITATION

Data collected from the tipping bucket rain gauges was summarized for each monitoring plot. Precipitation data was collected from June 30th, 2014 through October 17th, 2016. The total precipitation by treatment area and precipitation by monitoring year is shown below in Table 6.

Monitoring Plot	Total Precipitation (inches)
Treated	**57.57**
2014	14.73
2015	22.21
2016	20.63
Untreated	**51.04**
2014	13.99
2015	20.68
2016	16.37

Table 6: Tipping bucket rain gauge data for Signal Fire monitoring plots.

The monitoring plots are located in close proximity (<.5 miles), however localized rain events created differences in total precipitation. The treated plots received more total precipitation (6.53 inches) over the course of the monitoring study. Monsoonal storms can be extremely localized in the southwest and this was apparent when comparing the total monsoonal precipitation each plot received and the frequency of events. The treated plots received more monsoonal rain (July-September) than the untreated plots (Figure 8). The total monsoonal precipitation for the treated plot was 38.21 inches while the untreated plot received 33.66 inches. Significant storm events (>.5 in/hr.) were compared between treatment areas (Figure 9 and 10). The treated area received more total significant storm events (10) than the untreated area (8) over the 3 year monitoring period. Significant storm events have the potential to produce more erosion due to the intensity of rainfall.

Photo 2: Tipping bucket rain gauge installed at each monitoring site.

Photo 3: Tipping bucket rain gauge with data logger.

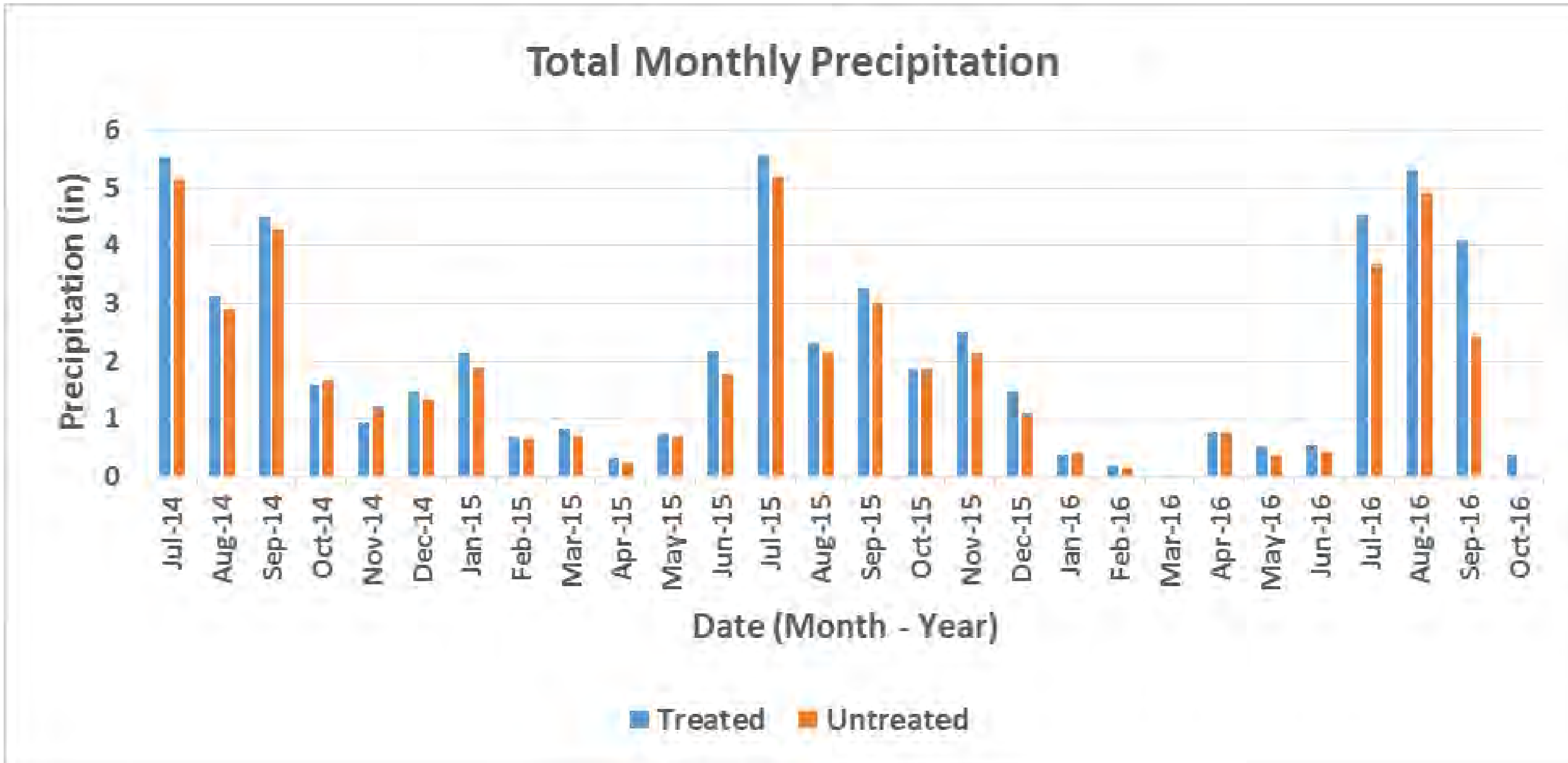

Figure 8: Total precipitation in inches for treated and untreated monitoring plots (June 30th, 2014 through October 17th, 2016). Monsoonal months July – September.

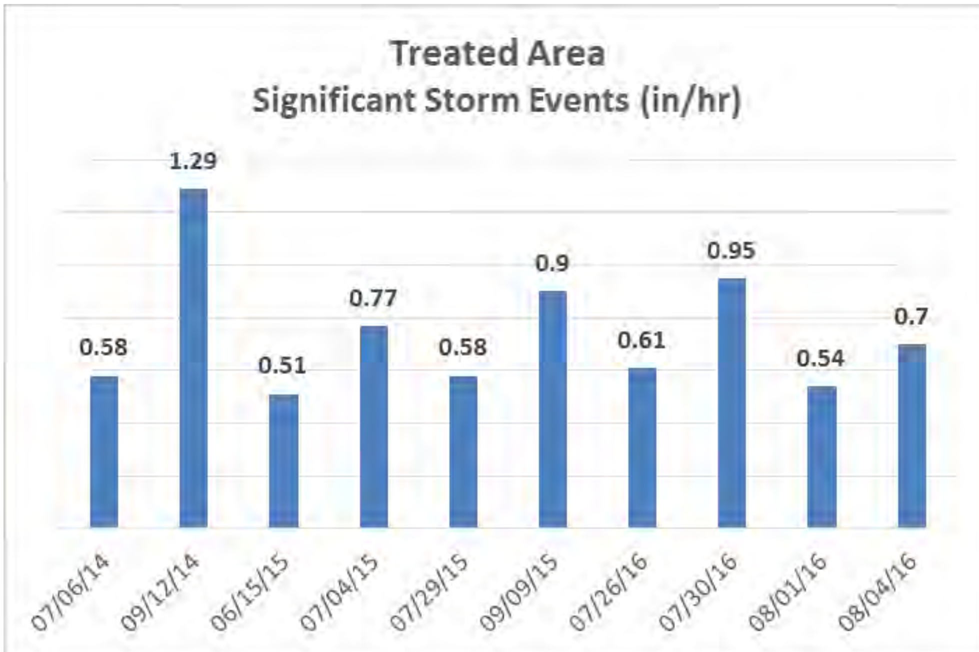

Figure 9: Significant storm events within treated area during the 3 year monitoring period. Reported in (in/hr.).

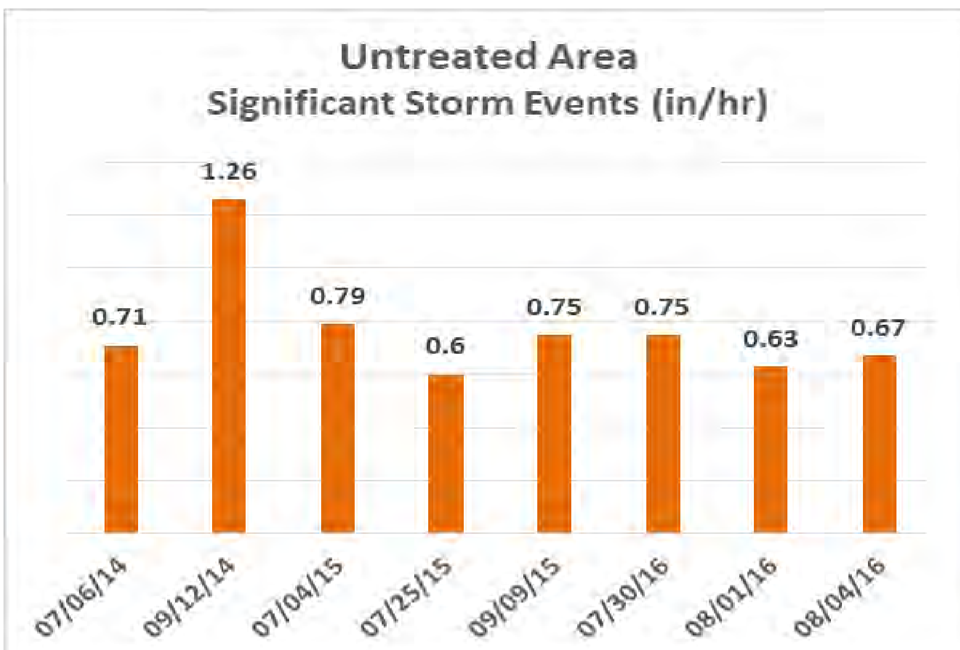

Figure 10: Significant storm events within untreated area during the 3 year monitoring period. Reported in (in/hr.).

COVER FREQUENCY ANALYTICAL PLOT

The initial cover frequency analytical plots were recorded for both treated and untreated monitoring plots on May 28th, 2014 before any storm events had occurred or treatments implemented. These were completed to provide baseline data of conditions immediately post-fire. The cover frequency analytical plots were recorded again annually at the end of the growing season during October.

GROUND COVER

Table 7 summarizes ground cover components for both treatments from the initial assessment through the final 2016 assessment.

Initial (2014)

Most of the litter recorded was comprised of charred coarse woody material that had not been completely consumed and was left after the fire including fallen trees. Basal area was comprised of standing dead trees and burned shrubs. Ash was still present in the initial assessment and was counted as bare soil. Baseline data indicated the treated site had slightly more basal area, litter, total rock fragments, but less bare soil.

2014

Basal area now included graminoids, forbs and exposed roots. A majority of the basal area increase was due to the barley (*Hordeum vulgare*) on the treated plots. Litter was still comprised of charred coarse woody material and fallen trees. The amount of litter was very similar across both treatment types. Total rock fragments increased on both treatment types with the treated at 30% and untreated at 28%. Cryptogams started to establish by this point and were more prominent on the treated monitoring plot. Bare soil decreased in both treatment plots with the treated area having slightly less.

2015

Basal area, litter, total rock fragments and cryptogams were all higher in the treated area as compared to the untreated area. Bare soil was more than double in the untreated type. Litter was approximately 5 times more and cryptogams were almost 6 times more in the treated area. Total rock fragments were double the amount in the treated area as compared to the untreated type.

2016

In the final monitoring year of this study the treated site had similar basal area, more than 6 times the amount of litter, similar total rock fragments and approximately 3 times the amount of cryptogams when compared to the untreated area. Bare soil was more than double in the untreated type compared to the treated type.

Ground Cover	Untreated Monitoring Plot Ground Cover Values (%)				Treated Monitoring Plot Ground Cover Values (%)			
	Initial	**2014**	**2015**	**2016**	**Initial**	**2014**	**2015**	**2016**
Total Rock Fragments	12	28	10	19	21	30	21	19
Fine Gravels (0.2-0.5 cm)	5	13	1	5	10	15	5	4
Medium Gravels (0.5-2.0 cm)	3	6	4	8	4	6	3	5
Coarse Gravels (2.0-7.5 cm)	3	8	4	5	4	7	10	6
Cobbles (7.5-25.0 cm)	1	1	1	1	2	2	2	3
Stones (25.0-60.0 cm)	-	-	-	-	1	.5	1	1
Boulders (> 60 cm)	-	-	-	-	-	-	-	-
Basal Area	.3	1	3	7	.5	2	4	8
Tree/shrub (standing dead)	.3	.95	2	5	.5	.1	1	.05
Graminoid	-	.05	.5	1	-	2	3	8
Forb	-	T	.5	1	-	T	.05	.08
Litter *	.9	3	6	5	2	3	29	29
Cryptogams	-	-	2	7	-	1	13	19
Bare Soil	87	68	79	63	76	63	34	28

Table 7: Total percent ground cover values for treated and untreated monitoring plots.

T = Trace amount *Litter is effective litter; >1.25 cm thick and includes charred CWM of this thickness.

SPECIES RICHNESS

2014

The total number of species of shrubs on the treated monitoring plot was twice that of the untreated. The total number of forbs was similar across both treatment areas with 17 species identified on the treated plot and 18 species on the untreated plot. The total number of graminoid species observed on the treated plot was five compared with three on the untreated plot. Perennial grasses were just starting to emerge making it difficult to identify at the time. See Table 8 for 2014 vegetative lifeform canopy cover values by treatment type. Cover frequency data from the treated area indicated Annual barley (*Hordeum vulgare*), New Mexico locust (*Robinia neomexicana*) and Gambel oak (*Quercus gambelii)* were the most abundant species by canopy cover with values of 41%, 3% and 3% respectively. Data from the untreated area indicated American vetch (*Vicia Americana*), Woodsorrel (Oxalis sp.), and an unknown graminoid were the most abundant species by canopy cover with values of 1%, 1% and .5%

respectively. The total canopy cover for all species on the treated plot was 49% while the total canopy cover for the untreated plot was 5%.

Lifeform	Untreated Plot Values (%)	Treated Plot Values (%)
Shrub	.2	6
Forb	3	1
Graminoid	2	42

Table 8. 2014 vegetative lifeform canopy covers by treatment type. Values rounded.

2015

Overall species richness was relatively similar across treatment areas. The untreated plots had 26 species of forbs, 4 graminoids and 5 shrub species while the treated plot had 22, 7 and 4 respectively. See Table 9 for 2015 vegetative lifeform canopy cover values by treatment type. Cover frequency data from the treated area indicated Mountain brome (*Bromus marginatus*), New Mexico locust (*Robinia neomexicana*) and White Mountain sedge (*Carex geophila*) were the most abundant species by canopy cover with values of 36%, 11%, and 10% respectively. Data from the untreated area indicated American vetch (*Vicia Americana*), New Mexico locust (*Robinia neomexicana*) and Beardlip penstemon (*Penstemon barbatus*) were the most abundant species by canopy cover with values of 18%, 9% and 7% respectively. Although the untreated plot had slightly more total species the treated area had higher total canopy cover (63%/78%).

Lifeform	Untreated Plot Values (%)	Treated Plot Values (%)
Shrub	12	20
Forb	43	9
Graminoid	8	49

Table 9. 2015 vegetative lifeform canopy covers by treatment type. Values rounded.

2016

Species richness on the untreated plot was almost double the amount as compared to the treated plot. The untreated plot had 22 species of forbs, 3 graminoids and 3 shrub species while the treated plot had 9, 4 and 3 respectively. See Table 10 for 2016 vegetative lifeform canopy cover values by treatment type. Similar results were found in 2015 that are observed in 2016 with the untreated plot having more total species, but less total canopy cover. Total canopy cover on the untreated plot was measured at 69% while the treated plot was measured at 112% (overlap of species canopy cover results in >100% cover). Cover frequency data from the treated plot indicated Mountain brome (*Bromus marginatus*), New Mexico locust (*Robinia neomexicana*) and White Mountain sedge (*Carex geophila*) were the most abundant species by canopy cover with values of 43%, 20% and 20% respectively. Data from the untreated plot indicated American vetch (*Vicia Americana*), Fringed Brome (*Bromus ciliates*) and New Mexico locust (*Robinia neomexicana*) were the most abundant species by canopy cover with values of 30%, 10% and 8% respectively.

Lifeform	Untreated Plot Values (%)	Treated Plot Values (%)
Shrub	8	33
Forb	47	15
Graminoid	14	64

Table 10. 2016 vegetative lifeform canopy covers by treatment type. Values rounded.

See Appendix C for a complete list of species present throughout the monitoring study.

Photo points of central location on **Treated Site**. Clockwise 6/14 (Initial), 10/14, 10/15, 10/16.

Photo points of central location on **Untreated Site**. Clockwise 6/14 (Initial), 10/14, 10/15, 10/16.

2014

The forb and graminoid production measurement was performed for each treatment type on October 16th, 2014. The treated site had over ten times more total production as compared to the untreated site. The majority of this production came from the barley (*Hordeum vulgare*) annual cereal grain. The untreated site had over seven times more annual forb production as compared to the treated site at the end of the 2014 growing season. See table 15 for a summary of production estimates by treatment type for the 2014 growing season.

Monitoring Plot	Graminoid (lbs./ac)	Forb (lbs./ac)	Total (lbs./ac)
Treated	1,613	15	1,628
Untreated	11	113	124

Table 15: 2014 total production data in pounds per acre by treatment.

2015

The forb and graminoid production measurement was performed for each treatment type on October 19th, 2015. The treated site had more total production as compared to the untreated site. Graminoid production decreased from the previous year on the treated site. The majority of the graminoid production on the treated site was produced by Mountain Brome (*Bromus marginatus*). Although the treated site had more total production, the untreated site had more than 5 times the amount of forb production. Very little forb production was produced on the treated site as compared to the untreated site, but did increase from the previous year. The untreated site had an increase in both graminoid and forb production when compared to the previous year's sampling. See table 16 for a summary of production estimates by treatment type for the 2015 growing season.

Monitoring Plot	Graminoid (lbs./ac)	Forb (lbs./ac)	Total (lbs./ac)
Treated	996	95	1091
Untreated	364	503	867

Table 16: 2015 total production data in pounds per acre by treatment.

2016

The forb and graminoid production measurements were performed for each treatment type on October 13th, 2016. The treated site had more total production than the untreated site and had an increase over the previous year's sampling. Graminoid and forb production both increased on the treated site. The majority of the graminoid production on the treated site was again produced by Mountain Brome (*Bromus marginatus*). The untreated site produced more than seven times the amount of forb production than the treated site, but only 1/10th the amount of graminoid production. The untreated site had a decrease in graminoid production, but an increase in forb production from the previous year. See table 17 for a summary of production estimates by treatment type for the 2016 growing season.

Monitoring Plot	Graminoid (lbs./ac)	Forb (lbs./ac)	Total (lbs./ac)
Treated	1310	110	1420
Untreated	170	790	960

Table 17: 2016 total production data in pounds per acre by treatment.

SILT FENCE – EROSION RATES

2014

Silt fences were cleaned out on October 17th, 2014 and the sediment was weighed and totaled for each silt fence individually. Samples were collected at each location to correct for water content of the soil and estimate dry weight. The average water content for all samples was estimated at 40%. Silt fence 4 with the 80 foot slope length on the untreated site experienced a failure at the top of the trap where the sediment cloth was compromised. This could have happened during the September 12th, 2014 rain event where over an inch of rain fell on both monitoring plots. The total amount of sediment collected in silt fence 4 would have likely been higher. Although silt fence 4 was compromised the remaining sediment measured was greater when compared with silt fence 2 (80 foot slope length) on the treated site. Overall the treated site measured less erosion than the untreated site. Comparing silt fence 1 (treated) and silt fence 3 (untreated) both with 66 foot slope lengths, silt fence 3 received more than double the amount of sediment than silt fence 1. Table 11 summarizes the total tons per acre of sediment collected in each silt fence by treatment type for 2014.

Silt Fence	Slope Length (ft.)	Total Wet Weight (tons/acre)	Total Dry Weight (tons/acre)
1 (treated)	66	25	15
2 (treated)	80	27	16
3 (untreated)	66	63	38
4 (untreated)*	80	33*	20*

Table 11: Erosion in tons per acre by treatment type at conclusion of 2014 monitoring. Weights are rounded.
*Silt fence 4 failed.

2015

Silt fence 4 was repaired during the 2014 cleanout and functioned properly throughout 2015. Silt fences were cleaned out on October 19th, 2015 and the sediment was weighed and totaled for each silt fence individually. Samples were collected at each location to correct for water content of the soil and estimate dry weight. Average water content varied by sediment trap and ranged from 14% - 21%. When comparing silt fences with similar slope length (i.e. 1 & 3, 2 & 4) the untreated plots received 10 times more sediment than the treated plots. Table 12 summarizes the total tons per acre of sediment collected in each silt fence by treatment type for 2015.

Silt Fence	Slope Length (ft.)	Total Wet Weight (tons/acre)	Total Dry Weight (tons/acre)
1 (treated)	66	.9	.7
2 (treated)	80	.7	.5
3 (untreated)	66	9	7
4 (untreated)	80	6	5

Table 12: Silt fence erosion in tons per acre by treatment type at conclusion of 2015 monitoring. Weights are rounded.

2016

Silt fences were cleaned out on October 13th, 2016 and the sediment was weighed and totaled for each silt fence individually. Samples were collected at each location to correct for water content of the soil and estimate dry weight. Average water content for all samples was estimated at 26%. The treated plots have returned to pre-fire erosion rates while the untreated plots are producing sediment between 40 and 600 times the treated plot levels.

Although the magnitude between the treated and untreated plots is very high, erosion rates within the untreated area are relatively low when compared with 2014 rates. Table 13 summarizes the total tons per acre of sediment collected in each silt fence by treatment type for 2016.

Silt Fence	Slope Length (ft.)	Total Wet Weight (tons/acre)	Total Dry Weight (tons/acre)
1 (treated)	66	.13	.11
2 (treated)	80	.01	.01
3 (untreated)	66	5	4
4 (untreated)	80	8	6

Table 13: Silt fence erosion in tons per acre by treatment type at conclusion of 2016 monitoring. Weights are rounded.

Models were used to evaluate differences in erosion estimates between measured and modeled erosion rates for the first year following the fire. This evaluation is included to give the reader a general idea of how the models performed for the Signal Fire BAER Assessment. WEPP is a physically-based erosion model developed by the USDA Agricultural Research Service (ARS), Forest Service, and Natural Resource Conservation Service, and the US DOI BLM and US Geological Survey. WEPP estimates soil erosion and sediment yield based on soil characteristics like texture and rock fragment content within the soil profile, ground cover components, and topographic components. It uses these values and PRISM derived climate data to determine soil water content, infiltration and runoff. The WEPP model used a simulation period of 100 years. The Rangeland Hydrology and Erosion Model (RHEM) was designed specifically for rangelands as compared to WEPP and other models which were developed initially from experiments on croplands where rill flow transport plays a larger role (Nearing et. al, 2011). Splash and thin sheet-flow transport act as the dominant set of processes in the RHEM model (Nearing et. al, 2011). RHEM was developed and evaluated from a series of rangeland experiments south of Tucson, Arizona (Nearing et. al, 2011). The results of both models are presented in table 14 along with the measured erosion from each treatment plot.

2014 Erosion Rate Comparison (Dry Weight tons/ac)

	Trap 1 (66’ slope length)	Trap 2 (80’ slope length)
Untreated Signal Fire Silt Fence	38	20*
Untreated WEPP (5 year return interval)	47	54

	Trap 1 (66' slope length)	Trap 2 (80' slope length)
Untreated **RHEM (5 year return interval)**	25	25
Treated **Signal Fire Silt Fence**	15	16
Treated **WEPP (5 year return interval)**	13	15
Treated **RHEM (5 year return interval)**	12	12

Table 14: WEPP and RHEM modeled erosion and measured erosion from Signal Fire sediment traps October, 2014. Erosion values are expressed as dry weights in tons per acre.
*This sediment trap was compromised.

DISCUSSION

The discussion will focus on addressing the objectives outlined below:

- To determine the persistence of annual barley
- To determine if this treatment introduces invasive species
- To determine if this treatment delays or has a negative effect on natural recovery and diversity
- To determine how effective seeding is in increasing vegetative ground cover
- To determine if this treatment reduces erosion rates
- To determine the effect that post fire seeding has on maintenance of site/soil productivity

The persistence of annual barley (*Hordeum vulgare*) is of concern because of the potential negative effects that could occur when introducing a nonnative plant to any system. Analytical plot cover frequency transects and field observations from this study show that annual barley does not persist through year three. The data collected along the cover frequency transects show that annual barley decreased from approximately 41% cover to less than 1% cover by the second year and no occurrence by the third year. There were no field observations of the barley documented outside the treatment areas in year three. The potential for barley to be outcompeted by native species or the site not being conducive to the germination of annual barley in years two and three may have led to the departure of this annual grass. Mountain Brome (*Bromus marginatus*) was not identified on the 2014 transects (although it may have been documented as an unknown grass), but by 2015 the cover frequency transects showed Mountain Brome at approximately 36% and by 2016 it had increased to 43% potentially outcompeting the annual barley.

Common mullein *(Verbascum thapsus),* which is identified as an invasive species was documented on both treatment types. However common mullein has been naturalized across the Gila National Forest and was likely introduced prior to post fire seeding. The common mullein seed bank is persistent with seeds germinating after 100 years or more in the soil. This species is a short-lived member of disturbed communities whose abundance decreases with increased time since disturbance (Fire Effects Information System). No other invasive species were documented on either treatment type throughout the 3 year study. However this fire did cover over 5,000 acres (1,525 acres of treatment) making it difficult to observe the entire area to detect annual barley or invasive species, but from data collected over 3 years, no invasive species (other than common mullein) were identified and the annual barley did not persist.

Natural recovery may or may not have been affected by the seeding treatment. A 3 year study is most likely not long enough to inform on natural recovery. What can be said is that species diversity on both sites remained relatively similar (in terms of number of species by life form) between years one and two. By year three the non treated site had a greater amount of diversity than the treated site. Production estimates indicate that forbs were much higher on the untreated site (which we translate into natural recovery) than on the treated site. The graminoids have taken the place of the forb component on the treated site. However there is still a diversity of forbs across the treated area, but the amount (weight and cover) is much lower when compared to the untreated site. One could deduct that natural recovery has shifted from a forb dominated response to a grass dominated response on the treated area. Although this is the case, long term studies are needed to show what effect if any this shift has on long term recovery and diversity of the site. When analyzing the shrub component of natural recovery seeding appears to have no effect on shrub response within this study. New Mexico locust (*Robinia neomexicana*) and Gambel oak (*Quercus gambelii*) were the dominant shrubs on the landscape post fire. The treated plot had more total canopy cover of both shrub species throughout all 3 years of monitoring. The driving force behind shrub recovery is most likely related to the pre-fire amount and types of shrub species on site.

Results of this study show that seeding is very effective in producing vegetative ground cover (cryptogams, effective litter and vegetation basal area) by year 2. Both treatment areas had similar and relatively low amounts of vegetative ground cover by the end of year one, but by year two the treated site had 35% more vegetative ground cover than the untreated site. By the conclusion of the study the treated site had 38% more vegetative ground cover than the untreated site as shown by the cover frequency transect data. Bare soil measurements across the untreated area showed little change. The amount of bare soil measured following the first growing season (68%) was only slightly less by the third year (63%). The treated area measurements indicated a downward trend from a high of 63% bare soil following the first year's growing season to 28% at the conclusion of the monitoring. Vegetative ground cover and bare soil are significant factors linked directly to soil erosion.

This study supports the idea that post fire seeding can reduce erosion rates and thus reduce the potential risk to the soil resource and values affected by increased erosion and sedimentation. When comparing erosion rates and canopy cover between the two treatments, in year one it is evident that canopy cover is likely the factor influencing soil loss. Canopy cover influences the amount and intensity of rain drop impact which influences soil detachment and erosion (Neary et. al, 2005). In years two and three it becomes less evident that canopy cover is the only factor influencing erosion. Canopy covers between the two treatment areas become similar in year two and three, but the treated site has more total canopy cover in both years. While canopy covers are similar between treatment types in years two and three the erosion rates are not. Other factors likely influencing erosion rates in years two and three are the rooting system of the species re-establishing these sites and the amount of litter and cryptogams. Graminoids increase the topsoil aggregate stability and resist concentrated surface flow to a large extent (Pohl et. al, 2011). The untreated site is dominated by forbs that have less of a fibrous root system than grass species, which dominate the treated site. Litter and cryptogams which absorb the energy of rain drops and increase surface roughness can also slow water movement downslope. These were more abundant on the treated site in all years. Cryptogams and litter have the potential to decrease erosion on site.

If one can deduce that the amount of soil loss (erosion rates) is directly related to site and soil productivity then we can conclude that seeding has a positive effect on maintaining site and soil productivity. Year one erosion rates on the untreated site were more than double the amount of the treated site. By year two erosion rates were ten times greater in the untreated site and year three erosion rates were 40 to 600 times greater (although erosion rates in tons per acre were relatively low) when compared with the treated site. The treated monitoring site has likely returned to prefire erosion levels while the untreated site is still producing between 4 and 6 tons per acre of sediment (dry weight). This level of erosion exceeds soil loss tolerance values for this map unit. Soil loss tolerance values are directly related to soil productivity.

Another observation made during this 3 year monitoring project occurred shortly after the seed had been applied. The monsoonal storms began in early July, when seeding occurred, but after one week and successful germination, the monsoonal pattern slowed and a 10 day dry period occurred. The precipitation began again after this 10 day dry period, but if the treatment area was to remain dry longer, this would have significantly reduced the seeding effectiveness due to die-off. The timing of seeding is very important in the southwest; applying the seed too early could have effects such as the one described above while applying the seed too late could decrease the amount of time the seeds have to germinate and grow.

Results from this study have shown seeding to be an effective treatment for reducing post fire soil erosion rates within the mixed conifer life zone in the southwest. Elevation and aspect (along with the timing and amount of precipitation) appear to be significant site characteristics in determining seeding establishment and effectiveness. More monitoring of post fire seeding is needed along with long term studies that show how these systems respond, on an ecological time scale, to this treatment.

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APPENDIX A: PRE-SIGNAL FIRE SPECIES RICHNESS AND CANOPY COVER

The table below summarizes species richness and relative abundance by ranges in canopy cover from transect and site data in map unit 569 near Signal Peak before the Signal Fire of 2014.

Species	Canopy Cover Range
Douglas Fir (*Pseudotsuga menziesii***)**	2 – 50
Ponderosa Pine (*Pinus ponderosa var. scopulorum***)**	2 – 15
Southwestern White Pine (*Pinus strobiformis***)**	0.01 – 14
Gambel oak (*Quercus gambelii***)**	3.5 – 22
Rocky Mountain Maple (*Acer glabrum***)**	0.01
New Mexico locust (*Robinia neomexicana***)**	0.1 – 22
Mountain Spray (*Holodiscus dumosus***)**	0.01 – 19
Fendler's ceanothus (*Ceanothus fendleri***)**	0.5
Rock Clematis (*Clematis columbiana var. columbiana***)**	1
Arizona Honeysuckle (*Lonicera arizonica***)**	0.5
Currant (*Ribes sp.***)**	2
Red Raspberry (*Rubus idaeus***)**	2
Screwleaf Muhly (*Muhlenbergia straminea***)**	0.01
Muttongrass (*Poa fendleriana***)**	0. 1 – 3
Fringed Brome (*Bromus ciliatus***)**	0.1 – 3
White Mountain sedge (*Carex geophila***)**	0.1 - 1.5
Cusp Clover (*Trifolium wormskioldii***)**	2
Western yarrow (*Achillea millefolium***)**	0.01 - 0.5
Small-leaf Pussytoes (*Antennaria parvifolia***)**	0.2 – 1
Tasselflower Brickellbush (*Brickellia grandiflora***)**	0.01 – 4
Longleaf cologania (*Cologania angustifolia***)**	0.1
Strawberry (*Fragaria virginiana***)**	0.1 - 0.3
Manyflowered Stoneseed (*Lithospermum multiflorum***)**	0.01
Woodsorrel (*Oxalis sp.***)**	0.2
Penstemon (*Penstemon sp.***)**	0.1
Solomon's Seal (*Polygonatum cobrense***)**	0.3
Alpine False Springparsley (*Pseudocymopterus montanus***)**	0.1
Senecio (*Senecio sp.***)**	0.1 – 0.5

American Vetch (*Vicia americana*)	0.01 – 1
Canadian White Violet (*Viola canadensis*)	0.1 – 1.5
Ticktrefoil (*Desmodium sp.*)	0.1 – 1
Pineywoods geranium (*Geranium caespitosum*)	0.01 – 0.2
New Mexico Groundsel (*Packeria neomexicana*)	0.5
Western Brackenfern (*Pteridium aquilinum*)	0.5 – 1.5
Fendler's meadowrue (*Thalictrum fendleri*)	0.01
Ragweed Sagebrush (*Artemisia franserioides*)	0.1 – 0.5

APPENDIX B: EXAMPLE TEUI SITE FORM

USDA Forest Service	**ECOLOGICAL SITE DESCRIPTION**	R3-FS-2500-6 (June 2013)

Map Symbol: **Component:**	**Representative for** **Map Unit:** **Taxon:**	**Soil Taxon:**	
By:	**Date:**	**Phase:**	
NRM-NRIS Data Entry - Date: By:		**Vegetation Taxon:**	
Plot - Shape:		**Climax Class:**	**MAP** (cm):
Dimension:		**Plant Association:**	
Flight/Photo/Stop:		**Stone Boulder Class:**	**Surface Morphometry -** Gradient (%):
GPS File Name:	**DC:** **AVG:**	**Erosion Kind:**	Aspect (deg.): Length (m):
UTM:		**Erosion Degree Class:**	Elevation (m): Complexity:
Township: **Range:**	**Section:**	**Drainage Class:**	Slope Shape - Horizontal:
State:		**Hydrologic Soil Group:**	Slope Shape - Vertical:
County:		**Formation:**	Slope Position: Position Modifier:
Forest:		**Parent Material -** Kind-Origin:	
District:		**Site Geomorphology -** GP: LsT:	
***		Lf: ELf: CLf:	

Horizon/Layer			**USDA Texture**	**Rock Frag**	**Color**	**Struc**	**Surface Features**	**Consist**	**Pores**	**Roots**	**Reaction**	**Accessory Properties**
Symbol	Depth Thick cm	Bdy	Tex Mod Texture % Clay	Gr Cb St By % Vol	p/d p/m c/d r/m	Gr Si Ty	Ki Am Dis Loc	Dr Mo St Pl Ce CA	Qu Si Sh VC	Qu Si Lo	pH CaCO3 Effervesce	Mottles, RMF Stress Features Concen., K_{sat}

Diagnostic Surface Epipedon:			Thickness: to cm
Diagnostic Subsurface Horizon:			Thickness: to cm
			Thickness: to cm
Control Section: cm	Av. Clay (%)	Av. Rock Frag. (%)	Thickness: to cm
Soil Notes:			

VEGETATION

Vegetation Cross Reference:

Trees		**Shrubs**						**Forbs**						**Graminoids**		
Species	%CC	Species	%CC	Ht	Species	%CC	Ht	Species	%CC	Ht	Species	%CC	Ht	Species	%CC	Ht
Totals		*************************					*******************************						***********			***

Dist.	**Treat.**	**Snags**		**Notes:**
Agent	Type	Decay Class	Count	
		1		
		2		
		3		
		4		
		5		

Surface Components	Ocular
Graminoids (BA)	
Forb (BA)	
Shrub (BA)	
Tree (BA)	
Litter (> 1.25 cm)	
Gravel (0.2 – 0.5 cm)	
Gravel (0.5 – 2.0 cm)	
Gravel (2.0 - 7.5 cm)	
Cobble (7.5 - 25.0 cm)	
Stone (25.0 - 60.0 cm)	
Boulder (> 60.0 cm)	
Rock Outcrop	
Bare Soil	
Cryptogams	
Total	
Overstory Cover	

Woodland Species Size Class – DRC (#, Av. Ht., Total CC)

Species																		***
≤ 0.9"																		***
1.0" - 2.9"																		***
3.0" - 4.9"																		***
5.0" - 8.9"																		***
9.0" - 11.9"																		***
12.0"- 17.9"																		***
18.0"- 23.9"																		***
> 24.0"																		***
Cords/Acre																		***

Forest Productivity – Site Index

Species									
Height									
Age									
SI									
Avg SI		**************			**************			**************	

Microbiotic Organisms	Ocular
Mosses	
Lichens	
Liverworts	
Algae/Cyanobacteria	

Down Woody Material

FWD	#	CWD ≥ 3"	
		Dia.	DC
¼"-1"			
1"-3"			
************			

CWD ≥ 3"	
Dia.	DC

***Carnegiea gigantea* Height Class**

	#	HC	RS
≤ .1m			
.1 -1m			
1-2m			
2-4m			
4-6m			
≥ 6m			
Total			

Forest Species Size Class – DBH (#, Av. Ht., Total CC)

Species												
≤ 0.9"												
1.0" – 4.9"												
5.0" – 8.9"												
9.0" – 11.9"												
12.0" – 17.9"												
18.0" – 23.9"												
≥ 24.0"												
Basal Area (ft^2/ac)												

APPENDIX C: COMPLETE SPECIES LIST (2014-2016)

Treated	Untreated
Shrubs	
New Mexico locust (*Robinia neomexicana*)	New Mexico locust (*Robinia neomexicana*)
Gambel oak (*Quercus gambelii*)	Gambel oak (*Quercus gambelii*)
Mountain Spray (*Holodiscus dumosus*)	Mountain Spray (*Holodiscus dumosus*)
Mountain snowberry (Symphoricarpos oreophilus)	Mountain snowberry (Symphoricarpos oreophilus)
Fendler's ceanothus (*Ceanothus fendleri*)	Fendler's ceanothus *(Ceanothus fendleri)*
Currant (*Ribes sp.*)	Currant (*Ribes sp.*)
Orange gooseberry (*Ribes pinetorum*)	Orange gooseberry (*Ribes pinetorum*)
---	Red Raspberry (*Rubus idaeus*)
Blue Elderberry *(Sambucus cerulea)*	---
Graminoids	
Barley (*Hordeum vulgare*)	---
Bluegrass *(Poa sp.)*	Bluegrass *(Poa sp.)*
Muttongrass (*Poa fendleriana*)	Muttongrass (*Poa fendleriana*)
Fringed Brome (Bromus ciliates)	Fringed Brome (Bromus ciliates)
Mountain Brome (*Bromus marginatus)*	Mountain Brome (*Bromus marginatus)*
White Mountain sedge (*Carex geophila*)	White Mountain sedge (*Carex geophila*)
Squirreltail *(Elymus elymoides)*	---
Junegrass *(Koeleria macrantha)*	---
Annual Muhly *(Muhlenbergia minutissima)*	---
Forbs	
Chiricahua Mountain mock vervain *(Glandularia chiricahensis)*	---
Southwestern cosmos *(Cosmos parviflorus)*	Southwestern cosmos *(Cosmos parviflorus)*
Chickweed *(Cerastium sp.)*	Chickweed *(Cerastium sp.)*
Nodding chickweed *(Cerastium nutans)*	---
Fastigiate mouse-ear chickweed *(Cerastium fastigiatum)*	Fastigiate mouse-ear chickweed *(Cerastium fastigiatum)*
Spreading sandwort *(Arenaria lanuginosa subsp. Saxosa)*	Spreading sandwort *(Arenaria lanuginosa subsp. Saxosa)*
Scarlet gilia *(Ipomopsis aggregata)*	Scarlet gilia *(Ipomopsis aggregata)*
Common mullein *(Verbascum thapsus)*	Common mullein *(Verbascum thapsus)*

Wheeler's thistle *(Cirsium wheeleri)*	Wheeler's thistle *(Cirsium wheeleri)*
Mt. Albert goldenrod *(Solidago simplex)*	---
---	Hawkweed *(Hieracium sp.)*
---	Hooker's evening primrose (Oenothera elata)
Senecio (*Senecio sp.*)	Senecio (*Senecio sp.*)
---	Brickellbush (*Brickellia sp.)*
Showy goldeneye (*Heliomeris muliflora*)	Showy goldeneye *(Heliomeris muliflora)*
Goosefoot *(Chenopodium sp.)*	Goosefoot *(Chenopodium sp.)*
Fetid goosefoot (*Chenopodium graveolens*)	Fetid goosefoot (*Chenopodium graveolens*)
Fremont goosefoot (*Chenopodium fremontii)*	Fremont goosefoot (*Chenopodium fremontii)*
Pea (*Lathyrus sp.)*	Pea (*Lathyrus sp.)*
Ticktrefoil (*Desmodium sp.)*	---
Woodsorrel (*Oxalis sp.)*	Woodsorrel (*Oxalis sp.)*
---	Tenleaf Woodsorrel (*Oxalis decaphylla)*
Alpine Woodsorrel (*Oxalis alpine*)	Alpine Woodsorrel (*Oxalis alpine*)
Pineywoods geranium (*Geranium caespitosum*)	Pineywoods geranium (*Geranium caespitosum*)
Fragrant snakeroot (*Ageratina herbacea*)	---
---	Vetch *(Vicia sp.)*
American vetch (*Vicia Americana*)	American vetch (*Vicia Americana*)
Beardlip penstemon (*Penstemon barbatus*)	Beardlip penstemon (*Penstemon barbatus*)
Western yarrow (*Achillea millefolium*)	Western yarrow (*Achillea millefolium*)
Sagebrush (*Artemisia sp.)*	Sagebrush (*Artemisia sp.)*
---	---
Carruth's sagewort *(Artemisia carruthii)*	Carruth's sagewort *(Artemisia carruthii)*
---	White sagebrush *(Artemisia ludoviciana)*
Fleabane *(Erigeron sp.)*	Fleabane (*Erigeron sp*.)
Canadian white violet (*Viola canadensis*)	Canadian white violet (*Viola canadensis*)
---	Scrambled eggs (*Corydalis aurea*)
---	Pussytoes (*Antennaria sp.)*
Whitemargin pussytoes *(Antennaria marginata)*	Whitemargin pussytoes *(Antennaria marginata)*
---	Birdbill dayflower (*Commelina dianthifolia*)
---	Fendler's meadowrue (*Thalictrum fendleri*)
---	Bedstraw *(Galium sp.)*

---	Beggarticks *(Bidens sp.)*
Fetid marigold *(Dyssodia papposa)*	Fetid marigold *(Dyssodia papposa)*
Alpine false springparsley *(Pseudocymopterus montanus)*	Alpine false springparsley *(Pseudocymopterus montanus)*
Cudweed *(Pseudognaphalium sp.)*	Cudweed *(Pseudognaphalium sp.)*

APPENDIX D: PHOTO POINTS

On the following pages photo points that were taken throughout the 3 year monitoring study are displayed. Photo points were collected from central locations on each treatment type. These photos compare upslope (south), west, east and downslope (north) views by treatment type and monitoring year.

Photo 1: Looking upslope from center of **treated** monitoring plot October 2014.

Photo 2: Looking upslope from center of **untreated** monitoring plot October 2014.

Photo 3: Looking west from center of **treated** monitoring plot October 2014.

Photo 4: Looking west from center of **untreated** monitoring plot October 2014.

Photo 5: Looking east from center of **treated** monitoring plot October 2014.

Photo 6: Looking east from center of **untreated** monitoring plot October 2014.

Photo 7: Looking downslope from center of **treated** monitoring plot October 2014.

Photo 8: Looking downslope from center of **untreated** monitoring plot October 2014.

Photo 9: Looking upslope from center of **treated** monitoring plot October 2015.

Photo 10: Looking upslope from center of **untreated** monitoring plot October 2015.

Photo 11: Looking west from center of **treated** monitoring plot October 2015.

Photo 12: Looking west from center of **untreated** monitoring plot October 2015.

Photo 13: Looking east from center of **treated** monitoring plot October 2015.

Photo 14: Looking east from center of **untreated** monitoring plot October 2015.

Photo 15: Looking downslope from center of **treated** monitoring plot October 2015.

Photo 16: Looking downslope from center of **untreated** monitoring plot October 2015.

Photo 17: Looking upslope from center of **treated** monitoring plot October 2016.

Photo 18: Looking upslope from center of **untreated** monitoring plot October 2016.

Photo 19: Looking west from center of **treated** monitoring plot October 2016.

Photo 20: Looking west from center of **untreated** monitoring plot October 2016.

Photo 21: Looking east from center of **treated** monitoring plot October 2016.

Photo 22: Looking east from center of **untreated** monitoring plot October 2016.

Photo 23: Looking downslope from center of **treated** monitoring plot October 2016.

Photo 24: Looking downslope from center of **untreated** monitoring plot October 2016.