South Fork of Dutch Creek Pilot Project Report

Photo Credit: EcoFlight

ROARING FORK WATERSHED PLAN at work

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Acknowledgements

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On-the-ground photos for this report were provided by the U.S. Forest Service, White River National Forest. EcoFlight, of Aspen, Colorado, graciously flew over the project area on several occasions, and contributed the aerial photos which are included in this report.

Summary

Fifty years of large-scale coal mining activities occurred in Coal Basin, a western Colorado watershed characterized by naturally steep, unstable and highly erodible slopes. Today, erosion from the prior resource extraction and the landscape alteration caused by these activities, as well as sedimentation from naturally-occurring soil erosion and mass movements are degrading water quality and stream habitat in Coal Basin and contributing to sedimentation issues downstream in the Crystal River. In addition, Coal Creek Road (FSR 307) and 17 miles of historic mining roads are causing stream bank instability and sediment transport issues throughout the basin. Although the Colorado Division of Reclamation, Mining & Safety (CDRMS) completed a series of restoration projects in Coal Basin from 1994-2004, *nearly 650 acres of disturbed area directly connected to the Coal Creek stream system remains*.

Decommissioned mining road reclamation work was conducted on 10 acres in Coal Basin. This pilot effort was designed to assess the cost-effectiveness and utility of using soil amendments on disturbed soils (including compost and a compost/biochar mixture), coupled with drainage improvements to reduce the volume of surface runoff, improve the water and nutrient-holding capacity of the soils, reduce soil compaction and bulk density, and enhance the growth of native vegetation.

Background

Large-scale mining and associated activities (such as roads, wash plants, and refuse piles) previously conducted on unstable, steep slopes, combined with major channel alterations at the mouth of Coal Creek, have severely impacted a large area within Coal Basin. Grazing and logging accompanied the mining activities to feed, clothe and shelter the miners and the residents of the original company town of Redstone. Currently, Coal Basin is used for a variety or recreational activities and grazing is permitted from June 26 to October 10th each year. The U.S. Forest Service (USFS) identified over 645 acres of Connected Disturbed Areas (CDAs)[1] in Coal Basin that may benefit from restoration (Figure 1). Noteworthy is the large area of natural clearings (approximately 6% of the watershed) that likely contribute high volumes of sediment to the stream channel.

The South Fork of Dutch Creek in Coal Basin (Figure 2) is a textbook example of an impacted stream - the channel has a high width to depth ratio, lacks riparian vegetation, and fine sediments clog the channel. The 10-acre South Fork of Dutch Creek pilot project was designed as a reclamation project for this severely-impacted area. In addition, the study evaluated costs and benefits of several different restoration techniques in order to determine the most favorable methods to be utilized in the planned landscape-scale restoration of Coal Basin.

The project is one of the first major initiatives developed under the 2012 *Roaring Fork Watershed Plan*, which identified as an *"Urgent Action"* the need to "[work] with landowners, resource experts, and other interested parties, [to] plan and implement riparian/ instream protection and restoration projects." The Coal and East Creeks confluence with the Crystal River (the largest tributary to the Roaring Fork River) was one of four areas identified for pursuing an initial voluntary project.

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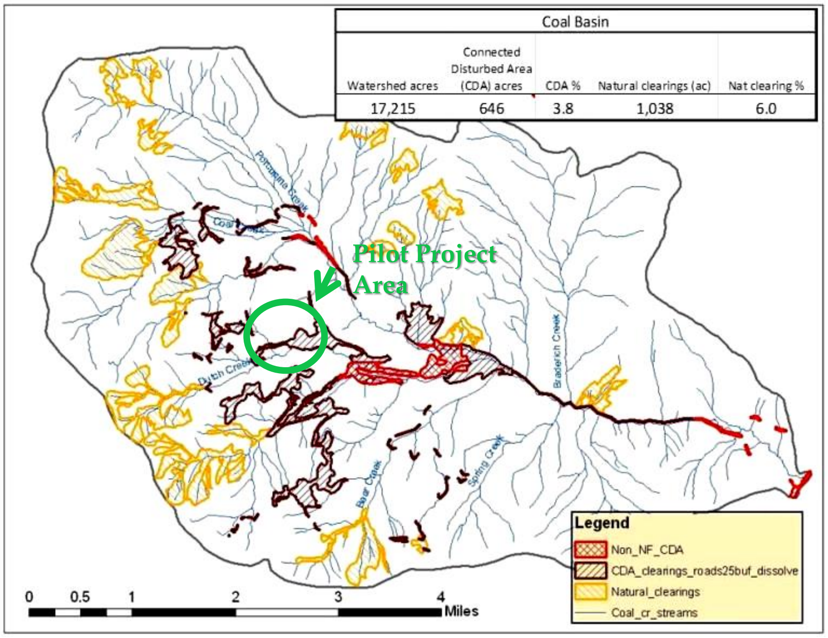
[1] CDAs are disturbed clearings and roads that artificially intercept and combine natural channels, thereby increasing flows, erosion, and sediment transport.



*Connected Disturbed Areas (CDAs) are disturbed clearings and roads that artificially intercept and combine natural channels increasing flows, erosion, and sediment transport.

Figure 1. Connected Disturbed Areas (CDAs) in Coal Basin; pilot project area is circled in green.

Figure 2. South Fork of Dutch Creek below the pilot project area.

To ensure that local residents, resource experts, and land owners and managers were informed about the project, extensive outreach was conducted by Roaring Fork Conservancy (RFC) and the USFS beginning in May of 2011. This effort included presentations and field trips for numerous groups, ranging from local civic organizations to USFS White River National Forest (WRNF) leadership - almost 700 contacts. Coal Basin was chosen as a featured stop on the Colorado Foundation for Water Education's Upper Colorado River Basin Tour in June 2013, an event attended by the general public, state legislators and a local county commissioner. Press releases and articles in the RFC bi-annual newsletter provided additional exposure for the project.

The *Coal Basin & Crystal River Area Restoration Workshop* was held over two days in May 2012 to develop strategies for continuing the critical restoration work undertaken by CDRMS in Coal Basin, and to discuss opportunities for improving the Coal Creek/Crystal River confluence area. The workshop brought nearly 50 hydrologists, soils scientists, geomorphologists, fish biologists, water quality analysts, plant ecologists and other technical experts together with highway engineers, mining reclamation experts, recreational planners, and other key stakeholders from multiple federal, state and local government entities, as well as local nonprofits and private interests (Figure 3). Workshop participants discussed several restoration tools and identified seven near-term (1-2 year) tasks, all of which built upon the "lessons learned" in the prior restoration efforts and utilized available information on the area's land use history, natural resources, and geomorphology.[2] The pilot project tracks one such recommended action:

> ***Support current USFS initiatives to rehabilitate sediment-producing mining-related disturbed areas with selected native plants in Coal Basin. Evaluate the efficacy of using biochar, or other soil-enhancing amendments, and selected native plant species as part of this restoration initiative.***

Figure 3. May 2012 workshop participants.

[2] The full workshop report can be found at http://www.roaringfork.org/your-watershed/crystal-river/coal-basin-project/.

Objectives

The South Fork of Dutch Creek Pilot Project was part of the larger Crystal River Assessment Project[3], with the overarching goal to integrate and complete site-specific watershed projects to:

- Improve riparian area function/wildlife value,
- Reduce anthropogenic sedimentation,
- Improve upland vegetation to stabilize soils,
- Improve instream habitat and fisheries,
- Address water quality issues,
- Protect the Town of Redstone from flood flow damages, and
- Increase late summer stream flows.

The two objectives of the pilot project are:

1. **Successfully reclaim and reduce sediment-loading from more than 10 acres of the decommissioned road network in the former mining areas of Coal Basin, and**
2. **Assess the cost-effectiveness and utility of using biochar and other carbonaceous soil amendments in future large-scale reclamation efforts in Coal Basin and similar locations.**

Methods

Based on 10 years of reclamation work in Coal Basin, CDRMS shared its key "lessons learned" at the *Coal Basin & Crystal River Area Restoration Workshop* which included:

1. Understand the environment at Coal Basin and work with its unique character;
2. Recognize that it is an exceptionally dynamic and mobile system;
3. Grazing should only be allowed after substantial maturity and diversity of vegetation have been established;
4. Build microclimates on site;
5. Disperse water on site at every opportunity; and
6. "Soils" and remnant refuse respond favorably to the addition of organic matter.

These "lessons learned" along with the workshop served as the cornerstone for the 10-acre road reclamation pilot project initiated by RFC and the USFS on the South Fork of Dutch Creek in September 2012.

The South Fork of Dutch Creek study site was chosen in order to reclaim some of the highest sediment-producing portions of the decommissioned road network in the former mining areas of Coal Basin, and to assess the cost-effectiveness and utility of using carbonaceous soil amendments in this type of reclamation effort. Figures 4 and 5 and Table 1 identify the treatments and reclamation areas. The tasks involved in this project included:

1. Using the USFS CDAs analysis (Figure 1) to select the pilot project reclamation site.
2. Reconnecting intermittent streams and ephemeral channels across old road prism using rocks for grade control and stability; eliminating headcuts; constructing water bars and cross-ripping road prism for water infiltration/routing and soil deposition; placing wood perpendicular to slopes on headcuts for stability and soil deposition; and constructing an intermittent stream alluvial fan.

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[3] Crystal River Assessment Project later became the Crystal River Management Plan.

3. Procuring biochar and compost and hauling these materials to the project site.
4. Amending soils in the pilot project area by incorporating a mix of biochar and compost.
5. Revegetating road prism and riparian areas adjacent to intermittent and ephemeral stream channels using ecotypic grass seed from the WRNF and USFS spruce seedlings.
6. Fencing the amended soil areas from livestock to allow for plant development.
7. Treating noxious weeds in the pilot project area.
8. Installing a soil moisture and temperature monitoring station on the project site.
9. Monitoring soil parameters and vegetation in the pilot project area.

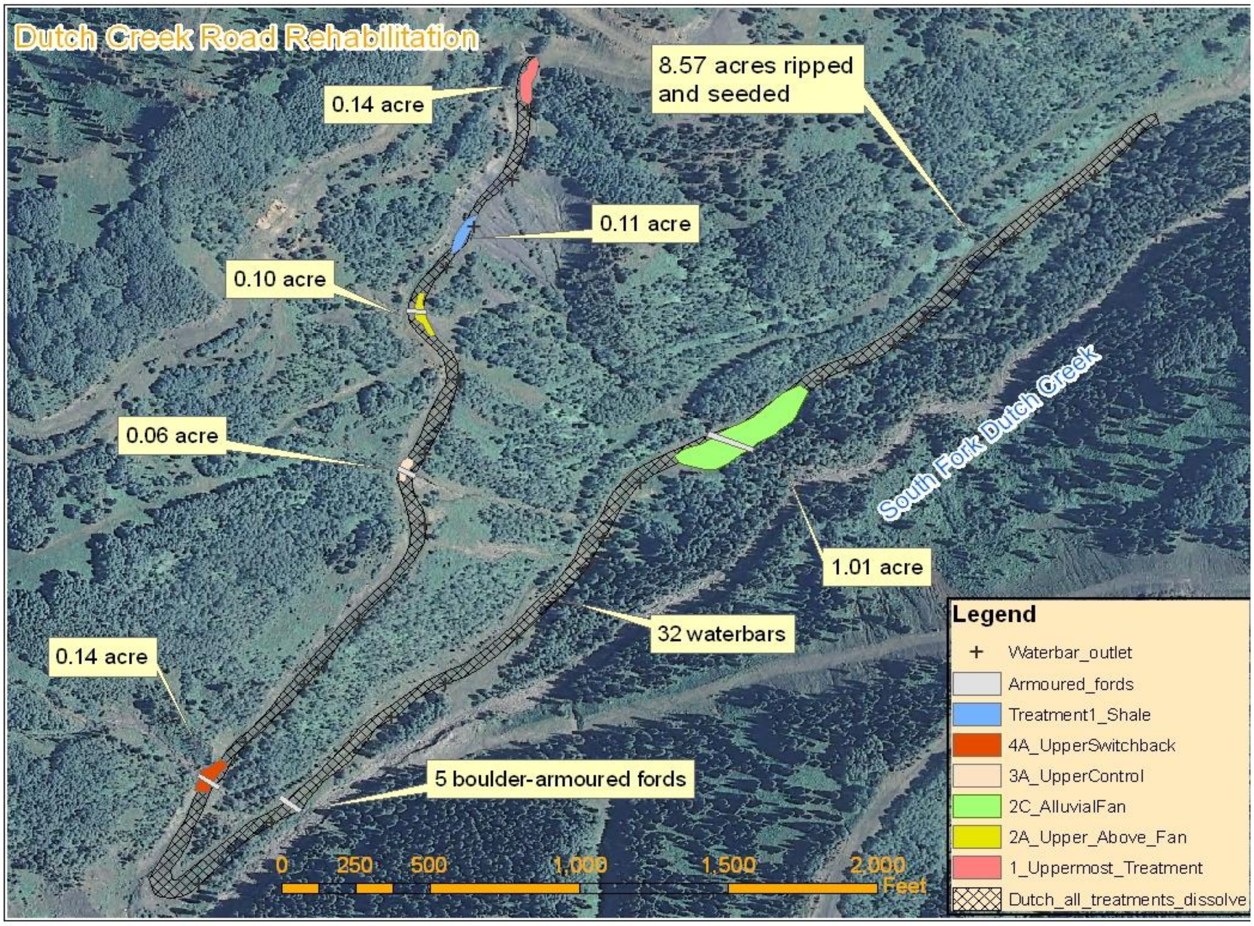

Figure 4. Pilot project area with treatment areas outlined.

Figure 5. Pilot project area with work ongoing, September 2012 (source: EcoFlight). Note the darkened surface at area 2c ("alluvial fan"), where the largest volume of compost/biochar was applied.

Name of Treatment Area	Acres
1 Uppermost Treatment	0.14
Treatment 1 Shale	0.11
2a Upper Above Fan	0.1
3a Upper Control	0.06
4a Upper Switchback	0.14
2c Alluvial Fan	1.01
Road seeded and ripped	8.57
Total:	**10.13**

Table 1. Acreage for the pilot project treatment areas.

Site Modification

Site 2a in Figure 6 shows an intermittent stream channel failure associated with a road crossing. Some of the water from the channel was routed down the road, causing the formation of gullies, rills and a headcut where water exited the road prism. The area was rehabilitated by reconnecting and hardening the stream crossing, cross ripping the road prism adjacent to the stream channel, placing wood perpendicular to the slope at the head cut, amending the soils with biochar and compost, and seeding the entire area with locally sourced, ecotypic native grasses (Figure 7).

Figure 6. Area 2a before restoration.

Figure 7. Area 2a during restoration.

Figures 8 and 9 show the road prism before and after reclamation. In Coal Basin there are approximately 17 miles of legacy mining roads that were built using the cut-and-fill method; these were in-sloped to convey water, which was subsequently routed through culverts under the road. The culverts contributed to channel degradation by increasing flows in channels not naturally designed to carry these flows. Part of the reclamation work done by CDRMS was to out-slope the road prism and remove the culverts. Additional work still needed to be done on the road prism to improve water routing, increase water infiltration and vegetative cover, and reduce soil losses by sheet flow and rill/gully erosion. To accomplish this, the road prism in the pilot project area was cross-ripped to a depth of 18”, water bars were constructed in-between the reconnected intermittent and ephemeral channels, and the entire road prism was broadcast-seeded in the fall of 2012. Selected areas were amended with compost and/or a compost-biochar mixture.

Figure 8. Road prism before treatment; road had minimal infiltration and excessive overland flow.

Figure 9. Cross-ripped road with compost/biochar soil amendment (above) and without soil amendment (below).

Figures 10-13 show the extensive work done on the intermittent stream channel (area 2c), road prism, and floodplain. The primary objective of this effort was to reduce overland flow and sediment delivery to the streams and to provide opportunities for water infiltration and sediment storage in the upland areas, all while increasing vegetative cover. Figure 10 shows the intermittent channel as it drops to the valley floor near the confluence with the South Fork of Dutch Creek. Low gradient areas and associated wide floodplains, exemplified here, are where sediment is naturally stored. To attempt to mimic this natural function, restoration began upslope at site 2a and continued to the confluence area at site 2c. A natural alluvial fan located near the confluence of Braderich and Coal Creeks was used for reference during construction of the alluvial fan shown in Figures 11 and 12. Several things were done as part of this site reclamation: the stream road crossing was stabilized (as discussed above); the road prism was cross-ripped and soil amendments were added; a 1-acre alluvial fan was constructed; grade controls were installed at the downstream end of the fan/intermittent stream channel using logs; and the area was revegetated with a grass seed mix, spruce seedlings, and willow cuttings.

Figure 10. Area 2c alluvial fan before restoration.

Figure 11. Area 2c alluvial fan during restoration.

Figure 12. Area 2c alluvial fan during restoration.

Soil Amendments

Figure 13 shows the application of soil amendments. The purpose of soil amendments is to reduce soil compaction/bulk density, increase soil moisture content, and provide nutrients for plants. Three treatment types were used: a control (no amendments); compost only; and compost with biochar. Compost was obtained from the South Canyon Landfill/Heartland Environmental Services[4] and biochar from Biochar Reclamation, LLC. Table 2 lists the location of the different treatment options.

Figure 13. Application of biochar/compost and compost only soil amendments in treatment areas. Top left photo is a close up of biochar. Piles in photos are compost/biochar blend.

[4] A small amount of "Mesa Magic" (Mesa County) compost that was left over from another Coal Basin project was used in the upper two treatment areas.

Treatment Polygon ID	Treatment Acreage	Soil Amendment Mix	Notes
1	0.14	several treatment types; two composts (South Canyon-Heartland and Mesa County-Mesa Magic), compost-char (Heartland), and control (no treatment)	upper treatment area
2a	0.21	.11 acre compost-char (near shale cliffs) and .10 acre compost-char (road prism) and Mesa Magic (on berm/large wood retention area)	two treatment polygons (.11 acre and .10 acre)
3a	0.06	compost-biochar (Heartland)	area around armored-ford; some patches of surface application (no ripping)
4a	0.14	compost only (Heartland)	1st switchback above alluvial fan
2c	1.01	compost-biochar (Heartland)	lower treatment area; alluvial fan. Soil moisture (OnSet/Hobo) station installation
Total:	**1.56**		

Table 2. Soil treatment types in the pilot project area.

Continuous soil monitoring probes were installed at the project site to collect data to facilitate the comparison of the effectiveness of a biochar/compost mix, compost, and no soil amendments for improving soil moisture (Figures 14 and 15). The system consists of a tipping bucket for precipitation data[5], a photovoltaic panel and battery for solar power, and soil moisture and temperature probes installed within the rooting zone for local vegetation (Figure 16). Soil moisture probes were located at 2”, 8”, and 20" depths, following protocols established by Natural Resources Conservation Service (Soil Climate Analysis Network) stations and in a manner compatible with local soil moisture data being collected under the auspices of the Aspen Global Climate Initiative (AGCI). Soil temperature was monitored at the 3” depth for compost with biochar to capture the seed germination zone and the zone of fine roots for grasses. Soil temperature data was not collected for the control or compost only due to equipment limitation. Data was collected from August 21 to November 1, 2013. Data was only collected at the 8” depth (heart of the planting rooting depth) for all three treatments and at the 20” depth for the biochar/compost mix for the two subsequent years: April 15 to November 4, 2014; and March 10 to September 10, 2015. The mean, minimum, and maximum soil moisture content by soil treatment was calculated for comparison among treatments.

[5] No precipitation data were collected due to equipment failure.

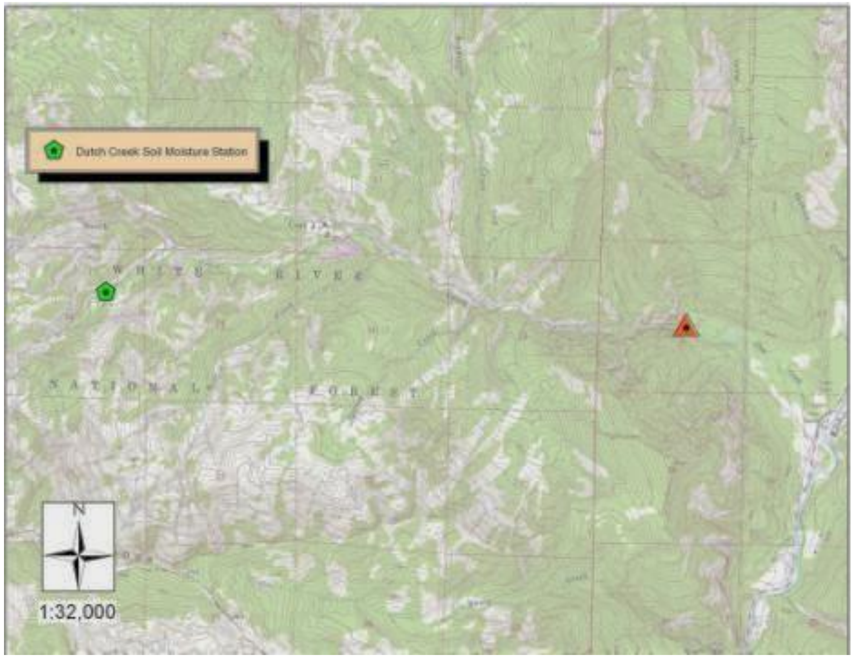

Figure 14. Location of the soil moisture monitoring station in Coal Basin.

Figure 15. Location of the soil moisture monitoring station in the pilot project area.

Figure 16. Soil moisture monitoring station. August 2013.

Revegetation

To improve vegetative cover, and subsequently increase water infiltration and decrease erosion, the treatment areas were seeded and trees were planted. In the fall of 2012, approximately 1.5 miles of road constituting a CDA to the Dutch Creek drainage were ripped and crossed ripped, and then broadcast-seeded at 35 pure live seed (PLS)/acre with a genetically local (ecotypic) grass seed mix (Figure 17). Individual grass species used in this project are described in the Appendix. The seed mix was comprised of 60% WRNF mountain brome and 40% WRNF slender wheatgrass. Prior to this project, the road had been revegetated with cultivar grasses, including both native and exotic perennial grass species. Additionally, a 1-acre alluvial fan reconstruction area was broadcast-seeded at 35 PLS/acre with a genetically local (ecotypic) grass seed (Figure 18). The grass seed mix was comprised of 40% WRNF mountain brome, 35% WRNF slender wheatgrass, and 25% WRNF blue wildrye. Prior to seeding, the native soil on this 1-acre site had been amended with 10% biochar/compost.

On June 3 and 4, 2013, 750 Engelmann spruce trees (provided by the USFS) were planted by USFS staff with the help of Colorado Parks and Wildlife and the brute strength of *"Aspen"*, a USFS mule (Figure 19). Each tree was planted in a hole where the soil was amended to improve conditions at the micro-site level. Planting took place over approximately 4 acres within a 9,000 foot- long decommissioned road prism. Wet draws were planted from the top to the alluvial fan and then down to the gate at the Lamphouse (an abandoned mining facility) in addition to all amended soil locations and other water bars that had visible water. The benefit of using cottonwood's ability to resprout was incorporated into an onsite project modification. On the newly constructed alluvial fan, green cottonwood logs were buried for three quarters of their length, perpendicular to the slope to provide organic material and future riparian vegetation.

Figure 17. Seeding with native (ecotypic) WRNF grass seed mix October 31, 2012.

Figure 18. Reconstructed alluvial fan seeding.

Figure 19. Engelmann spruce tree planting, June 2013.

On September 23, 2013 data was collected from one cover frequency transect (Dutch Creek #1-road prism) to determine source performance of the ecotypic seed sources utilized as well as the first year success of that revegetation effort (Figure 20). Plans to measure two additional transects along this 1.5 mile stretch of road were interrupted by the government furlough. No additional transects associated with the Dutch Creek road decommissioning were measured in 2013. Data were also collected from one cover frequency transect (Dutch Creek #2-alluvial fan) to determine performance of the seed sources utilized in relation to the soil amendments, and to determine the overall success of the revegetation effort. For comparison purposes, we had planned to record cover frequency data from the soil treatments to determine: a) vegetative success among soils amended with compost, b) vegetative success among soils amended with compost/biochar, and c) vegetative success where soils were not amended. We were not able to record data among soils amended with compost only also due to the furlough.

Figure 20. Dutch Creek transect # 1.

To protect the vegetation in the project area from cattle grazing, an electric fence was installed by USFS personnel in 2013, 2014, and 2015 (area 2c only). The fence was put up in the spring before cattle were turned out in the USFS grazing allotments (Figure 21). Mules and horses were used to haul fencing material to the project site. This fence was taken down each fall after the cattle were removed and stored for the winter.

Figure 21. Electric fence in alluvial fan area.

Weed Treatment

Due to the amount of ground disturbed from coal mining and associated activities (roads, wash plants, and refuse piles), large areas of Coal Basin are significantly impacted by noxious weeds (notably plumeless thistle, hounds tongue, oxeye daisy, and Canada thistle[6]). The ground disturbance associated with the pilot project compounded the problem. Though addressing this added infestation was outside the purview of the USFS annual weed spraying program, USFS personnel played an essential role in the design and implementation of a successful program to treat the pilot project area. USFS expertly identified potential applicators, most effective timing, application rates, chemicals, and methods. Sixteen acres of ground within and adjacent to the pilot project area were treated for noxious weeds during the week of June 18-21, 2013 (Figure 22). Subsequent hand treatments (pulling) followed throughout the growing season when resource specialists were at the site for monitoring events.

Figure 22. Spot spraying for weeds in the treatment areas.

Results and Discussion

Site Modification

Extensive site modification was conducted to disconnect some of the most disturbed areas on the South Fork of Dutch Creek from the stream channel. In the upper part of the project area where an intermittent channel crossed the road the area was rehabilitated by reconnecting and hardening the stream crossing, cross ripping the road prism adjacent to the stream channel, and placing wood perpendicular to the slope at the head cut. An alluvial fan was constructed at the lower end of this channel. Figure 23, taken after the work was completed shows the alluvial fan transporting water and dissipating sediment. As a continuation of CDRMS work, the entire road prism in the pilot project area was cross-ripped and water bars were constructed in-between the reconnected intermittent and ephemeral channels improving water routing and infiltration, and reducing soil losses by sheet flow and rill/gully erosion. Amending the soil, revegetating with a grass seed mix, spruce seedlings, and willow cuttings followed by treatment for weeds fostered vegetation growth on the modified sites (Figures 24 and 25).

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[6] All are List B species on Colorado's noxious weed list.

Figure 23. Area 2c alluvial fan transporting water and dissipating sediment (May 13, 2013).

Figure 24. Willow cuttings.

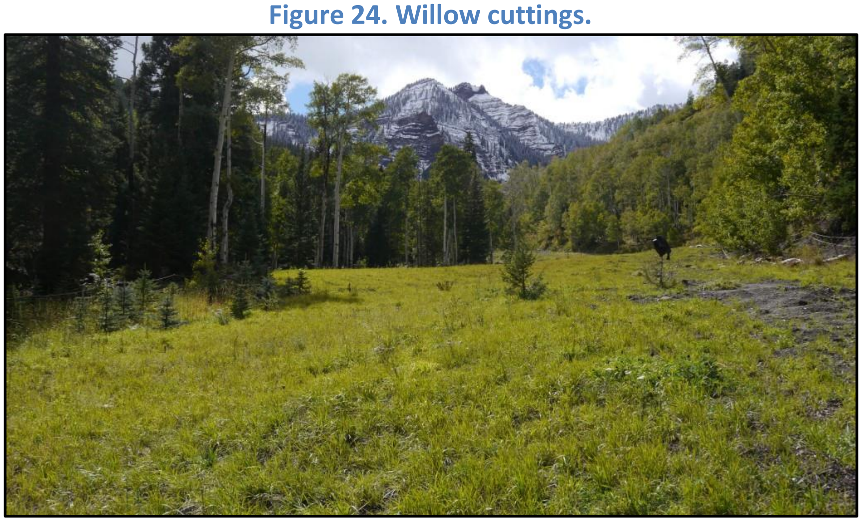


Figure 25. Revegetation of the alluvial fan following restoration (Sept 24, 2013).

Soil Monitoring

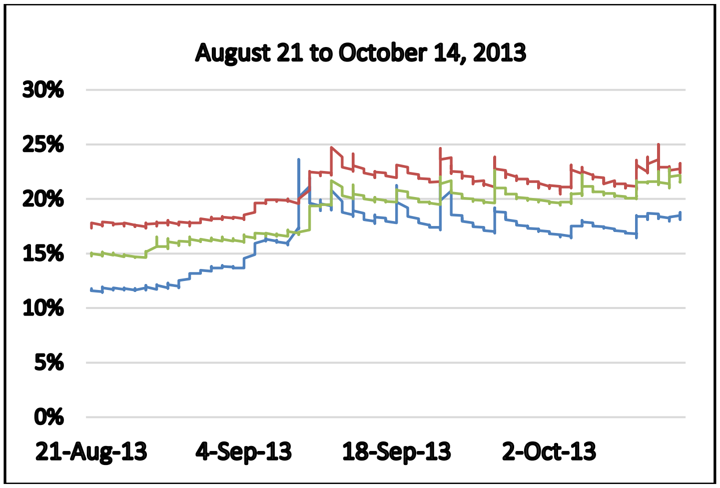
Soil moisture monitoring was used to evaluate the benefits of soil amendments. This report discusses only soil moisture data from the 8" depth probes because that depth is the most important for assessing water availability for plant growth. The following graphs and tables confirm our expectations that both treatments increase soil moisture more than the control and over time the addition of biochar appears to hold soil moisture better than the compost only. For all three years the control had the lowest minimum soil moisture, 3 to 6% lower than both the compost and the compost with biochar. The control also had the lowest mean soil moisture, 4 to 5% lower than the compost; and ranged from 3% lower in 2013 to 6% lower in 2015 than the compost with biochar (Tables 3-5 and Figures 26-28). Initially (2013) at the 8" depth the compost held slightly more soil moisture (2% on average) than the compost with biochar, however by the third year (2015) the compost with biochar held on average 2% more than the compost only (Figures 29-31).

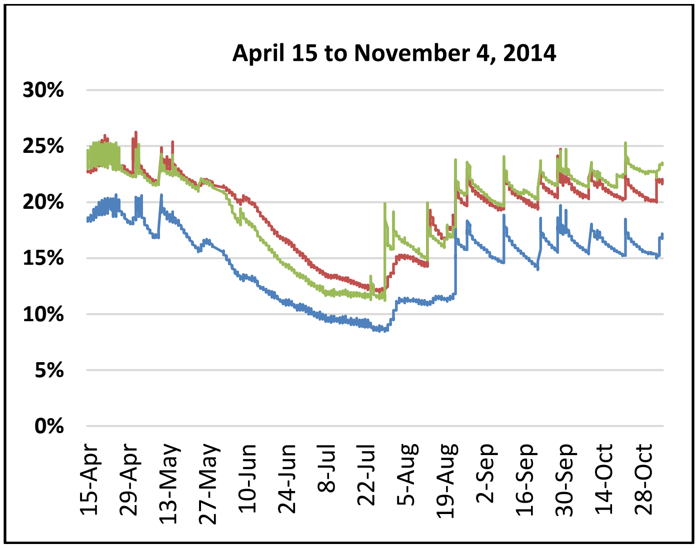
8.21 to 10.14, 2013	Control	Compost	Compost with biochar
Mean	17%	21%	20%
Min.	11%	17%	15%
Max.	24%	25%	23%

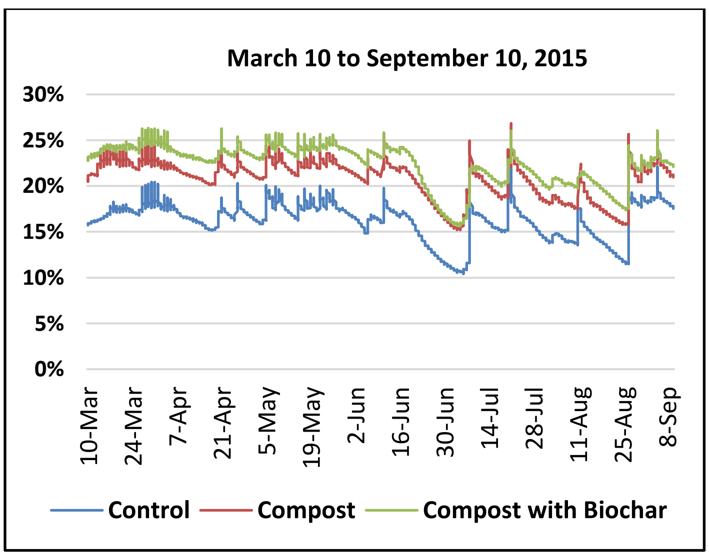
4.15 to 11.4, 2014	Control	Compost	Compost with biochar
Mean	14%	19%	19%
Min.	8%	12%	11%
Max.	21%	26%	25%

3.10 to 9.10, 2015	Control	Compost	Compost with biochar
Mean	16%	21%	22%
Min.	10%	15%	16%
Max.	22%	27%	26%

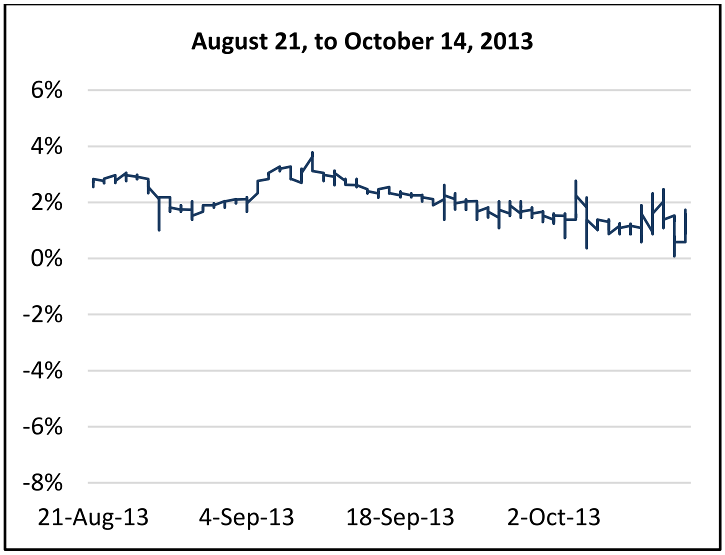
Tables 3, 4, and 5. Summary of soil moisture data at 8" depth: 2013, 2014, 2015.

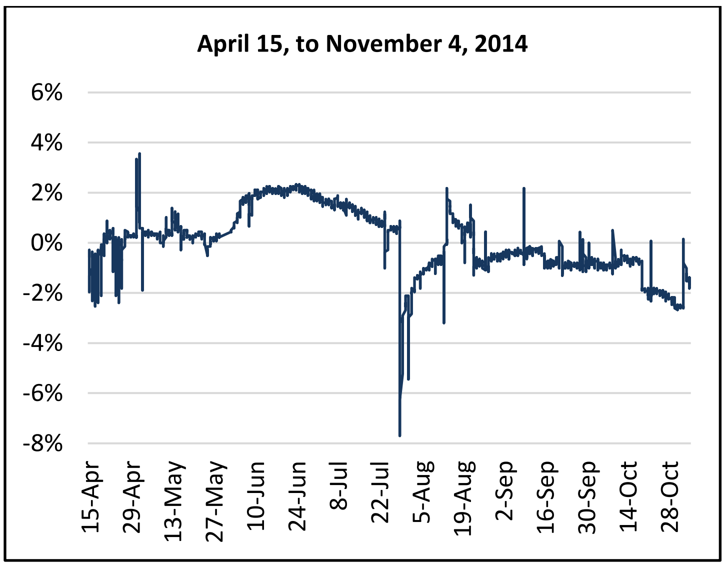


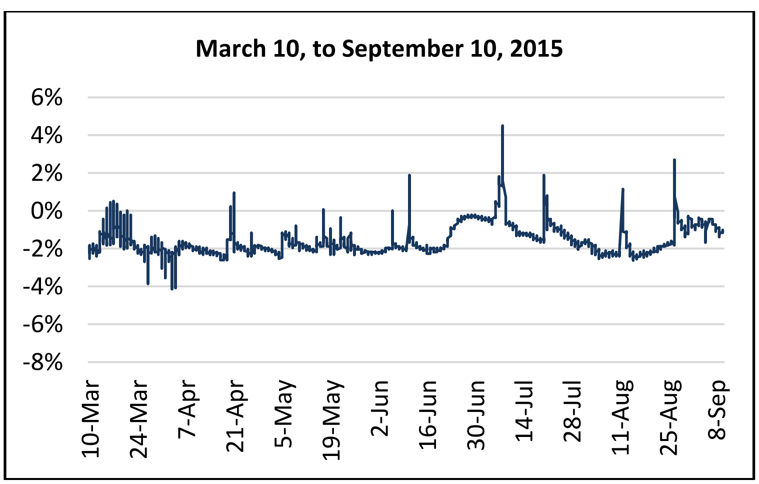




Figures 26-28. Results of the soil moisture monitoring at the 8” depth.







Figures 29-31. Comparison of the difference in soil moisture between compost and compost with biochar at the 8" depth (> 0 compost held more moisture and < 0 compost with biochar held more moisture).

Vegetation Monitoring

Cover Frequency Index (CFI) was calculated to measure, display and compare the density of a plant species within and between monitoring transects (Figure 32). Within Dutch Creek transect #1 (road prism), WRNF slender wheatgrass had the greatest plant density. While WRNF mountain brome was not observed at the time this transect was read, good germination was noted earlier in the spring. Douglas knotweed - a native dichotomous forb - was found in trace amounts. Cultivar grass species which were either present in the seed bank or already established from a previous seeding effort included: orchard grass, tall blue grass, and sheep fescue. Invasive species observed included trace amounts of hounds tongue.

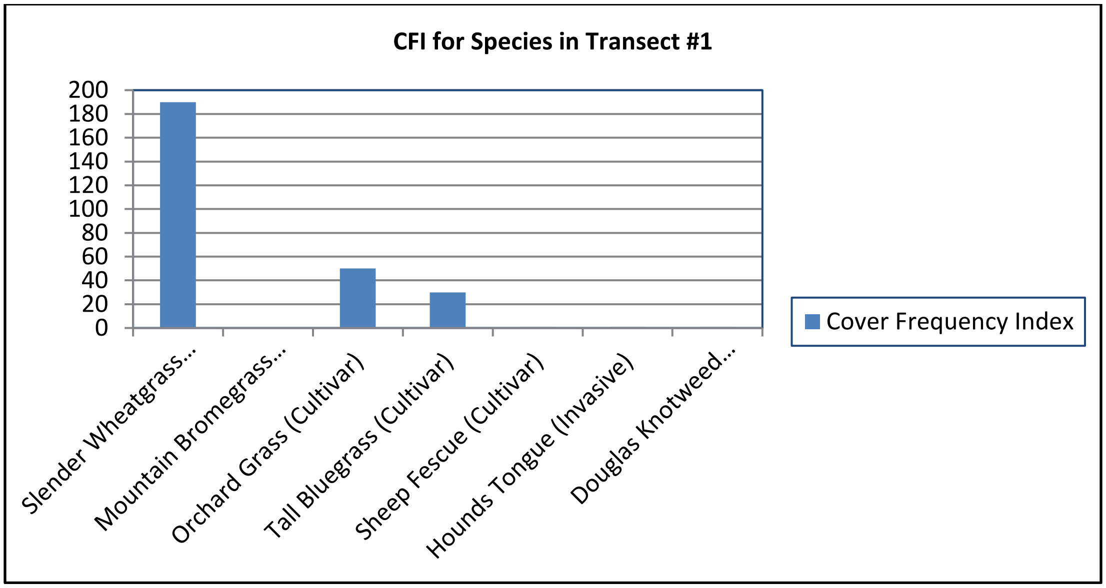


Figure 32. Cover Frequency Index for Dutch Creek transect #1, Fall of 2013.

Slender wheatgrass had moderately successful first year establishment because it is able to develop short rhizomes, making it more efficient at extracting water and nutrients from compacted soils and allowing it to better tolerate the extended dry period that occurred between May and July. Mountain brome had unsuccessful first year establishment in transect #1. This was likely due to the fact that it develops from a shallow root system, which does not have rhizomes, and the fact that it prefers deep, fertile, mesic soils. This species' root system is not well adapted to grow in compacted soils. The site conditions on Dutch Creek road were shallow, compacted, infertile, and experienced an extended dry period.

Within Dutch Creek transect #2 (alluvial fan), WRNF mountain brome had the greatest plant density and excellent first year establishment, WRNF blue wildrye had excellent first year establishment, and WRNF slender wheatgrass had moderate first year establishment (Figure 33). Native forb species that were observed in transect #2 included: Douglas knotweed, scorpion weed and willow herb. Invasive plants observed in transect #2 included: kochia and sweet clover. Cultivars utilized in previous revegetation efforts were noted in the treated area but outside of transect #2, including: stream bank wheatgrass, orchard grass, western wheatgrass, tall bluegrass, yarrow flower and Rocky Mountain beardtongue. Invasive plants observed in transect #2 included: kochia and sweet clover. It is unclear if they were introduced by the equipment utilized, the compost that was brought in to the project site, the seeds that were broadcast on-site, or if they were already present[7].

[7] Several precautions were taken to minimize the transportation of weeds: all heavy equipment was washed prior to delivering to the project site and all compost was tested for weeds by an independent lab and "passed".

The soil amendments were the key to the successful revegetation of this 1-acre alluvial fan reconstruction site (Table 6 and Figure 34). Prior to seeding, the native soil had been amended with a 10% biochar/compost mix. The revegetation site experienced good spring and monsoonal moisture, but endured an extended warm and dry period from late May through mid-July. Figures 35 to 37 show the revegetation progression from May through July. The water-holding capacity of the compost and biochar were critical in maintaining soil moisture and water availability to the establishing seedlings during the long dry period. The planting medium allowed the seedlings to obtain optimal root development and ultimately to establish and persist. The compost and biochar also provided nutrients (in the compost) and the ability to retain them (in the biochar), fertilizing the emergent vegetation and increasing the short- and long-term fertility of the growth medium.

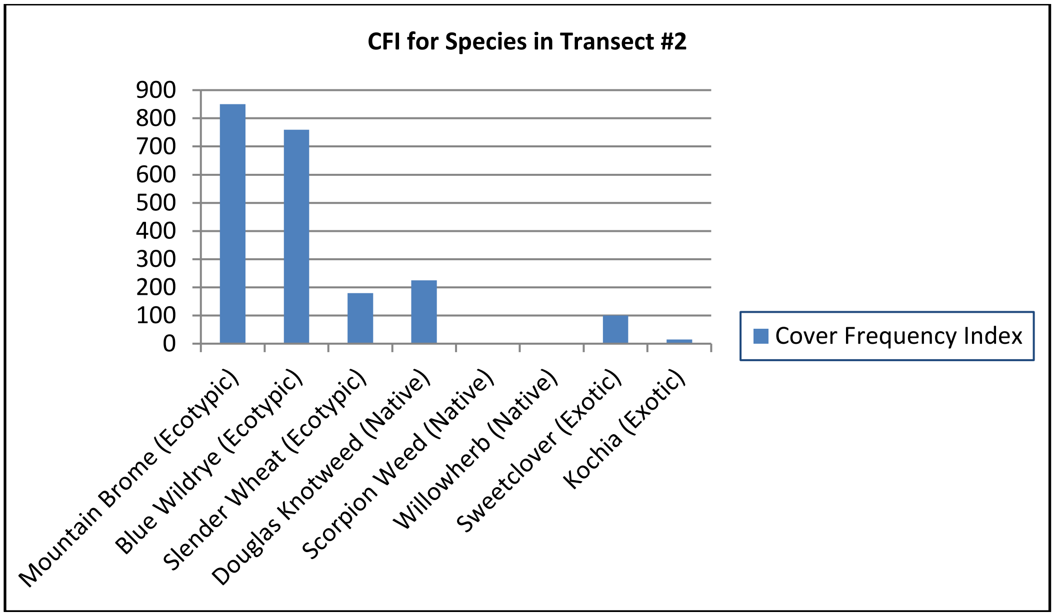


Figure 33. Cover Frequency Index for Dutch Creek transect #2.

Figure 34. Contrast between alluvial fan area amended with compost-biochar (left of red line) and without (control-right of red line). September 24, 2013.


Figure 35. Alluvial fan. May 13, 2013.


Figure 36. Alluvial fan. June 10, 2013.


Figure 37. Alluvial fan. July 10, 2013.

Species Seeded	Compost Amendment	Compost / Biochar	No Amendments
Mountain Brome (BRMA4)	NA	Excellent 1st year Establishment	No 1st year Establishment
Slender Wheatgrass (ELTR7)	NA	Good 1st year Establishment	Good 1st year Establishment
Blue Wildrye (ELGL)	NA	Excellent 1st year Establishment	NA

Table 6. Comparison of first year (2013) vegetative success between soil treatments.

Although not quantified, observations made during a site visit in the fall of 2016 noted that the 750 Engelmann spruce trees planted on the road prism had high survival rates. Planting timber stringers up draws to mimic naturally-occurring features and improving conditions at the micro-site level were important contributors to their survival rate. The project also took advantage of cottonwoods ability to re-sprout by leaving cottonwood logs in wetter areas. During the vegetation monitoring sprouting of cottonwood logs half buried on the upslope end of the fan was noted.

USFS Companion Project

The results of another USFS project in Coal Basin provide additional information for assessing possible techniques for future restoration projects in Coal Basin and other harsh landscapes. This project, located on a 40 acre mine tailing pile known as the Sutey Pile, evaluated the use of livestock as a restoration tool to improve soil condition and vegetation coverage (Ives, 2015). Utilizing a large number of cattle for a short period of time confined to selected one-acre sites, various mixtures of seed, straw, hay, and soil amendments (compost/biochar) were stomped into the soil. This technique allowed the cattle's hoof action to incorporate organic material and seed into the soil. Additionally, the livestock was naturally fertilized with urine and manure. Vegetation monitoring and soil testing- acidity (pH), percent organic matter, and soil nutrients- were used as evaluation techniques. Several of their conclusion should be considered in the evaluation of future restoration techniques.

- Use of soil amendments substantially improves soil conditions and ability to establish and maintain vegetative cover. Benefit vs. cost per acre is a major consideration when adding soil amendments.
- When soil amendments are used, it may be more practical to complete restoration with equipment already mobilized rather than using livestock.
- Where site access and available funds are limited, using livestock as a restoration tool is a viable alternative to conventional reclamation techniques.

Conclusion and Recommendations

This project reclaimed more than 10 acres of the decommissioned road network in Coal Basin's former mining areas to reduce sediment-loading to Coal Creek with the long-term goal of reducing sediment loading in the Crystal River. The urgency of this overall goal diminished based on the results of other associated work occurring at the time of the Coal Creek project. Namely, the planning and discussion that went into the Coal Creek Pilot Project led to an assessment of watershed-wide erosion and sediment supply dynamics using NetMap (Benda and Litschert, 2013). This work and concurrent discussions regarding conditions in the Lower Crystal River eventually led to the 2016 Crystal River Management Plan (CRMP). Based on a watershed-scale assessment of the sediment regime the CRMP concluded "*The Crystal River appears to transport elevated sediment loads from Coal Creek without the telltale signs of sediment transport functional degradation. Furthermore, bridge constrictions, levee construction and bank armoring near Redstone appear relatively innocuous in their impact on the continuity of sediment transport dynamics. A natural geological grade control north of Redstone causes the greatest disruption in transport dynamics in that part of the watershed. Impairments to sediment regime largely abate below Avalanche Creek where the influence of Coal Basin diminishes.*" The CRMP identified one Management Response Opportunity regarding the sediment regime: Limited erosion control projects on historical mining and roadway surfaces. The techniques used in the project and the monitoring results will be useful for subsequent restoration projects in this area as well as projects in other harsh environments.

Although limited, vegetation monitoring provided information that is useful for future projects. Most importantly, when contemplating source performance of the seed sources utilized in revegetation, species biology and ecology must be considered in relation to the site preparation conditions they will be seeded in. Specific conclusions include:

- Plant trees where they would naturally occur on the landscape such as draws and if possible amend the soil at the micro-site.
- If available, using partially buried green cottonwood logs can be considered in project design to increase vegetation.

- WRNF mountain brome did not persist in areas of un-amended and/or compacted soils but displayed excellent first year establishment in areas where soils were amended with compost/biochar.
- WRNF slender wheatgrass has broad ecologic amplitude and is suitable for future use in areas of un-amended and/or compacted soils as well as areas amended with compost/biochar.
- WRNF blue wildrye displayed excellent first year establishment in areas where soils were amended with compost/biochar. Although not evaluated in areas of un-amended and compacted soils it may be a good candidate for any future seeding that may be required along Dutch Creek Road.

The other project objective was to assess the cost-effectiveness and utility of using biochar and other carbonaceous soil amendments in future large-scale reclamation efforts in Coal Basin and similar locations. The soil moisture monitoring data show that compost and compost with biochar holds more soil moisture than untreated areas, with the compost with biochar treatment beginning to show better soil moisture holding capacity over time. Additional years of monitoring would be needed to see if the compost with biochar treatments continue to hold more soil moisture than the compost only. Assessing the cost-effectiveness of these treatments methods is difficult for a few reasons: 1) the value of increased soil moisture is very difficult or impossible to quantify; 2) the longevity and trajectory of the two treatments is unknown; 3) vegetation monitoring did not compare areas amended with compost to those amended with compost and biochar; and 4) the high cost of biochar could be reduced with a local supply and larger quantity production. For this project the compost cost approximately $5,000/acre with biochar adding an addition $10,000/acre. Half of this cost was to haul the material almost 300 miles to be blended with the compost. Hauling the material to the site was an additional expense. Creating economies of scale, reducing the distance from the material source to the project, and reducing the cost to blend the compost with the biochar would be needed to be cost-effective for a large-scale project.

We recommend that soil moisture monitoring continue. Adding an additional soil moisture station in the alluvial fan would be beneficial. For this project keeping the 8" deep probe is sufficient; the 2" is too shallow and the 20" too deep. Future projects may want to consider using 4" and 10" deep probes. To develop an understanding of the relationship between rain fall and soil moisture the tipping bucket rain gauge should be fixed. Soil temperature was only monitored for the compost with biochar treatment so comparisons could not be made among the treatments to determine if the soil temperature in the compost or compost with biochar was less than the control. A review the literature and consultation with resource experts would help determine if additional soil temperature data would provide valuable supplemental information for evaluating the benefits of compost and compost with biochar. If warranted, the equipment should be upgraded to accommodate additional inputs from all treatment types.

Additional vegetation monitoring would help determine if compost with biochar provide additional benefit in comparison to compost only. The trees should be checked to determine if they continue to have high survival rates. Weeds should be monitored and treated as necessary. The area should be monitored to determine if grazing or recreational use is impacting vegetation success since it is no longer being fenced. Additional fencing should be considered if plant growth is retarded and/or to minimize soil compaction.

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Appendix

Description of grasses used in the project

Slender wheatgrass is a cool season perennial tufted bunchgrass species with very short rhizomes (NRCS 2002). It is native to the mountain and intermountain areas of the western United States where it grows at elevations ranging between 4,500’-12,000’. Slender wheatgrass prefers loams and sandy loams in areas receiving at least 14” of annual precipitation. It grows on moist to dry sites and has moderate to good tolerance of alkaline conditions (pH = 8.8). Salinity tolerance ranges from 1-16 mmhos/cm depending on environmental conditions and ecotype. It does not tolerate excessive soil moisture. It is shade tolerant. Considerable genetic variability is present in slender wheatgrass populations and some ecotypes may be rather specific to their original sites due to self-pollination.

Mountain brome is a short-lived, perennial, cool season bunch grass native to the mountain and intermountain regions of Western North America (NRCS 2006). Plants develop from a shallow, non-rhizomatous root system. Mountain brome is well adapted to the foothills and mountains of the Intermountain West in areas with ≥16” annual precipitation. It can be found naturally at elevations ranging 5,000’ to 10,500’. It prefers deep, fertile, mesic soils of medium to fine textures, but also survives on thin, dry or coarse soils, resulting in lower levels of production. Mountain brome does not tolerate flooding or high water tables, but can tolerate very mild salinity. It is winter hardy and has good shade tolerance.

Blue wildrye is a large perennial bunchgrass found from California to Alaska and also the Great Plains and northern Mexico (NRCS 2005). In the southern Rocky Mountains, blue wildrye prefers mesic aspen stands which receive filtered light. It grows well in both disturbed and undisturbed areas and is a good competitor. It tolerates wide variations in soil and weather conditions, though grows best in good soils. It prefers moisture, but tolerates drought. Some ecotypes are adapted to sunny grassland habitats.

Vegetation Monitoring Transect Data

Transect #1 Data

ELTR7		t	1	t	t	t	1	t	t	t	t	1	1	1	1	1	1	1	1	1	
BRMA4																					
DAGL	1			T							3				1	1					
POAM	2				T								2								
FEOV											1										
CYOF			1																		
PODO							T						T								

Transect #2 Data

ELGL	2	2	1	1		1	1	2	2	2	3	2	1	1	1	1	1	T	T	T	0
ELTR7	1	1		1	1	1	T	T	2	T	T	T	T	T	1	2		2	1		190
BRMA4	1			2	2	2	1	1	T	2	1	2	2	2	2		3		2	2	
DAGL																					50

Common Name	Scientific Name	Abbreviation
Slender wheatgrass	Elymus trachycaulus	ELTR7
Mountain bromegrass	Bromus marginatus	BRMA4
Orchard grass	Dactylis glomerata L.	DAGL

Tall bluegrass	Poa ampla	POAM
Sheep fescue	Festuca ovina	FEOV
Hounds tongue	Cynoglossum officinale	CYOF
Douglas knotweed	Polygonum douglassii	PODO
Blue wildrye	Elymus glaucus	ELGL